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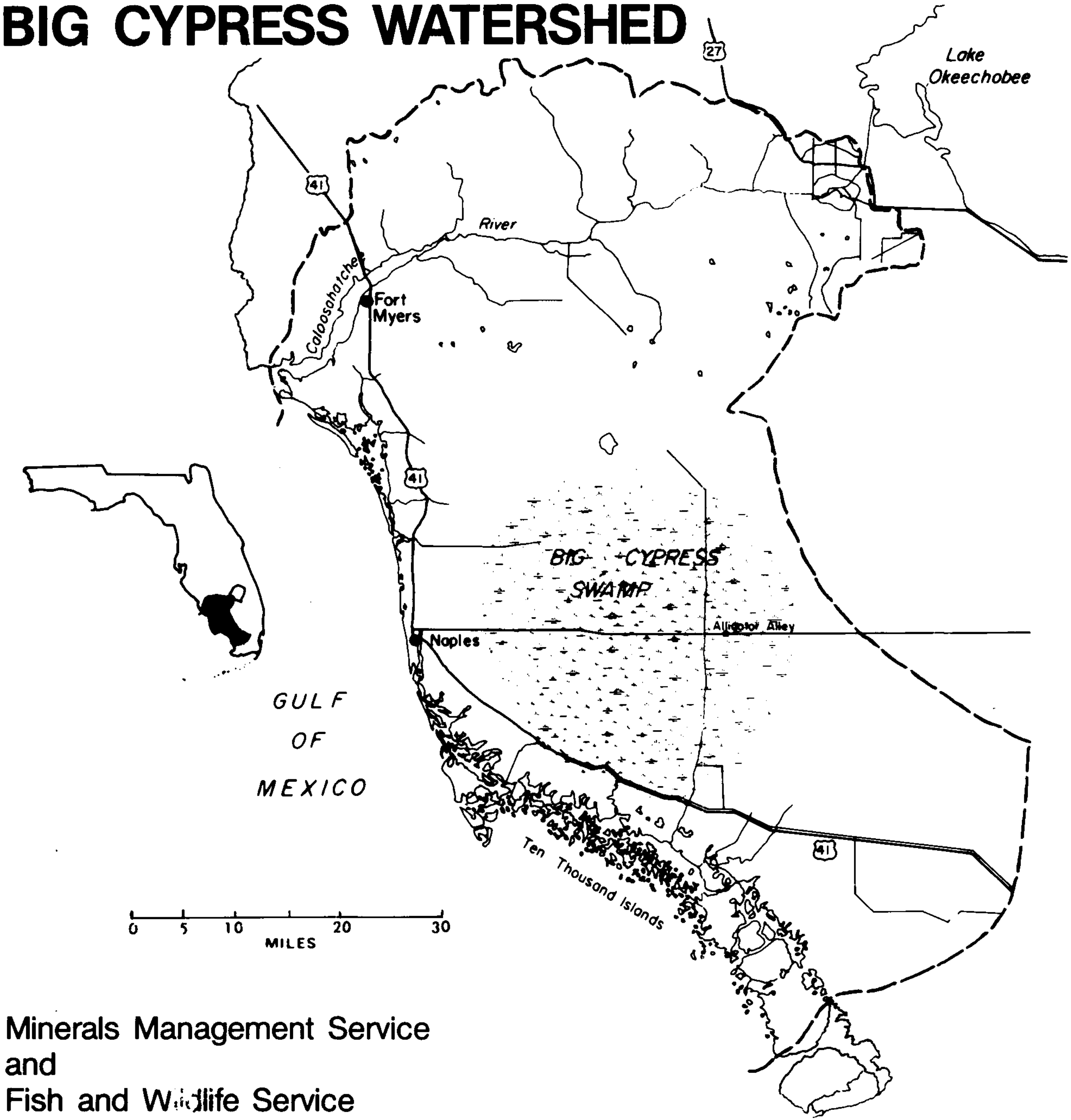

Minerals Management Service
and
Fish and Wildlife Service

U.S. Department of the Interior

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AN ECOLOGICAL CHARACTERIZATION OF THE CALOOSAHATCHEE RIVER/BIG CYPRESS WATERSHED

by

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PREFACE

This report is one in a series that provides an ecological description of Florida's gulf coast. The watershed described 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 that govern the use of the natural resources of the watershed.

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

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SUMMARY

Southwest Florida contains a variety of natural resources that have contributed to the development of the area into an important industrial, shipping, agricultural, sport and commercial fishing, recreational, and retirement center in the eastern Gulf of Mexico. As growth continues the finite natural resources of the area will diminish in both quality and quantity. Future management of the remaining resources requires careful consideration to preserve a productive balance between man and nature. Often, in deciding where this line lies, there is considerable uncertainty about the composition, interaction, and value of the living resources in an area. This report is an extensive review and synthesis of the available literature on the ecology of the Caloosahatchee River/Big Cypress watershed. The report will be used by the U.S. Fish and Wildlife Service, and the Mineral Management Service to plan for the development of oil and gas reserves offshore of southwest Florida. This document is divided into two parts. The first part describes the geology, physiography, climate, and the characteristics of ground and surface waters. The remainder of the report focuses on plant succession and communities, and with the watershed's fish and wildlife, their habits and habitat preferences.

CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 GEOLOGY AND PHYSIOGRAPHY

CHAPTER 3 CLIMATE

CHAPTER 4 HYDROLOGY AND WATER QUALITY

CHAPTER 5 WATERSHED ENERGETICS

CHAPTER 6 PLANT COMMUNITIES

CHAPTER 7 FAUNA

FIGURES

Figure **Page**

TABLES

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CHAPTER 1
INTRODUCTION

1.1 PURPOSE AND ORGANIZATION OF THE REPORT

In recent years man's cultural and economic development has accelerated at an unprecedented pace. Inevitably this development precipitates rapid change in the environment. Major examples are habitat alteration, such as urbanization and dredging, sewage and industrial effluent discharge, ground and surface water diversion, and urban and agricultural runoff.

Within the highly developed and rapidly changing coastal regions of southwest Florida, a fine line is emerging between vigorous economic development and the preservation of a productive balance between man and nature. Often, in deciding where this line lies, there is considerable uncertainty about the composition, interaction, and value of the living resources in a particular area. This report is an extensive review and synthesis of the available literature on the ecology of and environmental alterations in the Caloosahatchee River/Big Cypress watershed.

In contrast to most literature reviews and syntheses, this report deliberately crosses disciplinary boundaries in an attempt to focus on how a 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 Caloosahatchee River/Big Cypress watershed?"

This report is divided into two parts, one on physical/chemical background conditions, and the other on biological resources. The first part (Chapters 2 through 4) describes the geology and physiography of the study area, its climate, and the characteristics of ground and surface waters. Chapter 5 discusses the concept of watershed energetics for the Caloosahatchee River/Big Cypress watershed and attempts to describe the meshing of man's socioeconomic structure with the area's natural setting. Chapter 6 describes plant succession and communities, and Chapter 7 deals with fish and wildlife, their habits, and habitat preferences.

1.2 THE CALOOSAHATCHEE RIVER/BIG CYPRESS WATERSHED

This region (Figure 1) consists of the watersheds and estuaries of the Caloosahatchee River, the Big Cypress Swamp, Estero Bay, and Corkscrew Swamp, and corresponds to United States Geological Survey hydrologic units 03090205 and 03090204. The upper watershed is dominated by the canalized Caloosahatchee River that runs from Lake Okeechobee to the Franklin Locks. A series of three lock structures control flow and stage in the river. Many of the tributaries to the Caloosahatchee River have also been canalized for drainage and irrigation purposes and are equipped with weirs and pumps for localized control.

The upper reach of the Caloosahatchee River estuary is the salinity-control structure (Franklin Locks) near the town of Olga. This long and narrow estuary borders the

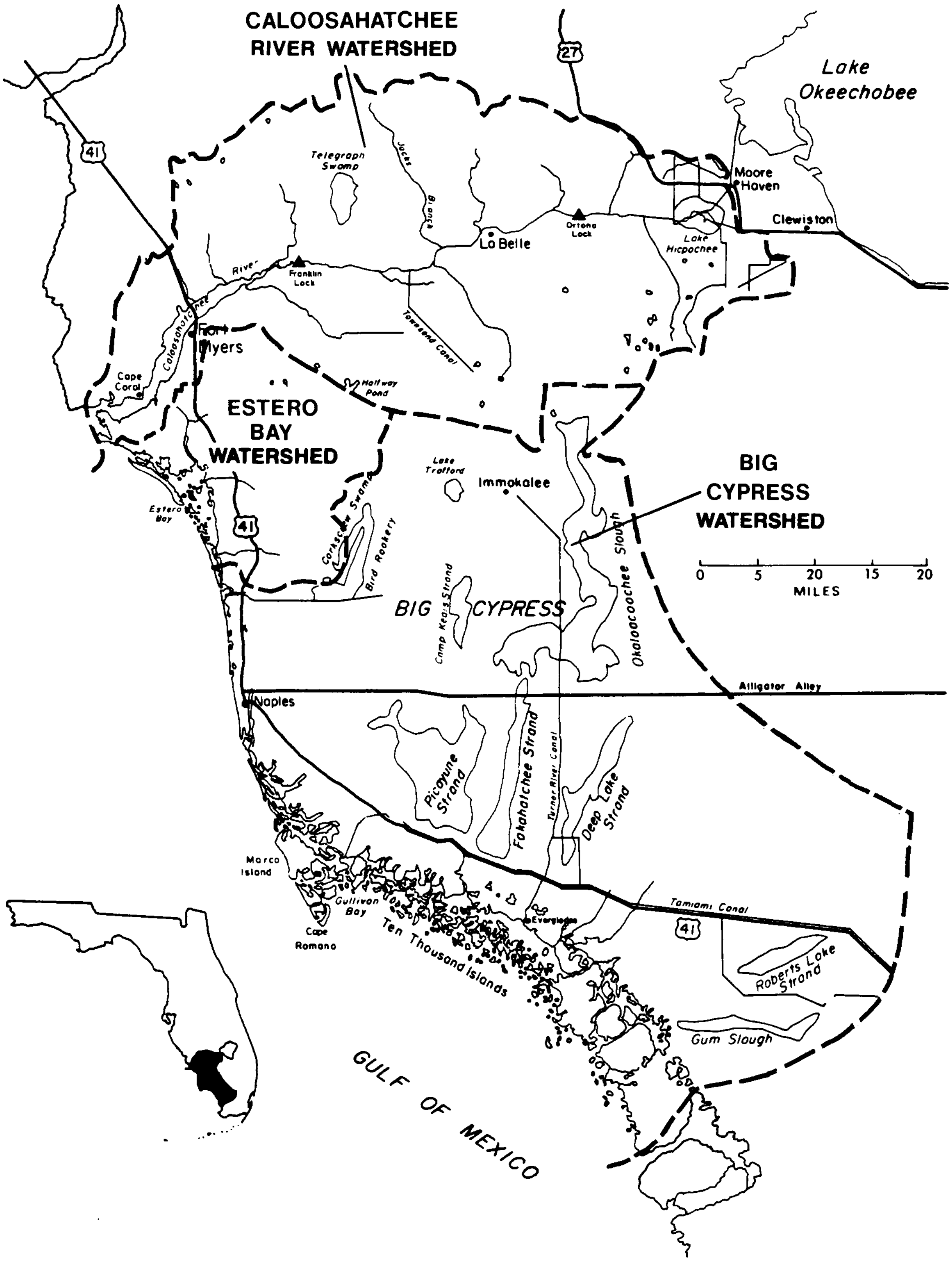


Figure 1. The Caloosahatchee River/Big Cypress watershed.

cities of Fort Myers and Cape Coral, and empties into San Carlos Bay in the lee of Sanibel and Pine Islands. These islands are considered part of the Charlotte Harbor estuarine system.

The Big Cypress watershed (hydrologic unit 03090204) consists of the Estero Bay watershed, the Corkscrew Swamp watershed, and the Big Cypress Swamp. The Estero Bay watershed encompasses the drainage of small streams into Estero Bay. The ill-defined Corkscrew Swamp watershed begins near Lake Trafford and runs southwesterly toward the coast. The Big Cypress Swamp includes the numerous cypress dominated sloughs and strands flowing roughly southwest and perpendicular to the Tamiami Canal. The surface waters of this gently sloping area discharge into the Gulf of Mexico through the Ten Thousand Islands region.

CHAPTER 2
GEOLOGY AND PHYSIOGRAPHY

2.1 STRUCTURE AND GEOLOGIC SETTING

The Floridan Plateau (Figure 2), originally named by Vaughan (1910), is the land mass that separates the Gulf of Mexico from the Atlantic Ocean. It includes not only the State of Florida but an equal area of submerged ocean shelf west to a depth of 50 fathoms (91 m or 300 ft). The plateau underlies the Caloosahatchee River/Big Cypress watershed 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 Keys, and Madison, Florida (Cooke 1945).

A reference chart for the ensuing discussion of geologic structure and stratigraphy is given in Table 1. 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).

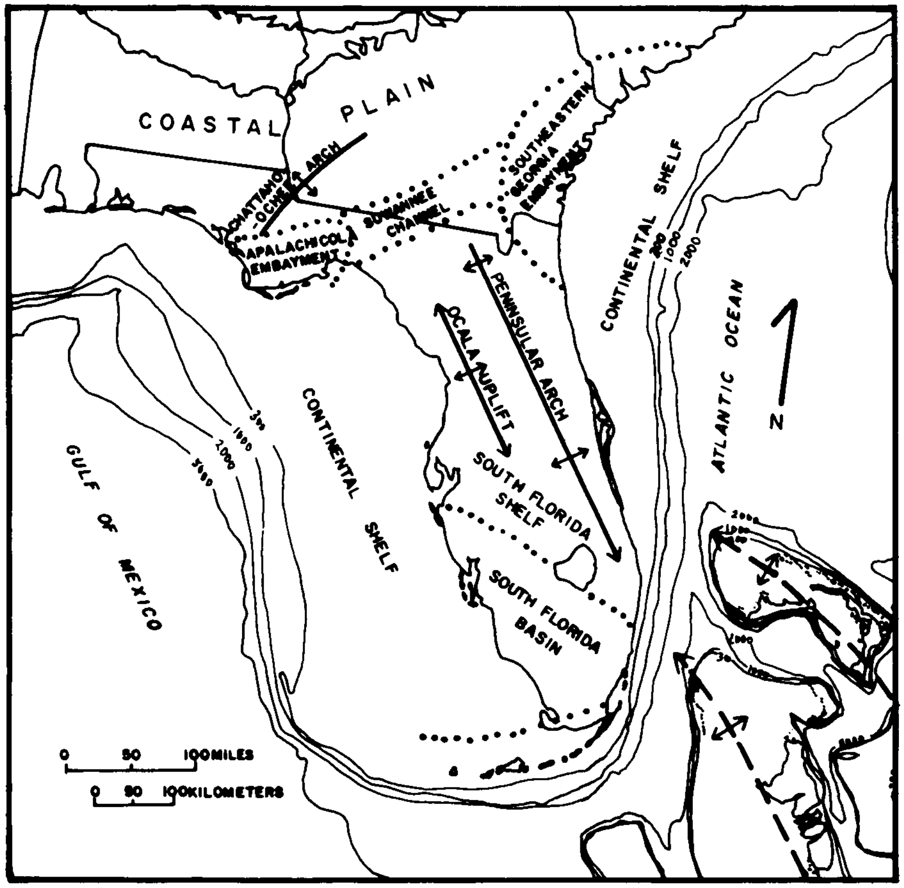


Figure 2. The Floridan Plateau (adapted from Chen 1965).

Table 1. Geological eras and formations of the Floridan Plateau.

GEOLOGIC TIME AND FORMATIONS					
ERAS	PERIODS AND SYSTEMS	EPOCHS AND SERIES	APPROXIMATE NUMBER OF YEARS AGO	EARLIEST RECORD OF	
				ANIMALS	PLANTS
CENOZOIC	QUATERNARY	Holocene (recent) Pleistocene (glacial)		mankind	
	TERTIARY	Pliocene Miocene Oligocene Eocene Paleocene	70,000,000		
MESOZOIC	CRETACEOUS	Upper		placental mammals	
		Lower		birds	grasses and cereals
	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			invertebrates	spores of uncertain relationship marine algae
ARCHEOZOIC			1,420,000,000 2,300,000,000		

Structurally, the area under consideration in this report lies within what Pressler (1947) refers to as the Florida Peninsula sedimentary province. This province is one of two distinct sedimentary facies, clastic (panhandle Florida) and nonclastic (peninsula Florida), that segregate Florida's early Tertiary stratigraphy (Paleocene and Eocene). These two sedimentary facies were separated by the Suwannee Channel (Figure 2), which served as a natural sedimentational and faunal barrier. It occupied a narrow NE to SW trending belt, from southern Georgia to northern Florida's Apalachicola Bay, during the late Cretaceous to upper Eocene (Chen 1965). Nonclastic sediments, which dominate the Florida peninsula, are primarily carbonates and anhydrites, that are chemically or biologically produced, in contrast to sediments generated by weathering or erosional processes.

Of particular significance in the watershed is the structural feature of the peninsula identified as the South Florida Shelf. This term was applied by Applin and Applin (1964) to a shallow shelf generally paralleling and inclusive of the lower southwest coast (Puri and Vernon 1964). Pressler (1947) believes that anticlinal folds are the most prevalent type of structures within the South Florida Shelf. Although probably occurring as secondary structural features, faults should also be common in this area. Based on the configuration of the surface of the submerged areas, Pressler (1947) believes 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. These factors contribute localized structural features significant to the accumulation of oil (Winston 1971).

The oil deposits of south Florida are generally confined to the Sunniland Limestone of the lower Cretaceous Trinity Age found in the Big Cypress watershed, as illustrated in Figure 3. Of the 72 holes drilled in the Big Cypress National Preserve, as of 1977, only 12 produced oil. The current status of each well, permit changes, and drilling progress are summarized in a weekly newsletter, "Florida Petroleum Report", which may be obtained from the Florida Bureau of Geology in Tallahassee. The oil-producing zone of the Sunniland Limestone varies in depth (2,925 to 3,590 m or 9,597 to 11,779 ft) and in lithology. A comparison of two of the more productive fields illustrates the stratigraphic variation. The Bear Island Field represents an elongated, low-relief anticline, whereas the Sunniland Field lies over a slight dome, possibly a reef structure, which may be associated with natural adjustments of rock masses within the earth's crust and associated faults. In both fields, the oil traps are gentle anticlines associated with biostromal reefs (Duever et al. 1979). More detail on the south Florida oil field geology may be obtained from the Florida Division of Resource Management or from reports listed in the Florida Bureau of Geology "List of Publications".

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

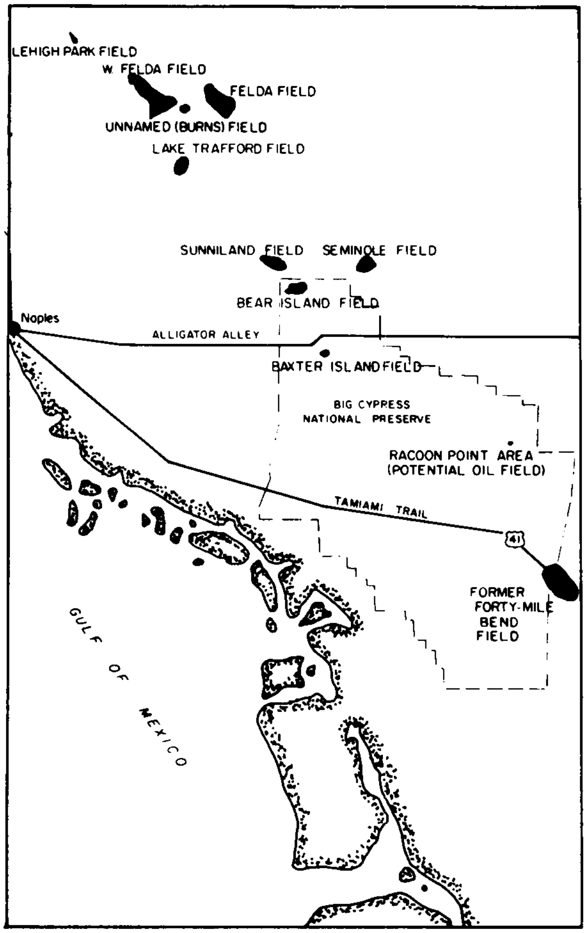


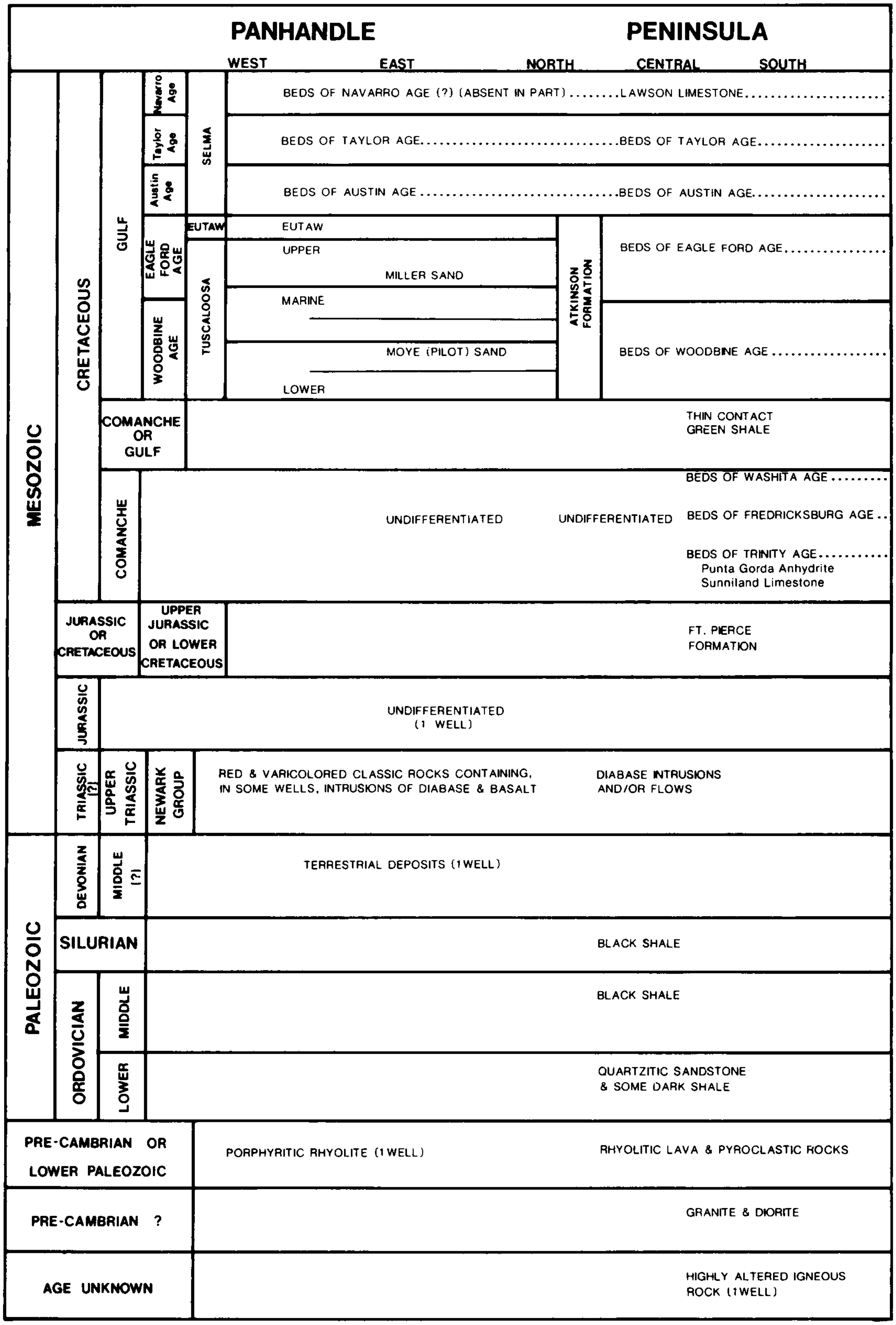
Figure 3. South Florida oil fields (adapted from Duever et al. 1979).

Florida is restricted to northern Florida. 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, Applin and Applin 1965) place the pre-Mesozoic floor at 3,658 to 6,096 m (12,000 to 20,000 ft) below mean sea level. Figure 4 (from Puri and Vernon 1964) summarizes the stratigraphic relationships of the pre-Cenozoic Floridan Peninsula.

2.2 TERTIARY STRATIGRAPHY

The generalized geologic column for Cenozoic rock in the watershed is illustrated in Figure 5. The oldest Tertiary rock layer beneath the Caloosahatchee River/Big Cypress watershed is the Cedar Keys Formation, a light-gray mixture of dolomites and evaporites (gypsum and anhydrite) of marine origin belonging to the Midway Group of the Paleocene Series of Florida (Chen 1965). In central and southern Florida, the formation is essentially nonfossiliferous with a relatively high evaporite content ranging from 25% to greater than 40%. The thickness of the Cedar Keys Formation exceeds 610 m (2,000 ft) in the study area near the Sunniland oil field.

The Oldsmar Limestone of the Sabine Stage overlies the Cedar Keys formation. This chalky white to light-brown, rather pure, finely fragmented, and fossiliferous limestone unit represents the earliest formation of the Eocene. A thick dolomite section of the Lake City Limestone overlies it. The Oldsmar Limestone is of marine and deltaic clastic origin and ranges from less than 244 to over 366 m (800 to 1,200 ft) thick in the watershed (Chen 1965). The Clairborne Stage (middle Eocene), which overlies the Oldsmar Limestone, is composed almost entirely of dolomite and limestone with minor amounts of evaporite and thin beds of compressed peat. Two formations, the Lake City Limestone and the Avon Park Limestone, form the Clairborne Stage in the study area. The older of the two, the Lake City Limestone, is a dark-brown, chalky limestone facies which gradually thins from central Florida southwestward (Chen 1965, Puri and Winston 1974). The Avon Park Limestone is a cream col-



					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 (1 WELL)		
	TRIASSIC (?)	UPPER TRIASSIC	NEWARK GROUP		RED & VARICOLORED CLASSIC ROCKS CONTAINING, IN SOME WELLS, INTRUSIONS OF DIABASE & BASALT	DIABASE INTRUSIONS AND/OR FLOWS	
PALEOZOIC	DEVONIAN	MIDDLE (?)			TERRESTRIAL DEPOSITS (1WELL)		
	SILURIAN					BLACK SHALE	
	ORDOVICIAN	MIDDLE				BLACK SHALE	
		LOWER				QUARTZITIC SANDSTONE & SOME DARK SHALE	
PRE-CAMBRIAN OR LOWER PALEOZOIC					PORPHYRITIC RHYOLITE (1 WELL)	RHYOLITIC LAVA & PYROCLASTIC ROCKS	
PRE-CAMBRIAN ?							GRANITE & DIORITE
AGE UNKNOWN							HIGHLY ALTERED IGNEOUS ROCK (1WELL)

Figure 4. Stratigraphic nomenclature of pre-Cenozoic strata in the Florida peninsula (adapted from Puri and Vernon 1964).

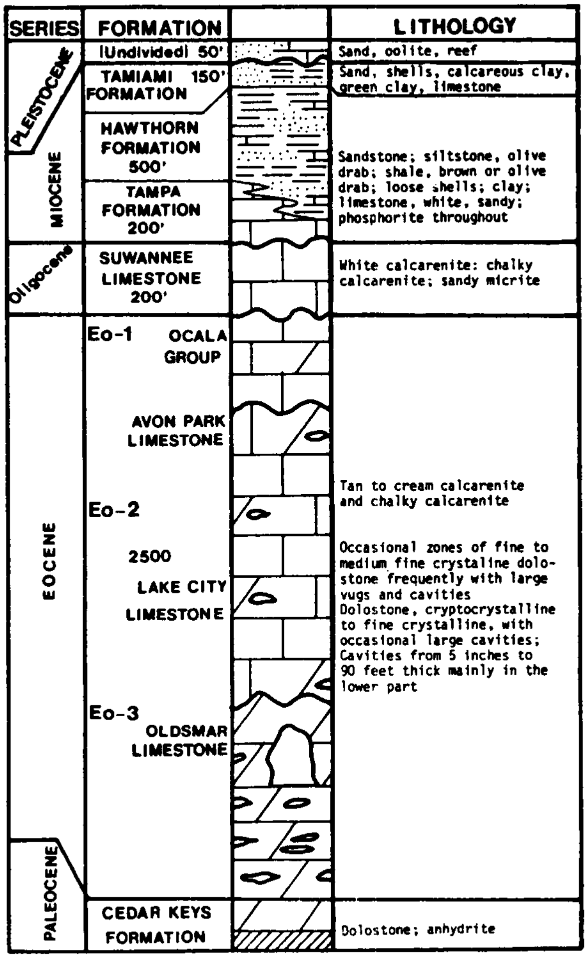


Figure 5. Generalized geologic column of Cenozoic rocks (adapted from Puri and Winston 1974).

ored chalky limestone, and brown to dark-brown, rather porous dolomite, which reaches a maximum thickness exceeding 244 m (800 ft). The last and most recent stage of the Eocene series is the Jackson, represented by limestones of the Ocala group. These limestones are chalky white to light brown, porous, and poorly consolidated, and reach a maximum thickness of more than 122 m (400 ft). Included in this group, in ascending order are: Inglis, Williston, and Crystal River Formations. Only the Crystal River Formation underlies the entire watershed, whereas the Williston and Inglis Formations thin out southward (Puri and Vernon 1964).

The sole representative of the Oligocene series is the Suwannee Limestone, which is a white to cream-colored, compact, finely porous, fossiliferous limestone (Jakob and Waltz 1980). The formation generally thickens to the south, varying from 61 to 107 m (200 to 350 ft) in the watershed (Puri and Winston 1974, Jakob and Waltz 1980, Burns 1983, Peacock 1983).

The Suwannee Limestone is overlain unconformably by either the Tampa or Hawthorn Formations of the Miocene series. These formations consist of approximately 213 m (700 ft) of intermixed clastic and nonclastic materials with varying lithologies, including mixtures of sandstone, olive-drab siltstone, brown or olive shale, loose shells, and white, sandy limestone, with phosphorite or plastic clay (Puri and Winston 1974). Clay portions of the Miocene formations exhibit very low permeability and act as an aquiclude over the porous and permeable Suwannee Limestone. These formations contain the first substantial deposits of clastic sediments from the Cenozoic era, marking a distinct shift of the Floridan peninsula's depositional environment. In the interval between the Suwannee Limestone (Oligocene) and the Tampa Formation (early Miocene), the Ocala Uplift developed. During subsequent formations deposition was controlled by this uplift, as evidenced by the thinning and pinching out of younger strata from south (Key Largo) to north (Ocala) or towards the crest of the uplift (Jakob and Waltz 1980). Shorelines during this time (Miocene) extended as far south as central Florida.

The lower Miocene is represented by the Tampa Limestone which is a grayish-yellow to cream, sandy limestone containing some marl. The sand content (predominantly quartz) increases to the north as the formation thins. In southwest Florida the Tampa Limestone thickens from northeast Glades County to western Lee County (Jakob and Waltz 1980, Burns 1983).

Above the Tampa Limestone is the Hawthorn Formation, which is an interbedding of marine, light-green to gray, sandy clays and sandy limestones containing numerous fish and invertebrate fossils. In the watershed the formation varies in thickness from 30 to 245 m (100 to 800 ft), and like the Tampa Limestone below it, thins toward the crest of the Ocala Uplift. In the western coastal areas, the formation most closely approaches the surface, ranging from 15 to 46 m (50 to 150 ft) below mean sea level (msl) (Puri and Vernon 1964, Jakob and Waltz 1980).

The upper Miocene to late Pliocene is represented in south Florida by the Tamiami Formation, which consists of approximately 46 m (150 ft) of limestone, calcareous clay, green-aluminous clay, and sand. The formation thickens to the south and east of the Caloosahatchee River basin and represents the oldest formation of its era to exhibit outcrops in the watershed, specifically along the Caloosahatchee River and in ditches along the Tamiami Trail (State Highway 41) for which it was named. Elsewhere the formation varies in depth from about 5 to 30 m (15 to 100 ft) below land surface (Puri and Vernon 1964, Dubar 1974, Hunter 1978, Jakob and Waltz 1980, Jakob 1983).

The post-Eocene stratigraphy in southwest Florida has recently been revised by some authors based on lithologic, rather than paleontologic criteria (King and Wright 1979, Mooney et al. 1980, Peacock 1983). The result is a recognition of the Tampa Limestone Formation only in west-central Florida, as spacially described by King and Wright (1979), and not in south Florida. The strata normally assigned to the Tampa Limestone is instead considered part of the Hawthorn Formation (Peacock 1983). Peacock (1983) also expands the Hawthorn to include the upper Suwannee Limestone (Cole 1941), and all but the upper Tamiami Formation (Parker 1951). The latter revision (reduction of the Tamiami Formation) is based on a recent redefinition of the Tamiami Formation by Hunter and Wise (1980).

In south Florida the Tamiami Formation extends to the late Pliocene (Dubar 1974, Hunter 1978). The only other formation that suggests a Pliocene origin is the Caloosahatchee Marl. The uncertainty reflects a current debate over the Caloosahatchee Formation's placement in the Pliocene (Parker et al. 1955), the Pleistocene (Dubar 1958a), or an undefined transition zone referred to as the Plio-Pleistocene (Brooks 1974). Hunter (1978) concurs with Dubar (1958a) and further suggests it be considered as a member of the Fort Thompson Formation, as such encompassing all the interbedded marine, brackish, and fresh water deposits of roughly Pleistocene age (10,000 to 1,800,000 years B.P.). The Pliocene (1.8 to 5.0 million years B.P.) would be represented only by the Tamiami Formation. Figure 5 illustrates Hunter's (1978) suggested stratigraphic classification and reported radiometric dates. Dubar's (1974) scheme is in agreement with a Pleistocene origin for the Caloosahatchee, but recognizes the deposit as a formation in itself rather than as a member of the Fort Thompson Formation. For purposes of this report, the Caloosahatchee will be recognized as a formation of the early Pleistocene.

2.3 PLEISTOCENE SERIES

Sea level prior to the initial Pleistocene glacial melt lay approximately 82 m (270 ft) above the present shoreline. 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. This successive dampening of sea-level rise is probably the result of sea-floor spreading, which concurrently increased the global volume of the oceans (Cooke 1945). Names of recognizable sea-level fluctuations of the Pleistocene in Florida and the respective heights to which they extended above present day sea-level are listed in Table 2. The Talbot and Pamlico are the only terraces important to the watershed.

The various elevations of the Pleistocene shorelines and the alternation of marine and freshwater beds in certain limestone and marl formations provide a record of sea-level fluctuations during the great ice age. The advances and retreats of great ice sheets over the North American continent alternately raised and lowered the regional sea levels that resulted in a variety of Pleistocene deposits, including quartz sands, shell beds, limestone, and marl (Klein et al. 1964).

In southern Florida the strata of the Pleistocene are composed of the sands of marine terraces; the Caloosahatchee, Anastasia, and Fort Thompson Formations; the Key Largo Limestone; and the Miami Formation. Of these, only the Caloosahatchee and Fort Thompson Formations, and two of the four to seven recognized marine terraces are located in the watershed. The Anastasia Formation may underlie a major portion of the Caloosahatchee River/Big Cypress watershed (Klein et al. 1964), but a lack of core data and the difficulty of distinguishing it from Caloosahatchee and Fort Thompson Formations makes it difficult to verify this claim (Missimer 1978).

Table 2. Recognized sea-levels during the Pleistocene era in Florida (adapted from Cooke 1945).

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

The most ancient of the Pleistocene rock layers in south Florida is the Caloosahatchee Formation, which is primarily a grayish-green, silty, sandy, shell marl with interbedded layers and lenses of sand, silt, clay, and marl. The formation occurs only in the eastern part of the watershed, ranging in thickness from a few meters to greater than 15 m (50 ft) near the western edge of Lake Okeechobee. It continues to thicken towards Florida's east coast (Dubar 1974, Jakob and Waltz 1980). The Caloosahatchee Formation consists of three members which collectively comprise a lithologic record of a transgressive-regressive depositional cycle (Figure 6). The

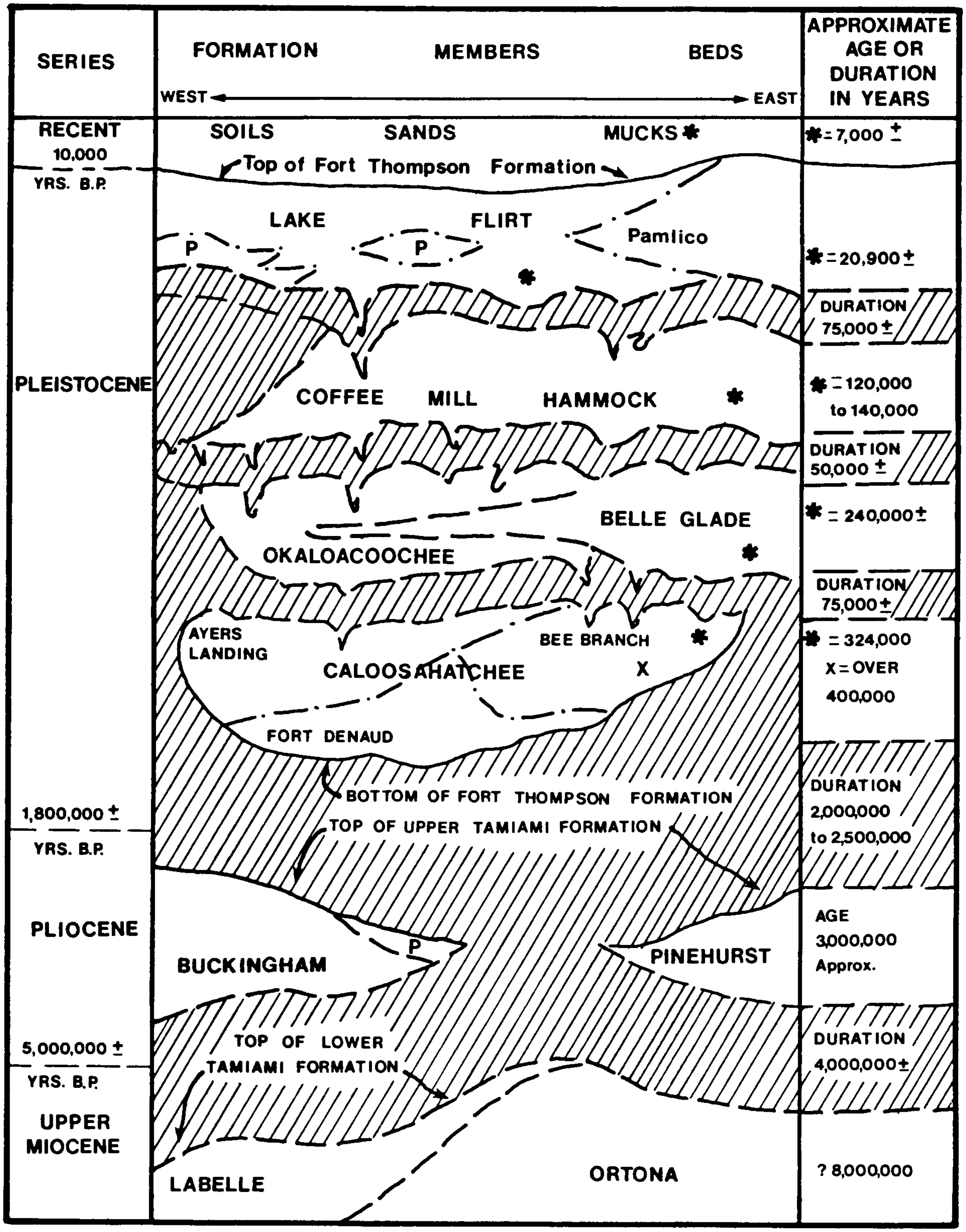


Figure 6. West to east schematic geologic cross section of Caloosahatchee River outcrops in the area near Fort Denaud, Fort Thompson, and Ortona Lock (adapted from Hunter 1978).

oldest (Fort Denaud Member) was deposited in fresh and brackish water during the early transgressive phase. A younger member (Bee Branch Member) represents a deposit of shallow-shelf and high-salinity bay origin, and corresponds to the maximum Caloosahatchee sea transgression. The most recent (Ayers Landing Member) occurred during a regression of the sea, in brackish to high-salinity bays and freshwater environments (Dubar 1974).

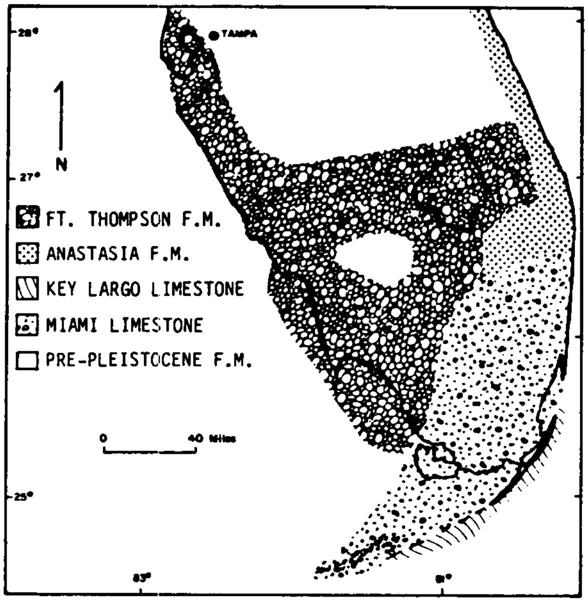


Figure 7. Distribution of surface-exposed Pleistocene formations (adapted from Dubar 1974).

The Caloosahatchee Formation is typically overlain by the Fort Thompson Formation--a name applied by Sellards (1919) to beds of freshwater marl and limestone, which alternate with beds of marine shell marl in the vicinity of Fort Thompson on the Caloosahatchee River (Dubar 1974). Deposits of this formation provide the best picture of the changing environments associated with sea-level fluctuations during Pleistocene glacial events (Jakob and Waltz 1980). The Fort Thompson Formation is often represented by discontinuous beds, particularly in the Big Cypress Swamp to the southwest. In this region the Tamiami Formation surface is thinly overlain by recent sediments, pockets of the Fort Thompson Formation, or terrace sands (Duever et al. 1979). The beds vary in size and thickness, and reflect the subsurface irregularity of the deeper Caloosahatchee and Tamiami Formations (Dubar 1974). Areal distribution of the formation is illustrated in Figure 7, in relation to more recent Pleistocene strata of south Florida. The deposit's thickness ranges from absent (0) to 5 m (15 ft) in the study area, increasing southeastward toward Miami, where it reaches a maximum thickness of 21 m or 70 ft (Klein et al. 1964, Dubar 1974, Jakob and Waltz 1980). The Fort Thompson Formation contains two distinct members, the younger Coffee Mill Hammock Member and the Okaloacoochee Member (Dubar 1958b) (Figure 6). The older Okaloacoochee Member is represented by two freshwater gray-marl units separated by a thin layer of brackish water marl and marine shell. This member was deposited during the initial transgression of the Fort Thompson sea in a bay-margin and freshwater environment. Over this member is the Coffee Mill Hammock Member, a marine shell bed, which was deposited in a shallow semirestricted, high-salinity bay similar to present-day Florida Bay (Dubar 1974, Jakob and Waltz 1980). The tops of the freshwater beds have been hardened into brittle limestone, but are perforated by solution holes that are filled with marine shells from succeeding strata. The Fort Thompson Formation is of special importance to the human population of south Florida because it forms a large part of the Biscayne Aquifer, the sole drinking-water source for the southeast coast. The Lake Flirt Formation is reported either as the youngest Fort Thompson Formation member (Hunter 1978) or as the youngest Pleistocene Formation whose deposition continued into the Recent epoch or Holocene epochs (Dubar 1974). Taking the latter case, this deposit lies unconformably on the Fort Thompson Formation and represents freshwater sediments deposited along the Caloosahatchee River. It consists of thin beds of mucky dark sands and marl shell that typically range in thickness from 1 to 3 m (3 to 8 ft).

Pleistocene marine terrace deposits. During the high Pleistocene sea level stands, terraces were formed over Florida by wave, current, and erosional actions. Today belts of these terrace sands extend around Florida, parallel to the present coastline. These belts are found in step-like formation, rising inland from the coasts with the oldest sediment being the highest in elevation. The actual number of terraces in Florida is the subject of much debate: estimates range from four to nine (Puri and Vernon 1964). The terraces and shorelines identified in the watershed, from the lowest in elevation to the highest, are Silver Bluff, Pamlico, Talbot, Penholoway, and Wicomico Terraces (Healy 1975). These Pleistocene terraces and shorelines are illustrated in Figure 8 and are accompanied by their approximate shoreline elevations. The terraces in the study area are composed of quartz sand and lie discontinuously upon the Fort Thompson, Caloosahatchee, and Tamiami Formations. Overlain unconformably by the Lake Flirt Formation and recent deposits, these sands typically range from

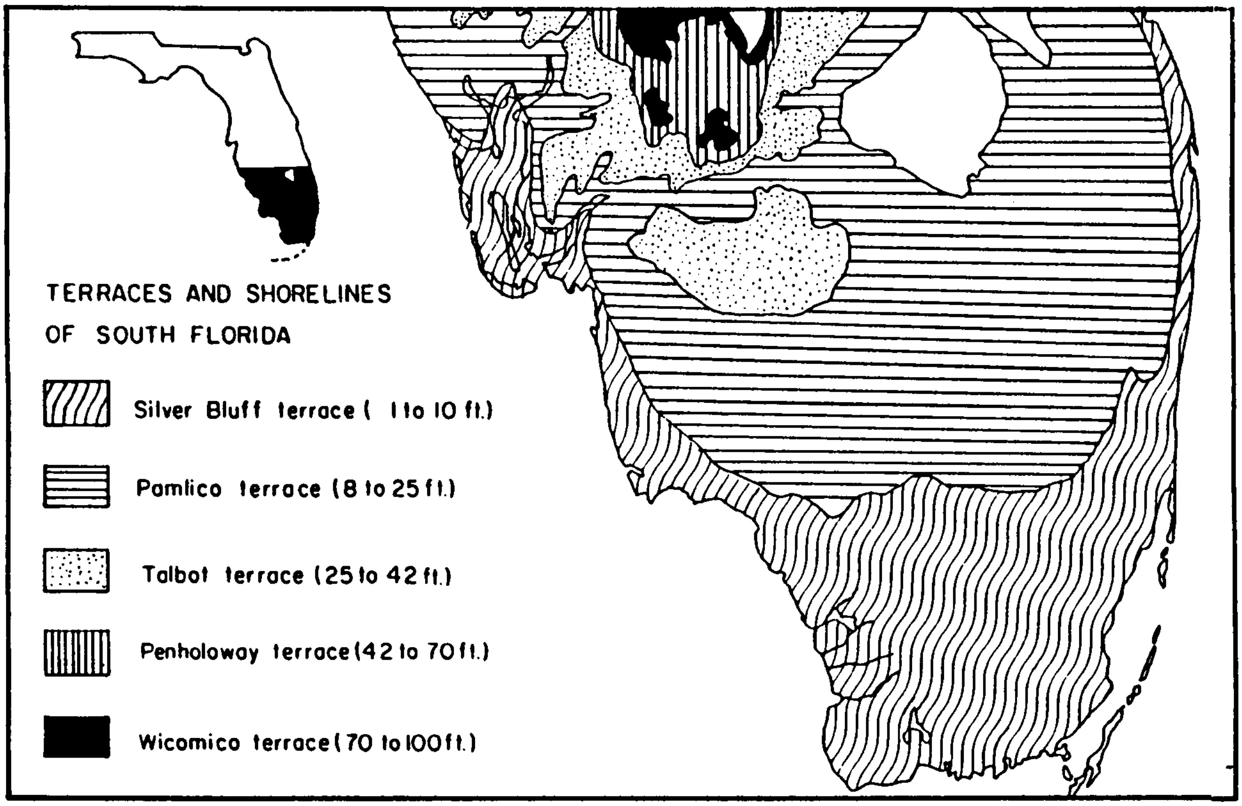


Figure 8. Pleistocene terraces and shorelines of south Florida (adapted from Healy 1975).

0.5 to 1 m (2 to 3 ft) in thickness, although pockets exceeding 5 m (15 ft) have been observed (Klein et al. 1964).

2.4 PHYSIOGRAPHY

The dominant physiographic feature of the Caloosahatchee River watershed is the Caloosahatchee River Valley (Puri and Vernon 1964, White 1970). The axis of the valley follows the Caloosahatchee River from Lake Okeechobee to San Carlos Bay. The valley "wall" known as the Caloosahatchee Incline (White 1970) slopes very gradually upward to the north of the river. At the peak of the valley wall lies the De Soto Plain, a very flat terrace extending down from the Polk Uplands of the Central Florida Highlands. To the south of the Caloosahatchee River the valley wall is formed by the Immokalee Rise, an elevated flat area of predominantly sandy soils. Both the Caloosahatchee Incline and the Immokalee Rise formed as erosional submarine terraces of the Pamlico shoreline. The De Soto Plain is generally regarded as a submarine terrace formed below the Wicomico shoreline.

The Big Cypress watershed (Figure 9) contains all or part of four major physiographic features of the lower Florida peninsula: (1) The Immokalee Rise, (2) The Big Cypress Spur, (3) The Southern Slope, and (4) Coastal Swamps and Lagoons.

As the Pamlico sea level dropped, the Immokalee Rise emerged as a sloping sand shoal south of the Caloosahatchee Valley. A somewhat parallel situation would occur today off Cape Romano, should sea-level fall.

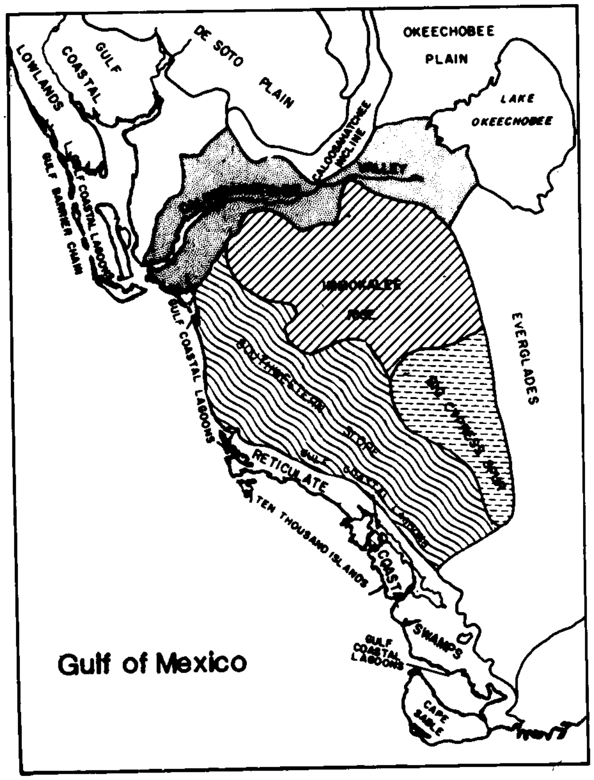


Figure 9. Major physiographic features of the lower Florida peninsula (adapted from Puri and Vernon 1964).

Southeast of the Immokalee Rise is the Big Cypress Spur, a sloping area transitional between the rise, the Everglades trough to the east, and the southwestern slope to the west. The spur is best characterized by its abundant dwarf cypress on marl soils to the west and its sawgrass/Everglades slough vegetation to the east.

The spur receives runoff from the north, off relatively higher lands of the Immokalee Rise. Historically, flow was probably in two directions (and fairly rapid): one to the Everglades trough, then down and out Shark River, and the other to the Southwestern Slope and out through the back bays north of Lostman's River. Today SFWMD levee L-28 tieback canal insures this drainage pattern by accentuating the naturally low ridge that separates Big Cypress Spur from the Southwestern Slope. L-28 was breached by culverts in 1983 to restore the high-water basin connection at certain times.

The Southwestern Slope is a northwest-southeast trending area that is gently tilted toward the Gulf of Mexico. Toward the south, a drainage pattern perpendicular to the coast is evident in the elongation of slough and strand vegetation. Here the substrate is thin sands overlying a dissected Tamiami Limestone. Toward the north sands are more prevalent and often deeper, as evidenced by increasing pineland vegetation and less distinct coast-perpendicular drainage.

Coastal swamps and lagoons. The Big Cypress estuarine and saltwater wetland zone is made up of two major components: (1) a coastal reentrant zone from Gullivan Bay south to Lostman's River, and (2) a coastal protuberant zone from Cape Romano north to Fort Myers Beach. The northern boundary of the coastal reentrant zone includes the Ten Thousand Islands. These numerous mangrove-covered islands appear to coalesce south along the coastline, eventually forming larger solid blocks. Dissected lagoons (back bays) characterize the upland side of this zone. These blocks are separated from one another by increasingly distinct drainage ways. Concurrently the inland extent of brackish vegetation (mangroves and salt marshes) increases north to south from about 4.8 km (3 mi) to 8.8 km (5.5 mi) from Gullivan Bay to Lostman's River.

This "reentrant" physiography is caused by a combination of offshore profile, substrate composition, and rising sea-level. Offshore bottom topography decreases in steepness toward the south of the watershed. The 5-fathom isobath only rarely lies more than 0.8 km (0.5 mi) offshore north of Marco Island, but in the coastal reentrant zone the 5-fathom isobath lies as much as 13 to 19 km (20 to 30 mi) offshore. The 5-fathom depth is considered close to the maximum depth at which waves scour oceanic shores. Where the 5-fathom isobath lies far from shore, wave energy is not sufficient to throw barrier sands onto the shoreline.

Another factor influencing the nature of the reentrant coastline is source of materials. Near-shore substrates in the reentrant section are more limey than sandy; limestone is not a good source material for building barrier beaches and islands. The effect of substrate is also seen by comparing (1) the highly dissected nature of the Ten Thousand Island area, which sits on erodable Tamiami Limestone with (2) the more solid blocks to the south, which rest on Pleistocene (Anastasia) sands. The latter are less soluble and more influenced (historically) by freshwater Everglades discharge (White 1970).

Recent sediments in the Ten Thousand Islands (Figure 10) have been deposited over the last 5,000 years during a more or less continuous marine transgression. Maximum sediment thickness reaches 7.6 m (25 ft) and consists of a mixture of clean, slightly peaty basal sands, relic vermitid (gastropod) reefs, silts, sands, oyster bars, and thick mangrove peats (Shier 1969). The Miocene Tamiami Formation forms the bedrock that underlies the entire Ten Thousand Islands area, and is discontinuously overlain by marsh sediments (clayey sands) that were deposited during the Wisconsin low sea-level stand, or during the subsequent sea-level rise. As the

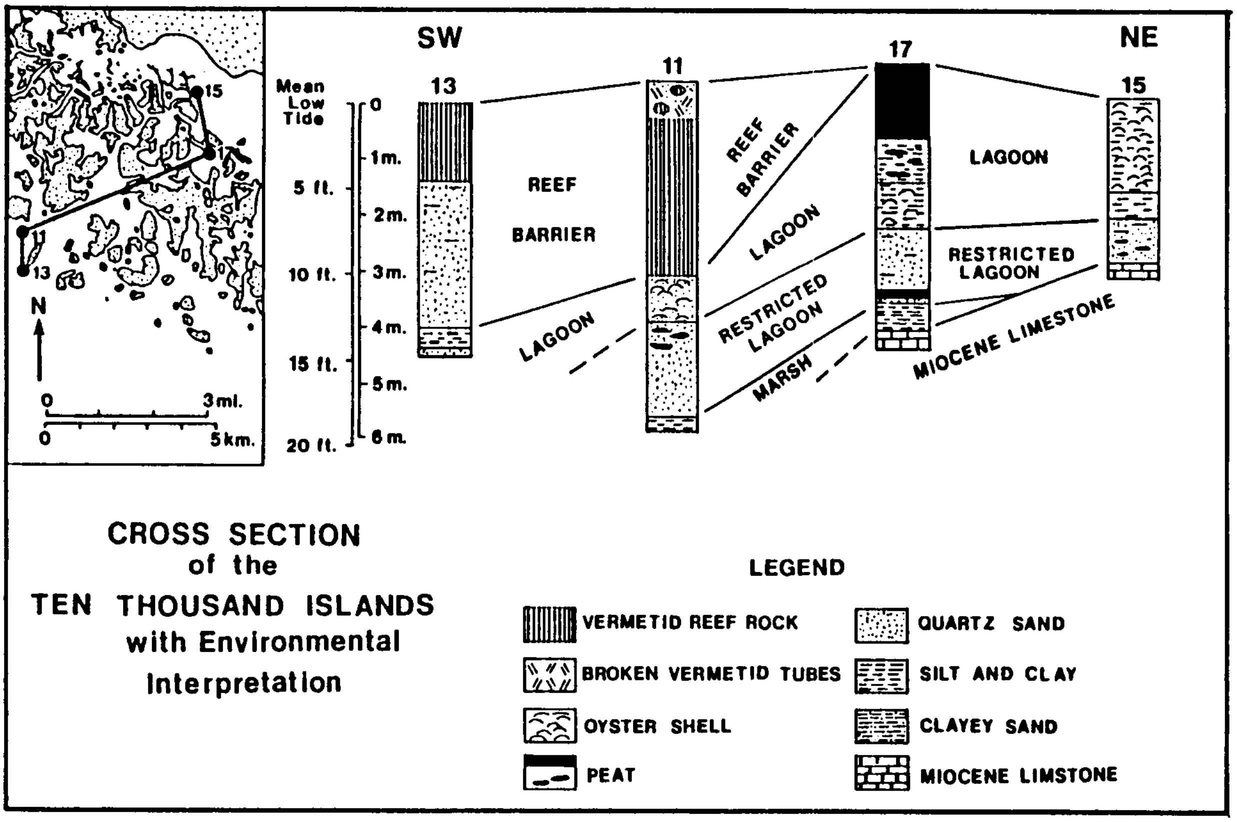


Figure 10. Geological cross section of the Ten Thousand Islands with environmental interpretations (adapted from Shier 1969).

post-Wisconsin sea-level rose over the gradual seaward slope of the Tamiami Limestone (5 to 10 cm per 1.6 km or 2 to 4 in per mi) a wide, shallow coastal sea formed. Along its outer edge ecological conditions favored the growth of a vermitid reef-forming gastropod, Vermetus (Thylaeodus) nigricans Dall (Shier 1969). A chain of vermitid reefs formed parallel to the coastline and created a lagoon as much as 6.4 km (4 mi) wide. A complex of bay bottom sands and silts, tidal pass sands, oyster bars, and thick mangrove peats has accumulated behind the reef barrier. Recent sediments along a landward-seaward transect of the Ten Thousand Islands are illustrated in Figure 10. The two basic island forms consist of (1) the outer or seaward vermitid reef based islands, and (2) the inner oyster reef-based islands. The former often exhibits an exposed vermitid-reef rock beach on the seaward side. Both are forested by mangroves. Sediments of the lagoonal and island environments are brought in by normal tidal currents and by waves and storm tides that accompany severe storms and hurricanes; they are also produced autochthonously (e.g. oyster shells, foraminifera, mangrove detritus, and peat).

To the north of Ten Thousand Islands and Cape Romano the brackish-zone vegetation decreases rapidly in lateral extent from 4.8 km (3 mi) in width at Gullivan Bay to only a fringing remnant along inner bays and barrier island lagoons north of Naples. High-energy barrier beaches and sheltered coastal embayments are prominent coastline features north of Marco Island.

The four major areas of gulf coastal lagoons behind barrier islands in the Big Cypress watershed are as follows:

(1) The Marco Island/Cape Romano leeward estuary (including Rookery Bay).
(2) The Gordon River estuary and Naples Bay near the town of Naples.
(3) Wiggins Bay at the downstream end of the Cocohatchee River.
(4) Estero Bay at the northern boundary of the basin.

Because of its size, shape, and hydrography the Caloosahatchee River estuary is considered a somewhat unique coastal lagoon. Though it is clearly protected by Sanibel and Pine Islands, its great length and relative straightness indicate a much more profound river drainage influence than in the more restricted estuarine embayments to the south.

2.5 RECENT SEDIMENTS AND SOILS

Holocene sediments in the Caloosahatchee River/Big Cypress watershed were products of a seasonal abundance of rainfall and a warm subtropical climate. This has, over the last 5,000 years, stimulated both luxuriant plant growth and case hardening of periodically exposed limestone rock. Much of the watershed "soils" are not actually soils in the textbook sense, that is, layers of mixed mineral and organic materials with characteristic profiles. Instead they represent only slightly weathered parent material, or modern sediments, some of which are still being formed; consequently the soils are generally described as surficial sediments. Horizons or layers that occur in the watershed usually reflect changes in sediment type, e.g., sand overlying calcareous marl, and are caused by successional sea-level transgressions and regressions or more subtle changes in wet and dry climatic conditions.

Chemical and biological processes have, within a relatively short period of time (5,000 years), modified the geologic features of the watershed. Rainwater, which combines with organic materials to form an acidic solution, accelerates limestone dissolution. Depending on the water-table height, the dissolved calcium carbonate may: (1) recrystallize within or on the rock surface to form a cap rock or (2) with the assistance of periphyton, be reprecipitated in low wet areas as calcitic marl (Duever et al. 1979). Roots, algae, fungi, storms, and fire provide forces that crack, tunnel, and otherwise destroy the structural integrity of the rock, exposing a greater surface area to dissolution processes. Exposed portions of the Tamiami Formation often exhibit these characteristics, particularly in the Big Cypress watershed (Duever et al. 1979).

The generalized soil-type distribution within the Caloosahatchee River/Big Cypress watershed is illustrated in Figure 11. Greater detail on the physical and chemical nature of soils is available from soil surveys published by the U.S. Soil Conservation Service (SCS 1975). These surveys contain 1:20,000 photomosaics overlain by soil series delineations; physiochemical descriptions of soil profiles down to a 2-m (6-ft) depth, where possible; and, a description of the soil series suitability for various land uses (Carlisle 1982). County soil surveys are at various stages of completion, which range

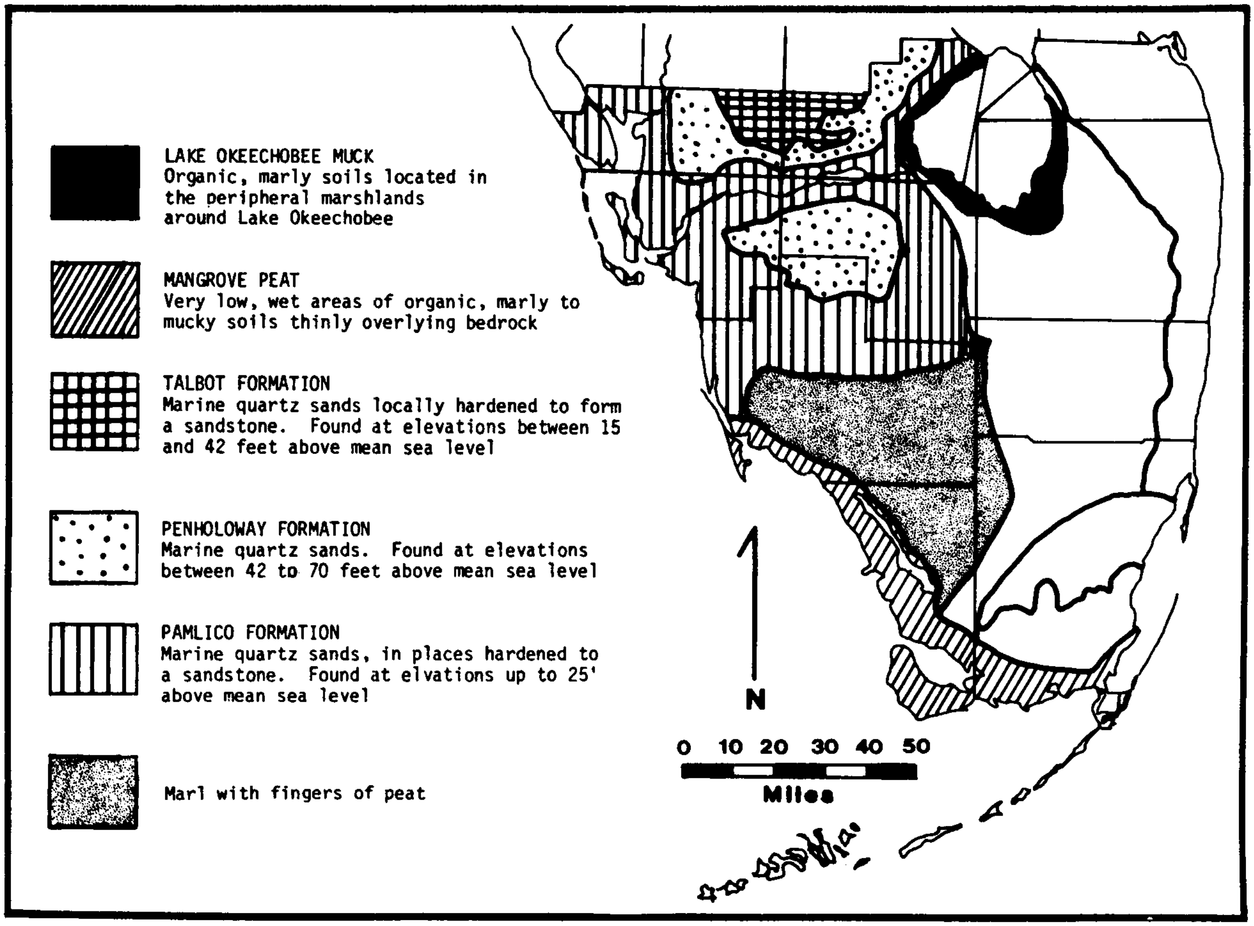


Figure 11. Generalized soil-type distribution in southwest Florida (adapted from Jakob and Waltz 1980).

from total absence of soils work in Glades County to the completed, but antiquated, Collier County soil survey. Another valuable information source on regional soils is reported in an annual publication, *Proceedings of the Soil and Crop Society of Florida*, which provides an academic forum for the most recent soil research in the state.

The soil types in the watershed (Figure 11) generally fall into one of the following five major substrate-sediment groups; limestone rock, calcareous muds (marls), sands (marine terraces), organic materials (peats and mucks), and mixed solids (Duever et al. 1979, SFWMD 1980). Although this classification departs from the more classical SCS county soil series, it is a much more practical system for the unique sediment characteristics of southwest Florida. The absence of either updated (e.g., Collier County), or completed county soil surveys also prevents a watershed or region-wide application of the soil series (Duever et al. 1979, Carlisle and Brown 1982). The five substrate groups differ from one another in terms of grain or particle size, homogeneity, chemical composition, and in many other chemical and physical properties that affect the type of plant communities found associated with them, and their suitability for use by man.

An additional substrate not specifically addressed in Figure 11 is man-altered or arent soils, e.g., dredge and fill, shell mounds, and landfills (Herwitz 1977). The soil composition is extremely diverse and its relationship to the surrounding environment has only begun to be studied. One example of this soil modification is in the inland and coastal man-made canals in the watershed. Modification of natural tidal tributaries to finger canals is prevalent in developments around Marco Island, Naples, Cape Coral, and numerous other coastal communities. Wanless (1974) and Wanless et al. (1975) studied the variation of sediments in natural and artificial waterways in the Marco Island area and noted numerous differences in the form and production of sediment. Possibly the most important distinction is the shift away from autochthonous sediment production in the natural waterways to a primarily allochthonous source of sediments in canal systems, carried into the canals by tidal and storm water movements. Also, decreases in particle size and bioturbation (infaunal) in the canals result in a more homogeneous and biologically sterile sediment composition (Wanless 1974). In situ sediment production in natural waterways was not only significant quantitatively, but also diverse in its composition. Sediment contributors include oysters and barnacles (prop root and bottom, along bay and tributary margins), mollusks, foraminifera, diatoms, benthic invertebrates in bays and channel-margin flats, seagrasses, and brown, green, and blue-green algae (benthic flora that provide detritus).

Marls are a muddy deposit of calcium carbonate silts, with occasional shells and shell fragments. In Florida, surface marl soils are basically the product of three processes: (1) physiochemical or biochemical precipitation of calcite crystals by freshwater periphytic blue-green algae that grow on sediment surfaces or as sheaths covering vegetation; (2) storm deposition of aragonitic marine muds in the mangrove keys, swamps, and other coastal areas; and (3) weathering of surficial limestone outcrops. Marl soils are often associated or mixed with sands or peats, depending upon local influences. For example, in mangrove forests, marls may occur along the margins of the mangrove peat. These marls are referred to as marly peat or peaty marl, depending upon the soils' major constituent. Marly sands or sandy marls are often found in the Big Cypress watershed and represent erosional products of the Tamiami Formation limestone outcrops. The production of calcite by blue-green algae generally occurs in seasonally wet marshes or wet prairies having sparse to medium density of vegetative cover and where limited shade permits penetration of sunlight to the surface sediments.

The major surficial marl deposits are located in the Big Cypress Swamp and in the marsh and prairie areas to the south. Marls and sand marls generally range in depth from 15 to 90 cm (6 to 36 in), exhibit a low-level relief, and, because of their low permeability to water, are often wet (Leighty et al. 1954, Duever et al. 1979, SFWMD 1980). Marl soils account for almost 400,000 acres or 29% of the soils surveyed in Collier County (Leighty et al. 1954).

Sands, which represent the dominant surficial soil in the Caloosahatchee River/Big Cypress watershed, are derived from old shoreline deposits, weathering of limestone, and the relocation of sands by wind and storm surges. Deposits are generally thicker and more extensive north and west of the Big Cypress Swamp, and consist either of marine quartz sands, carbonate sands, or a mixture of the two.

Marine quartz sands of the Pamlico, Penholoway, and Talbot Terraces dominate the surficial deposits from mid-Collier County to the northern reaches of the Caloosahatchee River watershed in Charlotte and Glades Counties. Surrounding Immokalee on the Immokalee Rise (White 1970) are sands, regarded as bars and swales, which thin to the south, east, and west, and eventually grade into the irregular western boundary of the Big Cypress Swamp to the east (Duever et al. 1979). Near the coasts is some carbonate sand fraction formed from shell material (SFWMD 1980). A mixture of the two sands has probably existed at one time in the terrace formations with the carbonate fraction subsequently being removed by dissolution and/or sorting.

The vegetation associated with sand soils exhibits tremendous variety in relation to (1) depth to water table, (2) presence of a hardpan, (3) character and depth of substrata, (4) grain size, (5) mixture of silt, clay, and organic material, and (6) elevation and slope. Vegetative communities range from seasonally inundated low-lying pine/palmetto flatwoods and prairies to elevated xeric dunes and ridges which support scrub oak and sand pines.

Limestone rock provides for one of the most unique and visually obvious surficial substrates in the Caloosahatchee River/Big Cypress watershed. The rock's appearance is caused by erosion, dissolution, and reprecipitation, which creates an irregular, undulating surface of hard, dense, and impermeable caprock. The processes involved in the caprock's formation are illustrated in Figure 12.

The Tamiami Formation dominates the surface rock substrates in the Big Cypress watershed. The facies which represent the formation are distinguished by several factors including sand content, fossil content, porosity or fragment size, degree of surface hardening, and topography (SFWMD 1980). The caprock is typically well laminated, thick, and highly indurated. The surfaces are perforated with solution features which contain caliche (dark-tan colored, finely laminated crusts), solution breccias, later marine deposits, sands, marls, and post-depositional cements (Duever et al. 1979). Of secondary importance, areally, are the Fort Thompson and Miami Limestone outcrops, which make up some of the surficial rocks along the eastern edge of Collier County and occur in isolated pockets in the Big Cypress watershed. Pinnacle rocks, which provide the most overt signs of these latter formations, exhibit a very irregular caprock or crust with sharp-pointed projections and small conical depressions (Cooke 1945, SFWMD 1980).

Vegetation associated with the rock outcrops include slash pine, cabbage palmetto, saw-palmetto, shrubs, grasses, and dwarf cypress. In Collier County, where most of the area's limerock substrate occurs, the rocklands (also referred to as pine rocklands) account for 6.4% (83,000 acres or 33,590 hectares) of the area (Leighty et al. 1954). Hardwood hammocks often appear on elevated limestone outcrops in the southern Everglades region of the Big Cypress watershed. Craighead

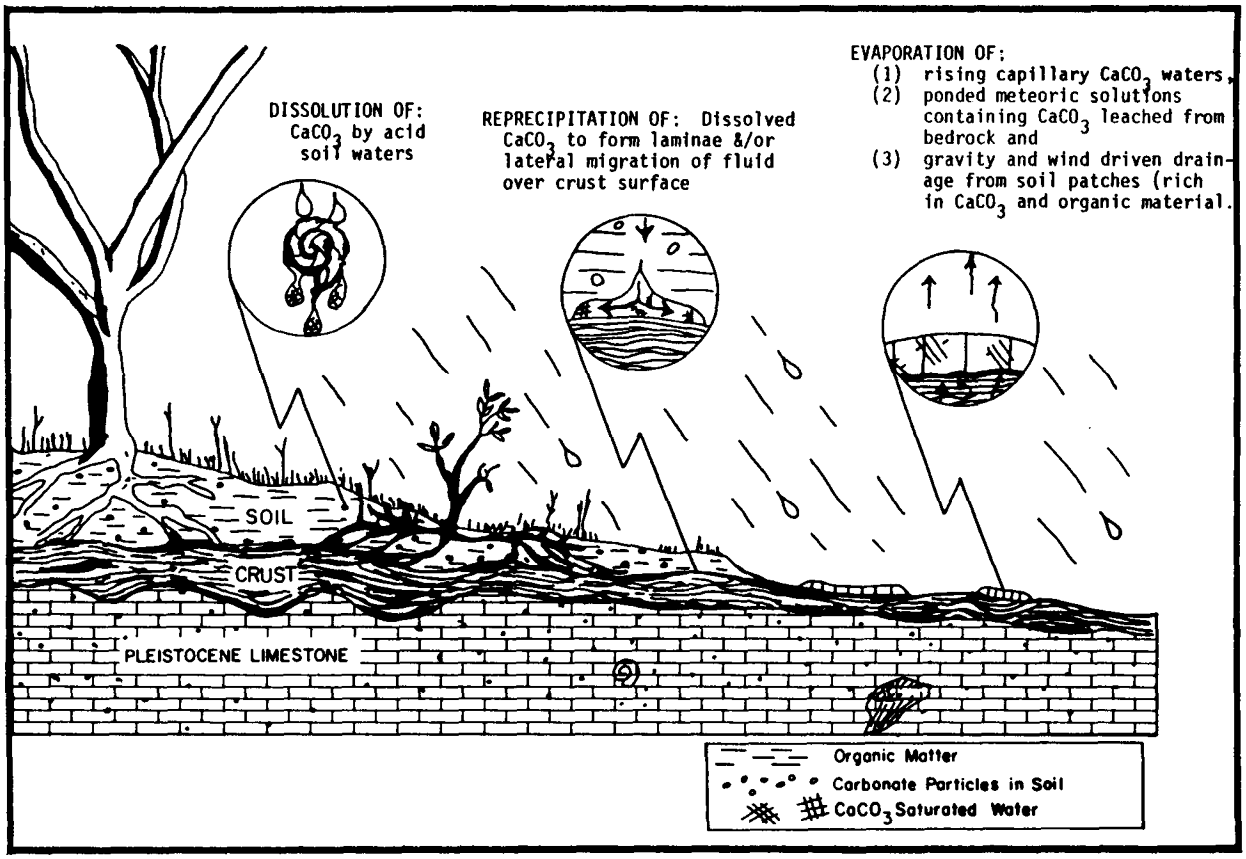


Figure 12. Environmental mechanisms involved in forming subaerial crusts (adapted from Multer and Hoffmeister 1968).

(1974) and Duever et al. (1979) suggest that the hammock develops along a self-destructive course. The outer trees in the circular or tear-drop shaped hammocks are more susceptable to fire or wind damage. When the dead outer trees are blown down (windthrown) their extensive root systems gouge or crack the existing caprock, which accelerates dissolution of the limerock. The opened cavities eventually encircle the hammock, forming a moat. Only sparse aquatic or emigrant vegetation lives around the moat's shaded inner wall to stabilize the rock and provide organic material. That, in combination with the organic acids produced from the hardwood litter decomposition, causes continued undermining of the hammock rock. The end result is the elimination of the hammock and the upper rock unit. Pine rocklands are characterized by extremely irregular, exposed, and elevated bedrock surfaces. The pines root in sediment-filled solution holes or crevasses as do the hardwoods in hammocks. Hardwoods are generally excluded from the pine rocklands because of the frequent fires that prevent an accumulation of organic litter in the soil. The low level of organic material and the alkaline nature of the limerock reduces the acid dissolution of the limestone. Also, the amount of marl in the soils is minimal because of the relatively elevated and drained conditions of these pinelands.

The organic substrates, peat and muck, are formed of partially decomposed plant material and a mixture of inorganics such as sand, clay, or silt. These substrates often develop in wetland environments where the inundation of water creates an anaerobic layer at the sediment-water interface. This permits and encourages the accumulation of partially decomposed organic materials. The difference between peat and muck is primarily the degree of decomposition. Peat represents a fibrous organic substrate that is only slightly altered from the original structure, retaining identifiable plant parts, (e.g., leaves, stems, seeds, and roots). The parent material is local (autochthonous), and the ash and inorganic content is typically low. In contrast, muck is a thoroughly decomposed, fine-grained, nonfibrous, organically-rich substrate, which is high in ash content and often mixed with inorganic sedimentary material. Source material for muck is either autochthonous or allochthonous (transported from outside the decomposition site).

The origin, structure, chemical qualities, deposition rates, environments/patterns, and other characteristics of organic sediments are well studied, but because of their complexity they will be only briefly mentioned here. A number of excellent reviews are reported in the literature. Davis (1946) gives an extensive review of peat deposits in Florida, including information on their nature, origin, type, and composition. This work is supplemented by Cohen and Spackman's (1974) description of south Florida peats, and Stone and Gleason's (1976) and Kropp's (1976) work in the Corkscrew Swamp Sanctuary.

The major surface peat deposits in the Caloosahatchee River/Big Cypress watershed are located along the southwest coast from Gordon Pass south, in the far eastern Caloosahatchee River region which borders Lake Okeechobee, and in the Corkscrew Swamp Sanctuary near Lake Trafford (Davis 1946, Leighty et al. 1954). In addition, small deposits are typically found in the area's numerous swamps, marshes, ponds, and sloughs, and along some stream margins. These smaller deposits are particularly common in the Big Cypress Swamp, where they are contained in wet depressions throughout the rockland, sand, and marl areas. Organic deposits range in depth from a few centimeters to 3 meters (up to 9 feet or more), and are high in carbon and nitrogen, but low in other nutrients, e.g., phosphorus (SFWMD 1980). The type and condition of a peat is dependent on the water depth, pH, hydroperiod, parent vegetation, topography, thickness, degree of decomposition, character of the underlying sediment, inorganic content, and pressure of incorporated layers such as marl, shell, limerock, or sand. Peats are most often classified by their parent material, e.g., mangrove peat, Conocarpus (buttonwood) peat, Spartina peat, and others (Cohen and Spackman 1974). Mangrove peat, which forms in much of the southwestern coast's tidal areas, typically retains much more of the original plant structure than its freshwater and brackish water counterparts. It also exhibits a greater ash content caused by the intermixing of shells and sands, which are transported into the swamps by tides and storms.

Compared to the freshwater peats of the Everglades, the Corkscrew

Swamp peats are more degraded and mucky, with less identifiable plant tissue structure. This condition may be indicative of a poorer preserving environment at the Corkscrew Swamp, possibly a shorter hydroperiod, or a deeper zone of aeration (Stone and Gleason 1976). The basal peat samples dated from this deposit have been carbon-14 dated in the range of 4700 to 5700 years B.P., the latter being the oldest peat deposit recorded in south Florida (Kropp 1976, Duever et al. 1979).

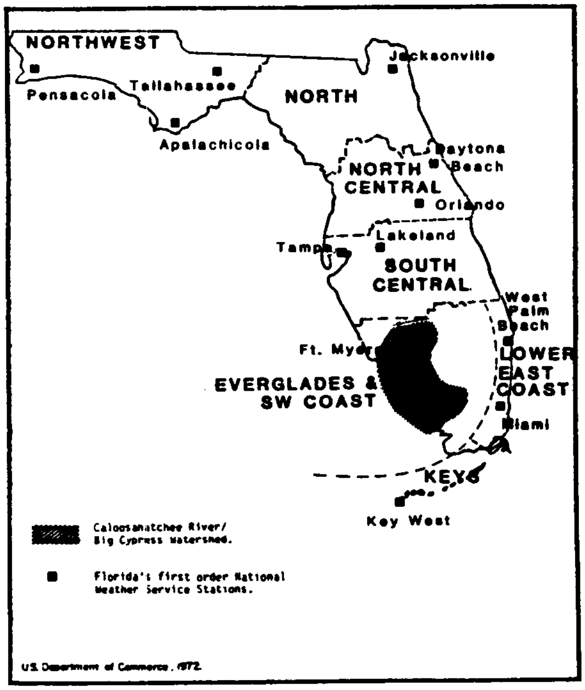
Along the eastern edge of the Caloosahatchee River watershed, brown to black peat and muck deposits reach a maximum thickness of 3 m. Westward these deposits integrate with quartz sands which originate from the major terraces (Klein et al. 1964). This deposit is the western extension of the large Everglades Peat Bed (Davis 1946).

CHAPTER 3
CLIMATE

3.1 INTRODUCTION

A classification system devised by the National Weather Service divides Florida into seven climatic divisions. The Caloosahatchee River/ Big Cypress watershed is contained entirely within the Everglades and Southwest Coast climatic division as illustrated in Figure 13. This division and each of the other climatic divisions encompass an area within which basic climatic variables, primarily temperature and rainfall, are generally consistent when averaged over extended periods of record. Obviously the boundary lines between the climatic divisions approximate general lines of change. Sometimes station-to-station differences within a division exceed divisional variation. This is particularly true between coastal and inland areas. Despite these differences, climatic divisions are a means for organizing statewide and basinwide climatic indicators.

The location of Florida's first-order weather stations operated by the National Weather Service are shown in Figure 13. These stations provide the most inclusive weather data base available. Each station's data base is supplemented by cooperative and research stations that provide weather data of a more limited nature (e.g., rainfall and air temperature). These secondary weather stations monitor the climate for a variety of applications. Agriculture, water management, and aviation are three of the most important. For the Caloosahatchee River/Big Cypress watershed, detailed meteorological information is available only from the Fort Myers station. For a more in-depth review of the weather stations adjacent to and within the watershed, refer to the publications of Parker et al. (1955), Thomas (1970), Bradley (1972), Thomas (1974), Duever et al. (1979), Bamberg (1980), and MacVicar (1981) and (1983).



US Department of Commerce, 1972

Figure 13. Florida climatic divisions (adapted from Gutfreund 1978).

In general terms, the mild subtropical climate of the watershed is a reflection of a low geographical relief, the encirclement by the large water masses of the Gulf of Mexico, the Everglades, and Lake Okeechobee, and a relatively low latitude (Bradley 1972, Pielke 1973, Gannon 1978). The slight relief permits the uninterrupted movement of winds and rains across the terrain. These movements are obstructed instead by the atmospheric changes caused by the surrounding water masses. The water bodies moderate temperatures (acting as a heat source in winter and a heat sink in summer) and provide a valuable source of moisture for rains. The inland areas are typically cooler (in the winter) or warmer (in the summer) than the adjacent coastal regions. The latitude indicates moderate winter temperatures.

Of the three climatic patterns that Hela (1952) associated with south Florida, two are applicable to the reference area. All of the Big Cypress watershed and the southern half of the Caloosahatchee River watershed are characterized by a tropical savannah climate, which has a relatively long and severe dry season and a wet season. North of the Caloosahatchee River a humid mesothermal climate predominates, characterized by a warm, moist summer and a moderate dry season.

3.2 RAINFALL

Mean annual precipitation for the Caloosahatchee River/Big Cypress watershed is about 135 cm (53 in) (Bradley 1972). The dry season, from November to April (Riebsame et al. 1974), provides between 16% and 26% of the annual rainfall, and the wet season (June-September) accounts for over 60%. The relationship between wet season, dry season, and total annual rainfall for individual stations and for geographical groupings (Coastal-Inland-Lake and North-South) is shown in Table 3. Mean annual rainfall patterns for the watershed are illustrated in Figure 14. Average annual rainfall exceeding 152 cm (60 in) is reported for coastal locations south of Sanibel Island (Bonita Springs and Marco Island) and northeast of Immokalee (Fig. 14). Near Estero, the annual average rainfall is greater than 178 cm (70 in). Overall, the average annual rainfall decreases from the coast to Lake Okeechobee and from south to north (Table 3). Rainfall is lowest (less than 125 cm or 49 in) north of the Caloosahatchee River from Charlotte Harbor to the Franklin Locks at Olga (Bamberg 1980). The region around and north of the Caloosahatchee River exhibits a more even annual distribution of rainfall than the tropical-savannah climate in the southern portion of the area. Contrary to a 5-year cycle of rainfall along the southeast Florida coast, and in the Everglades and Florida Keys, there are no discernible long-term cycles in the reference area (Gee and Jensen 1965, Thomas 1974, Duever et al. 1978).

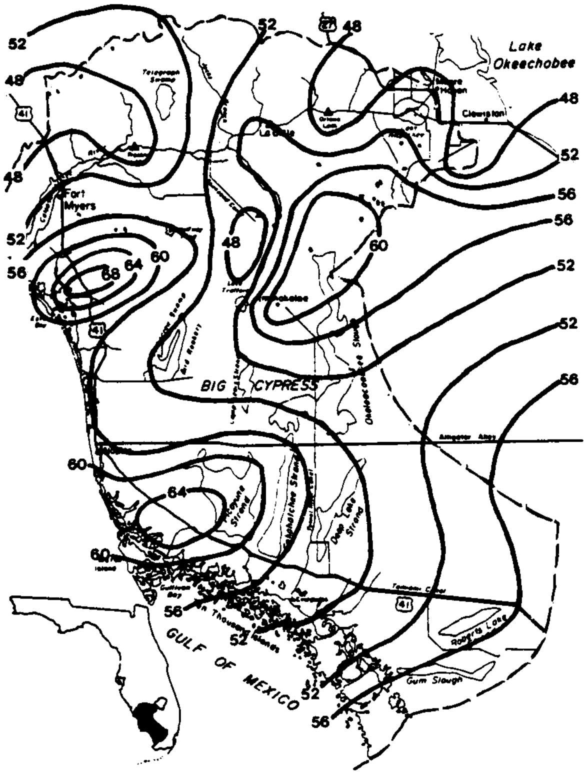


Figure 14. Average annual rainfall (inches) for the Caloosahatchee River/Big Cypress watershed (adapted from Bamberg 1980).

Table 3. Wet season, dry season, and total annual precipitation for the Caloosahatchee River/Big Cypress watershed.

	Station Location	n[1]	Rainfall in Inches Dry Season	(%)	Wet Season	(%)	Annual Mean Rainfall (inches)	Ref[2]
COASTAL	(S)Everglades	43	10.38	(19)	44.49	(81)	54.87	1
	(S)Marco Island	10	12.26	(19)	51.98	(81)	64.24	2
	(S)Naples Caribe Gardens	27	10.74	(20)	42.99	(80)	53.73	1
	(S)Bonita Springs	13	9.53	(17)	47.26	(83)	56.79	1,2
	(N)Estero	10	16.12	(23)	54.14	(77)	70.26	2
	(N)Captiva	29	12.44	(26)	36.30	(74)	48.74	1,2
	(N)Ft. Myers	98	11.52	(22)	41.48	(78)	53.00	1
	(N)Ft. Myers Airport	40	11.37	(21)	42.58	(79)	53.95	3
	(N)Punta Gorda 4ENE	48	12.64	(25)	39.05	(75)	51.69	1,2
INLAND	(S)Tamiami Trail 40 mi.	26	10.10	(18)	47.00	(82)	57.10	1
	(N)Big Cypress Res.	15	10.87	(21)	41.54	(79)	52.41	1
	(N)Lake Trafford	21	11.31	(23)	38.54	(77)	49.85	1
	(N)Devils Garden Tower	25	12.70	(22)	45.63	(78)	58.33	2
	(N)Felda	9	11.52	(26)	32.30	(74)	43.82	1
	(N)Olga Lock	12	12.29	(26)	34.35	(74)	46.64	2
	(N)La Belle	40	12.22	(23)	40.41	(77)	52.63	1,2
LAKE	Clewiston	22	10.61	(23)	36.26	(77)	46.87	1,2
	Clewiston U.S. Eng.	21	11.30	(22)	39.21	(78)	50.51	1
	Moore Haven Lock 1	51	11.36	(23)	39.04	(77)	50.40	1,2

Groupings	Dry Season	%	Wet Season	%	Total
Coastal	11.89	21	44.47	79	56.36
Inland	11.58	22	41.25	78	52.83
Lake	11.09	23	38.17	77	49.26
South	10.60	18	46.74	82	57.35
North	12.35	23	41.40	77	53.75

[1] n = years of record, (S) = Southern half of watershed, (N) = Northern half of watershed.
[2] References: 1) Thomas 1974; 2) Bamberg 1980; 3) USDC 1981a.

Rainfall in the dry season (November to April) is derived primarily from large-scale (synoptic) cold frontal systems that move into the area about once a week (Thomas 1970, Echternacht 1975, Bamberg 1980). Rainfall related to these fronts 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 temporal passage of the system (Echternacht 1975). Frontal rainfall typically extends along a line from the northeast to the southwest over Florida's peninsula, sweeping south or southeast. The warm, humid air masses to the south converge with the cooler, drier air carried with the front, generating rainfall along the frontal path. As a front passes, individual radar responses (areas of rainfall) move perpendicular to the frontal motion (Bamberg 1980). Data reported during its passage would be expected to come from a number of meteorological stations simultaneously (Gruber 1969), and would be independent of the diurnal cycles reported for convective storms (Asplidin 1967). Rainfall intensities depend on the strength of the interacting air masses and motions of individual precipitation 'pockets' within the front. Occasionally, large amounts of rainfall can fall within a narrow areal band if the front becomes stationary.

The dry season mean rainfall for the watershed is given in Figure 15. Rainfall is higher near the coast and decreases inland. Highest values (>41 cm or 16 in) are reported from Estero. Rain in the remainder of the watershed averages between 25 and 30 cm (10 and 12 in).

By mid-spring the incidence of frontal systems moving in from the north decreases in southwest Florida, and local sea-breeze/convection circulation becomes the dominant force controlling wet-season rainfall (Echternacht 1975, Bamberg 1980). The local sea breezes interact with large-scale (synoptic) air flow (primarily southeasterlies and southwesterlies) to form lines of convergence. These lines of convergence are the most probable sites for rainstorm development (Frank et al. 1967, Gruber 1968, Pielke 1973). The predominant form of the convective wet-season storm is the thunderstorm. These storms are brief (1 to 2 hours), usually intense, and occasionally attended by strong winds or hail (Bradley 1972). Thunderstorms in the Fort Myers area are more frequent (over 100 annually) than anywhere else along the eastern gulf coast and most frequent (75%) during the summer months (Jordan 1973, Duever et al. 1979). Day-long wet-season storms are infrequent and are generally associated with tropical disturbances. Since the short duration-high intensity thundershowers are related to cyclic land-sea breeze convective processes, the rainfall follows a diurnal pattern usually peaking during the late afternoon or early evening hours, a period of maximum atmosphere convergence (Gruber 1969, Echternacht 1975). The most intense convergence takes place a short distance from the west coast, where maximum wet season rainfall reaches 127 cm (50 inches) at Estero and 76 to 102 cm (30 to 40 inches) along the remainder of the coast. Rainfall patterns for the watershed's wet season are illustrated in Figure 16. Because of the enormous size of Lake Okeechobee, a lake breeze (similar to coastal sea breezes) develops to form an area of divergence over the lake (air and moisture diverging away from the center of the lake) that restricts vertical raincloud development and wet-season rainfall (Figure 16). The net effect minimizes wet-season rainfall directly over the lake (Pielke 1974, Riebsame et al. 1974, Woodley et al. 1974, Bamberg 1980). Convective wet-season storms show greater spatial and

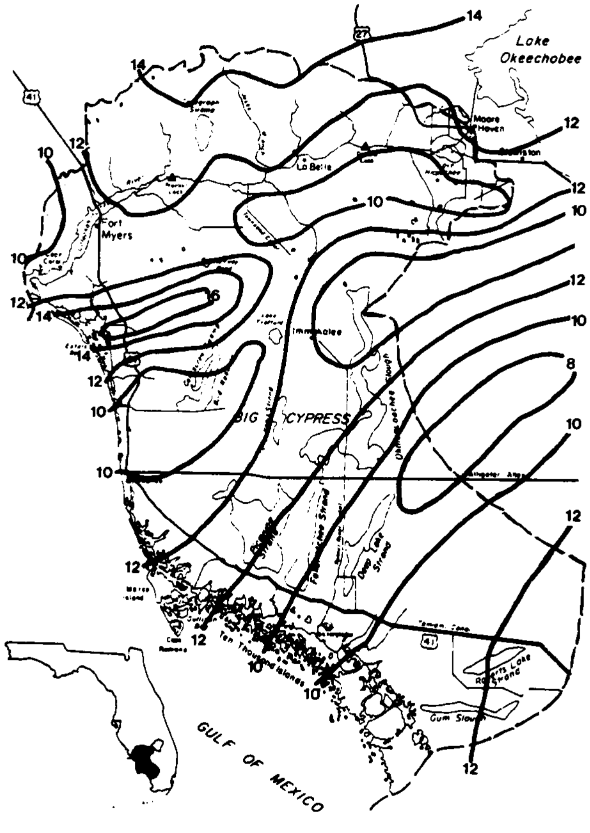


Figure 15. Average dry-season rainfall (inches), November through April, in the Caloosahatchee River/Big Cypress watershed (adapted from Bamberg 1980).

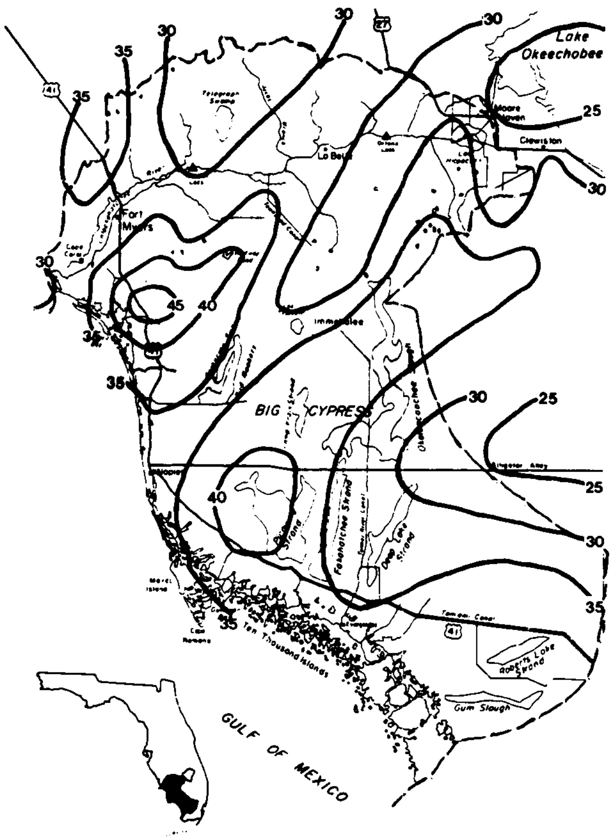


Figure 16. Average wet-season rainfall (inches), June through September, in the Caloosahatchee River/Big Cypress basins (adapted from Bamberg 1980).

temporal variation than the synoptic dry-season regime. Extreme gradients of 10 cm in 1.6 km (4 inches in 1 mi) and 36 cm in 6.4 km (14 inches in 4 mi) were reported by Woodley et al. (1974). Variations over 12 cm (5 in) in one month at stations less than 8 km (5 mi) apart at Corkscrew Swamp Sanctuary were reported by Duever et al. (1975). Woodley (1970) estimates the natural variability of rainfall from a single cumulonimbus cloud in south Florida to range from 200 to 2,000 acre-feet.

Distribution of rainfall over southern Florida in the wet season follows a bimodal pattern (Figure 17). The first of two peaks comes in May or June and the second in September or October (Thomas 1974). This biomodal seasonal distribution of rainfall is associated with an upper air trough that extends southward from the middle latitudes in June and centers itself over southern Florida. The trough is displaced westward into the Gulf of Mexico in July and August and returns again in September or October (Thomas 1970, Gruber 1969). Rainfall is heaviest when this trough is overhead (Riehl 1954).

A precipitation statistic commonly reported and of interest for air pollution and ecological studies is the number of days on which certain amounts of rainfall are reported, i.e., rainfall greater than or equal to 0.254 cm (0.10 inches). Mean number of days per month having rainfall greater than 0.0254 cm (0.01 inches) and 0.254 cm (0.10 inches) at stations in or near the watershed or shown in Table 4.

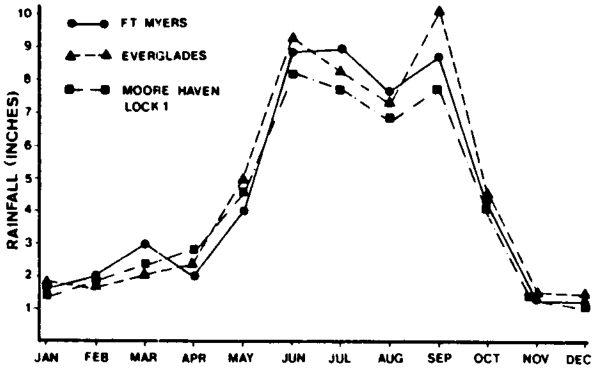


Figure 17. Average monthly rainfall at three locations in the Caloosahatchee River/Big Cypress watershed (adapted from Thomas 1974 and USDC 1981a).

Table 4. Mean number of days per month with rainfall greater than 0.0254 cm (0.01 inch) and 0.254 cm (0.10 inch) at stations in the Caloosahatchee River/ Big Cypress watershed (adapted from Gutfreund 1978).

DIVISION Station	MEAN NUMBER OF DAYS PER MONTH WITH RAINFALL >0.01 INCH (0.0254 cm)												
	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

DIVISION Station	MEAN NUMBER OF DAYS PER MONTH WITH RAINFALL >0.10 INCH (0.254 cm)												
	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

The monthly and seasonal distribution of rainfall is relatively uniform. The mean annual rainfall and the number of days with rainfall greater than or equal to 1.27 and 2.54 cm (0.5 and 1.0 inch) for the Everglades and Southwest Coastal climatic division follow the same temporal patterns that are shown in Table 4 (Gutfreund 1978).

Rainfall frequency-distribution curves developed from the 1975 to 1979 rainfall records for Clewiston and Fort Myers are illustrated in Figures 18 and 19, respectively, (Anderson 1982). These figures and the data in Table 4 show that approximately 75% of the rainfall events in the watershed contribute less than 1.27 cm (0.50 inch) each.

The SFWMD has recently completed the first phase of a project that 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 1 to 5 days, and wet, dry, and annual series for 1-, 3-, 5-, 10-, 25-, 50-, and 100-year return periods. The average annual maximum for 1-day rainfall is given in Figure 20. These rainfall-frequency maps cover south Florida and include data from all rain gauges with a minimum of 20 years of available daily records.

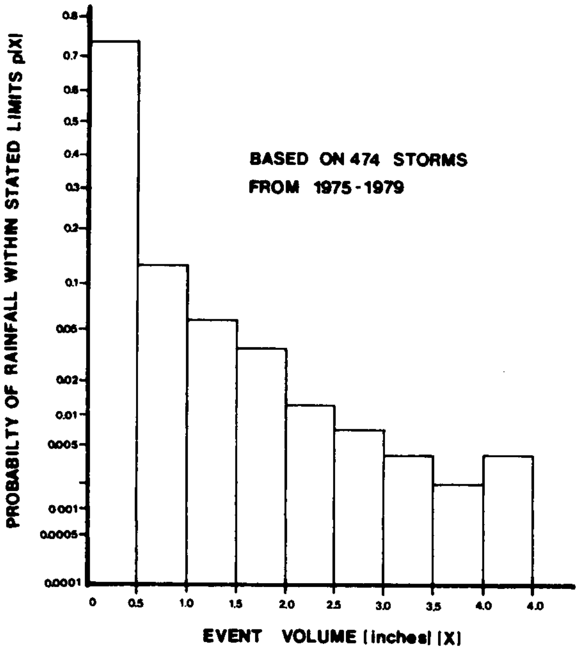


Figure 18. Frequency distribution of rainfall at Clewiston, 1975 to 1979 (adapted from Anderson 1982).

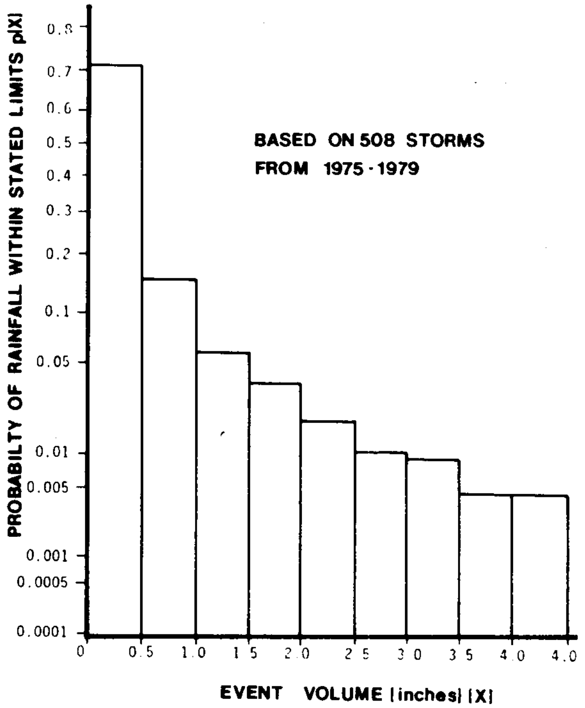


Figure 19. Frequency distribution of rainfall at Fort Myers, 1975 to 1979 (adapted from Anderson 1982).

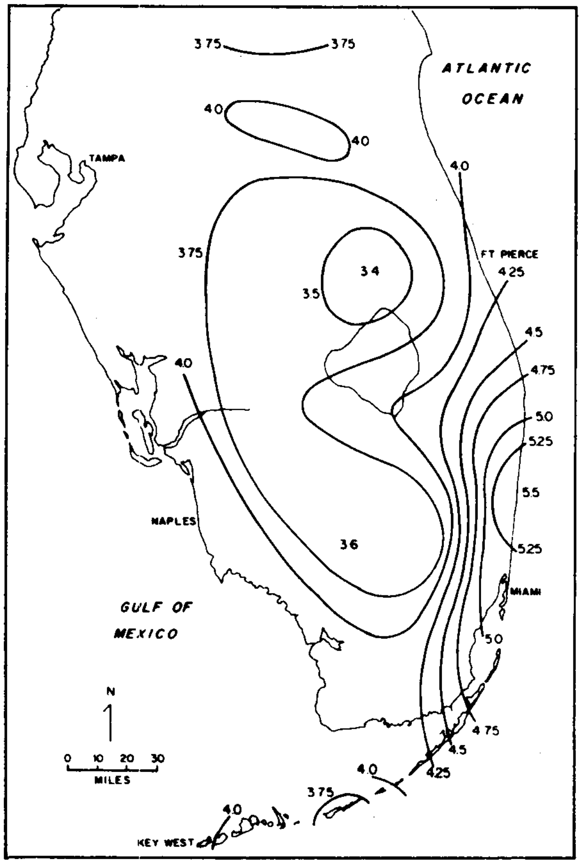


Figure 20. Average annual maximum rainfall (inches) for one day in south Florida (adapted from MacVicar 1981).

Despite the usually abundant wet-season rainfall, drought may occur in south Florida even during the wet season (Bradley 1972). During one of the worst droughts on record, in 1971, only 87.9 cm (34.6 inches) of precipitation was recorded in the Everglades and Southwest Coast Climatic Division, and wildfire caused severe damage throughout the Big Cypress watershed (Duever et al. 1979). Longterm spatial and temporal variation of droughts in south Florida is given in Figure 21. Of the nine droughts recorded from 1940 to 1980 for Lake Trafford (48 km or 30 mi ESE of Fort Myers) only four were concurrently observed at Fort Myers. The only drought to affect both Lake Trafford and Miami was in 1949. Miami and Fort Myers show no overlap of the ten worst droughts recorded at either station. This illustrates how localized even severe droughts are and how cautious we must be in extrapolation of weather data from first-order weather stations (Fort Myers and Miami) to nearby areas (Duever et al. 1979, MacVicar 1983).

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 on this is that of Gannon (1978). His model of the daily seabreeze circulation over the south Florida peninsula showed that developments on the land surface, such as urbanization and wetland drainage, inadvertently modify weather patterns by redistributing

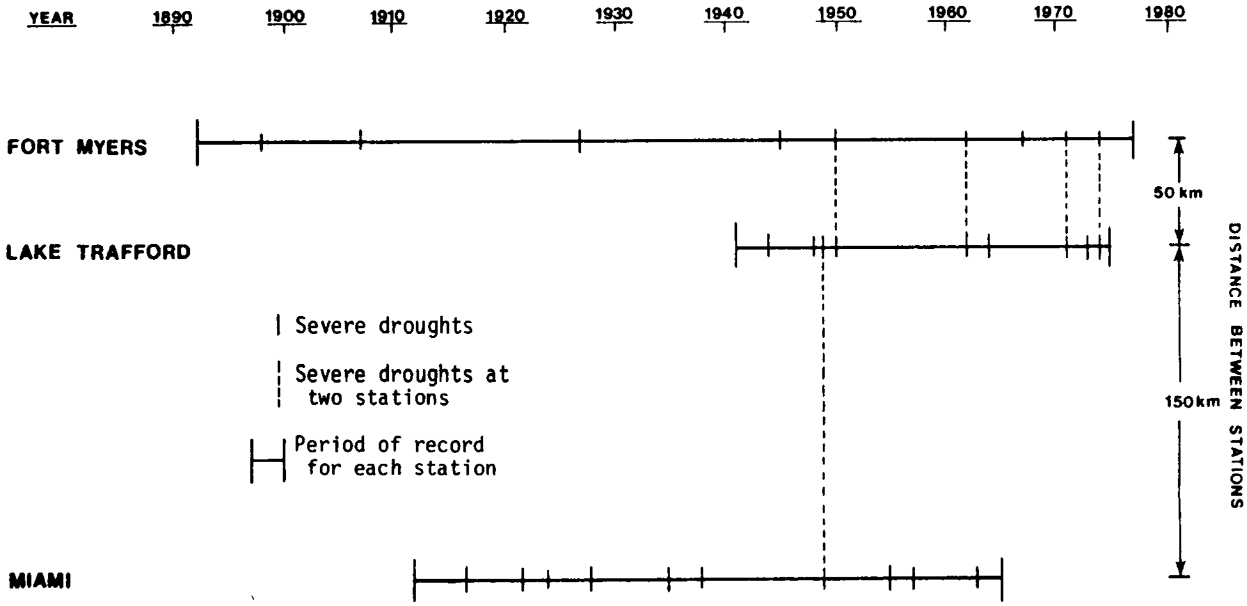


Figure 21. Severe droughts from 1890 to 1980 at Fort Myers, Lake Trafford, and Miami (adapted from Duever et al. 1979).

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 daily sea-breeze circulation in Gannon's model. Surface albedo in turn is inversely related to soil moisture; consequently, wetland drainage may exert something of a self-accelerating effect on the daily hydrologic cycle by lowering soil moisture (which itself changes the heat budget), by providing less moisture for evapotranspiration, and by increasing surface albedo (which increases daytime heating). The total removal of wetlands from the weather cycle through asphalt and concrete paving and other urban development further amplifies the shift toward higher temperatures.

The insidious implications of temperature change for fish and wildlife as well as for the human population of south Florida have recently been noted by A. 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". The wet-season rains, which are so vital to south Florida's ecosystems, are less frequent because of 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 in the wet season and 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), at 0 to to 610 m (0 to 2,000 ft); 500 mb, at 5,486 to 6,096 m (18,000 to 20,000 ft); and 200 mb, 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. The four seasonal wind-field patterns adapted by Echternacht (1975) at the 950-mb level (i.e., for low-level winds) are illustrated in Figure 22. A dominant easterly influence varying from east-northeast and east-southeast in fall and winter seasons, to southeast and south-southeast in spring and summer characterizes the Caloosahatchee River/Big Cypress watershed.

The prevailing easterly winds interact with the two seasonal wind patterns described previously. For the wet season (May to October) convective-scale winds initiated by thermal gradients at the land-sea interface counter the prevailing southeasterly winds (Pielke 1973). The heating of the land surface promotes sea-breeze circulation during the day, causing a convergence of warm moist air over the peninsula (Gannon 1978, Gutfreund 1978). At night the circulation reverses as 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 reference areas' wet-season climate because of the flat terrain and proximity to the water (< 40 km or 25 mi) (Bradley 1972, Echternacht 1975). The daily changes in divergence over the Florida peninsula from June through August were monitored by Frank et al. (1967). As illustrated in Figure 23, a pronounced diurnal pattern shows very strong convergence (i.e., negative divergence) peaking from 12:00 to 2:00 P.M. This pattern demonstrates that the convective scale is the fundamental scale of motion during the watershed's wet season (Echternacht 1975).

In the dry season (November to April) the convective influence diminishes as the sun's angle of incidence decreases. This reduces the radiant heating of the land surface during the day and minimizes the thermal gradient between the land-sea surfaces (Blair and Fite 1965). In the dry season, the wind patterns are influenced by synoptic-scale systems or winter frontals moving cold air masses southward. Although south Florida is far enough to the south to remain under the influence of the easterlies year round (Figure 22; winter), a northerly component, related to the synoptic-scale systems, affects the daily weather patterns (Echternacht 1975). Winter cold fronts typically pass over the watershed once a week during the dry season (Bamberg 1980). Warzeski (1976) describes the cold front in south Florida 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 watershed's first-order

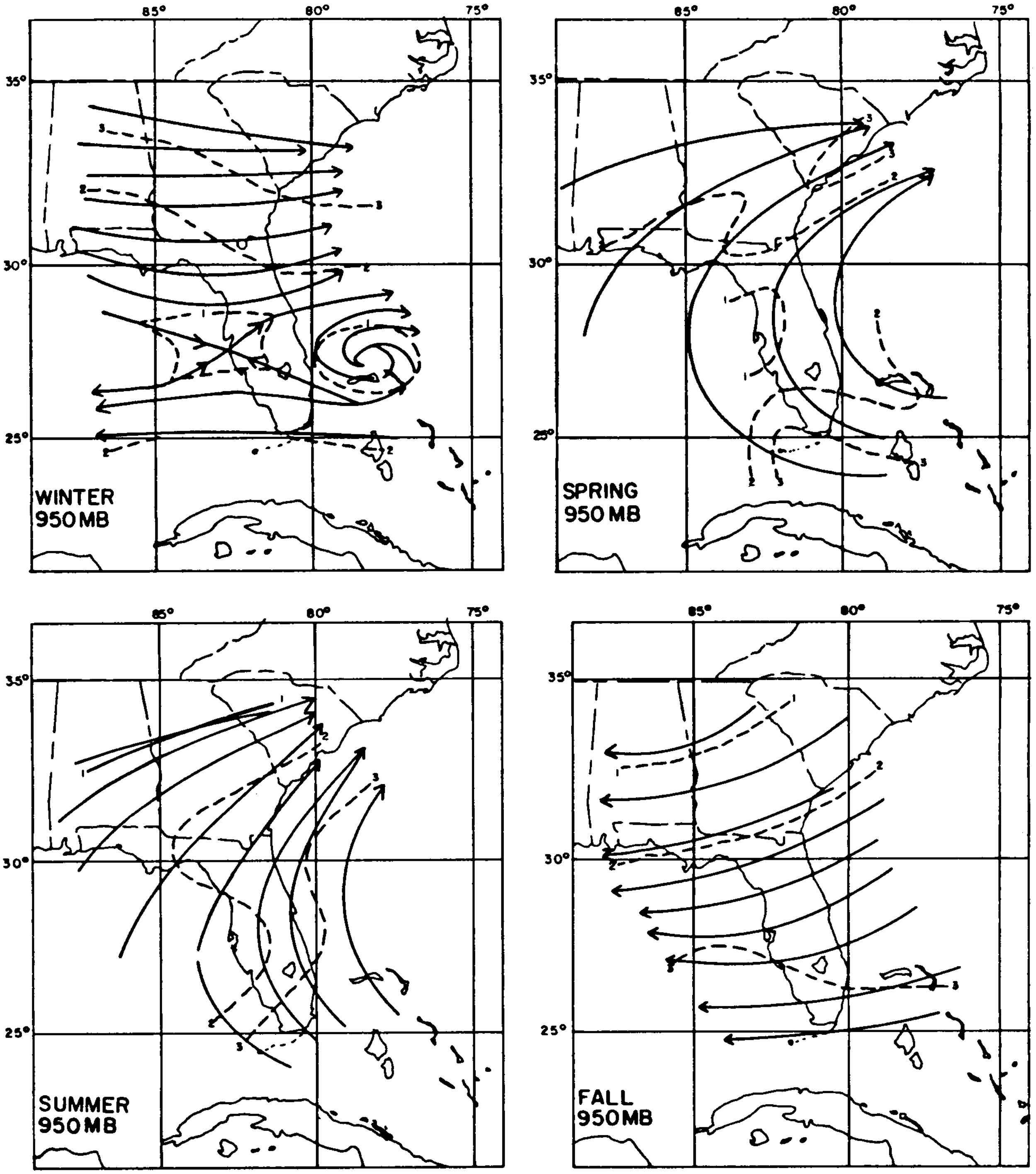


Figure 22. Representative seasonal streamlines and isotachs over the Florida Peninsula (adapted from Echternacht 1975).

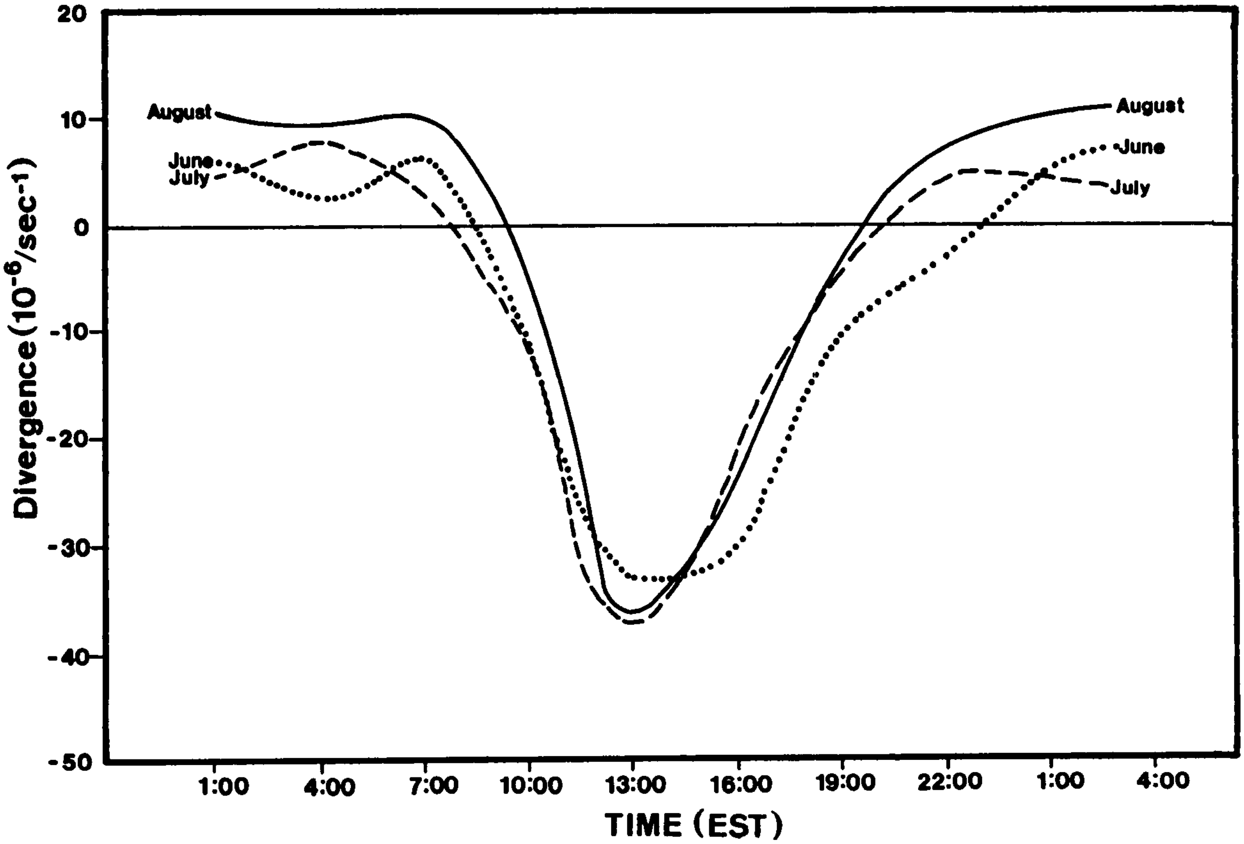
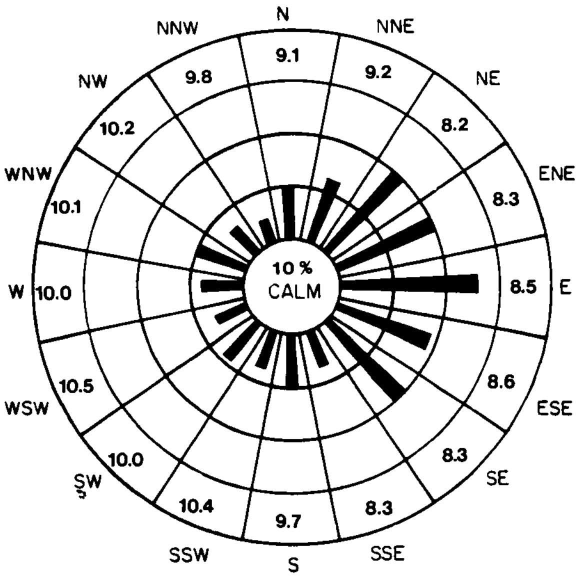


Figure 23. Average monthly divergence curves over the Florida Peninsula for June, July, and August, 1963 (adapted from Frank et al. 1967).

weather station (Fort Myers) is summarized in the wind rose in Figure 24 (Gutfreund 1978). Wind directions most frequent each month are given in Table 5. These two methods of presentation (Figure 24 and Table 5) do not give an adequate depiction of diurnal shifts in wind direction and speed caused by differential heating of air and water surfaces during the wet season, or the passage of individual winter frontal systems; however, Figure 24 and Table 5 do indicate the predominance of different seasonal factors controlling wind. On a seasonal basis, highest average wind speeds are likely in late winter and early spring, and lowest speeds are most likely in the summer. Localized high winds of short duration are generated by summer thundershowers and cold fronts (Bradley 1972). Wind speeds associated with convective systems follow a diurnal pattern. On a typical day, wind speeds are lowest in the nighttime, increase during the daylight hours to a peak in the late afternoon, and then decrease again in the evening (Gutfreund 1978).

Synoptic-scale influences are related to the passage of the front, as previously described, rather than with diurnal patterns (Warzeski 1976). The influence of synoptic-scale systems on prevailing wind direction is shown by the northerly component of the prevailing wind directions from October through January (Table 5).



Concentric circles represent 5 percent frequency intervals.

Average wind speed (mph) for each direction is shown along outer circumference.

Period of record: 1969-1973.

Figure 24. Annual wind rose for Fort Myers (adapted from Gutfreund 1978).

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 Caloosahatchee River/Big Cypress watershed (Gutfreund 1978). Seasonal variations in wind speed and direction at the 950-mb level (0 to 610 m or 0 to 2,000 ft) are given in Figure 22.

Table 5. Most common wind direction and speed by month for the Fort Myers first order weather station (adapted from USDC 1981a).

Ft. Myers International Airport		
Month	Wind Speed (mph)	Prevailing Direction
J	8.5	E
F	9.1	E
M	9.4	SW
A	9.0	E
M	8.2	E
J	7.4	E
J	6.8	ESE
A	6.8	E
S	7.7	E
O	8.5	NE
N	8.3	NE
D	8.2	NE
Average	8.2	E

3.4 TEMPERATURE

The southern latitude and maritime influences are the primary controls on air temperatures in the Caloosahatchee River/Big Cypress watershed. The climate is basically subtropical/marine characterized by a long, warm summer followed by a mild, dry winter (Bradley 1972).

Isotherms developed for south Florida (Thomas 1970) describing the mean annual temperature, and the mean monthly temperature for the coolest month (January) and the warmest month (August) are illustrated in Figure 25. Differences between coastal and inland areas are highlighted by isotherm contours that follow the coastline. Typically, the lower west-coast air temperatures vary about 1°F from Punta Gorda to the Everglades. Along coastal areas the maritime influence causes low daily fluctuations of air temperature and rapid warming of cold air masses that pass to the east of the State (USDC 1981a). Inland areas generally display a greater range of air temperatures because of more rapid heating and cooling of ground surfaces (Gerrish 1973, Gutfreund 1978).

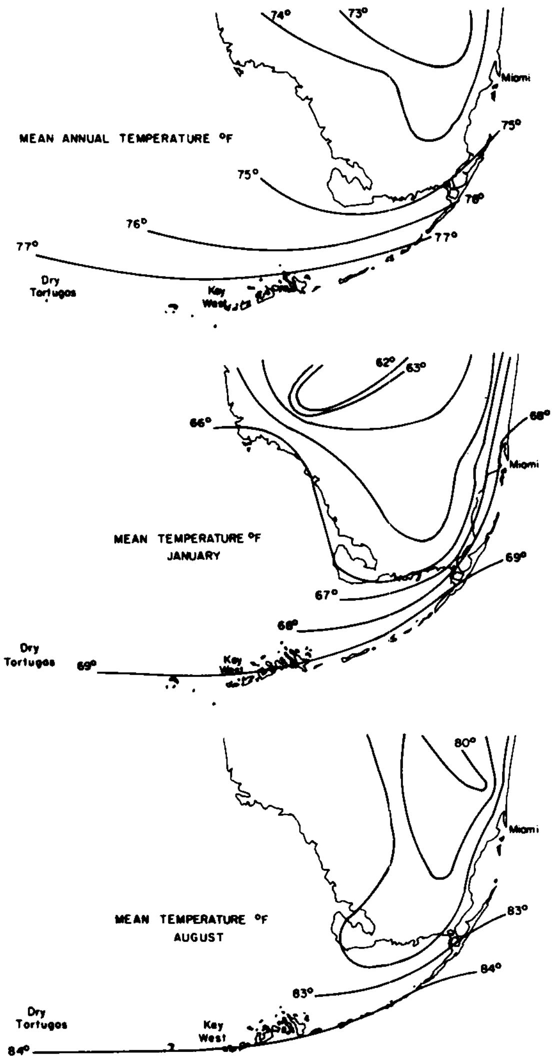


Figure 25. Isotherms for south Florida annually, and in January and August (adapted from Thomas 1974).

In winter, advective and radiational cooling processes, which follow frontal passages, cause sharp drops in temperature. As rainfall diminishes with the passage of a front, the cool, dry artic air from Canada causes brisk northwesterly winds, which at maximum velocity cause the lowest daytime temperatures. Nighttime cooling is prevalent when large quantities of heat are lost by radiation from the land surfaces (water is a poor radiator) during clear skies and calm winds. Cooling reaches a maximum a day or two after a front has passed, as the surface high-pressure system moves over or near Florida from the northwest. This cooling begins soon after sunset; and the lowest temperatures for the entire front are reached at dawn. Nighttime air-temperature gradients of 3.3°C to 8.3°C (6°F to 15°F) are typical a few miles inland from the southwest Florida coastline during the passage of the synoptic cold systems as a result of radiation. In addition to coastal/inland air temperature gradients, a similar gradient (3.3°C to 5.6°C or 6°F to 10°F) occurs between relatively high, dry land and adjacent moist lowlands.

During calm, cold, clear nights (maximum radiation cooling), frost may form, particularly in low-lying inland areas. The frequency of frost varies from infrequent near Everglades City to seven or eight times a year just west of Lake Okeechobee. When sustained freezing temperatures are combined with strong northwest winds, the penetration of cold is near maximum and crop and citrus damage is most severe. A severe freeze has been reported about once every 20 years (Table 6). Crops are most severely damaged if the freeze is followed by warm, dry weather. Water bodies are a natural heat source during these freezes, and moderate (via conduction) the surrounding air temperature.

Summer air-temperature gradients may be as great as or greater than those reported for the winter. The air-temperature variation in the wet season, compared to the winter's synoptic-scale frontals, is short-term, frequent, and spatially sporadic, i.e., tied to the behavior of

Table 6. Summary of severe freezes recorded in the Caloosahatchee River/ Big Cypress watershed (adapted from Bamberg 1980).

	Stations and Minimum Temperatures*						
DATE	FT. MYERS	MOORE HAVEN	EVERGLADES	LABELLE	PUNTA GORDA	CAPTIVA	COMMENTS
Dec. 12-13, 1934	24	23	28	20	28	—	Tender truck crops destroyed
Jan. 27-29, 1940	29	23	24	24	29	34	Cold winter, citrus dormant; all tender and much hardy truck crops killed.
Dec. 12-13, 1957	28	29	32	27	29	34	Strong winds and excessive rains; moderate to severe damage to cane and vegetable
Jan. 8-10, 1958	23	33	37	29	33	37	
Dec. 13-14, 1962	26	24	30	22	25	29	Warm dry weather followed heavy citrus damage. Extensive
Jan. 20-22, 1977	30	25	29	21	26	—	Cold weather, citrus dormant Snow all counties, all tender, hardy truck and cane killed.

*Includes minimum temperatures of each freeze occurrence from Weather Bureau data (1930-1979).

the wet-season thunderstorms. Air temperatures generally rise to the upper 90's (Figure 26) as a thunderstorm develops nearby, and drop 5.6°C to 16.7°C (10°F to 30°F) when cool downdrafts generated from the thunderstorm precede the downpour (Bradley 1972, Bamberg 1980). The area between the southwest coast of Florida and Lake Okeechobee is one of two areas in the southeastern United States where air temperatures exceed 32.2°C (90°F) more than 120 days a year (Figure 26).

3.5 RELATIVE HUMIDITY

A general description of relative humidity is difficult for many areas because of large diurnal and seasonal variations (USDC 1981a); however, in Florida, and especially south Florida, the situation is less complex because of the abundance of

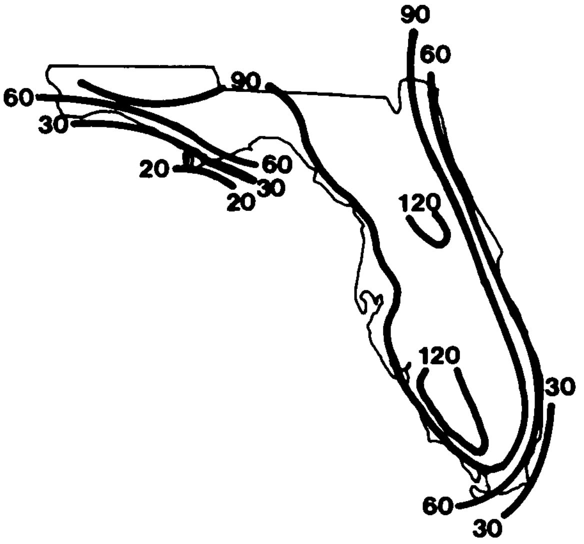


Figure 26. Average annual number of days with maximum temperatures of 90°F or above (adapted from Gutfreund 1978).

moisture throughout the year (Gutfreund 1978). Mean monthly relative humidities at the Fort Myers first-order weather station are summarized in Table 7.

The mean annual relative humidity is quite uniform throughout the watershed, averaging about 75% (USDC 1981a). Relative humidities are generally highest in early morning, about 80% to 90%, and generally lowest in the afternoon, about 50% to 70%. Although seasonal differences are not great, mean relative humidities tend to be lowest in the spring (April) and highest in the summer and fall.

Table 7. Mean monthly relative humidities (%) for 0100, 0700, 1300, and 1900 hours, and 24 hour average (adapted from USDC 1981a).

	Ft. Myers, Page Field				24-hr
Month	0100	0700	1300	1900	Avg
JAN	86	88	58	73	76
FEB	84	88	55	70	76
MAR	84	89	52	68	73
APR	84	88	48	65	71
MAY	85	88	51	67	73
JUN	88	88	59	74	77
JUL	88	88	60	75	78
AUG	88	89	61	77	79
SEP	88	90	62	78	80
OCT	86	88	57	73	76
NOV	87	89	56	74	77
DEC	87	89	56	75	77
20 YEAR AVERAGE	86	89	56	72	76

The daily variation in relative humidity for the Caloosahatchee River/Big Cypress watershed is much greater than reported for the lower Florida east coast and Keys, particularly during the dry season (Figure 27). This variation is caused by the prevailing easterly winds that bring more moderate and stable Gulf Stream air over the southeastern coast as opposed to alternating moist and dry air masses carried over the southwest coast.

3.6 SOLAR RADIATION

Atmospheric solar radiation varies little in the Caloosahatchee River/Big Cypress watershed (Gutfreund 1978). Factors that do vary are cloud cover, air pollution (particulates) and relative humidity, which modify the transmission, absorption, and reflection of solar energy (Blair and Fite 1965, Bamberg 1980). These factors largely determine the amount of solar radiation reaching the land and water surface.

Miami is the only first-order weather station that collects solar radiation data in or near the watershed (Bradley 1972). The average daily solar radiation is 447 langleys (gm-cal/cm^2). Monthly variations range from 319 langleys in December to 572 langleys in April (Bradley 1972, Multer 1977). The higher values are reported during middle to late spring rather than during the summer solstice (when the angle of incidence is least) because of increased precipitation and cloud cover preceding and during south Florida's wet season.

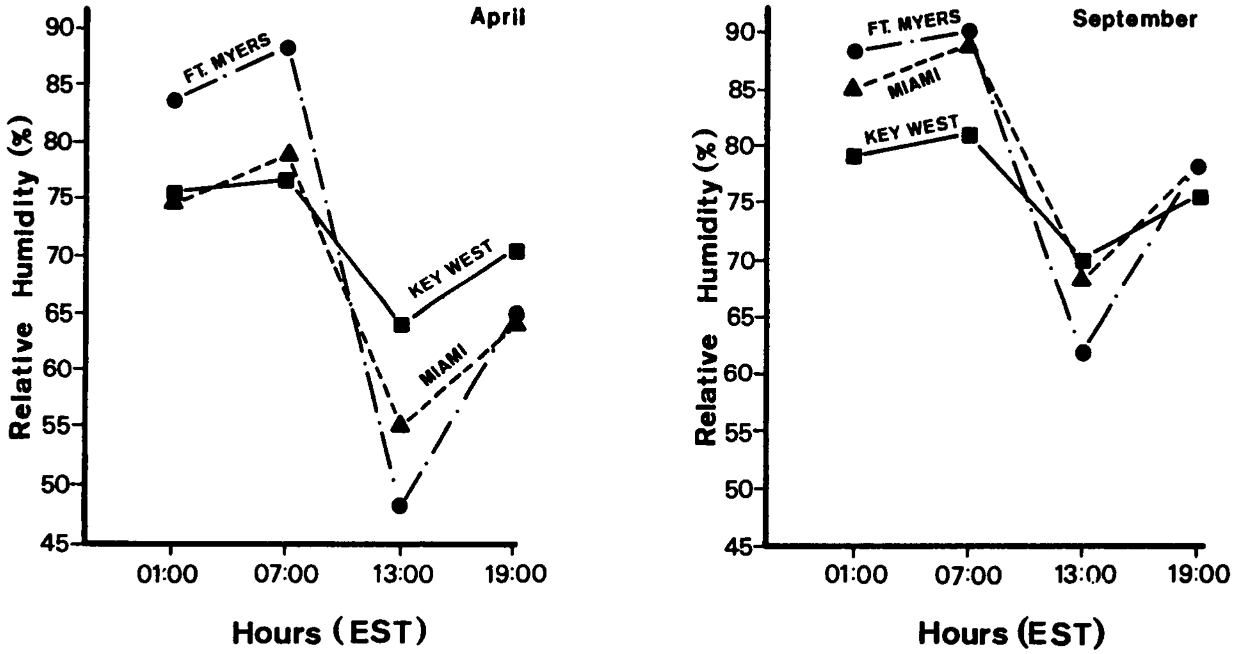


Figure 27. Diurnal patterns of relative humidity at three selected sites over south Florida in April and September (adapted from USDC 1981a, 1981b, 1981c).

Although atmospheric solar radiation is consistent in the watershed, the insolation (radiation reaching the ground/water surface) varies depending upon local atmospheric differences (Bamberg 1980). Climatic data observed at Fort Myers and Miami first-order stations are shown in Table 8. These data are either direct measurements of incoming solar radiation or observations that measure the factors affecting the passage of solar energy through the atmosphere (Bradley 1972, USDC 1981a, 1981b). Since the Miami station is located approximately 9 miles inland, data from this station is probably representative of the southwest Florida inland environment (USDC 1981b). It is also assumed that Fort Myers is representative of the coastal environment of the watershed. The coastal areas exhibit less cloud cover and more clear days than inland areas, especially in the dry season (Nov. to Apr.), when the highest number of clear days are reported. The number of days of heavy fog increases in south Florida from south to north, and from east to west (Table 8). In the dry season, fog is usually an early-morning or late-night phenomenon, and usually dissipates or thins soon after sunrise (USDC 1981a, 1981b). Heavy daytime fog is seldom observed in south Florida (Bradley 1972). The mean annual total sunshine for the watershed averages approximately 3000 hours (Gutfreund 1978).

Table 8. Solar radiation and related climatological data for Miami and Fort Myers first-order weather stations (adapted from Bradley 1972; USDC 1981a, 1981b).

	Miami International Airport							Ft. Myers Page Field					
Month	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)
JAN	61	5.3	10	12	9	1	334	N/A	5.0	11	12	8	5
FEB	61	5.3	9	11	8	1	397		4.9	11	10	7	3
MAR	78	5.4	8	15	8	1	475		4.9	12	11	8	3
APR	80	5.4	8	15	7	1	572		4.6	11	13	6	2
MAY	66	6.0	6	15	10	*	540		5.0	9	15	7	1
JUN	76	6.8	3	14	13	0	506		6.1	5	15	10	*
JUL	78	6.6	2	17	12	*	539		6.5	2	18	11	*
AUG	74	6.6	2	18	11	*	510		6.3	3	18	10	*
SEP	73	6.8	2	15	13	*	440		6.2	4	15	11	*
OCT	70	6.0	6	14	11	*	387		5.0	11	12	8	1
NOV	63	5.4	8	14	8	1	350		4.7	12	11	7	2
DEC	60	5.3	9	13	9	1	319		4.9	12	11	8	4
AVERAGE	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 clear days
(4) Mean number of partly cloudy days
(5) Mean number of cloudy days
(6) Mean number of days with heavy fog
(7) Average daily solar radiation in langleys

3.7 EVAPOTRANSPIRATION

Evaporation and transpiration (together called evapotranspiration, ET) describe two processes that move moisture into the atmosphere in the form of water vapor. Evaporation describes the passage of vapor to the atmosphere directly from the surface of water bodies, from surface and near-surface soils, and from impervious surfaces on which moisture has collected (Bamberg 1980). Transpiration describes the movement of water vapor from a living body through membranes, pores, and/or cellular interstitial spaces by diffusion to the external surface and then to the atmosphere, or the evaporation of water from living surfaces directly into the atmosphere. Although all living surfaces transpire, vegetation is the primary source.

The two major factors that control ET are solar energy and relative humidity. Solar energy provides the heat necessary to transform liquid water into vapor. The amount of solar energy reaching the earth's surface is modified by cloud cover, air pollution, and angle of incidence to the earth's surface. Relative humidity (RH) is a measure of air moisture percentage saturation. The RH of fog, for example, usually is 100%, whereas the RH during rainfall may be less. ET is inversely related to RH; as RH increases, ET decreases. Other factors controlling ET are wind (velocity and duration), wave action, ground cover (type and density), shade, barometric pressure, temperature (air and surface), soil type, soil moisture content, and water table depth (Parker et al. 1955, Dohrenwend 1977, Palmer 1978, Duever et al. 1979, Bamberg 1980, Wyllie 1981).

Evapotranspiration, especially during saturated soil conditions, becomes an important control of sea breeze intensity and ultimately the formation of convective storms. The heat-consumptive process associated with high evaporation rates causes slightly higher temperature gradients between cooler inland areas and warmer coastal urban strips (Gannon 1978, Bamberg 1980). These conditions are more prevalent one to two days following a heavy rainfall. Because ET is a cooling phenomenon, land-water gradients are reduced, convective processes are reduced, and the recently rained-on area receives less rainfall. The overall effect is the creation of a natural feedback mechanism which results in a more even spatial distribution of seasonal rainfall (Bamberg 1980).

Estimates of evapotranspiration in southwest Florida range from 76.2 cm (30 inches) per year to 121.9 cm (48 inches) per year (Dohrenwend 1977, Palmer 1978). Predicted evapotranspiration patterns for Florida are given in Figure 28. Estimated annual values range from greater than 100 cm (39.4 inches) in the central southern watershed to less than 95 cm (37.4 inches) in the north (Dohrenwend 1977).

3.8 HURRICANES

The climatic conditions of south Florida may be divided into three energy levels or intensities (Warzeski 1976). They are prevailing mild southeast and east winds, winter cold fronts, and tropical storms and hurricanes. The first two were discussed before in the sections on wind and rainfall. Tropical storms and hurricanes, because of their destructive capacity, importance as an ecological force, and unique climatic characteristics, are described here as a separate climatic element.

Figure 28. Predicted evapotranspiration patterns in Florida (adapted from Dohrenwend 1977).

In summer and fall, low-pressure areas that originate in the warm, moist air of the equatorial trough are relatively common. The winds are light and usually drift from east to west. At that time atmospheric waves appear in the easterly flow and proceed 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 easterly wave developments 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. The strongest winds are generally 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 or 38 mi per hour) 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 hour (74 mph) or more, a tropical hurricane is born (Gentry 1974). Still only a relatively small area is involved, i.e., a hurricane force wind radius of 32 to 48 km (20 to 30 miles) (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, and 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, causing 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 south Florida:

As such a storm approaches, the barometer begins 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 is subjected to more hurricanes and tropical storms than any other area of equal size in the United States (Gentry 1974). The Caloosahatchee River/Big Cypress watershed is exposed to both Atlantic and Carribean hurricanes. Generally, tropical cyclones 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 29 illustrates the frequency of hurricanes along the Atlantic coastline for 5 of 58 coastal segments delineated by Simpson and Lawrence (1971). Of the 38 hurricanes that passed over Florida's southwest coast from 1901 to 1971, 30 were in August, September, or October (Jordan 1973). Points of entry of tropical storms and hurricanes in south Florida are shown in Figure 29. Tropical storms cause destruction once every 3 years south of the Everglades and once every 5 years farther north in the watershed (Bamberg 1980). The average forward speed for hurricanes affecting south Florida is 10 knots; the radius of maximum winds extends 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 south Florida are reported in the U.S. Department of Commerce "Monthly Weather Review". This review summarizes all meterological data on the passage of tropical waves, disturbances, storms, and hurricanes for each year's hurricane season.

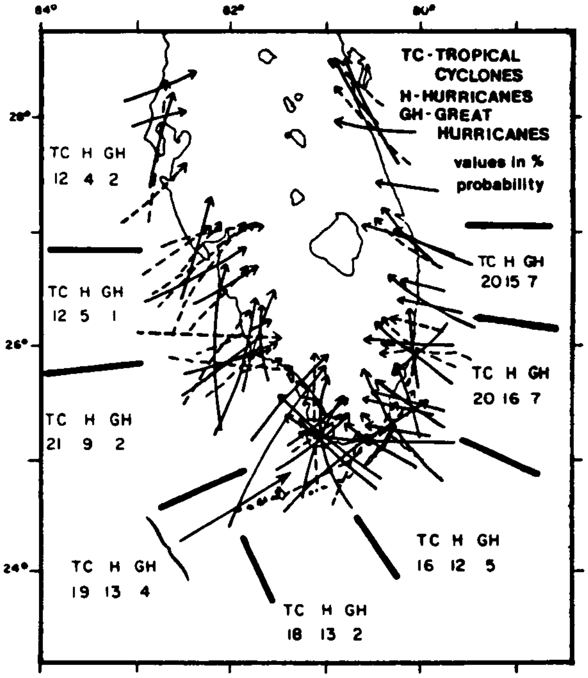


Figure 29. Points of entry and probabilities of hurricanes at selected coastal locations (adapted from Jordan 1973).

The three primary forces associated with the passage of a hurricane are wind, storm surge, and rain. Sustained winds over 200 km per hour (125 mph) are necessary 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 been reported in south Florida on several occasions during the last century (Sugg et al. 1971, see Figure 29). The most notable was the "Labor Day" hurricane in 1935, which passed over Long Key with highest sustained winds estimated at between 322 and 402 km per hr (200 to 250 mph), according to Bradley (1972).

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

A storm surge, of high tides and rough seas, is caused by a complex interaction of wind, air pressure, and the bottom topography of waters adjacent to the land (Gentry 1974). The effects are more pronounced when the storm moves onshore, as opposed to moving along the coastline. Since 1873, eight hurricanes have caused record storm tides in south Florida (Simpson et al. 1969). Some of the most pronounced surges along the coast are given in Table 9 (Jordan 1973). No discernible pattern of these great storms is apparent - all areas of the coast were equally affected. Record storm-surge tides range between 2.9 and 5.5 m (9.5 to 18 ft) above undisturbed waters (Simpson et al. 1969). In addition to high tides, coastal areas are also subject to strong wave action that causes waters to reach even further inland than indicated by tide heights alone (Gentry 1974). The highest recorded storm surge along Florida's southwest coast occurred in 1873 when a 4.3 m (14 ft) tide destroyed the island community of Punta Rassa (Sugg et al. 1971).

Table 9. Major hurricane storm surges between Fort Myers and Everglades City (adapted from Jordan 1973).

Location	Surge height (feet)	Month of occurrence
Ft. Myers	9	Oct. 1921
Punta Gorda	14	Oct. 1873
Naples	11	Oct. 1944
Marco Island	10	Oct. 1910
Everglades	10	Oct. 1910

The amount of rainfall from tropical storms varies according to the intensity of rainfall, the rate of 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 cm (5 to 10 inches) of rain are recorded at any one point during the passage of a tropical storm (Gentry 1974). Reports of excessive rainfall ($\geq$ 20 cm or 8 inches) in conjunction with hurricanes crossing the coast near the Caloosahatchee River/Big Cypress watershed are given in Table 10. Although Great Hurricane Donna (1960) passed over this coastline, it was a comparatively "dry" hurricane. Precipitation was only 5 to 8 cm (2 to 3 inches). Donna's winds, however, reached 241 km per hour (150 mph) and caused extensive damage to Everglades City and other areas along the coast (Bamberg 1980).

Table 10. Maximum hurricane rainfall for the Caloosahatchee River/Big Cypress watershed (adapted from Bamberg 1980).

Stations*	Oct. 1929	Sept. 1926	Sept. 1929	Sept. 1948
Moore Haven	9.14	--	--	10.26
Everglades	15.66	8.02	9.37	8.76
Ft. Myers	--	--	7.66	--
La Belle	--	--	8.69	11.15
Punta Gorda	--	--	8.00	10.26

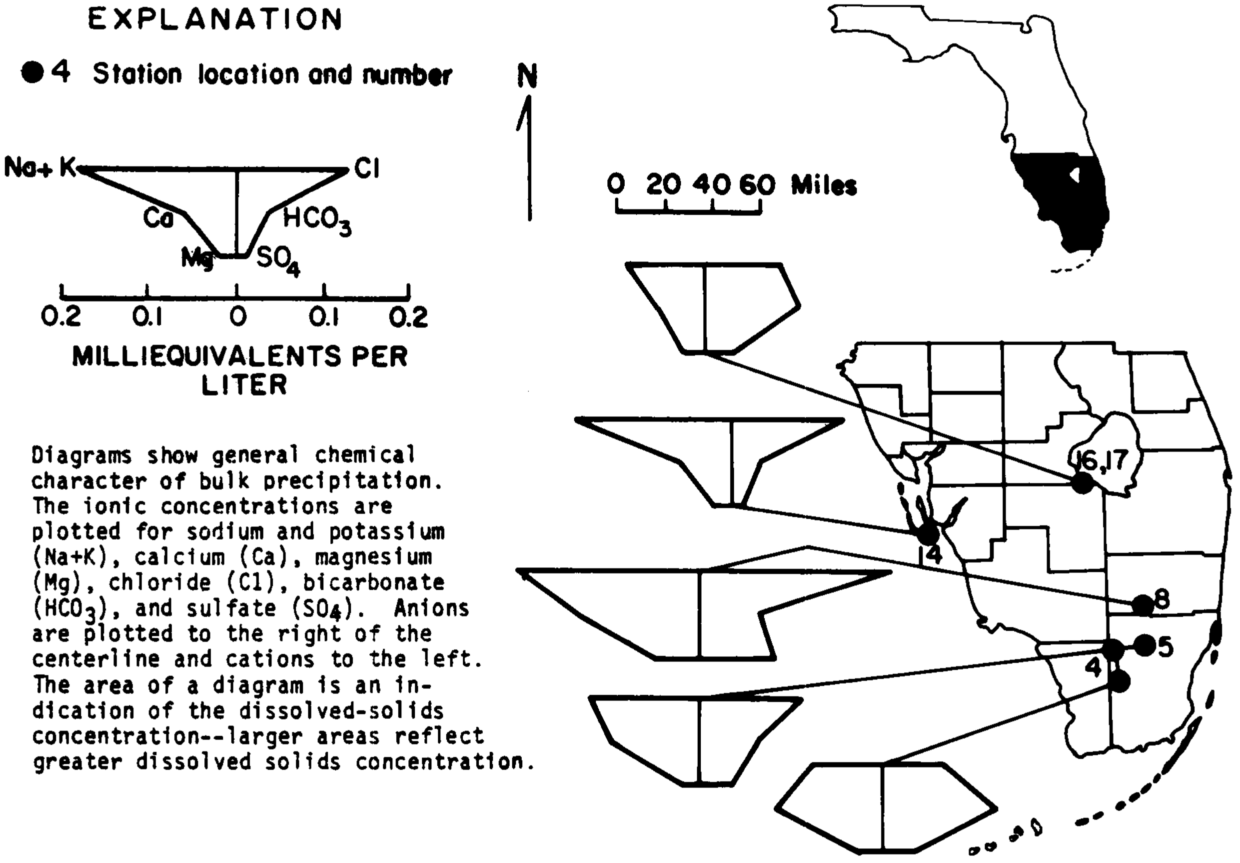
*Rainfall listed only if any single station received a total rainfall equal to or exceeding 8 inches during hurricane passage.

3.9 AIR POLLUTION

The three natural and man-made sources of atmospheric contaminants in south Florida 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 or cloud droplets (Echternacht 1975). Their geographic distribution is dependent on watershed weather patterns. For the Caloosahatchee River/Big Cypress watershed it is a wet-dry season variation. Passage of large-scale synoptic (or pressure) systems during the dry season (Nov. to Apr.) may contain pollutants from sources far removed from the State (Echternacht 1975), in addition to localized sources (Holle 1971). Wet-season convective systems, exhibiting diurnal activity related to land-sea breeze interactions, 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 surface. The material, inorganic and organic, is transported either by wet or 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 and 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 particulates by falling rain, and as dry fallout year round. In contrast, nitrogen as NO_x is 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 and consists of dissolved materials in aqueous precipitation, the water-soluble component of dry precipitation, and the water-insoluble component of either wet or dry precipitation (Irwin and Kirkland 1980).

Qualitative rainfall characteristics at selected USGS study sites in Florida, including six sites within or adjacent to the Caloosahatchee River/Big Cypress watershed, were summarized by Irwin and Kirkland (1980). The mean chemical composition of the more common inorganic ions in rainfall are illustrated in Figure 30. Site 4 (40 Mile Bend, Tamiami Trail) in the extreme southern end of the basin exhibits a predominantly calcium bicarbonate water type. Site 14 (Sanibel Island) is a sodium chloride water type reflecting the maritime influence on the island. The Moore Haven sites at Lake Okeechobee show a mixture of both types. Higher calcium/bicarbonate levels observed in this basin (site 4) are believed to be derived from fine rock and marl soils (Waller and Earle 1975).



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 30. Average chemical concentrations of precipitation at sampling sites in and adjacent to the watershed (adapted from Irwin and Kirkland 1980).

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 (Waller 1975). Davis and Wisniewski (1975) reported that nutrient loading via rainfall accounted for 19% and 11% of the total nitrogen and phosphorus loading to Lake Okeechobee. The majority of the loading is during the wet season. Concentrations in dry fallout tend to increase during the dry season (Waller and Earle 1975, Echternacht 1975). The South Florida Water Management District's rainwater chemistry data illustrates this seasonal difference of nitrogen and phosphorus concentrations (Echternacht 1975). Peak concentrations in the spring, characterized by high winds and low rainfall, are representative of high dry fallout conditions (Table 11). 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). Summer months, during peak rainfall and maximum dilution, show the lowest concentrations.

Spatially, nitrates in south Florida exhibit a north-south gradient and a maximum in the area east of Lake Okeechobee. Phosphorus is even more variable, but still shows a similar north-south gradient (with several maximums) around Lake Okeechobee (Echternacht 1975, Davis and Wisniewski 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 in nearby agricultural operations (Waller and Earle 1975). Lead and iron are attributed to motor vehicle emissions (Irwin and Kirkland 1980). Site 4 (Tamiami Trail, 40 Mile Bend) is the only site in the watershed monitored for trace metals in bulk precipitation. Of all trace metals, cadmium and zinc show up in the most potentially hazardous concentrations, but these concentrations are believed to result from contamination by nearby galvanized metals (Waller and Earle 1975). Single samples were analyzed from sites 14, 16, and 17; sites 16 & 17 (from Moore Haven) exhibited

Table 11. Seasonal averages of nutrient concentrations in rainwater at Tamiami Trail, 40 Mile Bend (adapted from Echternacht 1975).

Season	Ammonium NH+ ppm	Nitrate NO_3 ppm	Nitrite NO_2 ppm	Orthophosphate OP ppm	Total phosphate TP 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	2.20	0.49	0.06	0.13	0.30

much higher concentrations of lead than site 4 (40 Mile Bend, Tamiami Trail). Trace-metal sampling sites for measuring local phenomena are usually located near highways, so it is unlikely that they are representative (Irwin and Kirkland 1980).

The reported pH of rainfall at sites 4, 14, 16, and 17 in the watershed ranged from 5.5 to 8.8 (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. Trace amounts of malathion and diazinon were reported at 40 Mile Bend (site 4).

Airborn sulfur dioxides in the state of Florida have been monitored in Hillsborough, Duval, and Escambia counties and to a lesser extent in the remaining Florida counties. This survey showed very low sulfur-dioxide emission rates for the counties in the watershed. The largest source is the fossil-fueled power plant at Fort Myers. At this location the 24-hour maximum concentrations of SO_2 have been and should continue to be far below Florida and national air-quality standards, even at locations where the maximum combined effects are expected.

Normally, air temperature decreases with an increase in altitude, but occasionally the reverse occurs, i.e., the temperature increases with height within a given atmospheric layer or between layers. This phenomena is called an inversion of temperature or simply an inversion. Inversion is most common on calm, clear nights, when the soil cools rapidly by radiation. The adjacent near-surface air is cooled by conduction and radiation more rapidly than the air above it, creating an inversion. During the inversion, the air column involved is stable, but when air temperatures decrease with height (a condition favorable to convection) the air column is considered unstable (Blair and Fite 1965). The significance of an inversion to air quality is its effect on mixing, dilution, or dispersion of air pollutants. Air within an inversion is trapped and near-ground pollutants, e.g., vehicle emissions, can build up and create a health hazard in the more common near-surface inversions (Gutfreund 1978).

The general pattern of inversion frequency is consistent from season to season. Low-level inversions are least frequent in the south of the watershed, but increase to the north. Annual variation ranges from 10% at 40 Mile Bend along Tamiami Trail to about 30% of the time north of the Caloosahatchee River (Hosler 1961). Seasonally, inversions are more common in fall and winter and least common in summer. In addition to the north-south gradient, inversions tend to increase and are much stronger inland than along coastal areas (Gerrish 1973, Gutfreund 1978); however, because of the diurnal nature of inversion phenomenon, significant atmospheric pollutant build-up seldom occurs. The daily inversions are quickly dispersed by the dynamic wind and rain patterns over the watershed (Gutfreund 1978).

CHAPTER 4
HYDROLOGY AND WATER QUALITY

4.1 INTRODUCTION

The surface-water drainage of the Caloosahatchee River/Big Cypress watershed consists of a mixture of diffuse waterways (strands), relatively few distinct stream channels, and an extensive network of man-made canals. The identifiable drainage basins shown in Figure 31 are as follows:

(1) The Caloosahatchee Valley & River watershed.
(2) The Estero Bay and Imperial River watershed.
(3) The Golden Gate Canal/Gordon River/Cocohatchee River Canal drainage to Cocohatchee Bay, Rookery Bay, Naples Bay, and the Ten Thousand Islands.
(4) The Turner and Barron River Canals and the Big Cypress National Preserve drainage to Chokoloskee Bay and south.

Fresh groundwater for domestic, agricultural, and industrial purposes has a number of sources. In the upper Caloosahatchee Valley, a combination of shallow aquifers, including the shallow water table, the Tamiami, and the lower Hawthorn and Floridan aquifers are sources of groundwater. These same sources plus the upper Hawthorn Aquifer supply groundwater to the Estero Bay watershed. In southern Collier County, groundwater is drawn from the shallow water table and the Tamiami and Floridan Aquifers (SFWMD 1980, Burns 1983, Jakob 1983).

Some of the characteristics of the surface water drainage in the Caloosahatchee River watershed have been modified by agricultural practices and navigational channels. Sixty (60) tributaries make up the Caloosahatchee River watershed. The major tributaries are listed in descending (upstream to downstream) order in Tables 12 and 13. The Caloosahatchee River watershed (USGS Hydrologic Unit 03090205) is divided into the East Caloosahatchee basin, the West Caloosahatchee basin, the Telegraph Swamp basin, and the Caloosahatchee River Tidal Basin.

At one time the Caloosahatchee River was a natural water course that began in the vicinity of Lake Hicpochee and flowed about 78.8 km (49 mi) to the Gulf of Mexico. In 1884 a canal was constructed, connecting the river with Lake Okeechobee at Moore Haven. In 1918 three combination lock and spillway structures were constructed at Moore Haven, Citrus Center, and Fort Thompson. By 1937, after improvements authorized by the 1930 River and Harbors Acts, the Caloosahatchee River had a navigable channel about 2 m (6.6 ft) deep and 24 m (80 ft) wide (Miller et al. 1982). From 1962 to 1968 the last major improvements were completed under the auspices of the Central and Southern Florida Flood Control Project. The old lock structures were replaced by three primary facilities: S-77, S-78, and S-79. Farthest upstream at Moore Haven, Lake Okeechobee waters are released through a combination spillway (S-77) and navigation lock (HGS No.1). West of S-77 about 24 km (15 mi), a second lock and spillway (S-78, Ortoona Lock) controls water levels on adjacent upstream lands. The W.P. Franklin Lock and Dam (S-79) at Fort Myers prevents saltwater intrusion from the west and controls water

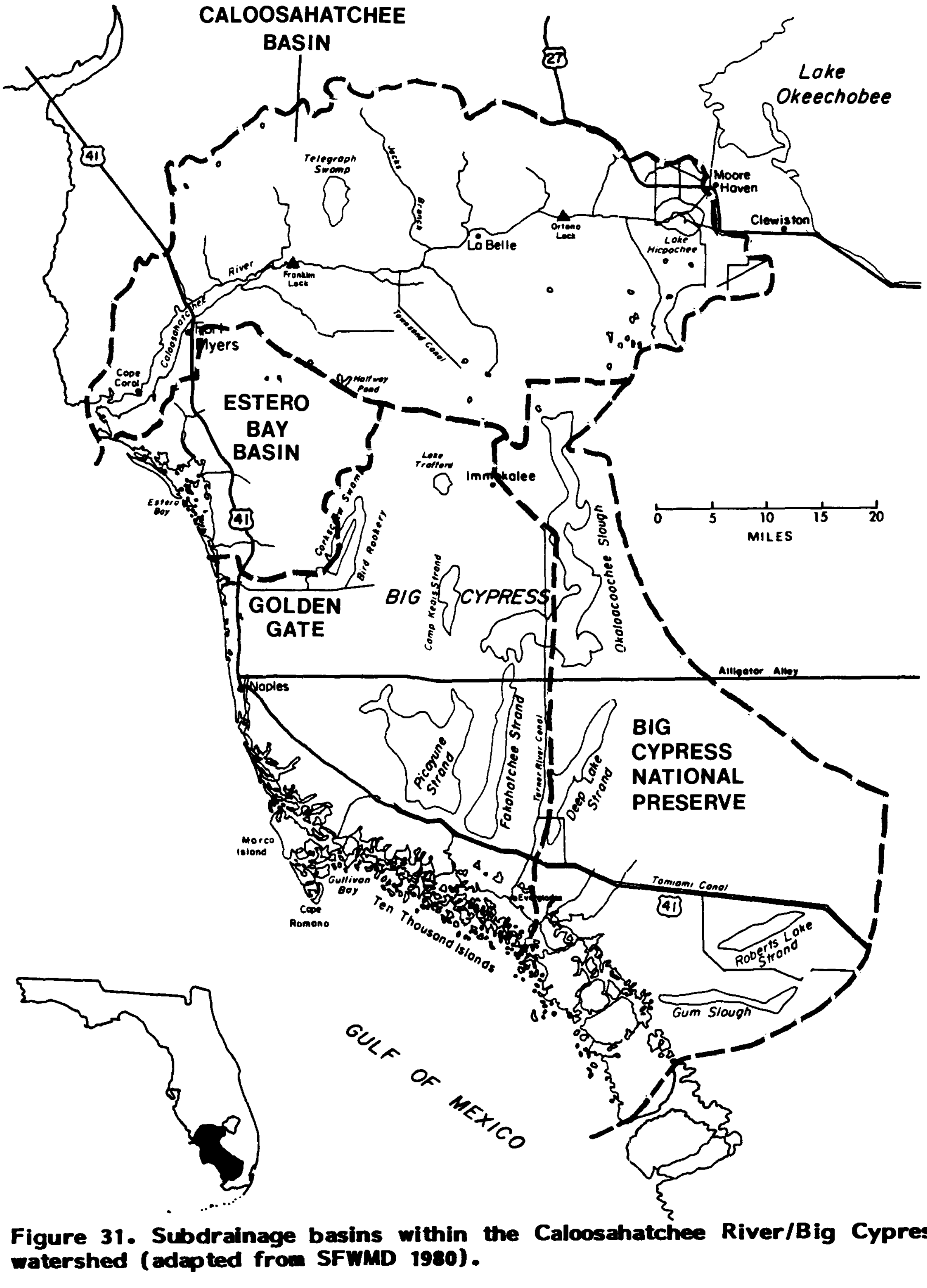


Figure 31. Subdrainage basins within the Caloosahatchee River/Big Cypress watershed (adapted from SFWMD 1980).

Table 12. Major upstream tributaries (above Ortona Lock) associated with Caloosahatchee River drainage (adapted from SFWMD 1980).

	Tributaries entering from:	
Moore Haven	South	North
	Diston Island Canal	C-19 Canal
	Nine Mile Canal	Rangeline Canal
	Whidden Corner Canal	Bayce Canal
	Lake Hicpochee Canal	Meander Line Canal
downstream to	Grassy Marsh East Canal	Citrus Center Canal
	Grassy Marsh West Canal	Turkey Branch
	42' Canal (Beautiful Hammock)	
	Long Hammock Canal	
	Goodno Canal	
Ortona Lock		

Table 13. Major downstream tributaries (below Ortona Lock) associated with Caloosahatchee River drainage (adapted from SFWMD 1980).

	Tributaries entering from:	
Ortona Lock	South	North
	Goodno #2 Canal	Cypress Branch
	Goodno #1 Canal	Deadman's Branch
	Okaloacoochee Branch	East Spoil Canal
	LaBelle Canal	West Spoin Canal
	Messer Canal	North LaBelle Canal
downstream to	Crawford Canal	Pollywog Creek
	Roberts Canal	Bee Branch
	Townsend Canal	Jacks Branch
	State Road 80 - Bedman Creek	Mouth Canal
	State Road 80	Mouth
		Mouth, Spanish Creek
		Mouth, Cypress Creek
Franklin Lock		Minor Basin
		Mouth
		Mouth, Telegraph Creek

levels for the remaining 42 km (26 mi) reach, west of S-78.

Presently the Caloosahatchee River (C-43) is an improved canal, 104.6 km (65 mi) long, 50 to 130 m (55 to 142 yd) wide, and 6 to 9 m (20 to 30 ft) deep (Miller et al. 1982). Since 1945 many of the river oxbows have fallen victim to the channelization. Thirty-five oxbows still remain between the town of LaBelle and the Franklin Locks (Milleson 1980).

Water flow and stage heights in the Caloosahatchee River canal are maintained for a variety of needs, including local drainage and flood control, irrigation and municipal water supply, navigation, salinity control, and maintenance of the Lake Okeechobee regulation schedule (SFWMD 1980). The canal stage is maintained at about 3 m (11 ft) above mean sea level at the Ortona Lock (S-78) and 1 m (3 ft) above msl at Franklin Lock (S-79). A summary of monthly average flows at several Caloosahatchee River stations is given in Figure 32.

4.2 CALOOSAHATCHEE RIVER WATERSHED

4.2.1 Freshwater Caloosahatchee River

Structure-78 (Ortona Lock) separates the freshwater portion of the Caloosahatchee River watershed into two distinct hydrologic units, the East and West Basins.

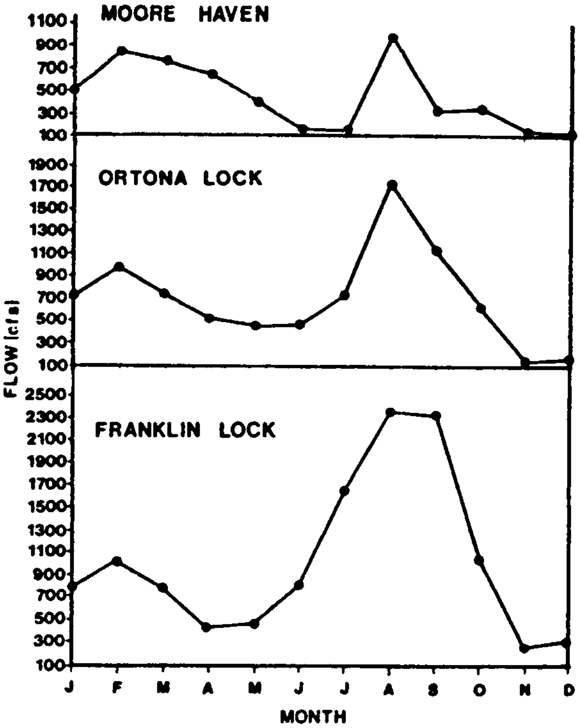


Figure 32. Monthly average stream flow (cfs) at three Caloosahatchee River stations (adapted from SFWMD 1980).

The East Basin or upperpool (Figure 33), encompasses an area of 875 km^2 (216,133 acres). Average discharge near its upstream end, at Moore Haven is 27.0 m^3/s (954 cfs). The maximum recorded discharge is 235 m^3/s (8290 cfs) and minimum discharge is -56.9 m^3/s (-2,010 cfs). The minus values indicate back pumping to the lake. Estimated seepage when the locks are closed averages as much as 0.142 m^3/s (5.0 cfs) according to USGS (1981).

Tributary drainage in the East Basin is more complex than the drainage of the West Basin, primarily because of the land use and water control (Miller et al. 1982). Land use in the East Basin is primarily agricultural; consequently, irrigation of croplands is the most important water use. Irrigation is controlled by extensive canal networks that drain flood waters during the wet season and recharge the shallow water table during the dry season. Tributary streams that drain into the east Caloosahatchee River are listed in Table 12.

To the north of the river in Glades County, four canals dominate the watershed. These, in descending order downstream are the C-19 Canal, the Bayce Canal, the Meander Line Canal, and the Citrus Center Canal. Turkey Branch enters the Caloosahatchee River from the north a few miles upstream from the Ortona Locks. To the south of the Caloosahatchee River, in Hendry County, the Whidden Corner Canal, the Lake Hicpochee Canal, the Grassy Marsh East and West Canals, and Long Hammock Canal dominate the watershed. The Goodno Canal enters the Caloosahatchee River at the Ortona Locks.

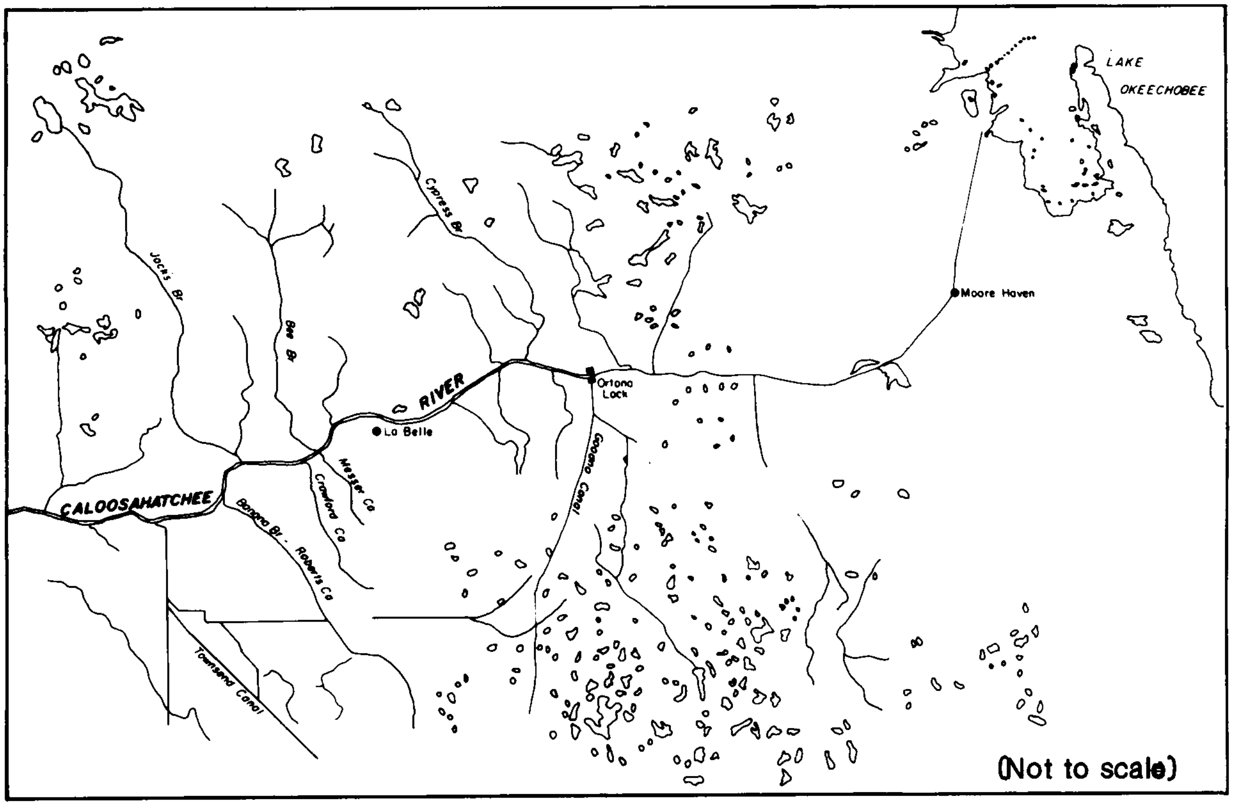


Figure 33. The East (upper) Caloosahatchee River basin (adapted from SFWMD 1980).

Drainage by these and numerous other canals and ditches opens much of the marginal and seasonal wetlands of the East Basin to intensive agriculture, and the crops grown on these predominantly sandy and highly permeable soils require rather intensive irrigation. A fine balance between drainage and irrigation must be maintained. The canals lower the shallow water table to allow cultivation and yet, during the wet season (summer), some of this water must be reused to irrigate the crops. In general, canals accelerate runoff and evaporation and decrease groundwater storage.

Maintaining the drainage/irrigation balance is made easier by external sources of water that were not historically a part of the near-surface water balance. These new external sources are the Floridan aquifer and the overflow of Lake Okeechobee. Because of the drainage operations, over half the predrainage storage capacity of the watershed has been lost (Debellvue 1976). Historically, the shallow surface water table and the slough-like drainage were able to hold considerably more water before agricultural development. During the dry season the watershed has an average 23 cm (9.2 inches) deficit that requires much of the wet season's 32 cm (12.4 inches) excess to be retained in order to sustain natural and cultivated vegetation. The loss of the natural storage capacity of the basin and increased consumption in the dry season sometimes makes it necessary to import water (e.g., backpumping) for recharge and irrigation.

The Floridan aquifer in the East Basin is composed of limestone ranging in age from middle Miocene to Eocene. The Tampa Formation and the Suwannee Limestone are the major strata that contribute to the water holding capacity of the aquifer, along with some interbedded limestone of the lower Hawthorn. These strata are overlain by clay, marl, and sandy clay of the Hawthorn Formation. Replenishment of this artesian aquifer comes largely from the Highlands Ridge area to the north (Klein et al. 1964).

Use of the Floridan aquifer for irrigation is limited because its excess of total dissolved solids is detrimental for most crops, although some crops (e.g., citrus) tolerate the high ionic content better than others. On the other hand, dilution from rainfall helps reduce mineral concentrations and makes the Floridan aquifer more useful for irrigation in the East Basin.

The shallow aquifer is generally of better quality than the Floridan aquifer because it is higher in calcium and bicarbonates but lower in concentrations of sodium, magnesium, sulfate, and chloride. The shallow aquifer is contaminated where there is seepage from the Floridan aquifer through unplugged or improperly cased wells (near LaBelle) and where surface waters contact rock bearing connate sea water near Lake Okeechobee (Burns 1983).

The West Basin, including Telegraph Swamp, encompasses an area of 1,287 km^2 (318,253 acres). Land use is largely agricultural, so the balance between adequate drainage and adequate recharge for irrigation is a primary concern of regional water management. In the West Basin the Caloosahatchee River water serves as a primary and secondary source of drinking water, which focuses greater public concern on the river water quality (SFWMD 1980).

The average annual upstream discharge to the West Basin through the Ortona Locks is 20.5 m^3/s (724 cfs). Flow ranges from 0 to 275 m^3/s (9,720 cfs). A list of tributary watersheds that drain into the West Basin is given in Table 13 and Figure 33. The monthly average flow in the West Basin at the inflow (Ortona Locks) and outflow (Franklin Locks) stations is given in Figure 32. The control of flow in response to the demands for water in the West Basin often leads to an irregular pattern of flow in tributary canals. The monthly average flow and standard deviation for the Townsend Canal during the water years 1970 to 1980 is shown in Table 14 and also illustrates the back-and-forth flow action in the canal. The river registers a net negative average flow in 7 months of the year, indicating heavy consumption for irrigation and surface loss to groundwater and/or evapotranspiration.

Table 14. Monthly average downstream and upstream (-) flow for the Townsend Canal 1970-1980 (SFWMD 1980).

Townsend Canal Sta. 02292780		
MONTH	FLOW (CFS)	FLOW (STD)
JAN	30	147
FEB	-23	76
MAR	-47	152
APR	-151	114
MAY	-15	181
JUN	<-1	188
JUL	121	122
AUG	117	202
SEP	153	260
OCT	-45	192
NOV	-27	122
DEC	14	155

Groundwater in the West Basin is supplied by the surficial aquifer, the Hawthorn aquifer, and the Floridan aquifer (Boggess et al. 1981, Burns 1983). The surface aquifer is contained within terrace deposits (Pleistocene to Holocene origin) and the Tamiami Formation (Pleocene). Unconsolidated quartz sands, shell beds, calcareous clays, and interfingering limestones characterize the terrace deposits. Sandy biogenic limestones that identify the Tamiami Formation are occasionally separated from the terrace deposits by a semi-confining calcareous clay bed.

The surface aquifer ranges from 25 ft to 125 ft, thickening to the west and southwest in Lee County. Rainfall, surface waters, and discharge from deep wells recharge this aquifer, and the top of the aquifer fluctuates about 1 m (3 ft) seasonally. Major areas of recharge are Telegraph Swamp, north of the Caloosahatchee River, and the region around the Immokalee Rise, south of Lehigh Acres.

The Hawthorn aquifer consists of three semi-confining beds and two sub-aquifers, the Sandstone and the Mid-Hawthorn (Sproul et al. 1972, Boggess and Missimer 1975, Burns 1983). The upper Hawthorn acts as the upper confining layer. The Sandstone aquifer, the upper water-bearing unit of the Hawthorn aquifer, is absent in Cape Coral and northwest Lee County and thickens to 200 ft to the east. Potentiometric peaks correspond to the surface aquifer recharge areas. The water quality is good except in northeast and southwest Lee County where chlorides exceed 250 mg/l.

The mid-Hawthorn is more extensive than the Sandstone aquifer but rarely exceeds 75 ft in thickness. Chloride content of the mid-Hawthorn is higher, exceeding 1000 mg/l along the west coast (Burns 1983). Recent intensive pumping from the aquifer has reduced its artesian pressure to below mean sea level in most of the West Basin. Average seasonal fluctuations range from 6.2 m (17 ft) in heavily pumped areas to about 1.0 m (3 ft) where pumping is minimal (Boggess et al. 1981).

Deepest of the three aquifers is the Floridan aquifer, and the only zone of consequence to the West Basin's water supply is the lower Hawthorn/Tampa producing zone. This zone, located in the upper Floridan aquifer, ranges from 75 ft to 250 ft thick and provides water for agriculture and for the Cape Coral, Pine Island and Sanibel reverse osmosis plants. Chlorides range from 250 mg/l to 5,000 mg/l (Burns 1983).

Water quality of the East and West Basin. Water quality in the Caloosahatchee River is controlled largely by the low relief, semitropical climate, discharge from Lake Okeechobee, and land use. Where shallow sands are underlain by clay or marl hardpans, water may pond up because of the extremely low relief of the land, and form sloughs or seasonal wetlands that affect surface water quality and rate of runoff. Wet and dry seasons alternately dilute and concentrate surface water constituents. Agriculture and urbanization have caused extensive channelization that changed the hydrologic cycle of the watershed, as well as its surface water quality.

Water quality data for the Caloosahatchee River is available from (1) USGS and Florida Department of Environmental Regulation (FDER) monitoring stations, (2) an extensive sampling and analysis program that assessed the effect of runoff on the river and its tributaries (ESE 1977), and (3) most recently, a series of studies aimed at developing a comprehensive water-management plan for the Caloosahatchee River watershed (SFWMD 1980, Miller et al. 1982).

The upper Caloosahatchee River, from Moore Haven to the Lee-Hendry County line, is classified as Class III waters by the FDER. This classification requires that water quality meet standards for recreational contact and the propagation of fish and wildlife. From the Lee County line to Franklin Lock, waters are classified I-A, suitable for potable or drinking water use. The City of Fort Myers pumps surface water from the Caloosahatchee River into a nearby shallow-well field to augment groundwater recharge. Lee County takes water directly from the river, treats it, and uses it for domestic supply purposes (Klein et al. 1964).

Water quality in the Caloosahatchee River (Moore Haven to Franklin Lock) is dominated by Lake Okeechobee discharges and tributary drainage from the surrounding agricultural lands (McPherson and La Rose 1982, Miller et al. 1982). Based on a 1978 to 1980 sampling program, inflow from Lake Okeechobee contributed 55% of the Caloosahatchee River water, 62% of the total nitrogen, and 64% of the chloride load (Miller et al. 1982). The East Basin contributed the least amount of water (21%) and the greatest amount of total phosphorus (43%).

Total phosphorus at S-77 (Moore Haven) exhibits a seasonal pattern which is sensitive to flow releases from Lake Okeechobee. Concentrations are lowest in winter when the Moore Haven structure is discharging and are highest in the summer when there is no discharge. Total phosphorus along the river increases between S-77 and S-78 (Ortona Lock) and decreases downstream to S-79, the Franklin Lock and Dam (FDER 1980, Miller 1980). The change in concentration is related to the nutrient levels observed in the East and West Basin tributaries. The East Basin tributaries contain phosphorus concentrations that are higher than observed in the upper river, whereas the West Basin tributary levels are lower than the river's total phosphorus levels. The difference between basins is probably related to land-use practices that vary between the two areas. Although agricultural activities (improved pasture, cropland, and citrus) are similar in the East and West Basins (Isern and Brown 1980), the intensity and drainage practices between the two basins are not. Nutrient polishing ponds and water reuse systems are used in the West Basin but not in the East Basin (ESE 1977, Miller et al. 1982).

Total nitrogen gradually decreases from Lake Okeechobee (S-77) to the Franklin Lock (S-79). The tributaries in both East and West Basins exhibit lower concentrations than those observed in the river except for the five easternmost tributaries that drain organic or muck soils high in nitrogen. Organic nitrogen, the dominant nitrogen form, represents 81% and 90% of the total nitrogen in the East and West Basins, respectively. An inverse relationship was found between the inorganic nitrogen species (ammonia and nitrate). Moving downstream from S-77 to S-79 ammonia decreased while nitrate increased. In the East Basin 83% of the inorganic nitrogen is in the form of ammonia, and 77% of the West Basin's inorganic nitrogen is nitrate. No seasonal trend is apparent as illustrated in Table 15 (Miller et al. 1982).

Table 15. Average constituent concentrations during the wet (summer) and dry (winter) seasons (adapted from Miller 1980).

	TOTAL PHOSPHORUS mg P/L		TOTAL NITROGEN mg N/L		CHLORIDE mg/l	
STATION	Wet (summer)	Dry (winter)	Wet (summer)	Dry (winter)	Wet (summer)	Dry (winter)
S-77	0.109	0.057	2.37	2.15	82.4	90.3
S-78	0.145	0.082	2.10	1.92	61.6	71.5
S-79	0.119	0.078	1.78	1.77	64.6	77.0
Tributaries:						
East Basin	0.161	0.109	2.90	3.10	77.9	77.4
West Basin	0.055	0.038	1.47	1.41	66.8	73.2
River:						
East Basin	0.112	0.064	2.29	2.07	74.2	78.9
West Basin	0.130	0.077	1.90	1.95	65.9	72.0

Chloride follows a trend between S-77 and S-79 that is the opposite of the pattern observed for phosphorus. Chloride decreases from S-77 to S-78 and then increases to S-79. Tributary flow is partially responsible for this trend, particularly in the West Basin. However, the lower river increases did not compensate for the upstream dilution, and chloride concentrations at S-79 were generally lower than at S-77. A seasonal trend showed slight decreases of chloride concentrations in the summer and high concentrations in the winter. High chloride concentrations are caused by saltwater intrusion, particularly near Franklin Lock, and by unplugged, abandoned, and poorly constructed wells that mix the poorer aquifer waters (high in dissolved ions) with surface or ground waters (Boggess 1972, Burns 1983).

Water temperature, pH, and specific conductance are generally well mixed along the vertical profile, and only water temperature showed a significant seasonal trend that peaked in summer. Mean water temperatures in the West Basin tributaries are generally lower than in the East Basin, particularly in Jack's Branch and Cypress Creek, where littoral and streambank vegetation shades much of the stream.

Dissolved oxygen profiles are responsive to both flow and time of year. Both East and West Basins exhibit higher dissolved oxygen (DO) concentrations in winter than summer. Generally, there is no vertical stratification of DO in winter during either high or low flow conditions. A gradient forms in the summer during low flow but is rapidly dissipated with an increase in flow.

Chlorophyll a concentrations, which serve as a measure of phytoplankton, are usually higher in the East Basin (McPherson and La Rose 1982). Seasonal minimum concentrations of less than 10 mg/m^3 during autumn and winter correspond to seasonal low temperatures. In May and early June concentrations increase and reach a maximum mean level of 40 mg/m^3. Decreases of nitrate and flow, in addition to increases in water temperature, correlate with increases in chlorophyll a (Milleson 1980, McPherson and La Rose 1982, Miller et al. 1982). When chlorophyll a concentrations reach a level that is visually obvious it denotes an algal bloom. This condition often results in a massive die-off of the plankton, and the subsequent decomposition depletes the water of oxygen and occasionally causes a fish kill. One such algal bloom was observed in the West Basin, adjacent to the Lee County Water Treatment Plant, in early June 1976 when concentrations reached 753 mg/m^3 (Milleson 1980). The blue-green algal species Anabaena flosaquae and Microcystis aeruginosa dominated the bloom. Subsequent blooms were reported in May, June and July 1977 and June 1980 (Miller et al. 1982). In all cases the bloom was reduced by freshwater releases from Lake Okeechobee. The relationship between chlorophyll a and the rate of flow in the Caloosahatchee River in late spring of 1978 is shown in Figure 34. Although higher chlorophyll a levels are reported annually in the East Basin, the reported algal blooms are located in the West Basin just upstream from the Franklin Lock. One possible reason for this is the presence of a nutrient-rich, low-volume source of water entering the Caloosahatchee River between Alva and S-79 (Miller et al. 1982). This supposition is based on dramatic increases of the river's total phosphorus, orthophosphorus, ammonia, and nitrate in the 4-mile reach from S-79 to Alva. The increase is most pronounced in the wet season and probably is caused by agricultural runoff from intensive flower nurseries and citrus groves close to the river. The influence of this runoff on the Caloosahatchee River is a decrease of chloride concentrations west of Alva.

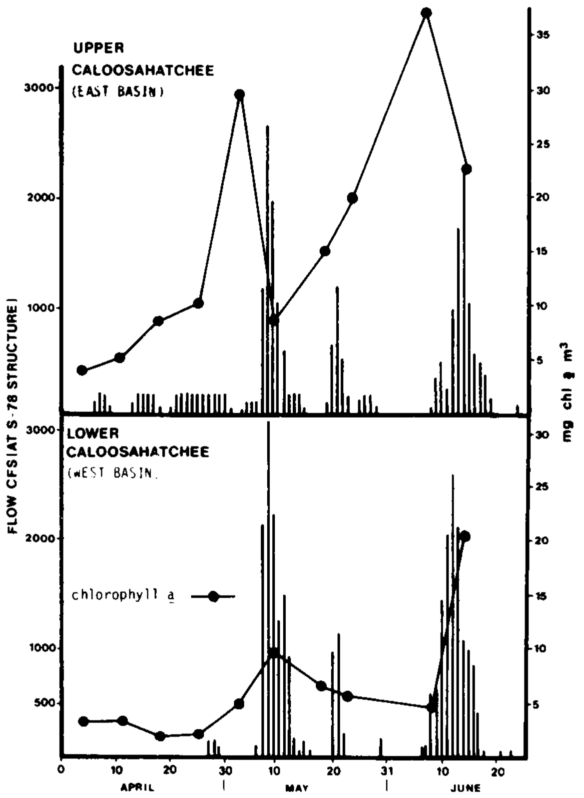


Figure 34. Algal concentrations measured as mg of chlorophyll a per m^3 in the upper and lower Caloosahatchee River in 1978 (adapted from SFWMD 1980).

The agricultural pesticides Aldrin, Dieldrin, DDT, and chlordane exceeded Florida Water Quality Standards in October 1979 at S-77 and S-78 (Miller et al. 1982). In April 1981 only chlordane exceeded State standards. Of the heavy metals only total iron and zinc exceeded State standards, on occasion.

Urban stormwater runoff from Fort Myers, LaBelle, and other population centers along the Caloosahatchee River contribute suspended and settleable solids, pathogenic microbes, nutrients, heavy metals, and pesticides (ESE 1977). Lead and mercury are among those metals detected at relatively high concentrations. The effect that urban stormwater has upon the Caloosahatchee River is either poorly documented near the major urban center of Fort Myers or dwarfed by the inflow of agricultural runoff and Lake Okeechobee discharge.

4.2.2 Tidal Caloosahatchee River

The portion of the Caloosahatchee River influenced by tides extends about 45 km (28 mi) downstream from Franklin Lock to San Carlos Bay (Figure 35). The upstream portion is dominated by the Okeechobee waterway, a channel maintained at a 2.43 m (8 ft) depth. Sporadic flow releases apparently have scoured the channel to depths up to 6.7 m (22 ft). At Orange River, about 11.3 km (7 mi) downstream from the locks, the winding Caloosahatchee River widens considerably. Dredged bottom sediments are deposited on either side of the channel from Beautiful Island downstream to the Highway 41 bridge, a distance of about 9.6 km (6 mi). These spoil deposits are more extensive on the north side of the channel than on the south side. The width of the river in this section averages 2.0 km (1.25 mi). The cities of East Fort Myers and Fort Myers are on the south bank, and North Fort Myers is on the north bank.

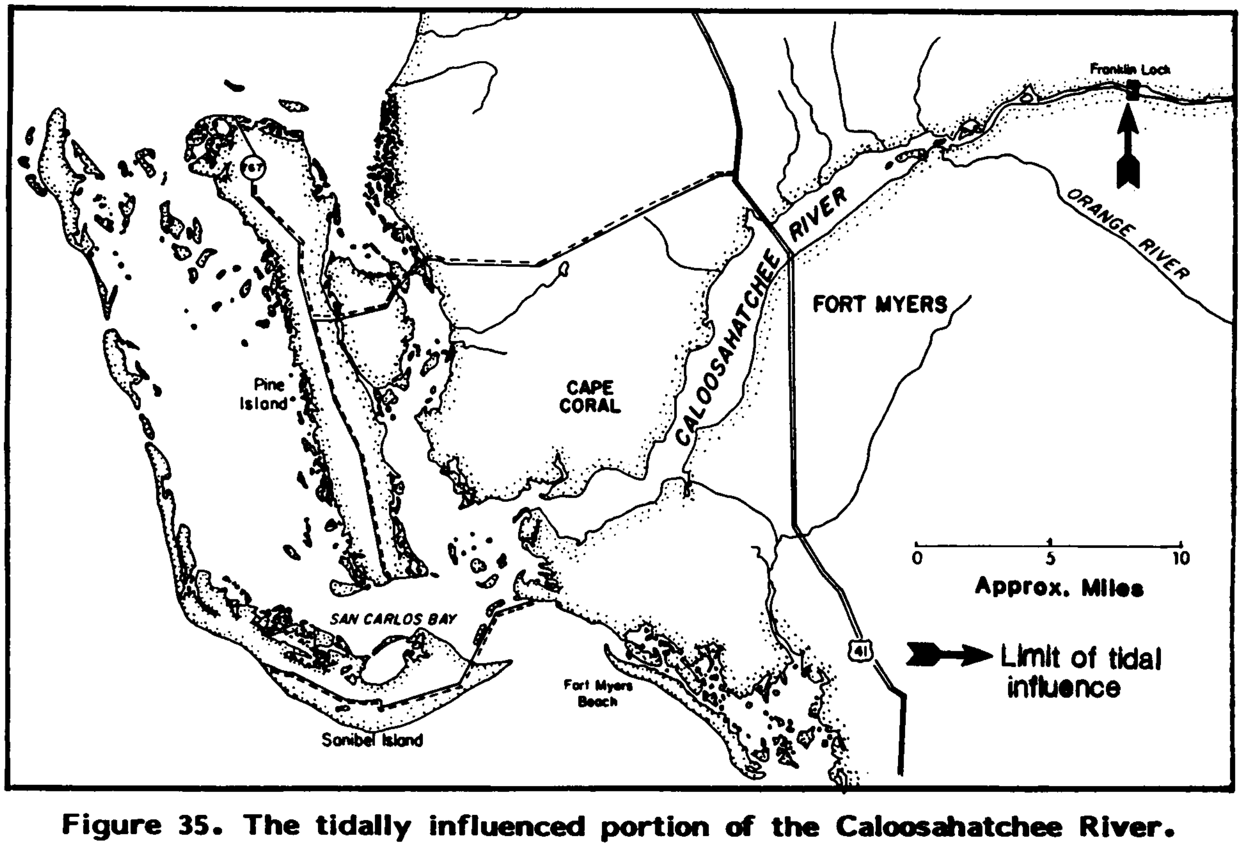


Figure 35. The tidally influenced portion of the Caloosahatchee River.

Water depths toward the middle of the river exceed 1.82 m (6 ft) beginning near the Highway 41 bridge. The Okeechobee waterway is shunted along the south side of the river near the Fort Myers Port facilities. The depth of these waters once averaged between 0 and 1.5 m (5 ft), but the average range now is 2.4 to 3.3 m (8 to 11 ft). The Caloosahatchee fixed bridge is located 0.8 km (0.5 mi) downstream from the Highway 41 bridge. On the north side of the river, some prominent spits of land jut out from the bank between the two bridges.

About 4.8 km (3 mi) below the second bridge the river widens to a maximum of 3.05 km (1.75 mi), then narrows again at Fourmile Point. Most of this oscillation in geography is on the northern side of the river, creating a broad, shallow shelf, whereas on the south side the main channel reunites with the Okeechobee Waterway at depths from 2.7 to 4.3 m (9 to 14 ft). The nearshore shelf of shallow water is much less extensive along the southern bank. The city of Fort Myers continues along the southern bank of this stretch and the eastern end of the Cape Coral subdivision lies on the north side.

From Fourmile Point to Shell Point, a distance of about 18.5 km (11.5 mi), the Caloosahatchee River estuary oscillates in width between 1.6 and 2.9 km (1.0 and 1.8 mi). The diversity of the depth contours increases in this stretch, particularly near Redfish Point. Islands of shallow water (< 1.82 m) located in deeper water suggests that some strong and complex currents flow toward the mouth of the estuary. A third bridge traverses the estuary near the midpoint of this segment, connecting the relatively undeveloped south bank with the extensively canalized city of Cape Coral subdivision along the northern bank.

Water movement in the Caloosahatchee River estuary has not been extensively studied. Two attempts to model water flow and quality in the estuary have produced only limited information on flushing characteristics and circulation patterns. The straight and narrow shape of the estuary and the well controlled inflow at its upstream boundary suggests ideal conditions for testing general textbook theories of estuarine hydrodynamics. Longitudinal profiles of salinity and temperature tend to confirm that there is a distinct increase in salinity downstream in the estuary, which varies with the season and the rate of freshwater inflow (Figure 36a to 36c).

In a detailed study of salinity, DeGrove (1980) was unable to demonstrate a convincing agreement between observed and calculated isohalines along the length of the estuary from Fort Myers to Shell Point. Water masses frequently appear oriented in a direction opposite to that predicted, suggesting that movement patterns are much more complex than the model was able to depict. Limited synoptic data on tidal relations and water quality along the length of the river also ruled out model development. During low flow the author estimated a retention time of about 25.3 days for particles traveling over the length of the estuary between Fort Myers central sewage plant discharge and San Carlos Bay.

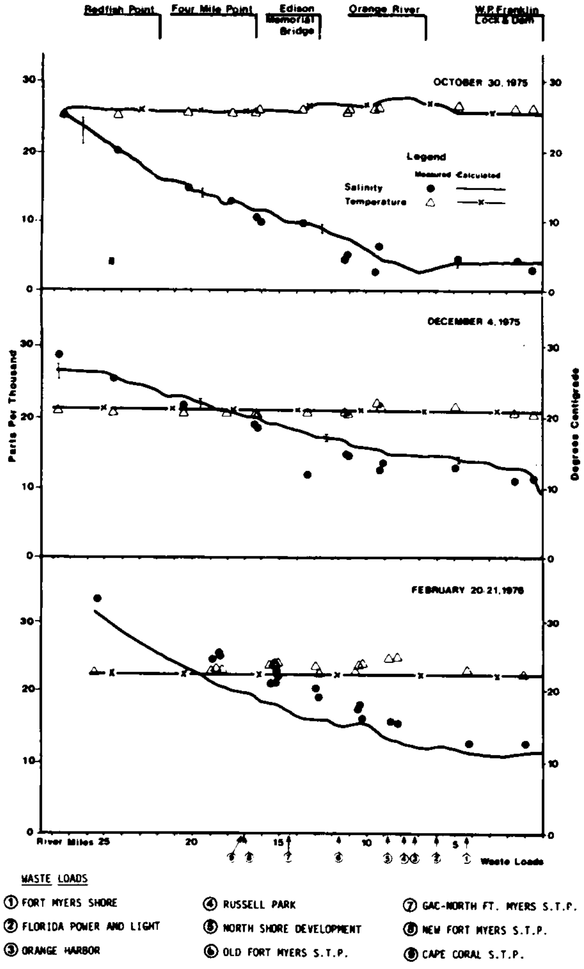


Figure 36. Temporal variations in salinities and water temperature along the Caloosahatchee River (adapted from Post, Buckley, Schuh and Jernigan, Inc. 1976).

Because the estuary is so long (45 km or 28 mi), it is conceivable that different sections may be responding to different local conditions. At the upstream boundary, lock operations may complicate expected flow and tidal patterns. A change in the orientation of the estuary's axis may influence tidal movement. Axis orientation relative to wind direction also causes different hydraulic effects at different locations. The location of causeways, tributaries, extensive urban centers, and canals also influence the characteristics of local hydraulic conditions by changing water storage capacity, velocity, and runoff.

Water quality in the Caloosahatchee River estuary has been studied by a number of agencies from 1973 to 1981. Yet routine monitoring of background conditions at fixed locations is generally lacking. Data collected from synoptic surveys for specific purposes, such as the allocation of domestic wasteloads, is the prevailing information source.

Water quality data from three surveys from October 1975 to February 1976 were reported by Post, Buckley, Schuh and Jernigan, Inc. (1976). Their sampling included transects at eight locations along the axis of the estuary in addition to grab samples at selected stations between the transects. These samples were taken largely to help model the dissolved oxygen balance of the estuary. A summary of the data collected on these surveys is given in Figure 37.

In all three surveys the data reveal a rise in dissolved oxygen concentration from 12.8 to 16 km (8 to 10 mi) downstream from the Franklin Locks and Dam. In October and December, in the upper reaches of this segment, concentrations of dissolved oxygen are generally less than 4.0 mg/l. A relatively intense mixing between salt and fresh waters was observed about 17 km (10.5 mi) downstream. Upstream from the mixing zone, tidal dampening of river flow increased residence time, which increased the probability of oxygen deficits in the water column. Because of salinity increases downstream, the solubility of oxygen and dissolved (DO) oxygen decreased.

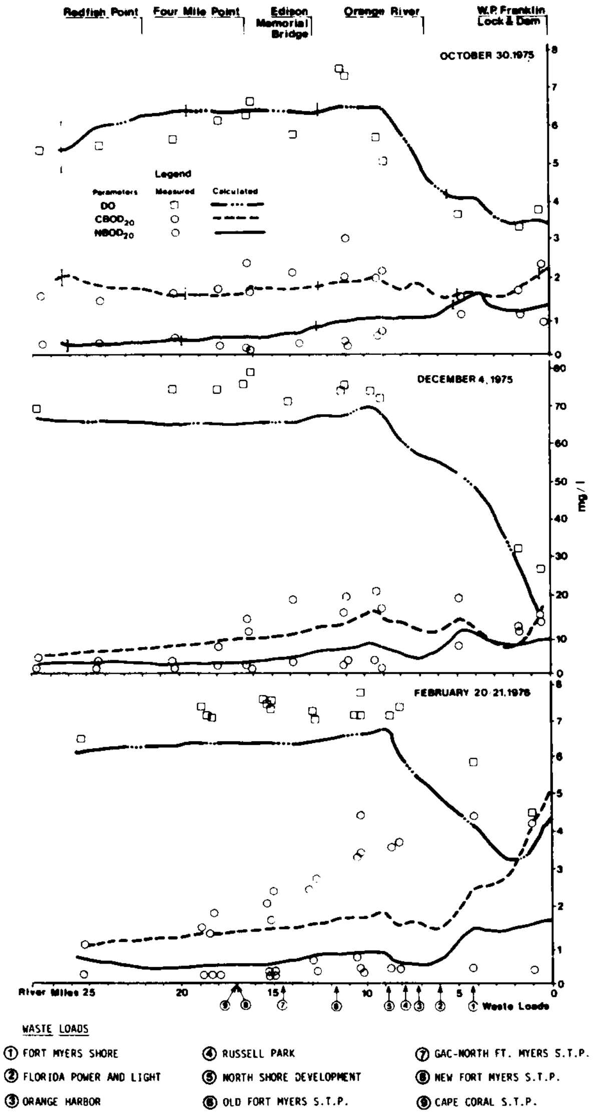


Figure 37. Temporal variations in water quality data along the Caloosahatchee River (adapted from Post, Buckley, Schuh and Jernigan, Inc. 1976).

The average water temperature in December was about 5°C less than in October, and salinity increased slightly. The flow in December dropped sharply, which increased the residence time of upstream waters. Higher salinities and resident times in upstream waters, and lower water temperatures (and consequently lower metabolic rates) apparently lowered DO near the locks. From the locks to a point 16 km (10 mi) downstream, the DO increased and seaward of this point the DO level remained stable.

Continued low flows and low temperatures by February created a semi-steady-state condition in which oxygen concentrations hovered near 4.5 mg/l at the locks and rose fairly rapidly to 7.0 mg/l downstream. The prolonged suppression of metabolism in cooler waters combined with increased settling of oxygen demanding materials (BOD, COD) during low flow is believed to be responsible.

Carbonaceous oxygen demand ($CBOD_{20}$) along the estuary follows a pattern opposite to DO; the 17 km (10 mi) point appears to be an inflection point. This pattern is least obvious in October when levels of $CBOD_{20}$ are nearly uniform along the estuary axis. In December and February there is a distinct tendency for $CBOD_{20}$ to decline with distance seaward of this point. Nitrogenous oxygen demand ($NBOD_{20}$) also shows a tendency to decrease with distance from the Franklin Lock, but this pattern is less obvious. $NBOD_{20}$ levels are highest in October and December and uniformly low in February.

The seaward changes of dissolved oxygen, $CBOD_{20}$, and $NBOD_{20}$ indicate a conspicuous convergence of physical and chemical conditions about 16 to 17 km (10 mi) downstream from Franklin Lock. This reach is where the upper Caloosahatchee River estuary widens. From 19 to 21 km (12 to 13 mi) the upper estuary is constricted by two bridges. The area between receives inflow from the Orange River and the city of

Fort Myers waste discharge. These conditions tend to promote relatively high algal productivity (Figure 38). During high nutrient inflow (wet season), moderate salinity, and high temperature, chlorophyll a in this area may reach bloom concentrations (250 mg/l). In winter and early spring when river flow and temperature are low, and salinities are high, chlorophyll a concentrations tend to be lower (PBSJ 1976).

An analysis of water quality in the tidal Caloosahatchee River indicates that there are five major sources of pollution (DeGrove 1981). These are the downstream flow from Franklin Lock, the Orange River inflow, the Fort Myers sewage treatment plants (central & southern plants), the Cape Coral subdivision and sewage treatment plant, and the Waterway Estates sewage treatment plant. Most of these areas or locations are shown on Figures 31 and 35. According to DeGrove (1981) all but one of the sewage treatment plants are required to cease surface-water discharge in the near future. The remaining plant, Fort Myers south, is required to treat and discharge effluents that will not cause total phosphorus concentrations to exceed 0.165 mg/l and total nitrogen to exceed 1.1 mg/l. Degrading influences from surrounding urban and agricultural nonpoint sources may be somewhat curbed through implementation of the recent stormwater permitting requirements and voluntary "best management" practices.

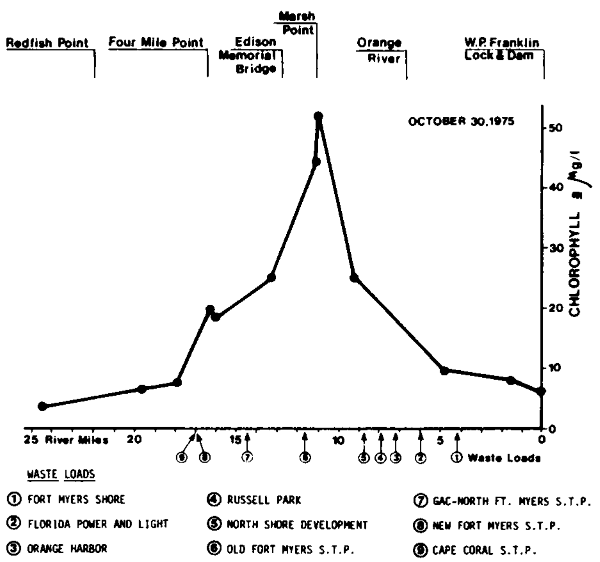


Figure 38. Chlorophyll a concentrations in the Caloosahatchee River estuary (adapted from Post, Buckley, Schuh and Jernigan, Inc. 1976).

4.3 ESTERO BAY WATERSHED

Relatively little is known about hydrology and water-quality dynamics in the Estero Bay watershed. Information on tides, physical/chemical characteristics, and nutrients in the northern bay were reported by Tabb et al. (1974). A report on water quality in the bay was made by Duane Hall and Associates (1974), and reports on salinity and temperature in the central and southern bay were provided by Jones (1980). Data on tides, currents, and runoff were summarized by Estevez (1981). In addition, the Florida Department of Environmental Regulation (FDER) maintains a water quality monitoring station at San Carlos Pass, a major inlet to Estero Bay.

Freshwater inflow into the Estero Bay estuary generally peaks in September (Kenner and Brown 1956). Flows measured in the Imperial River from 1940 to 1952 indicate that flow in the dry months (December to May) averages only about 7% of the total annual inflow. Virtually no published information on the quality of this or other freshwater inflow into Estero Bay is available.

Tidally induced flows in Estero Bay are far greater (volume and velocity) than the freshwater inflow (Jones 1980). The generally mixed type tides average about 0.54 m (1.75 ft), or 0.94 times those of the open coast (Estevez et al. 1981). At the three major passes between the bay and the Gulf of Mexico, flood tides can be as high as 1.07 m (3.5 ft). Velocities in the pass range from 0.64 m/s (ebb) to 1.52 m/s (flood). Tidal prisms (ft^3) calculated at the three major inlets to Estero Bay are shown in Table 16.

Freshwater inflow into Estero Bay is so low that even in its upper reaches salinities seldom fall below 10 ppt in the wet season. In the dry season, tidal flushing and freshwater inflow from ungaged sources apparently is sufficient to prevent widespread hypersalinity. Water samples taken over a year's time at 20 stations in the northern and central bay revealed salinities as high as 34.0 ppt (Tabb et al. 1974).

Concentrations of inorganic nitrate (NO_3) and phosphate (PO_4) in the north and central bay are relatively low. Nitrate ranges from 0 to 0.10 mg/l in the bay and phosphate ranges from 0.02 to 0.26 mg/l (Tabb et al. 1974). Concentrations of both tend to decrease toward the Gulf.

Table 16. Tidal prisms in Estero Bay on February 8, 1976 (adapted from Estevez 1981).

	INLET PRISM (ft^3)	
INLET	FLOOD	EBB
Big Hickory Pass	1.20×10^6	
New Pass	2.71×10^8	2.02×10^8
Big Carlos Pass	8.19×10^8	5.75×10^8

4.4 GOLDEN GATE CANAL WATERSHED

The drainage areas of the Golden Gate Canal, Gordon River, Cocohatchee River Canal, Henderson Creek Canal, and the Fahka Union Canal are depicted in Figure 39. The Fahka Union Canal is the largest of the artificial drainage systems, averaging about 30 m (100 ft) in width and just less than 2.4 m (8 ft) in depth over a distance of about 48 km (30 mi). The Golden Gate Canal is similar in width and depth but is slightly shorter, 41.6 km (26 mi). The Henderson Creek and Cocohatchee River Canals are smaller, averaging 7.6 m (25 ft) in width, less than 1.5 m (5 ft) in depth, and 11.2 and 20.8 km (7 and 13 mi) in length, respectively (McCoy 1972).

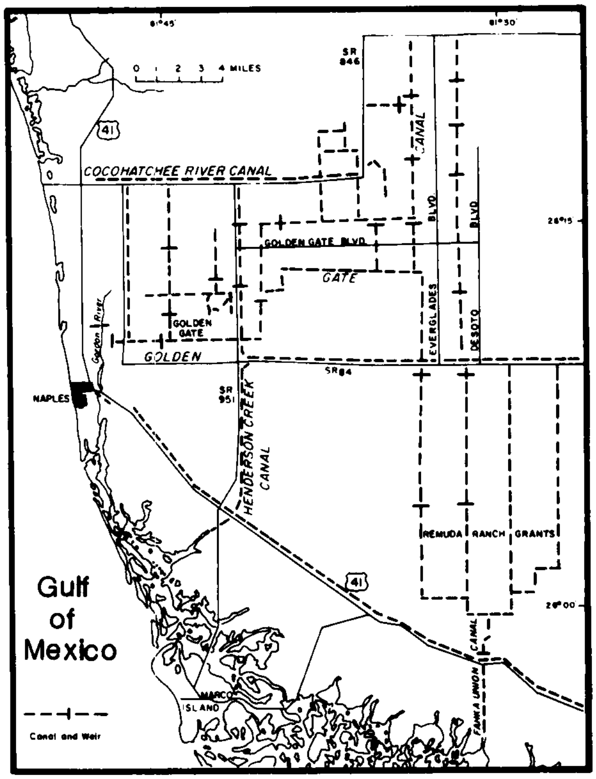


Figure 39. Canals in western Collier County (adapted from McCoy 1972).

Downstream freshwater flow through this extensive maze of canals is partially controlled by a set of 30 weirs ranging in elevation from 5.16 to 0.6 m (17 to 2 ft) above mean sea level (msl). These weirs are designed to prevent excessive drainage during the dry season. All canals except the Cocohatchee and Henderson Creek are controlled by at least one weir.

During the dry season, the Cocohatchee River Canal drains the area southwest of Lake Trafford. During the extremely dry years, e.g., 1971 and 1974, no flow is reported (USGS 1980). Outflow from the canal has averaged 0.82 m^3/s (29.1 cfs).

During very wet periods, the Cocohatchee River Canal functions as an overflow valve for excess drainage from the Golden Gate area to the south. Maximum discharge from the Cocohatchee River Canal is 15.3 m^3/s (542 cfs), in August, 1973. The average peak velocity is 0.4 m/s (4.3 ft/s) as compared to an average velocity of 0.02 m/s (0.23 ft/s).

The Golden Gate area and the Cocohatchee River Canal basin apparently draw from the same water table. The construction of weirs W-4 and W-8 in the Golden Gate Canal in 1964 correlates with an unexpected rise in the water table at the Cocohatchee Canal outlet. The water table at the Cocohatchee River Canal well rose higher in the 1965 rainy season than in the two previous rainy seasons, even though rainfall in 1965 was below average (McCoy 1972). At the same time, inland construction of Golden Gate Estates canals diverted upstream drainage away from the Cocohatchee River Canal, effectively reducing peak water levels and flows downstream. The net effect of these hydraulic shifts is that the Cocohatchee River Canal becomes both a supplier of water to the Golden Gate area during low flow and a discharge valve for Golden Gate Estates during high flows.

The Golden Gate canal was constructed in the early 1960's in an attempt to reduce the hydroperiod of a vast tract of land known as Golden Gate Estates. Simultaneously, the tract was platted and rezoned for residential development; roads and auxiliary canals were constructed, and the land was offered for sale. In conjunction with concerns over the environmental effects of such massive drainage, Collier County officials in about 1970 initiated actions to revise the earlier development plan. In addition to the alteration of natural habitats, there were other shortcomings in the plan. A typical graph of water levels in a well 1.12 km (0.7 mi) from the Golden Gate Canal is shown in Figure 40. This graph clearly demonstrates that the Golden Gate Canal drained these former wetlands and lowered the water table.

To the southeast of the Golden Gate Canal, a second grid-like series of canals was also constructed in the early 1960's as part of the same residential development. These canals, which culminate in the Fahka Union Canal, discharge into the Ten Thousand Islands area. The canals were designed to drain the Remuda Ranch Grants, a large section of former wetlands south of State Road 838 (Alligator Alley).

Between these two larger networks of canals, a third drainage way, the Henderson Creek Canal, flows south/southwest from the Golden Gate Estates to the Gulf of Mexico. Like the Cocohatchee River Canal, Henderson Creek Canal serves

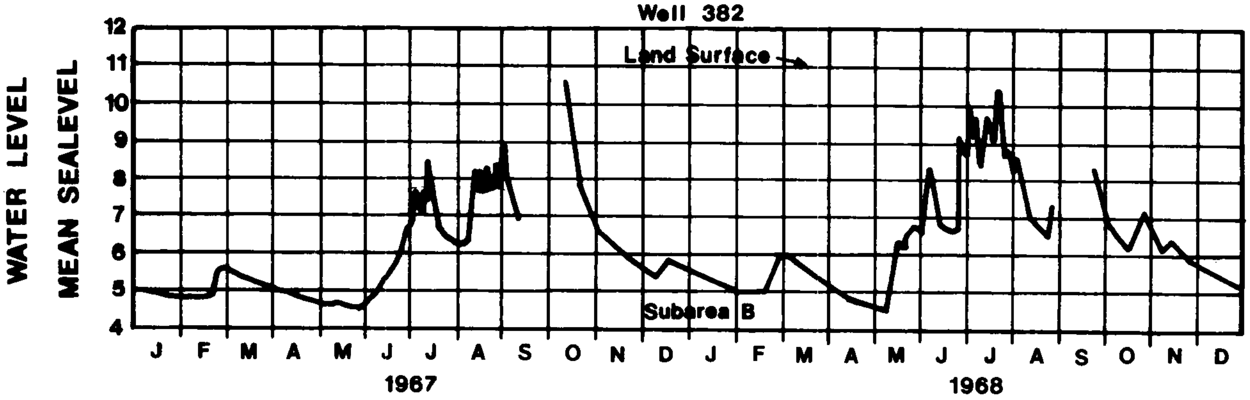


Figure 40. Water levels near the Golden Gate Canal (adapted from Klein et. al. 1970).

as an overflow valve for Golden Gate Estates during peak wet periods.

During the dry season (November to May) most or all of the flow in the upstream end of the Golden Gate Canal system may recharge the shallow ground-water aquifer. Surface discharge during the dry season ranges from 0.28 to 1.27 m^3/s (10 to 45 cfs). Further downstream dry season flows range from 0.28 to 3.4 m^3/sec (10 to 120 cfs). At Naples reports of no flow were common in 1975, but on the average, flows of 1.70 to 8.5 m^3/s (60 to 300 cfs) are released to the Gordon River/Naples Bay estuary during the dry season. Dry-season flows in the Henderson Creek Canal range from 0 to 0.71 m^3/s (0 to 25 cfs) and in the Fahka Union Canal, the range is from 1.27 to 3.54 m^3/s (45 to 125 cfs). The ranges and extremes of wet-season flow in these three canals are given in Table 17.

The seasonal characteristics and magnitude of water discharges from these canals have profound effects on regional hydrology and ecology. Tabb et al. (1976) estimate, through a simplified mass balance technique, that during average rainfall years there is little if any surplus runoff from the watershed canals. Based on the saturation capacity of the soils and monthly rainfall, hydroperiod is estimated at between 4 and 6 months. These figures agree well with observations of long-term residents. These canals, since their construction, have effectively drained off surface waters, shortened the hydroperiod by about 4 to 6 months, and lowered groundwater recharge.

A number of topographic clues suggest that the area underlying the Golden Gate and Henderson Creek Canal drainage basins is relatively impermeable to recharge. Tabb et al. (1976) call this area the "Golden Gate Highlands" (Figure 41) and reason that its impermeability is due to an underlying caprock of the Fort Thompson Formation. These authors speculate that recharge of this area is more likely due to lateral inflow through cavernous subterranean limestone channels which undergo solution by acidic fresh waters, rather than through direct downward seepage. The presence of actively forming karst topography is strongly suggested by Deep Lake (30 m or 97 ft in depth) on the east of the

Table 17. Wet-season flow ranges and extremes for Golden Gate Canal, Henderson Creek, and Fahka Union Canal.

	Wet season	
	Flow Range m^3/sec (CFS)	Extreme m^3/sec (CFS)
Golden Gate Canal		
Upstream	0.6 - 2.8 (22-100)	5.1 (181)
Mid reach	1.1 - 10.5 (40-370)	20.2 (714)
Downstream	3.0 - 18.7 (105-660)	98.1 (3,460)
Henderson Creek	0.4 - 0.8 (16-30)	10.0 (353)
Fahka Union		
Upstream	0.4 - 1.1 (15-42)	4.5 (160)
Mid reach	1.4 - 7.4 (50-260)	10.3 (362)
Downstream	2.8 - 17.0 (100-600)	90.7 (3,200)

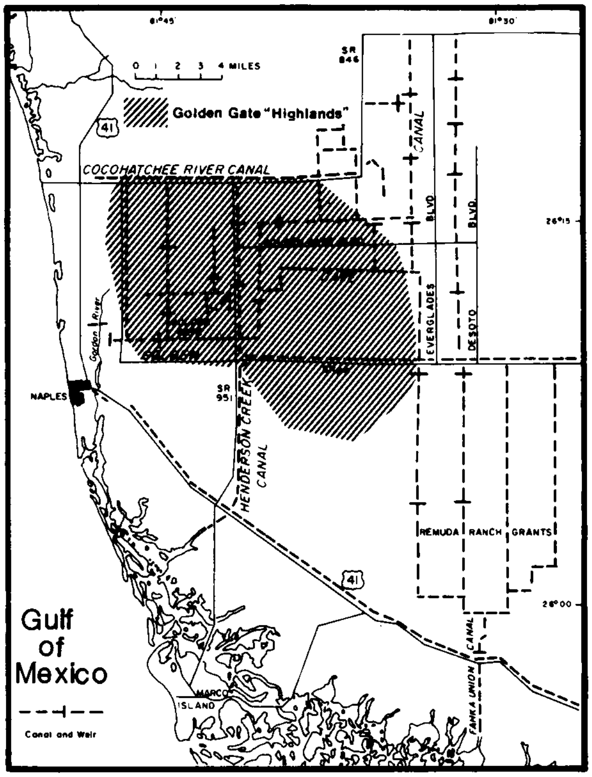


Figure 41. The Golden Gate Highlands area (adapted from Tabb et al. 1976).

Highlands and a well-defined line of cypress strands running along their western margin. These strands are underlain by deep sands in eroded solution channels that are believed to have connections with deeper channel systems.

The area along the eastern perimeter of the "Highlands" acts as a kind of leaky roof for recharging the underlying aquifer to the west. The Golden Gate Highlands is less permeable to seepage flow because of a shallow Fort Thompson caprock that overlies deeper Tamiami caprock of dense clays. Removing upstream surface waters via canals may therefore amplify the loss of recharge to the down-gradient aquifer by short-circuiting the leaky roof connection. Tabb et al. (1976) estimated that the construction of the 293 km (183 mi) of Golden Gate Estates canals accelerated the rate of drainage of stored water to about 16 times normal.

To the south, the Highlands is drained by what is known as the

Gulf American Corporation (GAC) canal network into Fahka Union Canal and Fahka Union Bay. The area drained by the GAC canal network is also known as the Remuda Ranch Grants. The borrow canal of State Road 84 (Alligator Alley) cuts across this canal system and connects with the Golden Gate Estates canals and Henderson Creek Canal. Further south the Tamiami Canal also crosses the Fahka Union. Groundwater levels here have been lowered approximately 61 to 122 cm (2 to 4 ft) by the more extensive regional drainage canals (Klein et al. 1970).

To the north and west of the GAC canal network are five major strand systems, the Deep Lake Strand, Okaloacoochee Slough, Fahkahatchee Strand, Roberts Lake Strand, and Gum Slough (Figure 31). Although not directly within the Golden Gate Estates canals, the Camp Keasis strand is close enough to the regional drainage system to be affected by it.

Okaloacoochee Slough begins near the Hendry-Collier County line and runs southwest to near Alligator Alley. Here there appears to be a short discontinuity between the slough and Fahkahatchee Strand to the south, although both Carter et al. (1973) and Tabb et al. (1976) believe there is a hydrologic connection between them. The Okaloacoochee Slough is crossed in the north-south direction by the Barron River Canal and the Fahkahatchee strand is crossed by the east-west borrow canal of Alligator Alley.

The hydrology of the Fahkahatchee strand was monitored by Carter et al. (1973) from 1970 to 1972. These authors reported the curious phenomenon of relatively high flows emanating from the strand during 2 years of below normal rainfall, followed by a low discharge during a year of high rainfall. Even more curious was that ground-water levels during the high rainfall/low runoff year decreased rather than increased, indicating seepage to deep storage. The easternmost GAC canal intercepted water from the Fahkahatchee strand and effectively lowered ground-water levels as designed.

Fresh ground water for domestic, agricultural, and industrial purposes in the Golden Gate's Estates canals came from a shallow unconfined or semi-confined aquifer (Jakob 1983). The permeable limestones and sands of the Pleistocene and the upper permeable limestones of the Miocene-Pliocene Tamiami Formation are the major components of the shallow aquifer. The maximum depth of the aquifer is 39.6 m (130 ft) near the city of Naples. It tends to thin toward the northeast, east, and southeast (McCoy 1962, 1972; Jakob 1983).

Water-quality data in the Golden Gate Estates canal drainage area was reported by Little et al. (1970), McPherson (1970), Carter et al. (1973), Tabb et al. (1976), and ESE (1978a). The most prominent influence on natural background water quality is rainfall. During the wet season, abundant rainfall dilutes most chemical substances, whereas diminishing rainfall in the dry season concentrates the sediments and chemicals in solution. Superimposed on this cycle are the effects of drainage canals that tend to alter the magnitude and timing of natural flow. Localized variations due to land use, uneven rainfall distribution, and inherent physiographic differences also are evident.

Some water-quality characteristics, such as conductivity and chloride concentration, generally follow the wet/dry season cycle described by Carter et al. (1973). Conductivity, which reflects the ionic content of the water, increases in the dry season as inorganic constituents become more concentrated. Near the coast the effect is amplified by the inland migration of salt water. If uncontrolled, canals tend to amplify this inland migration by providing more rapid access to coastal aquifers. The use of weirs and earthen dams reduces this problem. Wimberly (1973, 1974) reported short-term increases in conductivity and chloride concentration near oil-exploration sites, but no detectable effects at oil-producing sites.

Other water-quality characteristics, such as alkalinity, may also decrease during the wet season but are strongly influenced by localized drainage (Little et al. 1970). Canals may release more buffered ground water into the surface water drainage system than do uncanalized sloughs. The water at all canal stations is higher in alkalinity, on the average, than at slough stations (Carter et al. 1973). Little et al. (1970) also reported higher levels and greater variation in alkalinity, hardness, and sulfate at canal stations. Increased groundwater influence is again believed responsible.

Although pH fails to show any distinct variation during the general wet/dry season cycle, water color does. Drainage of organic tannin and lignin-like substances from swamps during the wet season is believed to be responsible for this increase. Apparently the buffering capacity of surface waters is sufficient to mask seasonal variations in pH.

Relatively little information exists on dissolved gases, nutrients, and organic matter from the Golden Gate Estates canals. Tabb et al. (1976) report oxygen concentrations of 4.2 to 5.4 mg/l during October 1976 and 3.3 to 7.0 mg/l in January 1976. Depth of the canal is a major factor influencing oxygen concentrations. Deep canals are fed more by low-oxygen ground-water than shallow canals. Nitrate concentrations ranged between 0.45 and 1.00 mg/l in October and from 0.60 to 0.75 mg/l in January. Total phosphate ranged from 0.04 to 0.21 mg/l in October and 0.17 to 0.38 mg/l in January. Once again, higher and more variable nitrogen and phosphorus levels are reported from canal stations than from slough and strand stations (Little et al. 1970).

Diurnal oxygen and temperature curves from four locations in the Corkscrew Swamp are presented in Figure 42. The cypress locations and the "pond with floating vegetation cover" display characteristically little variation because of shading. The relatively more open sawgrass marsh has a more distinct diurnal cycle, although DO levels are clearly below saturation. Diurnal variations of DO are greatest in open, mixed-marsh environments where daily ranges of 7.0 to 7.5 mg/l have been recorded (Duever et al. 1975).

To the south, in the GAC canal network, Fahka Union Canal, and Fahkahatchee Strand, highest oxygen concentrations have been reported in March to June at most stations (Carter et al. 1973), with the lowest concentrations in September to October. Fahka Union Canal station samples were consistently higher in dissolved oxygen than water samples from strand stations. The authors attribute this phenomenon to higher flow rates and the

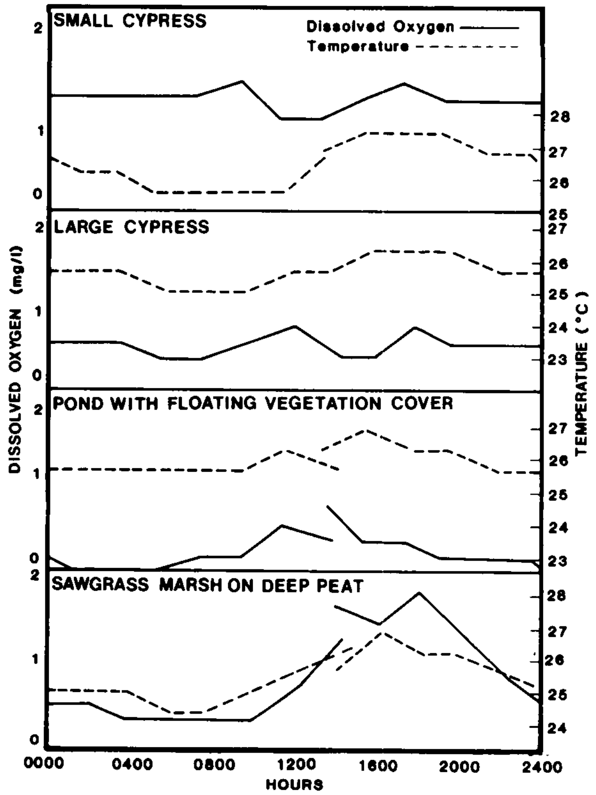


Figure 42. Diurnal dissolved oxygen and temperatures for Corkscrew Swamp, September 1975 (adapted from Duever et al. 1975).

abundance of aquatic vegetation in the canals compared to the slower moving, more shaded waters of the strand.

Water temperatures in shaded strands and sloughs average about 1.1°C (2°F) below those in more open canal waters (Little et al. 1970). This condition could help bring about lower oxygen concentrations in canals. Where dense mats of floating aquatic vegetation thrive in shallow canals (e.g., Tamiami Canal), oxygen concentrations, and diurnal variation may be similar to that in strands and sloughs.

Comparisons show that the annual transport of total Kjeldahl nitrogen (TKN), total phosphorus (TP), and total organic carbon (TOC) from the Fahka Union and Barron River Canals is much higher than from the relatively undisturbed Fahkahatchee Strand (Carter et al. 1973). Canals cause a shift in the timing and relative magnitude of the delivery of nutrients to the estuary and an accelerated loss of water, nutrients, and organic matter from the uplands.

Most authors who have studied the water quality of the Golden Gate Estates canal waters agree that metal and pesticide pollution was not a problem, nor were mercury, copper, chromium, arsenic, and nickel detected in the water column in the GAC canals or the Barron River Canal (Carter et al. 1973). Zinc and lead were only rarely detected. Iron concentrations ranged from 100 to 1,150 mg/l, but this is not considered unusual. Wet-season copper concentrations in the GAC canals ranged from 0.20 to 0.30 mg/l (Tabb et al. 1976).

Little et al. (1970), Carter et al. (1973), and Duever et al. (1978) attribute occasional higher than normal levels of aluminum, copper, lead, and zinc to locally intense vehicle use, urban construction, and agriculture.

The six estuaries within the Golden Gate Estates area from north to south are as follows:

(1) Wiggins Bay at the downstream end of the Cocohatchee River; Wild Turkey Bay and Naples Park lie to the south of Wiggins Pass.
(2) Naples Bay surrounded by the city of Naples; Dollar Bay to the south of Gordon Pass is considered a part of the same system.
(3) Rookery Bay, a National Audubon Society Wildlife Sanctuary lying downstream of Henderson Creek directly behind Marco Island.

(4) The Marco Island estuary within and surrounding Marco Island and Cape Romano.
(5) Fahka Union Bay downstream of the Fahka Union Canal.
(6) Fahkahatchee Bay downstream of Fahkahatchee Strand. Gullivan Bay refers to the embayment behind Cape Romano and seaward of the Ten Thousand Island area of Fahka Union and Fahkahatchee Bays.

Very little information is available on the hydrology and water quality of Wiggins Bay and Gullivan Bay: consequently our discussion is brief.

The monthly average water flows in the Cocohatchee River Canal, which drains into Wiggins Bay, are given in Figure 43. Flows from November to June average less than 0.56 m^3/s (20 cfs). Beginning in July average flows increase, reaching a peak in September (mean = 3.05 m^3/s or 109 cfs). The convoluted topography of the natural drainageways and the construction of finger canals slow the flushing of bay water through Wiggins Pass.

The existing physical/chemical quality data on the Wiggins Bay system were summarized by ESE (1978a). Salinities in April and June are close to those of the Gulf (27.2 to 33.9 ppt). During September, at the peak of the wet season, salinity ranges between 17.9 and 21.9 ppt. Average monthly water temperatures are 23.1°C in April, 30.1°C in June, and 29.5°C in September.

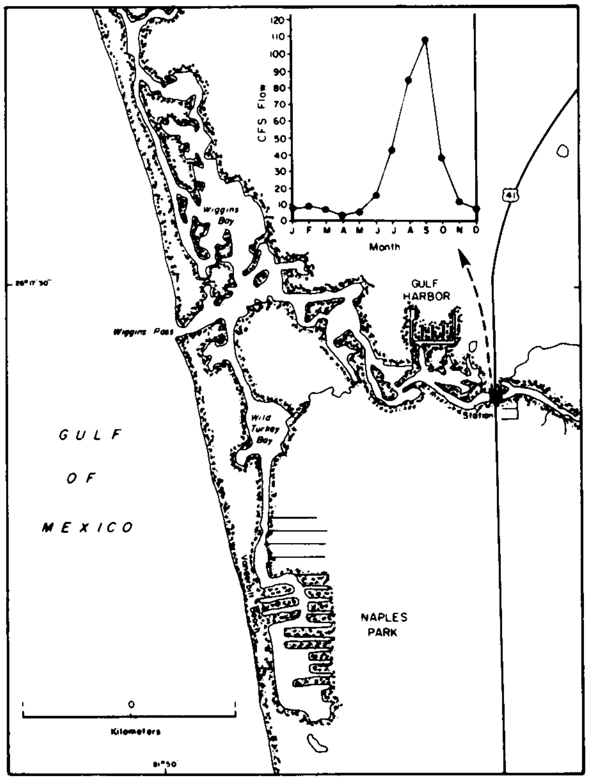


Figure 43. Average monthly flow (cfs) in the Cocohatchee River Canal (adapted from ESE 1978a).

The Naples Bay estuarine system receives freshwater input from the Golden Gate Canal, the Gordon River, Haldeman Creek, and Rock Creek. Of these four, only the Golden Gate Canal is equipped with a flow gauging device. Monthly average flows emanating from the Golden Gate Canal are shown in Figure 44. Toward the south, Naples Bay connects to the Gulf through Doctor's Pass and to Rookery Bay via the Intracoastal Waterway.

According to van de Kreeke (1979) salinities upstream from the U.S. Highway 41 bridge approach zero during high flow (August to September). The middle section of Naples Bay may average as low as 20 ppt. Restricted water exchange between the mid and upper bay causes salinities to decrease rapidly above the bridge. Salinity stratification tends to increase toward the southern end of Naples Bay. The frequent variations in freshwater inflow and the short distances within the bay

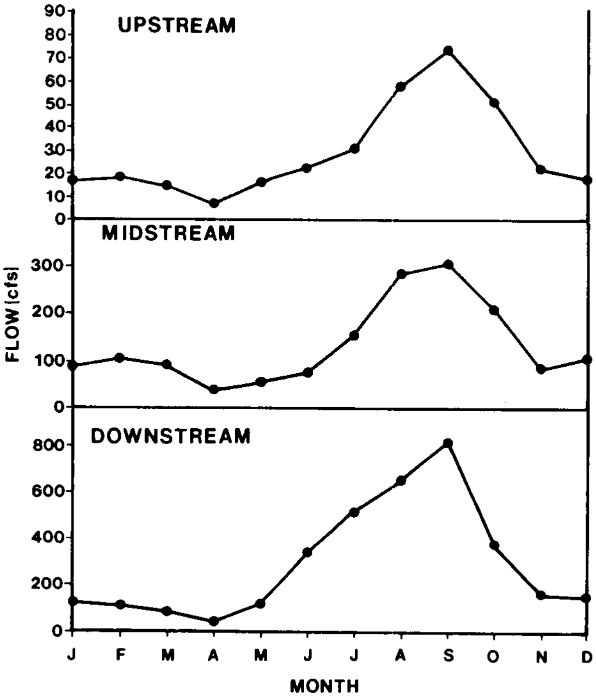


Figure 44. Average monthly flow (cfs) in the Golden Gate Canal.

relative to tidal excursion generally preclude stable flow and circulation patterns. Tidal excursions of 4,000 to 6,000 m (4,376 to 6,564 yd) are estimated for the open portion of Naples Bay.

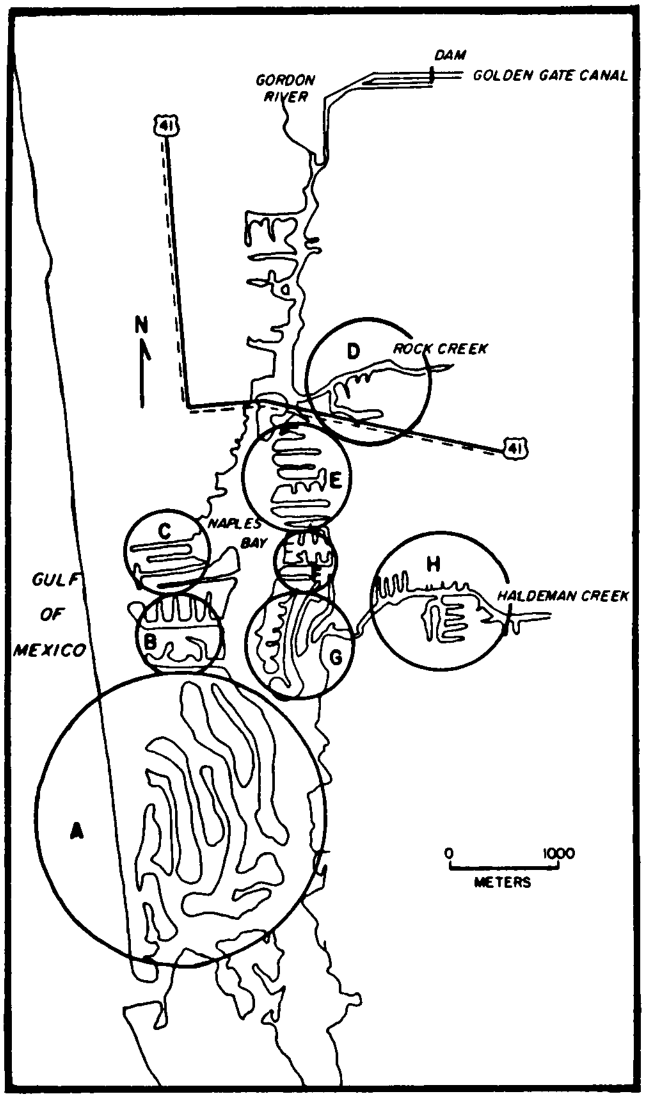
One of the more prominent factors influencing Naples Bay hydrology and water quality is the extensive network of finger canals carved out of the once mangrove-lined tidal creeks that border the bay system. The extensive dredge-and-fill activity, along with shoreline development, has created a very irregular bathymetry in and around the periphery of the bay.

Eight types of canal development are based on canal width, length, depth, proximity to one another, and type of shoreline stabilization (Figure 45), according to van de Kreeke (1979). All canal developments except Port Royal (A) and Aqualane Shores I (C) exhibit numerous finger canals branching off from the main canals. Many of the finger canals are deeper at their heads than at their mouths, effectively trapping high-salinity waters.

In attempting to model the hydrodynamics of Naples Bay, van de Kreeke (1979) found that observed tide ranges and currents fit reasonably well with predicted values. A consistent error in predicting time lags during flood-tide cycles was believed to result from underestimating the amount of water storage capacity in the natural mangrove areas and small canal systems.

Current velocities and circulation patterns within the canal systems are extremely complex. Canal velocities often are larger than predicted (Monopolis 1978). Winds are discounted as an important factor. Rather, current reversals within the vertical velocity profile and the existence of lateral cross-canal currents suggests that the main driving force is oscillating-density currents induced by salinity fluctuations in the main bay. These oscillating salinities along the axis of Naples Bay are considered essential to flush the peripheral canal systems (van de Kreeke 1979). In addition, flushing of canals is highly dependent upon their length and bathymetry. Shorter canals exhibit an exponential flushing curve whereas longer canals show a level curve for a time, then an exponential curve as the dye mass reaches a critical excursion length. Typical canal flushing curves are shown in Figure 46.

Water quality in the Naples Bay estuary is reported by Hicks (1979) from December 1976 through November



CANAL TYPES
With respect to construction and geometry the canals connected to Naples Bay are divided into different groups:

A. Port Royal
  typical length 1800 m; typical width 70 m
  depths vary between 2 m and 6 m
  shoreline protected by rip-rap
  no finger canals
B. Aqualane Shores I
  typical length 700 m; typical width 50 m
  typical depth 1.5 m
  shoreline protection: mixture of vertical sea walls and rip-rap
  finger canals
C. Aqualane Shores II
  typical length 700 m; typical width 20 m
  typical depth 1.5 m
  shoreline protection: mostly wooden and concrete vertical sea walls, some areas unprotected
  no finger canals
D. Rock Creek
  typical length 500 m; typical width 30 m
  typical depth 0.6 m
  shoreline protection: vertical sea walls
  finger canals
E. Boat Haven/Golden Shore/Oyster Bay
  typical length 400 m; typical width 20 m
  typical depth 0.4 m
  shoreline protection: vertical sea wall, rip-rap, natural
  finger canals
F. Oyster Bay
  typical length 500 m; typical width 20 m
  typical depth 0.7 m
  shoreline protection: vertical concrete sea walls
  finger canals
G. Royal Harbor
  typical length 750 m; typical width 20 m
  typical depth 1.2 m
  shoreline protection: vertical concrete sea walls
  finger canals
H. Haldeman Creek
  typical length 250 m; typical width 20 m
  typical depth 0.4 m
  shoreline protection: vertical sea walls, rip-rap, natural
  finger canals

Figure 45. Types of canal development in the Naples Bay area (adapted from van de Kreeke 1979).

1977. Water sampling and analysis was designed to focus on metabolism in the bay as opposed to levels of toxins such as pesticides or heavy metals. Seasonal and diel trends in selected physical/chemical constituents in both water and sediments were analyzed from samples taken throughout the bay system.

Salinity and water temperatures in Naples Bay generally exhibit a typical response to freshwater inflows and air temperature. For salinity, vertical stratification is often evident even during the wet summer season. This stratification is amplified by freshwater inflow and restricted circulation; consequently, the head ends of slow-flushing canals frequently exhibit a high degree of salinity stratification, particularly during the summer, when freshwater from urban/

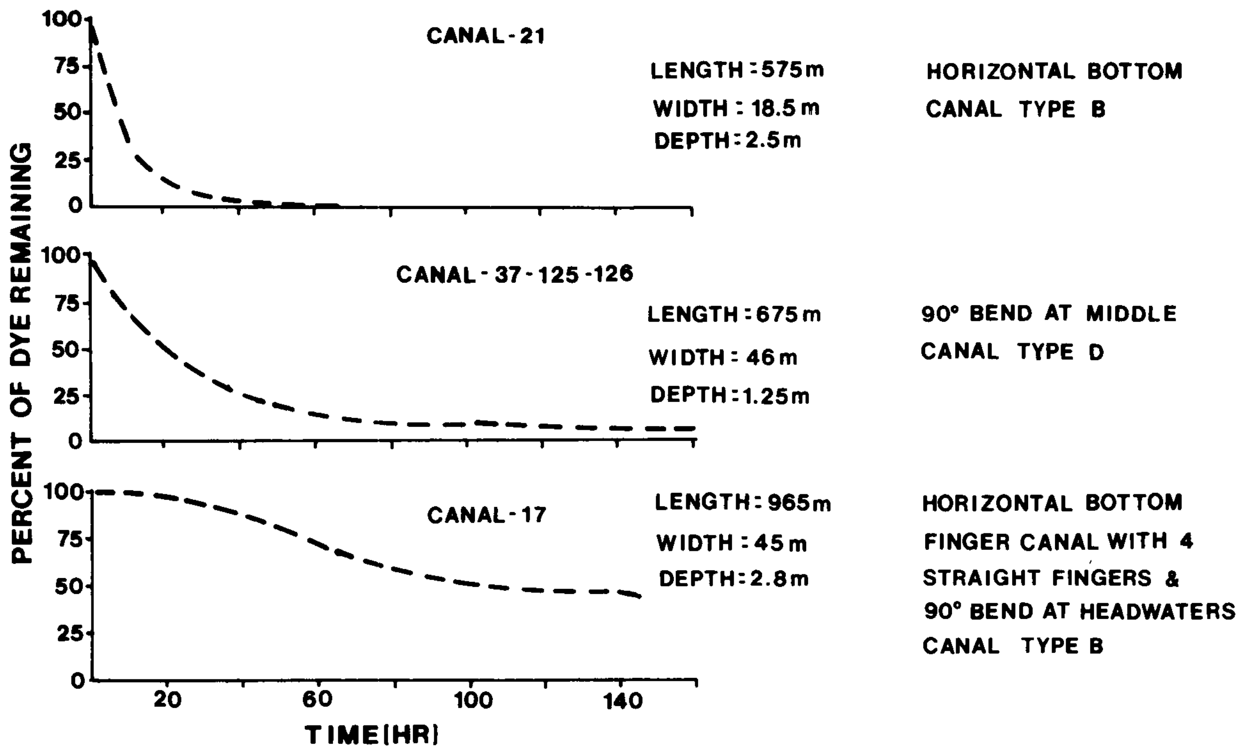


Figure 46. Typical canal flushing curves in and around Naples Bay (adapted from van de Kreeke 1979).

residential runoff tends to "float" on the more dense, higher salinity canal waters. Restricted circulation combined with the density differential also tends to inhibit gas exchange, thereby leading to dissolved oxygen stratification. The rate of oxygen consumption in the lower water mass often exceeds the rate of oxygen supply, leading to increasingly anoxic conditions toward the bottom. Hicks (1979) associates substandard (< 4.0 mg/l) oxygen concentrations with canal depths greater than 1.45 m (4 ft).

A summary of salinity, temperature, and dissolved oxygen in August 1977 at selected locations in Naples Bay show that salinity and dissolved oxygen are most variable at the canal stations (Table 18). The most moderate and highest average concentrations of oxygen occur at the relatively well-flushed lower bay stations.

During the year of study (1976 to 1977), the seasonal cycles of inorganic nitrogen and phosphorus abundance appeared to be reciprocal to one another in the Gordon River-Naples Bay system. Inorganic nitrogen, particularly NO_2-NO_3, correlates fairly well in waters with localized urban runoff. Ground-water inflow during winter months (when north winds tend to drain the bay) is also cited as a possible cause of reduced nitrogen (NH_3) input to the bay, where the more oxidizing environment favors conversion to NO_2-NO_3. Organic nitrogen, on the other hand, appears to peak in response to upland runoff during the wet season. Phosphorus tends

Table 18. Salinity, temperature, and dissolved oxygen in Naples Bay, August 1977 (adapted from Hicks 1979).

	DO (mg/l)	% Sat.	Salinity (%)	Temperature (°C)
Gordon River	4.3	52	0.4	27.6
(upper)	(2.8 - 5.3)		(0.2 - 0.7)	
Mid Bay	4.2	57	13.1	27.6
	(1.9 - 7.6)		(4.7 - 32.9)	
Lower Bay	4.9	73	28.0	29.2
	(2.3 - 6.4)		(8.1 - 35.2)	
Canals	3.8	56	18.5	29.5
	(0.0 - 12.6)		(2.9 - 35.8)	

Numbers in parenthesis represent ranges in parameters.

to peak in the dry season in some areas, probably in response to point source inputs.

Nitrogen and phosphorus both tend to reach highest concentrations at the head end of the Gordon River. Concentrations typically decrease longitudinally toward the gulf. The longitudinal decline in nitrogen is probably due to dilution by gulf waters, whereas the phosphorus decline is probably due to a combination of dilution and settling (Hicks 1979). Sediment concentrations of phosphorus tend to increase after the wet season, suggesting flocculation and settling of phosphorus imports.

Consistent with the hydraulic assessment of van de Kreeke (1972a), Hicks (1979) reports a close correlation between certain chemicals in the main axis of the estuary and nearby canals. The canals often act as carbon traps, importing organic matter from the river estuary but not returning it in equal quantity. Chemical concentrations in short canals tend to be more closely correlated with river concentrations than do concentrations in long canals.

A distinct vertical stratification of total organic carbon (TOC) is reported by Hicks (1979) in Naples Bay canals. Concentrations are relatively high near the surface, lower at mid-depth, and high again on the bottom. This layering is believed to be caused by salinity stratification and deprives Naples Bay of a useful detrital food source by prematurely shunting surface waters to the gulf (Hicks 1979).

Chlorophyll a, like nitrogen and phosphorus, generally exhibits a longitudinal decrease in concentration from the head end of the estuary to the gulf. Peak seasonal concentrations of chlorophyll a correspond with peak salinity and low flow. Mean annual concentrations at canal stations range from 9.5 to 31.0 mg/m^3 with a maximum of 87.2 mg/m^3, and at river stations range from 9.7 to 28.9 mg/m^3 with a maximum of 111.2 mg/m^3. The frequency of algal blooms in the river and bay decline with the onset of wet-season runoff. Blooms in canals tend to extend into the wet season because of restricted mixing with bay waters.

The Rookery Bay estuary (Figure 47) receives freshwater inflow from Henderson Creek to the west and Stopper Creek to the northwest. Monthly average flows in Henderson Creek are presented in Figure 48. Johnson Bay to the south of Rookery Bay also is considered a part of the estuary although it is not part of the Audubon Sanctuary. On the seaward side, Rookery and Johnson Bays are bordered by mangrove-covered islands and long channels that extend to Little Marco Pass and Hurricane Pass on either side of Little Marco Island. Keewaydin Island is a barrier island lying seaward of Little Marco Island.

The relatively small size of the watershed upstream from Rookery and Johnson Bays is reflected by the low flow in Henderson Creek. Any substantial freshwater dilution in bay waters is a short-lived phenomenon. The salinity in Rookery Bay and lower Henderson Creek sharply decrease during local rainfall and runoff (Lee and Yokel 1973).

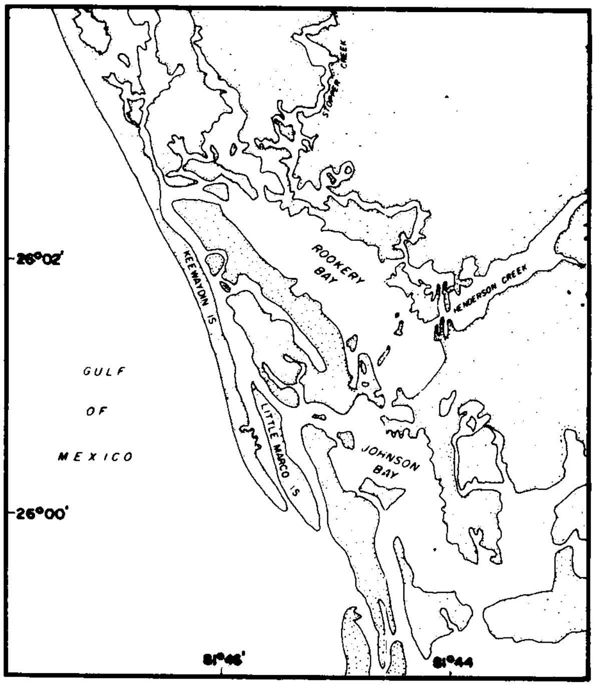


Figure 47. The Rookery Bay estuarine system (adapted from Lee and Yokel 1973).

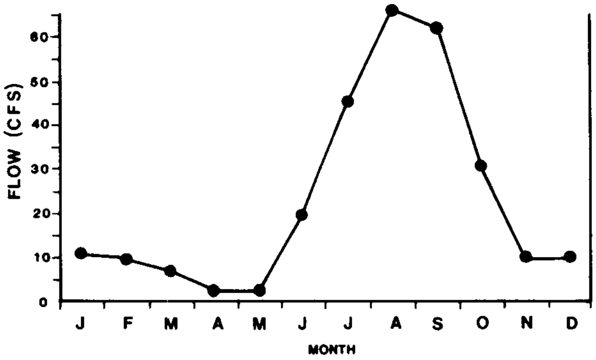


Figure 48. Average monthly flow (cfs) in Henderson Creek, from 1970 to 1980.

The water residence time ranges from 1 to 6 days in Henderson Creek and 1 to 10 days in Rookery Bay. The shallow, winding creeks along the periphery of the bay system are generally slow flushing. These and other physical constraints, such as oyster bars, reduce tidal exchange of waters. Under drought conditions hypersalinity (> 35 ppt) is likely in the upper waters of the bay (Lee and Yokel 1973).

Rookery Bay lies at a physiographic "inflection point" along the southwest coast. To the north, high energy beaches dominate the coastline. To the south, coastal swamps and lagoons are the dominant feature; consequently, Rookery Bay is a transitional estuary. The forces that form and maintain Rookery Bay are a combination of those that shape barrier-island estuaries (e.g., impoundment behind a bar and coastal erosion) and those that shape lagoons (e.g., differential solution and erosion of peat and marl). Recent sea-level fluctuations and hurricanes are major forces that control the development of both types of shoreline.

Most of the tidal exchange between Rookery Bay and the gulf is through Little Marco and Hurricane Passes. Lee and Yokel (1973) report that the physical interplay between Keewaydin Island and Little Marco Pass is highly dynamic. Aerial photographs and older survey maps reveal that the barrier island has migrated to the south at an increasing rate from 1885 to 1970 (Table 19).

From March to June 1972 a 72.6 m (200 ft) retreat of Keewaydin Island was observed (Lee and Yokel 1973). Concurrently, the sand spit off Little Marco Island migrated southwest at a rate of 76.3 m (210 ft)/year. The authors speculate that the large tidal flows around Little Marco Island may stabilize drifts to the south but cause Keewaydin Island to grow in width.

The Marco Island estuary (Figure 49) lies in the physiographic transition zone between the coastal protuberant and reentrant zones (White 1970). On the seaward side, the barrier islands of Marco Island and Cape Romano provide shelter for leeward embayments and mangrove lined tidal creeks. South of Cape Romano the coastline recedes into the Ten Thousand Islands, a dissected network of low, mangrove-covered islands. The open-water embayment seaward of the islands and in the lee of Cape Romano is Gullivan Bay. The leeward estuaries of the Marco Island system include the Big Marco River, and Collier, Barfield, Roberts, and Blue Hill Bays. The Big Marco River and Collier Bay flow into the Gulf of Mexico through Big Marco Pass on the north side of Marco Island. Roberts and Barfield Bays flow into the gulf on the south side of Marco Island through Caxambas Pass. Blue Hill Bay connects to Barfield Bay, as well as to Gullivan Bay, through Coon Key Pass.

Table 19. Migration rate of Keewaydin Island seaward of Rookery Bay (adapted from Lee and Yokel 1973).

PERIOD	MIGRATION RATE(South)
1885 - 1927	15.6m (43 ft)/year
1927 - 1957	42.5m (117 ft)/year
1957 - 1970	50.1m (138 ft)/year

Freshwater inflow into the Marco Island estuary from coastal wetlands ranges between 0.27 x 10^6 m^3/yr and 3.51 x 10^6 m^3/yr (van de Kreeke and Daddio 1981). Groundwater inflow from the freshwater aquifer to the coastal saline aquifer averages 489 m^3/day/kilometer (Amy 1981). During the wet season, daily tidal fluctuations in culverts draining nearshore wetlands are nearly obliterated by high water levels. During the dry season, daily tidal fluctuations may range as much as 0.38 m (1.3 ft) between high and low water. Surface runoff from these wetlands is approximately 100 to 200 times subsurface outflow. Total surface outflow is estimated to be about 53% of the input from rainfall. This relatively high percentage is believed to be at least partially caused by drainage operations that accelerate runoff.

A simplified stick diagram of major flow conveyance channels of the Marco Island estuary is given in Figure 50. According to van de Kreeke (1972a), the tidal waves at the Gulf

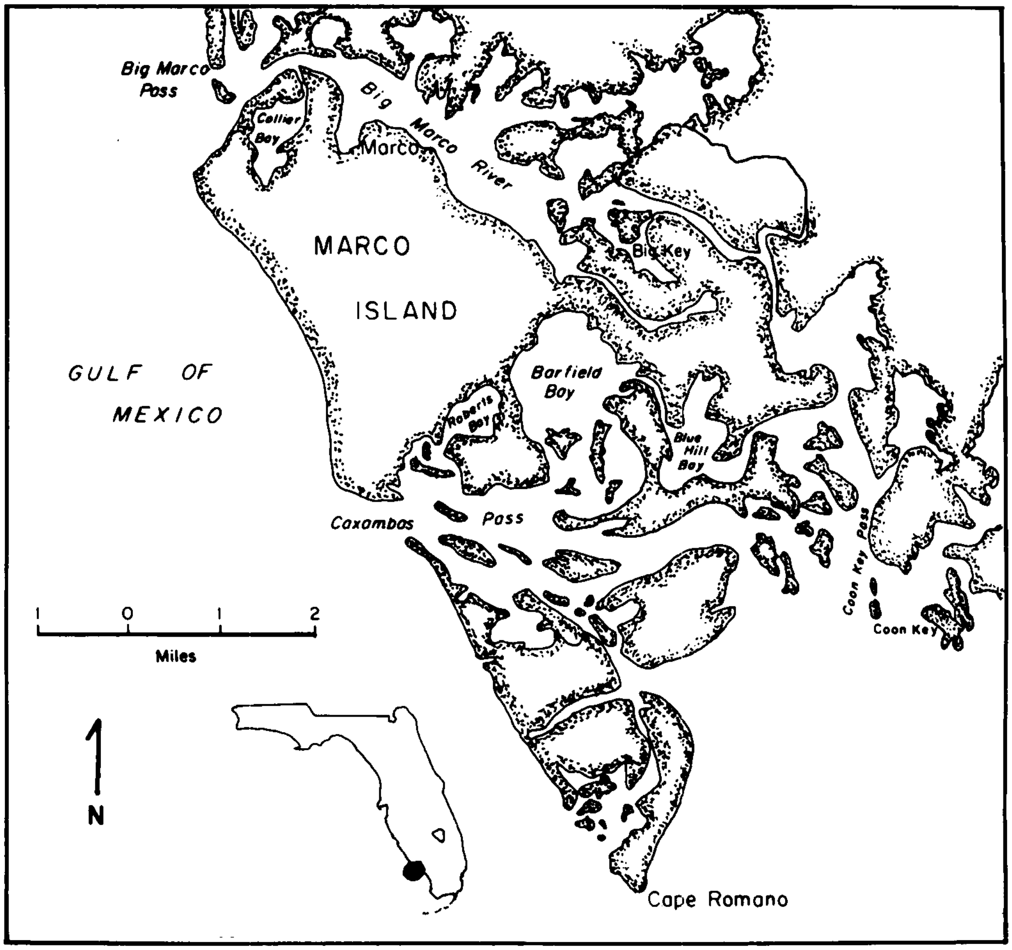


Figure 49. The Marco Island estuarine system (adapted from van de Kreeke 1972a).

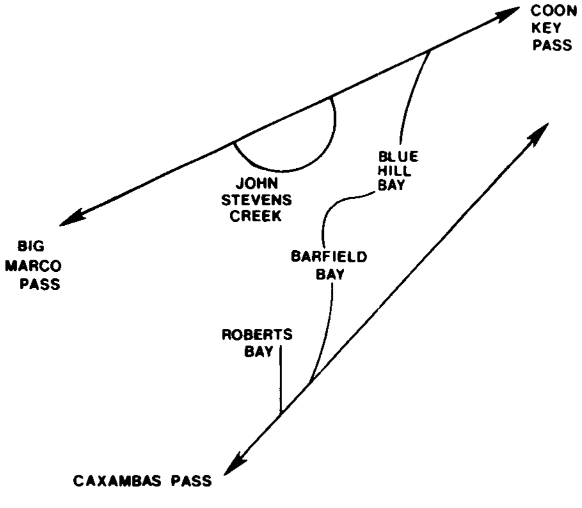


Figure 50. Diagram of flow conveyance channels in the Marco Island estuarine system.

of Mexico (Big Marco Pass) and Coon Key on the sheltered side of Gullivan Bay are about an hour out of phase. The major flow conveyance channel is between Big Marco Pass and Coon Key Pass along the Big Marco River. The second most important flow pathway (in terms of volume) is the Caxambas Pass to Coon Key connection. Numerous short circuits and dead ends also contribute to the net circulation pattern (Figure 49).

Tidal excursions through these major channels are about 4.8 km (3 mi) long; not long enough to flow through on one tidal cycle but nonetheless significant. Current velocities are generally highest in the primary channels near the major passes and lowest where the tidal waves meet. Three areas in the estuary where maximum velocities are barely measurable are Big Marco River near Goodland, Blue Hill Creek west, and John Stevens Creek (van de Kreeke 1972a).

The net effect of urban development of Marco Island canals is to increase velocities in these waterways (van de Kreeke 1972a). This increase is brought about by dredging, which increases the cross sections of channels and thus their water storage and transport capacities; and by filling, which decreases the upland/wetland storage provided by shoreline mangroves. In general, the effect of dredging amplifies the effect of filling, producing not only a net increase in canal storage but faster water movement as well. Although flushing increases in the deepened canals, it does not necessarily improve the overall water circulation in the canals, possibly because stratification, either due to salinity or temperature gradients or the physical structure of the canal (e.g., presence of sills), shields the underlying and stagnant waters, and restricts flushing to the upper layer (Chesher 1974, Carpenter and van de Kreeke 1975).

Urban development of shorelines and wetlands in the vicinity of Marco Island generally involves the deepening and/or excavation of natural waterways. Such activities may create some unique hydrologic conditions where the excavated body of water does not connect with the Gulf of Mexico (Figure 51). Courtney (1981) published data on one such excavated "lake" in the Marco Island Shores golf course. Due to the extremely pervasive influence of saline ground waters, the lake is permanently stratified. Vertical diffusion is the only means of chemical exchange between the upper and lower strata. As a consequence of such high stability, the lakes function well as sedimentation basins for stormwater runoff. The lower saline stratum ultimately receives the stormwater runoff, while the upper freshwater stratum remains relatively unaffected by the nutrient loading.

In response to intensive urban development, a number of water-quality studies have been conducted on the Marco Island estuary. Baseline information on dissolved oxygen, salinity, and temperature is provided by van de Kreeke (1972b). Carpenter and van de Kreeke (1975), and van de Kreeke and Roessler (1975) discuss projected and observed conditions within selected waterways of the estuary. Weinstein et al. (1977) gave a detailed summary of physical, chemical, and biological data collected from 1971 to 1975. Most recently a series of papers has appeared (Cross and Williams 1981) documenting the relationships between urbanization and water-quality dynamics in the Marco Island area.

The relative paucity of rainfall at Marco Island compared with stations on the mainland was described by Weinstein et al. (1977). Low rainfall combined with high rates of evapotranspiration (and canalization, which promotes rapid loss of freshwater) often leads to seasonally hypersaline conditions in estuarine surface waters. Minimum salinity usually lags behind peak rainfall periods by about one month. A westerly salinity gradient forms where freshwater inflow is significant, such as in the Big Marco River, which receives seasonal

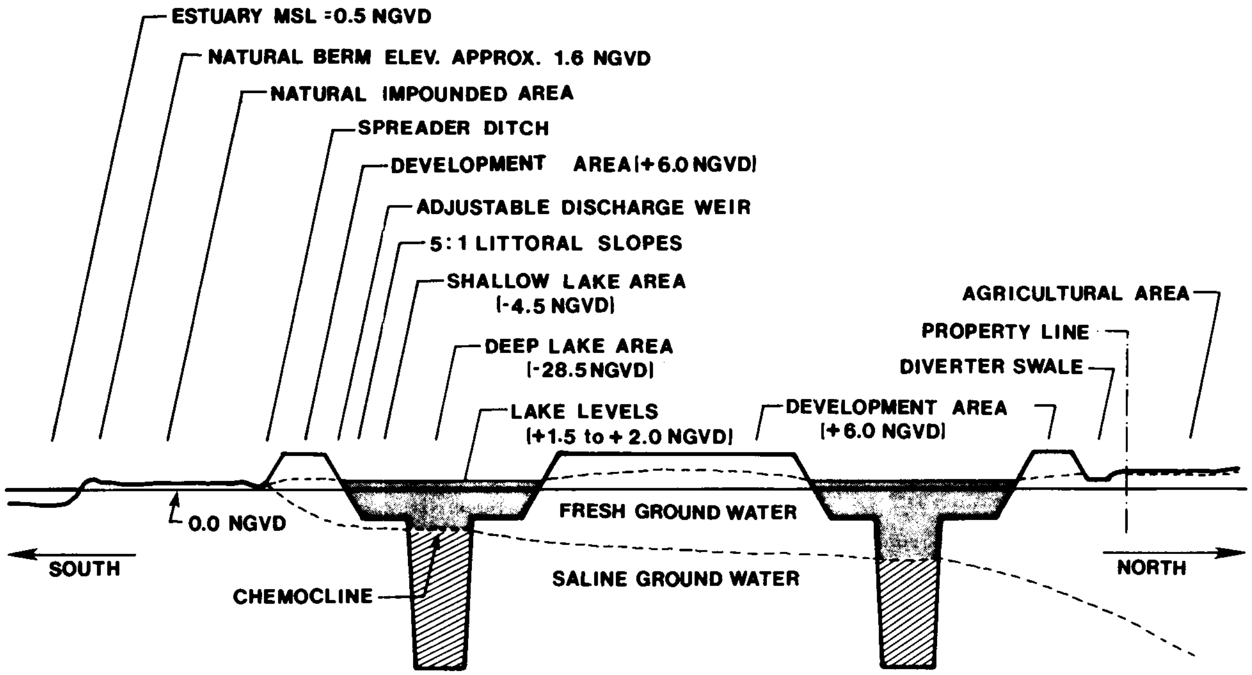


Figure 51. Hydrologic cross section in the vicinity of Marco Island (adapted from Courtney 1981).

sheet-flow runoff from the Big Cypress Swamp watershed.

Nutrient concentrations in both natural and developed estuarine areas are generally low, although some artificial waterways may act as nutrient sinks. Under certain wind conditions, nutrients may be released from sediments into the water column, creating locally high concentrations. Maximum nutrient levels were reported for Henderson Creek, which drained both natural and developed areas. Chlorophyll *a* concentrations are generally highest in canal waters that are dominated by a phytoplankton-based food chain (Weinstein et al. 1977).

The lake-like coastal excavations upland on Marco Island are essentially meromictic, with highly saline, nutrient-rich, deeper ground water and relatively nutrient-poor freshwater in the surface layer. Water quality in these lakes will probably stabilize in the mesotrophic to slightly eutrophic condition. Nutrient overenrichment reportedly will not be a problem (Huber and Brezonik 1981), nor will the discharge of nutrient-laden surface water from the lakes tributary to the estuary.

The dissolved-oxygen daily minima at several stations and depths in both artificial and natural waterways in the Marco Island estuary were compared by van de Kreeke and Roessler (1975) and Van Belle (1974). Because of the input of mangrove detritus and the restricted backwater circulation, natural areas frequently exhibit lower oxygen than disturbed areas. Canal waters tend to have a greater degree of oxygen stratification and variability with depth than waters in natural areas.

Carpenter and van de Kreeke (1975) conclude that the vertical-mixing coefficient and detritus-based respiration are more influential in the dissolved-oxygen budget of canals than are atmospheric transfer, water-column photosynthesis, and respiration.

Fahkahatchee Bay and Fahka Union Bay (Figure 52) to the southeast of Marco Island are located behind a line of dissected mangrove islands. Fahka Union Bay receives freshwater inflow from the Fahka Union Canal, which drains the Remuda Ranch Grants development. Fahkahatchee Bay is less influenced by freshwater inflow because drainage is by sheet flow from the Fahkahatchee Strand and through the East River (Carter et al. 1973).

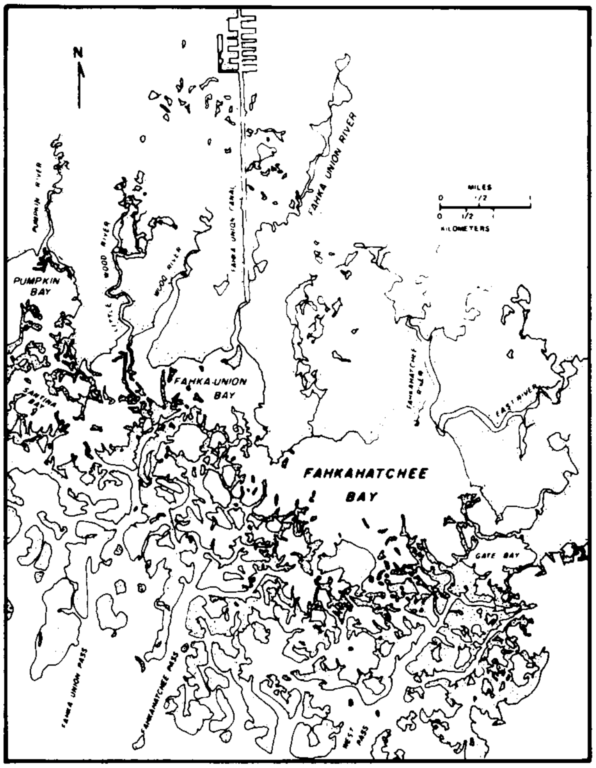


Figure 52. Fahkahatchee Bay and Fahka Union Bay (adapted from Carter et al. 1973).

The proximity and physical similarity of the two bays permit an interesting comparison on the effects of hydrologic modification. Because of higher freshwater inflow to Fahka Union Bay, salinities there are lower at all times of the year. In addition, during high flow in late summer, rapid delivery of runoff from GAC canals not only affects Fahka Union Bay, but western Fahkahatchee Bay as well. During low flow, saltwater intrusion in the channel in Fahka Union Bay is very pronounced. Because of greater freshwater inflow, salinity intrusion into Fahkahatchee Bay is much less pronounced. Salinity stratification occurs in both bays during low flow, but again in Fahka Union Bay it is greater. In both bays the wind is a dominant force that governs tidal flux and water level. In winter north winds tend to drain the marshes and shallow bays, whereas in the summer south winds tend to pile water up and inhibit flushing (Carter et al. 1973). Seasonal salinities for both bays are as low as 0 to 2 ppt in late summer and as high as 40 ppt in late spring and summer during droughts.

Total nutrient loading to Fahka Union Bay greatly exceeds that of Fahkahatchee Bay, even though the mean nutrient concentrations for the two bays are similar. The differences in loading are related to the increased flow from the extensively ditched and drained Fahka Union Bay estuary. Although total Kjeldahl nitrogen (TKN) levels in the two bays are similar, Fahkahatchee Bay exhibits an occasional high TKN value because of local marshland drainage. Mean total phosphorus concentrations and total organic carbon in Fahka Union Bay are slightly lower than in Fahkahatchee Bay.

Water quality and hydrologic data on these two bays reveal that the major effect of drainage is the loss of chemical energy to the estuary. Relatively high loads of nutrients entering Fahka Union Bay pass more rapidly through the channelized bay into the gulf than the smaller loadings to the unchannelized Fahkahatchee Bay.

Water and sediment concentrations of 10 heavy metals at four freshwater sampling stations draining into Fahka Union and Fahkahatchee Bays were reported by Carter et al. (1973). None of the four sites were contaminated by nickel, zinc, manganese, cadmium, mercury, copper, chromium, arsenic, or iron. Lead concentrations greater than State standards (0.05 mg/l) were reported from stations that receive roadway runoff. Detectable concentrations of heavy metals were reported most frequently from the Tamiami Canal Station. The salinity at this station was more like stations in the Fahka Union Bay estuary, which frequently exhibited detectable concentrations of heavy metals in the water column. Exceptions to this general rule were mercury, chromium, and arsenic. Arsenic and mercury were relatively scarce in freshwater and bay sediments. None of the sediment samples contained alarming concentrations of heavy metals.

Analyses for at least 24 pesticides per station in the water and sediment of Fahkahatchee Bay, Fahka Union Bay, and the upstream drainageways were reported quarterly by Carter et al. (1973). Of these pesticides, none was detected in the water column and only six (DDT, DDD, DDE, Methoxychlor, PCB's, and Dieldrin) were reported from sediment samples. Highest concentrations were at stations downstream from farmlands near Immokalee where pesticide use is extensive. More recent data for comparison are not available. Generally these waters are relatively uncontaminated with pesticides.

4.5 SOUTHERN BIG CYPRESS SWAMP

The Big Cypress National Preserve (BCNP) (Figure 53) is a 230,000 hectare (568,100 acre) area encompassing a large fraction of the southern half of USGS hydrologic unit 03090204 (the Big Cypress Swamp watershed). The western portion of the preserve is hydrologically affected by the shallow borrow canals of the Turner and Barron Rivers. The remainder of the area is a broad southwesterly slope much like the wet prairies of the Everglades.

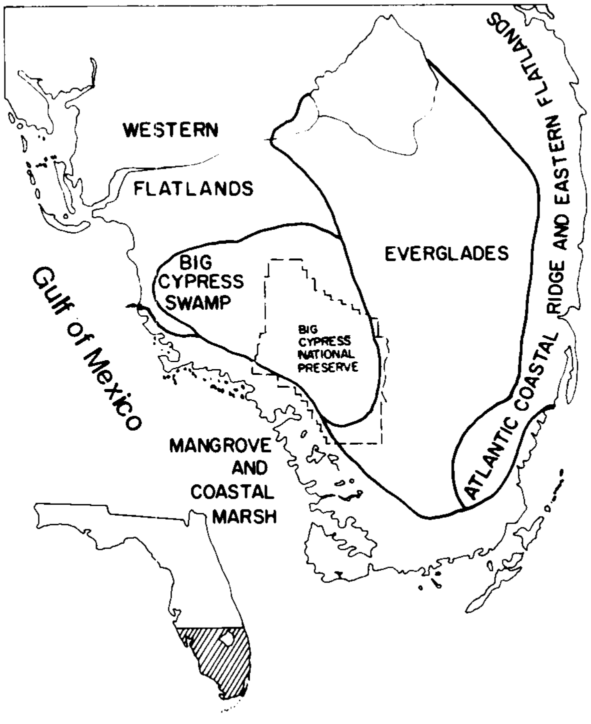


Figure 53. Major physiographic regions of south Florida (adapted from Duever et al. 1979).

Unlike the Golden Gate Estates canals, the canals in the Turner and Barron River watershed were not expressly built for draining the land. The Barron River Canal, Turner River Canal, Everglades Parkway Canal, and even the Tamiami Canal were all originally constructed as borrow canals, sources of fill for nearby roadbeds. A typical graph of water levels at bridge 105 along the Tamiami Canal is shown in Figure 54. This graph illustrates that the few environmental impacts caused by upland drainage activities are relatively minor compared to that of the Golden Gate Estates.

Flow in the Barron River canal ranges from 0 to 8.27 m^3/s (0 to 292 cfs). Dry-season flows range from 1.42 to 2.84 m^3/s (50 to 100 cfs) and wet-season flows range from 2.84 to 4.96 m^3/s (100 to 175 cfs). Mean flow over a 28 year period of record is 2.89 m^3/s (102 cfs). Because of the age of the canal network in eastern Collier County (30 to 40 years) and the relatively sparse distribution of canals, water levels in the Barron/Turner River watershed have probably stabilized (Klein et al. 1970). Seasonal flows in the Barron River Canal are illustrated in Figure 55.

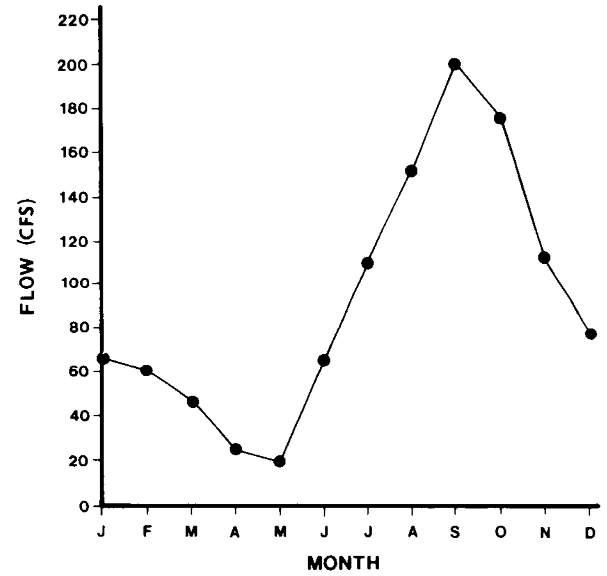


Figure 55. Average monthly flow (cfs) in the Barron River Canal from 1970 to 1980.

Both the Turner and Barron River Canals receive freshwater flow from the strands and sloughs through which they cut. Okaloacoochee Slough contributes to both the Barron and Turner River Canals; Deep Lake Strand also contributes to the Turner River Canal. Since flow often exceeds 100 cfs in the Barron River Canal, inflow from the shallow aquifer is substantial (Klein et al.

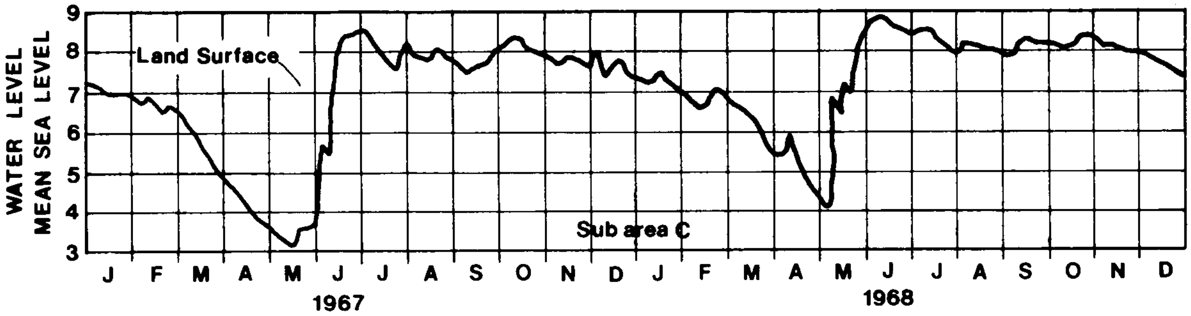


Figure 54. Monthly water levels at bridge 105 at the Tamiami Canal (adapted from Klein et al. 1970).

1970). The flow is controlled in the Barron River Canal by a series of stop-log gates that are removed during the wet season to increase local drainage and replaced in the dry season to preserve local aquifers.

In the eastern section of BCNP, the gradually sloping topography follows bedrock undulations running southwest toward the coast (Duever et al. 1978). The slope of the land is about 8 to 16 cm/km (Carter et al. 1973). The shallower undulations are occupied by marshy sloughs much like those of the Everglades. The deeper undulations are generally occupied by cypress strands. These strands and sloughs largely control drainage and water storage patterns. The water table often lies above the ground level. Water-level contours during typical wet and dry seasons are illustrated in Figure 56.

The estuaries and brackish water wetlands southwest of Big Cypress National Preserve are almost entirely within the Everglades National Park. An exception is a small part of Chokoloskee Bay lying just behind the southernmost extension of the Ten Thousand Islands. The Barron River Canal discharges to Chokoloskee Bay at Everglades City. Outside of a relatively few physical/chemical measurements in 1976 to 1977 (ESE 1978a), virtually nothing is published on the hydrology of Chokoloskee Bay. Salinities vary at the mouth of the bay from 2.5 to 20.2 ppt. Ebb tide velocities range from 0.15 to 0.70 m/sec and flood tide velocities range from 0.08 to 0.59 m/sec (Scholl 1963, ESE 1978a).

Despite the paucity of hydrologic data, Harris et al. (1971) and Horvath (1973) reported considerable data on heavy-metal concentrations

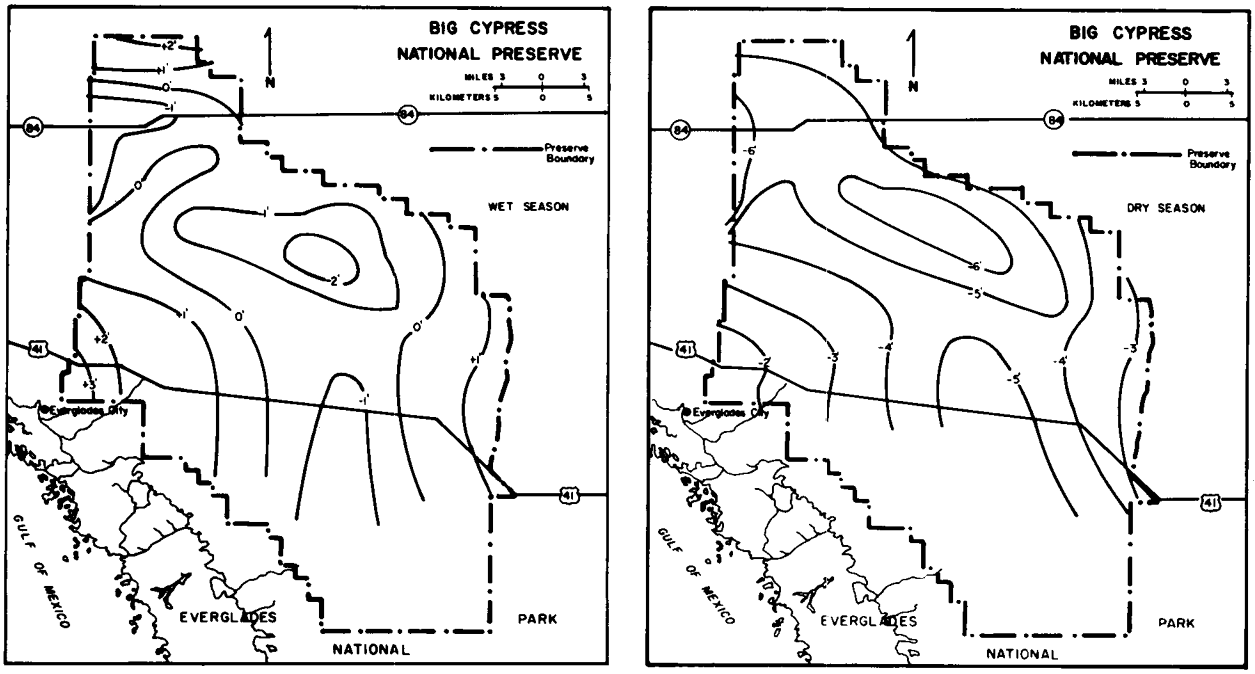


Figure 56. Wet and dry season water-level contours in the Big Cypress National Preserve (adapted from Duever et al. 1979).

in tidal canals and bay waters. Analyses indicate that salinity variations are often responsible for as much as 84% to 99% of the variation in dissolved inorganic concentrations of manganese, copper, zinc, and lead. All metals except iron showed a net increase in concentration with increasing salinity, probably as a result of desorption by dissolved ions in seawater.

Concentrations of heavy metals in Chokoloskee Bay were reported to be 1.5 to 3 times those in other nearby estuaries receiving natural drainage (Horvath 1973). During the wet season, increases in nutrient concentrations were apparently caused by inflow from the Barron River. Not known is whether enrichment is caused by agricultural or roadway runoff or increased oxidation of drained soils. The fact that elemental ratios remain constant in all estuaries suggests that the cause is probably a combination of the two sources.

Measured concentrations of iron, copper, manganese, zinc, and lead showed a migration of these metals into estuaries. Oxidation of soils may enhance this migration since the metals are found predominantly in particulate form associated with the organic fraction of sediments. Oxidation of organic matter in sediments and soils reduces their cation-exchange capacity, thus contributing to increased migration of metals to estuarine waters. Mercury content in sediments was strongly correlated with cation-exchange capacity (Harris et al. 1971).

CHAPTER 5
WATERSHED ENERGETICS

5.1 ENERGY AND MATERIAL FLOW THROUGH THE COASTAL WATERSHED

The concept of watershed energy and material flow probably is best described by Odum (1971) as follows:

> *...it is the whole drainage basin, not just the body of water that must be considered as the minimum ecosystem unit when it comes to man's interests. ... the watershed is a practical ecosystem unit for management that combines (both) natural and cultural attributes.*

Watershed energy flow is affected by two fundamentally different but related types of work, i.e., inorganically mediated work and biologically mediated work. Inorganically mediated work refers to the effects of basic physical/chemical background conditions, such as climate, which influence all biological, physical, and chemical processes. Physical forces such as sunlight, winds, tidal fluctuations, heat flux, rainfall, atmospheric chemical fallout, and osmotic gradients form the basic energy sources that largely determine the composition of the biota, soils, and water.

Biological forces cause the transformation and storage of energy and matter into plant and animal biomass, its subsequent degradation, and its transportation within biological tissues. Examples are the uptake of nutrients from the soil and water, the evolution of oxygen or carbon dioxide, and the transformation of one type of biomass (e.g., fish) into another type of biomass (e.g., bird feathers). Also, as organisms move within and between watersheds, they perform work by transporting energy and materials in the form of their own tissues.

The hydrologic boundaries between watersheds may serve as complex biophysical membranes. They naturally divide the landscape into a mosaic of distinct units (or watersheds), each possessing a physical/chemical integrity defined by topography and drainage. At the same time these membranes are also permeable. Each watershed, upon closer examination, is itself partitioned into a mosaic of natural habitats and cultural land uses which often transcend hydrologic boundaries. Through biological transport, cultural activities, and atmospheric processes, energy and matter are constantly exchanged across watershed boundaries. Within each watershed there also appears to be a systematic partitioning of physical/chemical resources by competing plants and animals. The variety of land uses in the watershed actively tap into and modify available resources to produce a wide range of fish and wildlife as well as industrial and agricultural goods.

The four major systems identified with coastal watersheds are terrestrial, freshwater, estuarine, and marine. Each of these systems consists of a set of habitats supported and maintained by a unique group of environmental conditions. Such conditions include background physical/chemical similarities, successional (developmental) relationships between habitats, and the shared use of habitats by the same and different plant and animal species.

In addition to relationships within each system, there are many important interactions between systems as well. As terrestrial habitats develop they often induce changes within their boundaries that influence internal background conditions and other nearby habitats. For instance, as grasslands succeed to pines and pines to hammocks, the growth and development of a forest overstory may mitigate the effects of the wind and temperature fluctuations in microclimates, increase physical diversity, and change the chemical composition of the soil.

By storing nutrients and other chemical energy in slow-turnover forms of biomass (e.g., woody tissues) or by binding them to organic matter in soils, the terrestrial system affects the rate of energy and material flow to downstream freshwater habitats. Evapotranspiration by terrestrial plants tends to conserve upland water tables and help regulate the amount and timing of downstream flow. Increased penetration of the soil by plant root structures and the absorptive capacity of humus in the soil also helps conserve or recharge upland aquifers. Conversely, the disruption of natural upland habitats by either natural or man-induced factors has a reverse effect. Land clearing, mining, agriculture, and urbanization, as well as fire, flooding, and wind or hurricane damage, indirectly disturb aquatic habitats by altering terrestrial habitats. Urban development tends to increase flooding downstream by removing permeable surfaces upstream. Land clearing and agricultural practices generally increase erosion, accelerate oxidation of soil organic matter, and amplify extremes of drought and flood. These alterations sometimes elevate turbidities, excessively transport nutrients and other chemical loadings to streams and lakes, destabilize the soils, and amplify highs and lows in surface water and groundwater.

Aquatic habitats are lotic (running waters), such as springs, streams, and rivers, or lentic (standing waters), such as lakes, ponds, swamps, and bogs. As natural background conditions dictate, freshwater lotic habitats assume characteristic channel sizes and shapes, bottom and bank topographies, and stream meanders. In these waters emergent, submerged, floating, and attached plants may proliferate and compete for available light, space, and nutrients. As conditions change (again due to either natural or man-induced factors) physical/chemical background conditions are redefined and biological communities change accordingly.

In lentic habitats similar physical processes such as the amount of runoff, the size and shape of the catchment basin, its natural outflow, and drainage and development within the upstream basin determine basic background characteristics. Again, the biological communities change in response to changes in background factors.

In estuaries, physical/chemical background conditions depend upon three major factors: (1) the combined energetics of upstream terrestrial and freshwater habitats that determine the timing, quantity, and chemistry of freshwater inflow; (2) the energetics of offshore marine systems that force tidal mixing, set up current structures, and provide seasonal habitats for many estuarine plants and animals; and (3) natural and man-induced activities that alter biological communities as well as the natural shape and orientation of an estuarine basin and its connection with the open ocean. These three factors influence wind mixing of the water column, flushing rate, circulation pattern, and the nature of benthic environments. Local urban-industrial activities or shoreline development may also influence physical/chemical conditions by adding pollutants and nutrients or altering important habitats.

5.2 CONCEPTUAL MODELS OF REGIONAL ECOLOGICAL PROCESSES

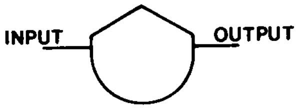
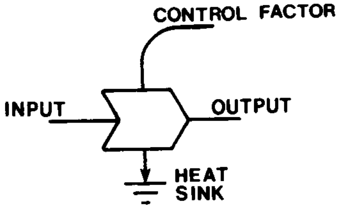
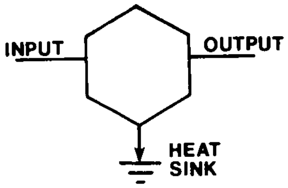
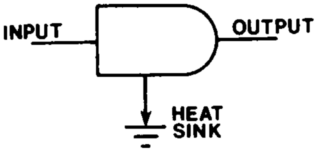
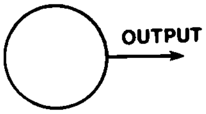
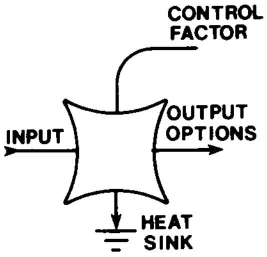
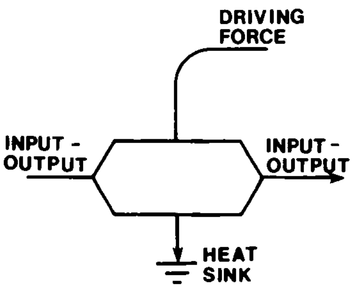
To better demonstrate the ecological processes in terrestrial, freshwater, estuarine, and marine systems in the Caloosahatchee River/ Big Cypress Swamp watershed, three conceptual models have been prepared. The first model shows terrestrial energy flow; the second, socioeconomics of the area; and the third, the combination or energy flow through ecosystems in a socioeconomic structure. Taken together the models show how the various components of the watershed are interrelated by the flow of energy (biological, chemical, physical). The symbols used in the conceptual models are given in Table 20, along with a brief explanation of the meaning and general use of each of these symbols.

In some respects, a conceptual model is similar to a painting of a natural habitat: 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 energy system. Through this perspective the viewer may be able to see the forest in spite of the trees.

The terrestrial ecosystem is chosen to illustrate a conceptual model of energy and material flow through the Caloosahatchee River/ Big Cypress watershed (Figure 57). Only the major forces and internal cycling processes are explicitly diagrammed. To the right of the model, a dashed line leads off to an abbreviated list of the overlapping habitats that this ecosystem encompasses. Arrows that leave the larger ecosystem "box" point to explanations of specific ecosystem energy flow, storages and pathways. External forces which help to drive or power the ecosystem processes are described in the large circle to the left of the "box". One of the forces, hurricanes, is extremely important to south Florida watersheds, particularly as viewed in a time frame of centuries.

The second conceptual model (Figure 58) examines man's role in the energy flow of the Caloosahatchee River/Big Cypress watershed. Man might be viewed as a recently introduced exotic species to the watershed. High and dry habitats such as urbanized areas and citrus groves in the uplands and native range in the pine flatwoods are colonized first. As more area is needed, drainage systems are constructed and wet areas are made more suitable and accessible to agriculture, timber production, and urbanization. As agriculture, industry, and government expand, their management functions increasingly become nature's

Table 20. Explanation of energy circuit language symbols used in the conceptual models (Snedaker and Lugo 1972).

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) that makes possible another flow of energy (input-output). It is used to show the multiplier inter-action of two system components. Energy transformations are never 100% efficient. The heat sink represents energy lost during work.
	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 and demand. 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 causal force shown operating the gate. The heat sink shows the action to follow the second law of thermodynamics.

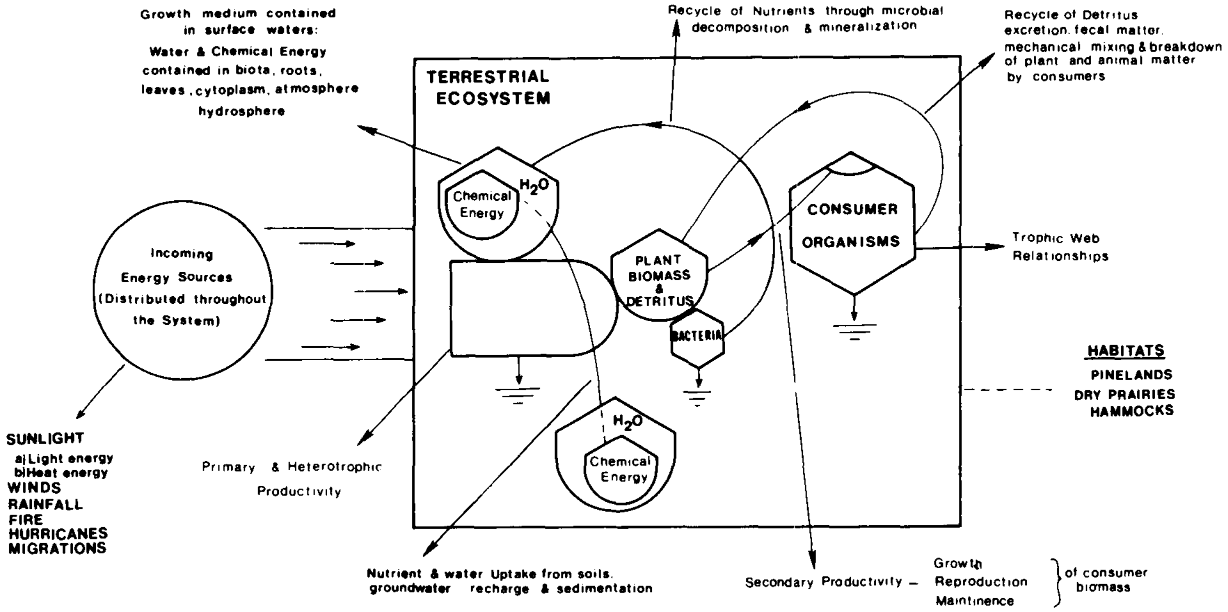


Figure 57. Conceptual model of a terrestrial ecosystem in south Florida (Snedaker and Lugo 1972).

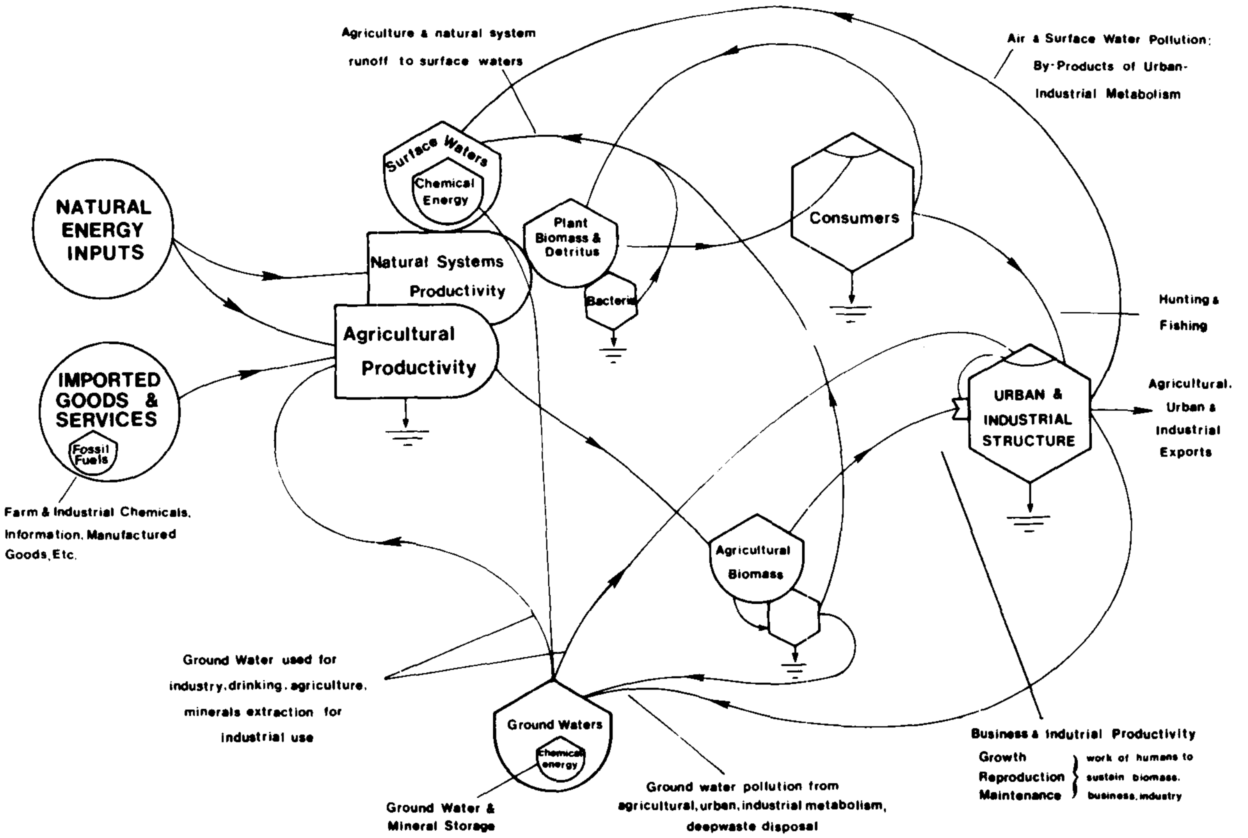


Figure 58. Conceptual model of an ecosystem influenced by man in south Florida (Snedaker and Lugo 1972).

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, but 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.

The third conceptual model (Figure 59) combines the previous two models and is expanded to include wetland, estuarine, and continental-shelf ecosystems. The result is a conceptual model of the entire watershed. The habitats included in each of the ecosystems are listed in Table 21. Major energy forces are shown entering the model from the left side of Figure 59. Natural chemical and physical energy forces are augmented by imported goods and services which support the activities of man. Energy and materials are exported from the watershed by evapotranspiration, emigration of species, fishery industries, tidal flushing, surface runoff, and export of agricultural and manufactured goods. Within each system the energy flow of plants and animals is symbolized by a combination of symbols given in Figure 57. At the downstream end of the watershed, the estuarine system is physically and biologically linked with the continental shelf of the southeastern Gulf of Mexico. The arrows linking the major systems show energy and matter flow between the respective systems. These links take the form of physical/chemical energy transfers.

Table 21. Habitats corresponding to conceptual model zonations.

Terrestrial & freshwater wetlands	Estuarine & saltwater wetlands
Pinelands	Salt prairies and marshes
Hammocks	Mangrove forests
Prairies, marshes, sloughs, and ponds	Oscillating salinity open waters
Cypress and swamp forests	Beach and dune
Rivers and lakes	Disturbed sites
Disturbed sites	

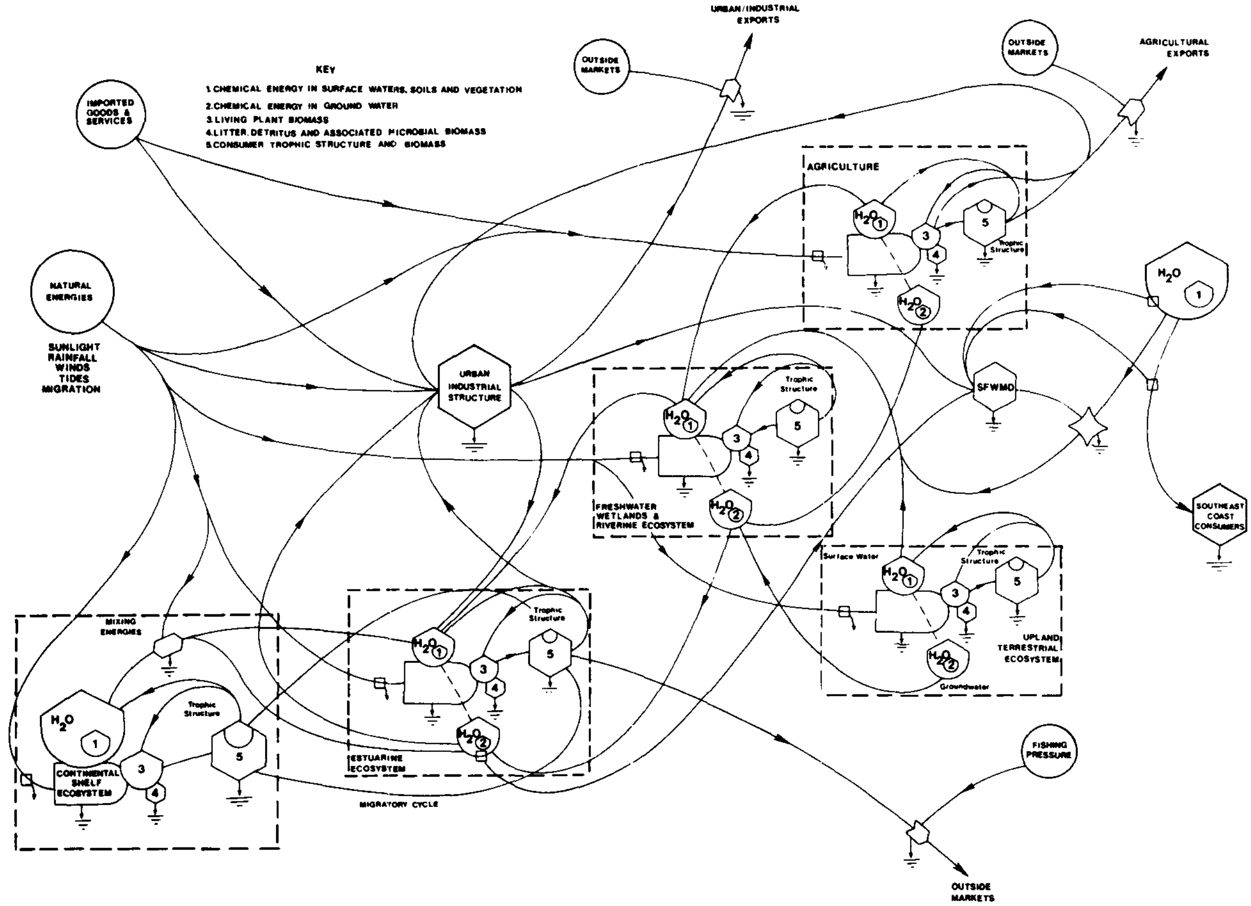


Figure 59. Conceptual model of the Caloosahatchee River/Big Cypress watershed (Snedaker and Lugo 1972).

Man's role in watershed energetics is represented by the following three consumer-management functions:

(1) The urban/industrial system, located primarily along the coast from Cape Romano to Fort Myers and inland on the shores of the Caloosahatchee River, consumes local resources such as water, space, nutrients from the soil, natural products (wood), and minerals (sand, limestone, and oil), as well as many imported goods and services. Some of the products are exported, while some are consumed locally by other industries and people. Still another component of the output is fed back to other systems within the watershed in the form of effluents and nonpoint source runoff.

(2) Agriculture is concentrated in the upper Caloosahatchee River watershed. In addition to consuming much space and significantly altering natural habitats, modern agricultural practices require considerable subsidies of

imported goods and services. Such items include machinery, oil and gas, chemicals, and sometimes labor.

(3) The South Florida Water Management District (SFWMD), which essentially controls and redistributes water throughout south Florida, attempts to reduce the negative effects that flooding and drought may exert on urban, industrial, and agricultural activities.

CHAPTER 6
PLANT COMMUNITIES

6.1 INTRODUCTION

Plant associations that develop in response to background physical/chemical conditions are integrating links between the watershed as a physical unit and the watershed as a habitat for fish and wildlife. In a manner of speaking, plant communities are the "fixed" components of an ecosystem, and fish and wildlife (fauna) are its moving parts.

Actually, the fixed nature of the flora is only relative because abundance and species composition often change rather sharply over time. Plants possess a wide variety of adaptive mechanisms for spreading and competing with one another and for responding to changes in the total environment.

The structural and functional aspects of these fixed components of the environment within the terrestrial and freshwater wetlands of the study area are described in Section 6.2. Section 6.3 relates to similar topics in estuary and saltwater wetlands. Section 6.4 deals with disturbed communities and Chapter 7 outlines the composition and function of the faunal (or "moving parts") component of the watershed as an ecosystem.

6.2 TERRESTRIAL AND FRESHWATER WETLANDS

Successional patterns of major plant communities in the Caloosahatchee River/Big Cypress watershed are given in Figure 60. The instantaneous composition and distribution of plant communities are determined by a combination of physical/chemical background forces that may arrest or promote certain changes in vegetation, and competitive interactions between species for resources (e.g., substrate, space, nutrients, and light). In the upland portion of Caloosahatchee River/Big Cypress watershed, the four major plant communities are pine forests, hardwood hammock forests, cypress and mixed swamp forests, and prairies and marshes (sloughs and ponds). Any of these plant communities may be disturbed by man's land use practices. The disturbed communities include urbanized lands, agricultural operations, industrial sites, canalized waterways, and exotic plant communities. The specific effects that man-made modifications exert on plant communities depends largely upon local conditions and the intensity of the alterations. Natural factors that influence the native vegetation distribution are fairly well delineated in terms of some combination of soils, hydroperiod (or elevation), catastrophic events (fire, hurricanes), or natural succession process.

Natural succession is usually (but not always) associated with changes in one or more of the preceding physical/chemical background conditions. For instance, the continued success of pinelands is commonly attributed to periodic fires which arrest succession to hardwood hammocks. When fires are absent for many years, the susceptibility of older pines to disease, the lack of fire-stimulated regrowth of pine seedlings, and the generally more efficient resource partitioning by hardwood species may eventually lead to the hardwood hammock. This is not

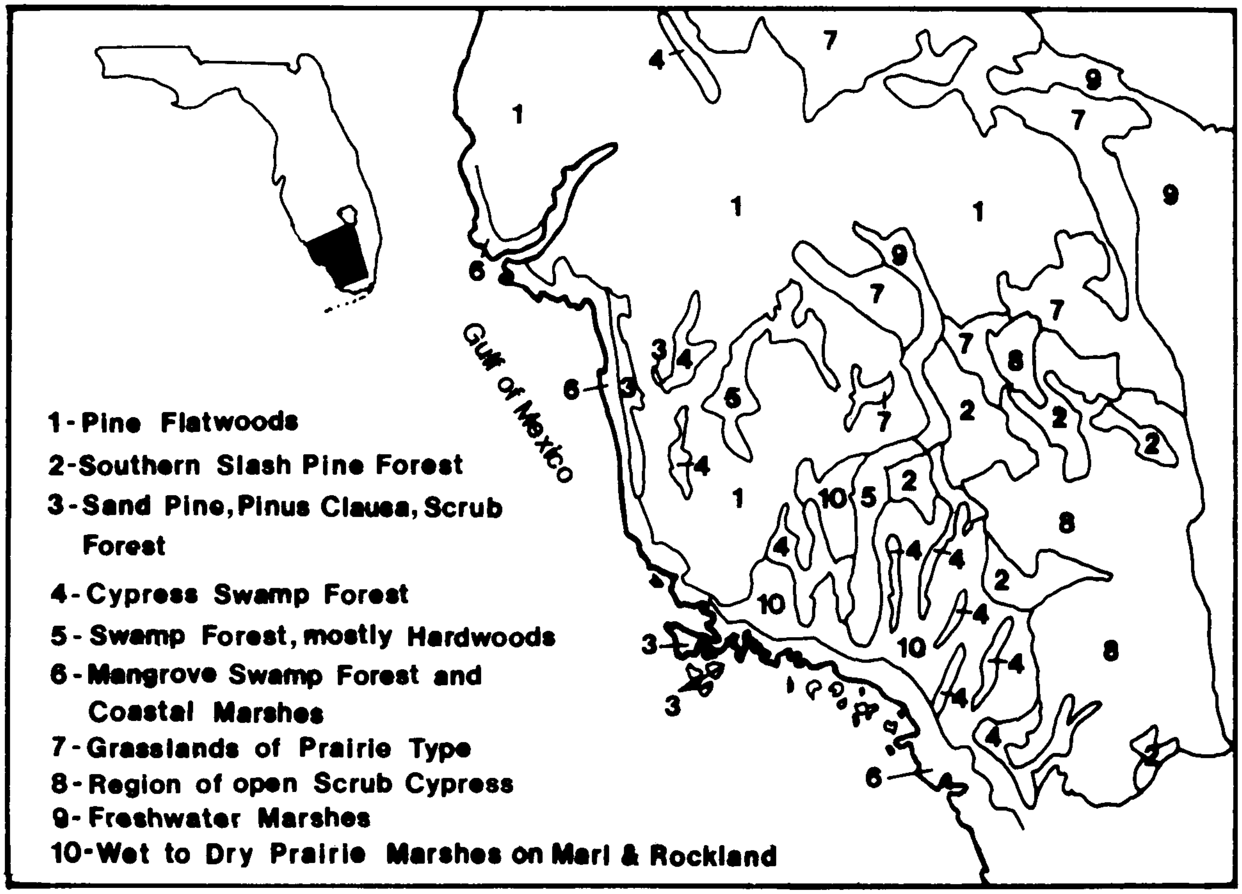


Figure 60. Major plant communities in the Caloosahatchee River/Big Cypress watershed (adapted from Davis 1940).

the only scenario. Other factors aside from the presence or absence of fire may also control or modify the pine-to-hardwood successional process. The most obvious of these is forestry management and planting (silviculture). Another example of natural change is seen in exceptionally sandy soils where a pine forest may be more or less semipermanent simply by virtue of its greater tolerance to more mesic conditions.

Where succession occurs, physical/chemical changes are often induced in the environment by changes in dominant species and relative species abundance. For instance, the understories of hammocks are generally more shaded than those of pinelands. The shading provides a cooler, moister, and more stable microclimate. In addition there is less ambient light available to hammock understories than to pineland understories. The cooler, darker, moister microclimate promotes the formation of a humus layer on the hammock floor that is lacking in pinelands. The relative increase in organic matter adds cation-exchange capacity to the hammock soils which increases their holding capacity for essential nutrients. These conditions together favor understory species that have shallow root systems and are extremely shade tolerant, as opposed to pineland understories where species with deeper root systems, less shade tolerance, and higher heat/drought tolerances are favored.

Successional processes that lead from aquatic or shallow wetland communities into hammocks or cypress-dominated sloughs also relate closely to induced changes in physical/chemical background conditions. Over the years, autochthonous productivity and runoff contribute organic matter to the sediments, creating a deep layer of marl or peat that gradually decreases water depths. Eventually this shifts the competitive edge in favor of plant species that more efficiently partition the available substrate and light.

Disturbed communities add a whole new dimension to successional trends. Exotic communities, for instance, encompass those sites where the introduction of nonnative species disrupts the natural succession. Invading species include cajeput (*Melaleuca quinquinervia*), Australian pine (*Casaurina equisetifolia*), brazilian pepper (*Schinus terebinthifolius*), hydrilla (*Hydrilla verticillata*), and water hyacinth (*Eichhornia crassipes*). These species are extremely competitive under conditions often prevalent in south Florida.

Two studies in particular describe plant successional relationships in the study area. One (Figure 61) emphasizes the combined effects of land elevation and soils as well as sea-level fluctuations on regional successional patterns (Alexander and Crook 1974). On high, moist limestone or sand, pine forests are an edaphic climax community. This plant community grades into pine-hardwood forests and pure hardwood (true climatic climax) forests. In lower areas, (i.e, bedrock troughs or areas occasionally inundated by water) other communities that may prevail are cypress-hardwood forests, cypress strands, mixed cypress-marsh, and marsh-prairie communities. Long-term sea-level fluctuations cause shifts in plant communities by modifying regional runoff, freshwater head, soil moisture, hydroperiod, and soil salinity.

The second (and more recent) approach to regional successional patterns emphasizes the controlling influences of periodic fire and length of hydroperiod (Duever et al. 1975). This approach (Figure 62) estimates the rate of succession without the arresting influence of fire. The diagonal line separates common successional stages from rare ones, and estimates the recurrence interval at which the most devastating fires impact plant communities with increasing hydroperiods. For example, fire is the most important factor limiting the development of the hardwood hammock. Some of the major floral changes involved in wetland-to-hammock succession for the watershed are illustrated in Figures 63 and 64.

6.2.1 Pinelands

Pine forests in the watershed are either wet pineland or dry pineland (Long 1974). Wet pineland, as suggested by Figure 63, is a transition stage in the succession between the shallow wet prairie community and the hardwood hammock. Dry pinelands are found in higher, drier locations (Figure 64). Floristically the two stages can be distinguished by differences in their understory vegetation and consequently their gross physical appearance (Duever et al. 1979).

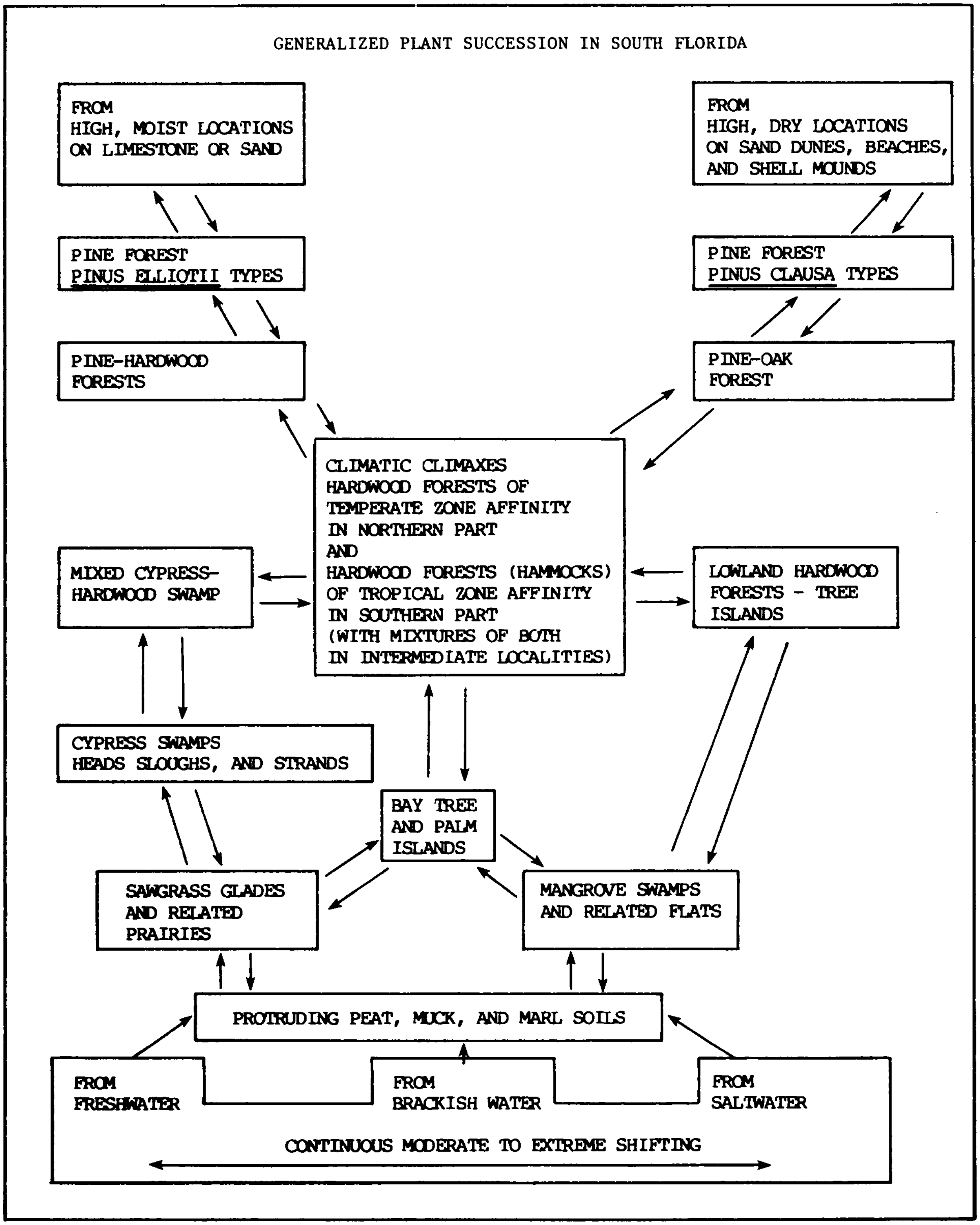


Figure 61. Successional patterns in south Florida plant communities (adapted from Alexander and Crook 1974).

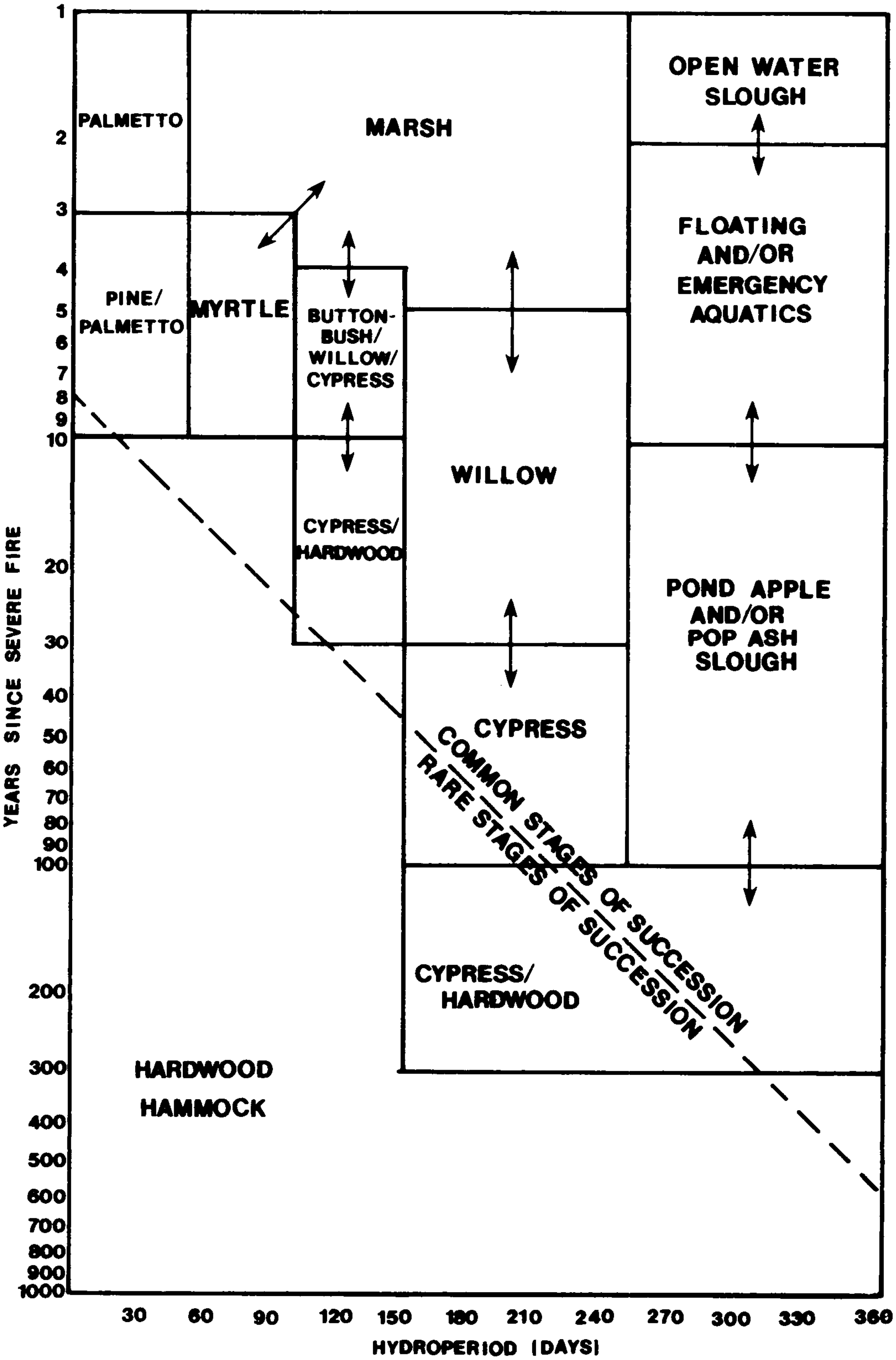


Figure 62. Successional stages in inland plant communities in south Florida (adapted from Duever et al. 1976).

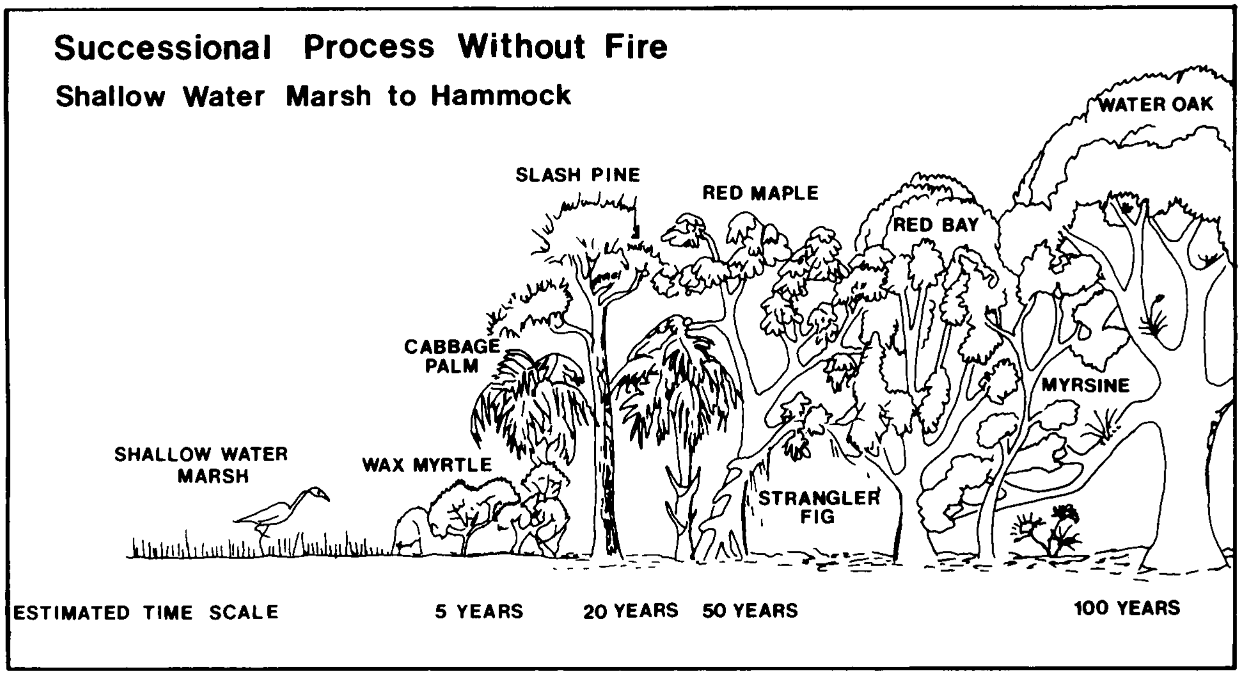


Figure 63. South Florida successional stages without fire: shallow-water marsh to hammock (adapted from Wharton et al. 1977).

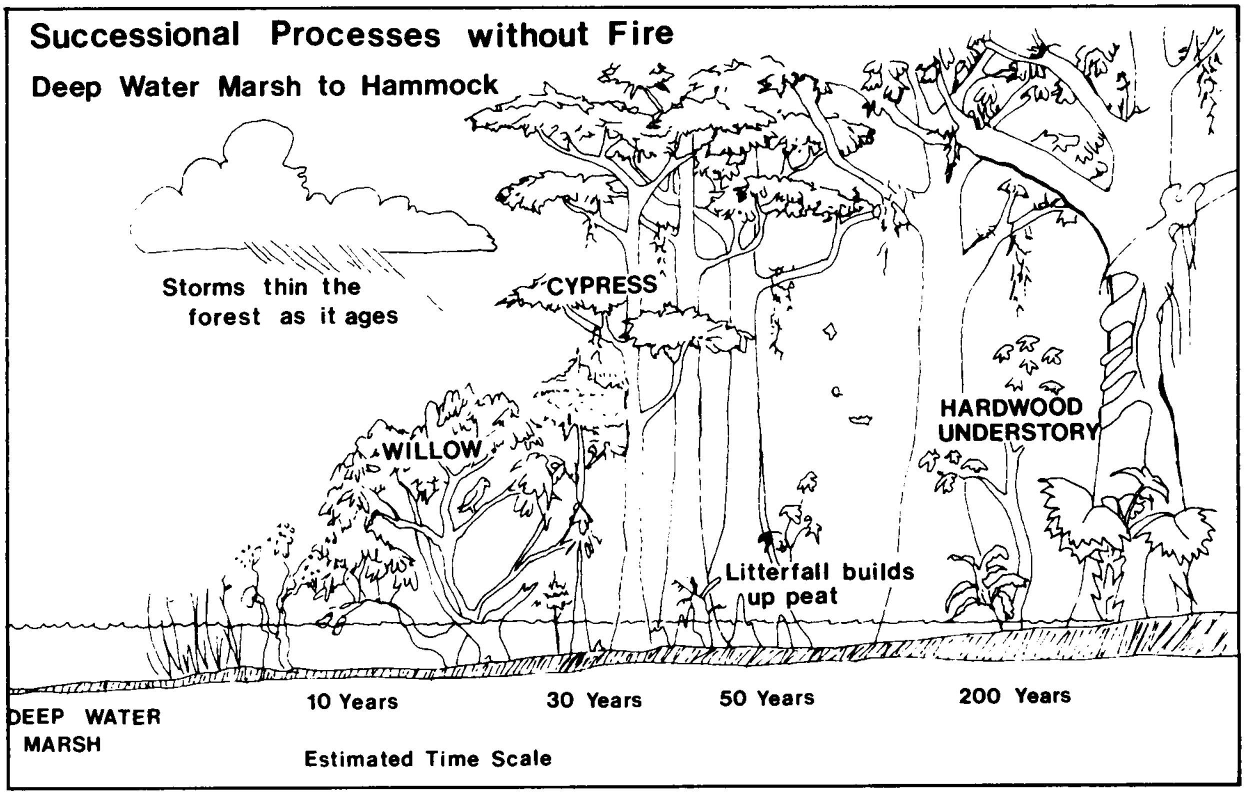


Figure 64. South Florida successional stages without fire: deep-water marsh to hammock (adapted from Wharton et al. 1977).

Both categories of pine forests are dominated by slash pine (*Pinus elliottii* var. *densa*). This variety of the species is particularly suited for survival in south Florida where fire and water are recurring factors. It is well known that fire actually stimulates slash pine seedlings to sprout, promoting them as pioneers of burned over lands (Ketcham and Bethune 1963). The thick bark of older trees tends to give them some measure of protection from milder fires, whereas both adult and seedling hardwoods tend to succumb to such stress more easily. In addition to these general characteristics, slash pine possesses longer taproots and smaller needle size than its northern relative, a fact that McNab (1965) and McMinn (1970) believe favor it under the variable soil water conditions of spring drought and summer flooding. The major monthly trends and environmental factors which influence a slash pine stand are summarized in Figure 65.

Since wet pinelands are associated with prairie to hammock succession, many of the characteristic prairie species also occur in the understory of pine forests. Common species include grasses of the genera *Muhlenberghia*, *Andropogon*, and *Paspalum*, and herbs of the genera *Sabatia*, *Polygala*, and *Asimina*. Long (1974) lists 361 species of plants in wet pine forests in south Florida, making it the most diverse habitat in the region. He reports 303 plant species from the dry pinelands of south Florida, ranking it third behind wet pinelands and hardwood hammocks.

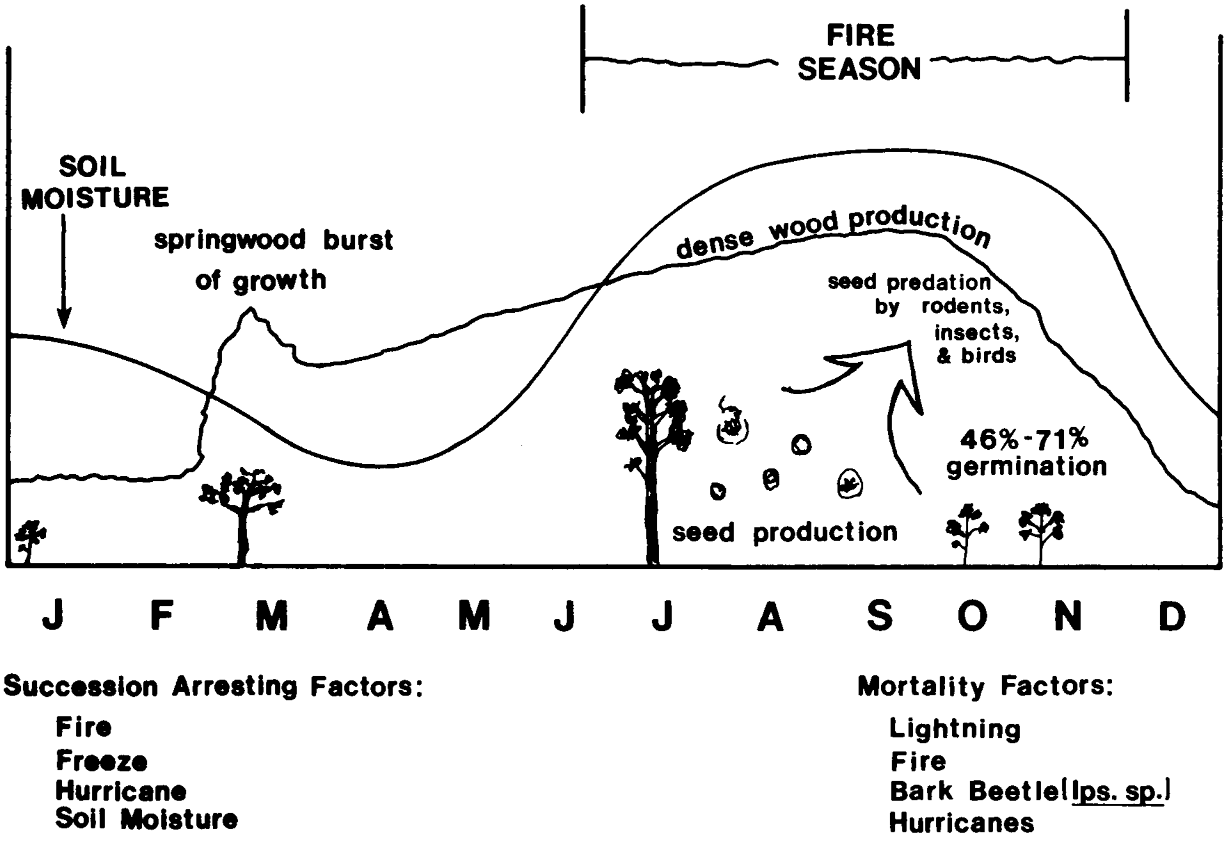


Figure 65. The annual cycle of a slash pine stand.

Dry pinelands are generally characterized by an abundance of palms, particularly cabbage palm Sabal palmetto and saw palmetto Serenoa repens. Like slash pine, these palms are also fire adapted. Both species possess a deeply embedded bud within a fire-resistant trunk (Duever et al. 1979). Cabbage palm adapts to flooding through the production of adventitious roots, a capacity less characteristic of the saw palmetto.

Pure stands of cabbage palms (palm savannahs) sometimes occur as a result of logging the pine overstory (Duever et al. 1979). Other species common in the palm understory are varnish leaf (Dodonaea viscosa), wax myrtle (Myrica cerifera), gallberry (Ilex glabra), lyonia (Lyonia spp.), sumac (Rhus copallina), snowberry (Chiococca alba), velvetseed (Guettarda scabra), and penny royal (Satureja rigida).

The upper physical structure of pine forests is usually an open one with canopy coverages in the range of only 10% to 20%, even in unlogged stands. Tree heights in mature forests may reach 30 m (100 ft) and diameters at breast height (dbh) approach 40 cm (16 inches). Fire or other catastrophic factors are evident in second growth forests that have a variety of tree sizes and age classes. In sabal palm understories, some pines may grow as high as 20 m (65 ft).

The lower physical structure of pine forests ranges from highly dense shrubbery (saw palmetto, wax myrtle) to thick grass. Midcanopy layers of palm and palmetto are rare, although saw palmetto may form a dense cover all the way from the ground to as high as 2 m (7 ft).

The continued success of pinelands as groundcover is promoted through a balance of structural and functional adaptations that both encourage fire and limit it. A list of the physical and biological features of pinelands that simultaneously promote fire and limit fire is given in Table 22.

Table 22. Physical and biological features of pinelands that simultaneously promote and limit fire (adapted from Duever et al. 1979).

PROMOTE FIRE	LIMIT FIRE
1. Open canopy: promotes wind and moisture loss thus initiation and spread of fire.	1. Open canopy: relatively wide spacing of trees tends to slow the spread of fire.
2. Net litter or duff accumulation: without fire, accumulation rate of litter far exceeds decomposition rate creating much dry kindling promoting either fire or succession.	2. Sensitivity of juvenile trees: leads to fairly widely separated year classes; fuel of larger trees thus separated from effects of lower ground fires.
3. Species adaptations to fire: heat induced germination and sprouting of seedlings, fire resistance of older trees gives relative advantage to pinelands over hammocks.	3. The same adaptations i.e. resistance to fire, also tend to limit the spread of fires by limiting the fuel supply.

6.2.2 Hammocks

Hardwood hammocks, though relatively rare throughout the watershed, are more common toward the south. Hammocks are generally found on elevated bedrock areas that are overlain by sandy peat (Craighead 1971). Such soils, known as the Pinellas-Copeland complex (Leighty et al. 1954, Carlisle and Brown 1982), are composed of organic matter mixed with fine sand overlying limestone, sometimes with a layer of marl sandwiched between.

The hardwood hammock is considered to be the climatic climax community for south Florida (Davis 1943, Craighead 1971, Alexander and Crook 1974). Dominant overstory and pioneer species are laurel oak (*Quercus laurifolia*), water oak (*Q. nigra*), live oak (*Q. virginiana*), and tamarind (*Lysiloma bahamensis*). Species domination tends more toward the temperate oaks to the north of the watershed, with progressively more tamarind to the south. Frost tends to limit the abundance and distribution of tropical flora at higher latitudes.

As pioneer hammock species invade other plant communities, they pave the way for a variety of shade-tolerant trees and shrubs. At full development, hammock overstories characteristically exhibit a 75%-90% crown cover, creating a stable, moist microclimate that is exploited by a diverse understory. Though hammocks support fewer total species than do wet pinelands, a greater number are woody plants. Representative species are cabbage palm (*Sabal palmetto*), strangler fig (*Ficus aurea*), pigeon plum (*Coccoloba diversifolia*), gumbo limbo (*Bursera simaruba*), poisonwood (*Metopium toxiferum*), red bay (*Persea borbonia*), and cocoplum (*Chrysobalanus icaco*) (McPherson 1973). Farther to the north in the watershed, southern magnolia (*Magnolia grandiflora*), American holly (*Ilex opaca*), blue beech (*Carpinus caroliniana*), and hop hornbeam (*Ostrya virginiana*) are more characteristic species (McCoy 1981).

The relatively stable, moist microclimate of hammocks is also conducive to an abundance of orchids (family Orchidaceae) and bromeliads (pineapple family, Bromeliaceae). Orchid species in hammocks include ionopsis (*Ionopsis utricularoides*), clamshell orchid (*Encyclea cochleata*), mule ear orchid (*Oncidium luridum*), and cowhorn orchid (*Cyrtopodium punctatum*) (Luer 1972). Bromeliads are generally less habitat-specific than the orchids. Major species in hammocks include yellow catopsis (*Catopsis beteroniana*), ball moss (*Tillandsia recurvata*), Spanish moss (*T. usneoides*), and twisted air plant (*T. flexuosa*) (Long and Lakela 1971). The bromeliads are particularly significant to the wildlife of hammocks in that their unique construction often serves as a miniature aquatic reservoir. These plants may provide drinking water for mammals, birds, and reptiles; hideouts for amphibians; and breeding or feeding grounds for insects, birds, and amphibians (Duever et al. 1979). Because of their extreme sensitivity to changes in the environment and their past commercial exploitation, many orchids and bromeliads are also endangered or threatened (see McCoy 1981).

Hardwood hammocks exhibit structural and functional features that promote their self-perpetuation. In contrast to the features of the wet prairies, in which hammocks frequently occur as rounded, elevated islands, the hammocks are a very radical departure in structure and function. The hydroperiod in hammocks is brief - 10 to 45 days per year at the most - compared to a 3- to 5-month hydroperiod in the surrounding prairies (Duever et al. 1979). The slight (30 to 90 cm) elevation prevents "drowning" of the generally shallow-rooted dominants of the hammock. A potential disadvantage of the slight elevation is that dominant shallow-rooted hammock plants are under stress because of deficiencies in moisture and nutrients close to the soil surface during the dry season. However, gradual changes in microclimate help solve this problem. Increased shade, less evaporation, and lower air temperatures create a more favorable environment for the formation of humus (organic matter) in the soil of hammocks. This organic matter holds vital ions and moisture that would otherwise leach out from purely sandy soils or underlying limestone bedrock. Litter accumulated on the floor of a hammock tends to conserve nutrients and water so that shallow-rooted species may recycle them.

Fire is a major threat to hardwood hammocks; however, they exhibit considerable fire-resistance because of their external shape and high internal moisture content. Hammocks are usually round, and often have a "moat" encircling them. The moat provides a definite barrier against the spread of fire into the hammock. The relative impermeability of the hammock to wind helps keep sparks from reaching burnable tissue. High moisture content in hardwood hammocks diminishes the probability of fire from lightning.

These same habitat characteristics help reduce the threat of freezing temperatures and hurricanes. In the Caloosahatchee River/Big Cypress watershed, where there is a marginal chance of frost, the added protection provided by an enclosed canopy can make a difference between life or death for purely tropical plants. In addition, hurricane wind damage is minimized by the hammock's circular shape, which tends to deflect strong winds away from the interior of the hammock (Craighead 1971).

6.2.3 Cypress and Mixed Swamp Forests

According to Duever et al. (1979) the four types of swamp forests in the southern part of the watershed are mixed swamp forests, cypress domes and strands, monospecific stands (willow, pop ash, pond apple), and dwarf or scrub cypress. These types are especially obvious in the Big Cypress National Preserve, where swamps are a prominent feature of the landscape. North toward the Caloosahatchee River watershed, dwarf cypress are rare and swamps are less prominent.

The distribution of cypress and mixed swamp communities is largely determined by surface topography, bedrock undulations, and surficial sediments. These factors control hydroperiod and soil composition, which have direct effects on the types of communities that may develop on the substrate. A series of hypothetical transects that illustrate various gradients of plant communities in the watershed are given in Figures 66a-66d. All four of the mixed and cypress swamp communities are represented in these transects.

The overstory of unlogged mixed swamp forests is dominated by baldcypress (Taxodium distichum). Large-scale logging of many of these swamps has resulted in domination of such forests by species previously in the subcanopy, such as red maple (Acer rubrum), pop ash (Fraxinus caroliniana), dahoon holly (Ilex cassine), myrsine (Myrsine quianensis), willow (Salix caroliniana), and swamp bay (Persea palustris). The understory of these swamps is composed of a wide variety of ferns, vines, aquatic plants, and saplings of overstory species. Representatives are swamp fern (Thelypteris kunthi and Blechnum serrulatum), Boston fern (Nephrolepsis exaltata), hemp vine (Mikania batatifolia), green brier (Smilax laurifolia, S. bona-nox), ludwigia (Ludwigia repens), mermaidweed (Proserpinaca palustris), lemon grass (Bacopa caroliniana), and pickerel weed.

Structurally, the mixed swamp forest exhibits a relatively closed canopy (70%-90%) and high internal humidity. The hydroperiod ranges from 3 to 10 months. Much of the understory in these forests grows around the base of larger trees where the "micro" elevation gradient and accumulated detritus well support terrestrial vegetation. Elsewhere the long hydroperiod and low light restricts growth to purely aquatic vegetation. Even under "dry" conditions the extremely acid, organic soils of mixed swamp forests may limit the abundance or density of the vegetation (Wharton et al. 1977).

In regard to succession, the mixed swamp forest is considered to be intermediate to the hardwood hammock and cypress domes and strands (Alexander and Crook 1974). One distinct factor limiting succession is that mixed swamps usually overlie soils of biogenic origin, and hardwood hammocks usually overlie the bedrock. As cypress domes and strands accumulate peat soils and slowly develop into mixed hardwood cypress swamps, they inevitably reach a point where any increase in elevation (peat soil buildup) is counterproductive to the survival of the swamp community. At higher, drier elevations, hardwood hammock vegetation would clearly be favored over water-loving cypress, red maple, and gum (Figure 62).

Where underlying bedrock depressions are less channelized in form (i.e., more like circular depressions) with shallow peat development, the mixed cypress hardwood swamps give way to cypress domes or strands (Figure 66a). The cypress communities are characterized by a nearly monospecific overstory of pond cypress (Taxodium ascendens) growing in either circular or elongated bedrock depressions. Common understory plants are bladderwort (Utricularia spp.), swamp fern (Blechnum serrulatum), spike rush (Eleocharis cellulosa), and marsh fleabane (Pluchea foetida), as well as many species of bromeliads and orchids. Woody species of the understory may include buttonbush (Cephalanthus occidentalis), cocoplum (Chrysobalanus icaco), willow (Salix caroliniana), and wax myrtle (Myrica cerifera).

Mixed cypress swamps and the cypress domes and strands tend to assume a characteristic shape as implied by the descriptors 'dome' and 'strand'. The shape appears to be a function of localized site factors, compounded by the effects of fire. At the periphery of these communities unfavorable soil conditions tend to limit the growth rate of trees, making them generally smaller than those toward the center (Harper 1927). This effect is augmented by periodic fires and recurring droughts and floods which tend to remove the more stressed peripheral trees. The net result is to create a younger age class

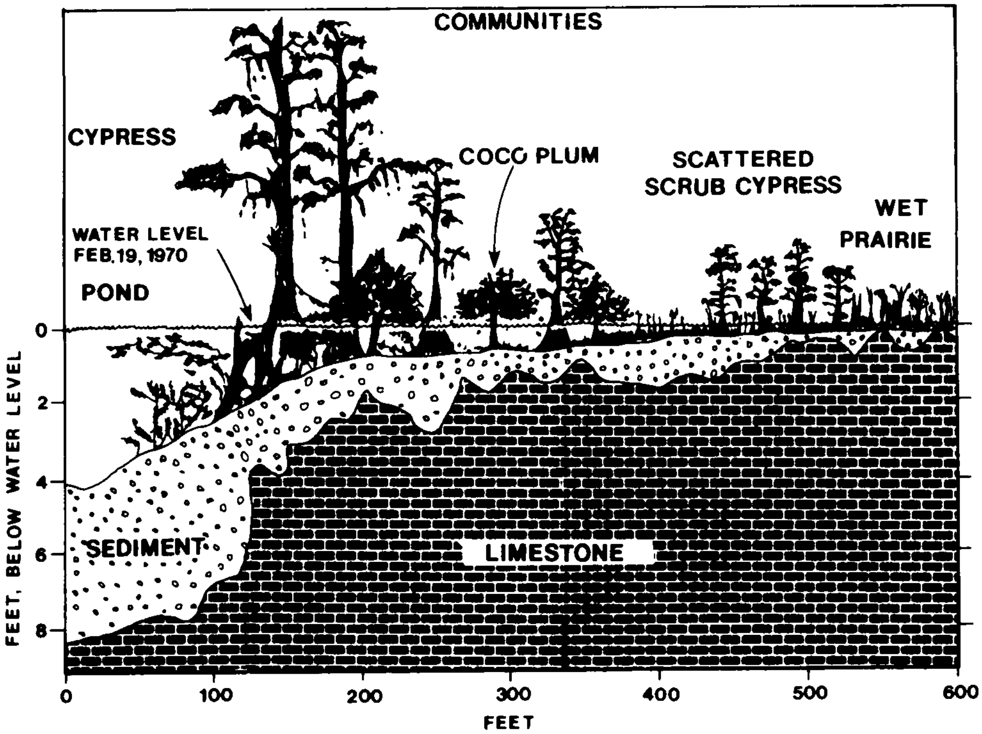


Figure 66a. Plant community profiles in the Big Cypress Swamp: wet prairie into cypress stand (adapted from McPherson 1970).

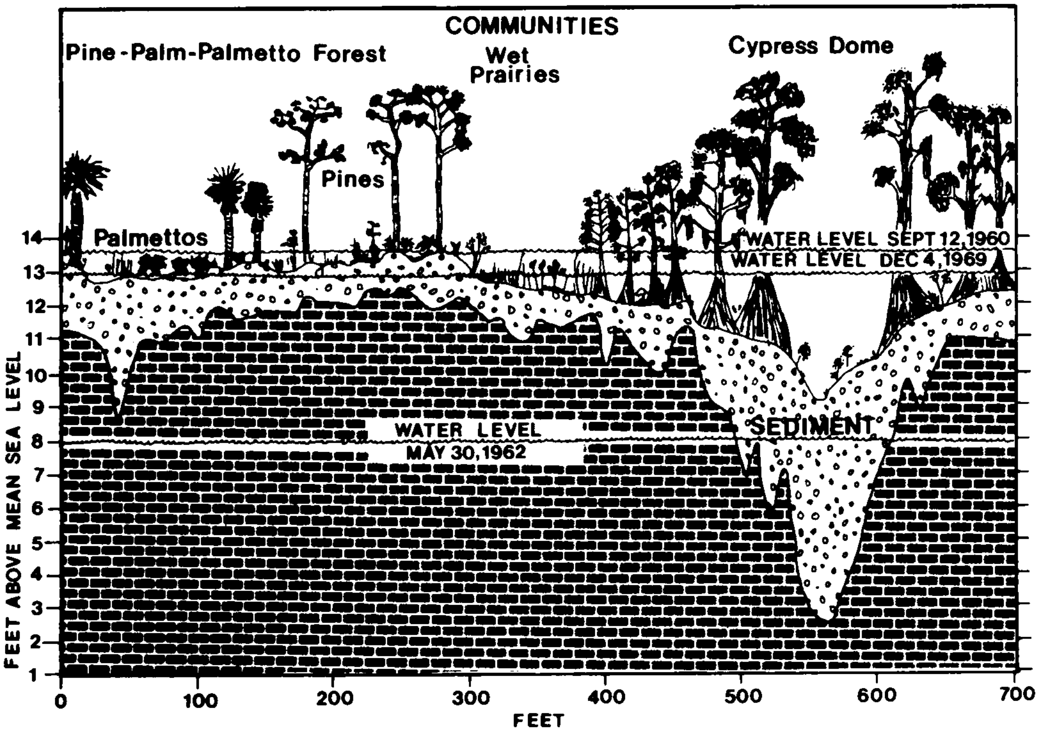


Figure 66b. Plant community profiles in the Big Cypress Swamp: pine-palm-palmetto forest through cypress tree community (adapted from McPherson 1970).

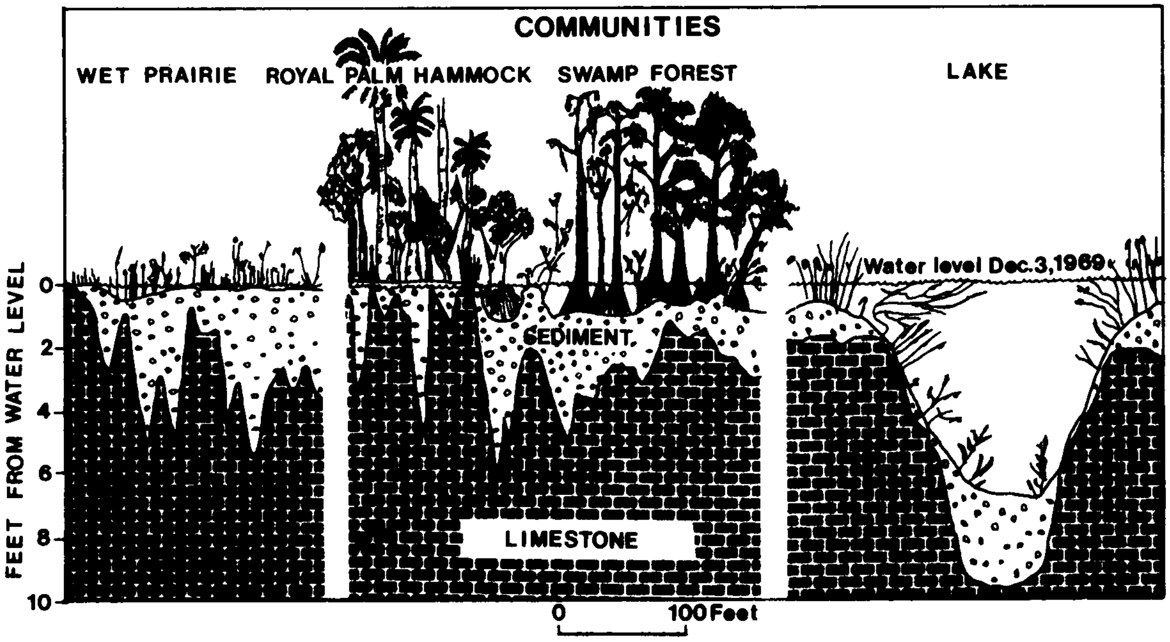


Figure 66c. Plant community profiles in the Big Cypress Swamp: wet prairie, hammock, swamp forest, and lake (adapted from McPherson 1970).

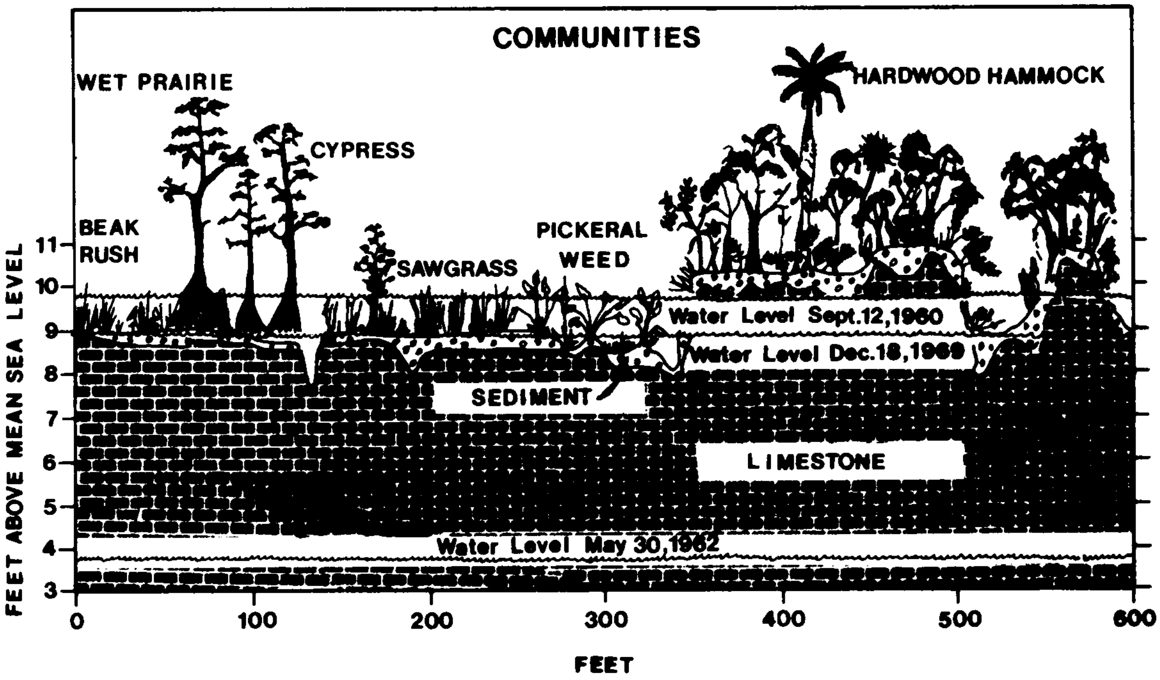


Figure 66d. Plant community profiles in the Big Cypress Swamp: wet prairie into hardwood hammock (adapted from McPherson 1970).

of trees in a suboptimal growth medium at the edges of the community (Kurz and Wagner 1953, Duever et al. 1976).

Although this pattern is generally upheld throughout the basin, Duever et al. (1978) also report a dome shape caused by a somewhat different combination of cause and effect. In certain smaller domes and strands the larger central trees may actually be younger than the smaller peripheral trees. This condition tends to prevail only at sites where peat depth is less than 0.7 m (2 ft). The authors hypothesize that a severe fire probably destroyed the interior cypress trees, which were rooted in shallow peat. In contrast, peripheral trees rooted in more mineral soils survived. As the interior was reseeded, the optimal soil conditions promoted rapid growth into larger but younger trees than in the periphery (Duever et al. 1978, 1979).

Scrub or dwarf cypress (T. ascendens) grows in shallow sand or marl soils about 7 to 15 cm (3 to 6 inches) deep, overlying bedrock (Craighead 1971). The trees are small - generally less than 10 m (33 ft) - and density is low. Canopy coverage ranges from 30% to 45% (Flohrschutz 1978) with trees being as much as 15 to 20 m (50 to 65 ft) apart. Individual cypress trees that are quite old (100 + years) may have a diameter at breast height (dbh) less than 15 cm (6 inches).

Scrub cypress forests often cover extensive areas that would, without the cypress, look very much like wet prairies. The dome or strand shape is absent and the understory is almost exclusively grasses and sedges such as Rhynchospora, Cyperus, Muhlenbergia, and Cladium.

Monospecific stands of willow (Salix caroliniana), pop ash (Fraxinus caroliniana), pond apple (Annona glabra), and cocoplum (Chrysobalanus icaco) (in the south) may form thickets in burned-out cypress domes and strands. These thickets eventually give way to cypress as litter fall builds peat and cypress seedlings find their way into the community.

Some controversy remains over whether baldcypress and pond cypress are two different species or merely adaptions of one species to different environmental conditions. Whatever the answer, cypress ecology is intricately linked to the hydrologic and soil conditions that prevail in the Caloosahatchee River/Big Cypress watershed, especially in the southern half. Changes in the distribution of cypress act somewhat like a living monitor of the combined effects of drainage and fire control. In this regard, some of the more salient aspects of cypress ecology are summarized below.

Male and female cones grow on a single tree. Female cones appear in March or April and mature from October to December, each containing anywhere from 18 to 30 seeds. Male cones are produced between December and March. The seeds are generally too large to be carried by the wind and frequently fall to the ground, some still in the cone (Duever et al. 1979).

Water is necessary not only as a dispersal medium but also to permeate the thick seed coat (Murphy and Stanley 1975). The seed must soak from 1 to 3 months before it germinates. Although seeds may remain viable underwater for as much as a year, they will not germinate. Dry but not excessively drained soils are required for germination.

Survival and growth of seedlings the first year are controlled largely by the timing and extent of flooding and drought, and soil conditions. Loss of soil moisture causes irreversible wilting (Dickson and Broyer 1972). Growth must be sufficient the first year for the seedling to escape protracted inundation because this also will cause mortality (Demaree 1932, Bull 1949, Betts 1960, Gunderson 1977). Seedlings may survive inundation for as long as six weeks. Growth in flooded soils that are anaerobic is less than in flooded soils that are aerobic (Dickson and Broyer 1972).

Cypress seeds are consumed by squirrels (*Scurius niger*), sandhill cranes (*Grus canadensis*), and several species of ducks (Gunderson 1977). The now extinct Carolina parakeet (*Conuropsis carolinensis carolinensis*) fed heavily on cypress seeds and was believed to be an important vector in their dispersion (Sprunt 1954). Rabbits (*Silvilaguo* sp.) are believed to feed on the branches, bark, and roots of seedlings (Duever et al. 1979). Little is known about the effect of insect predation or diseases on cypress.

Comparative data on the energetics of cypress forests are given in Table 23, for drained and undrained sites. Carter et al. (1973) and Burns (1978) report that forest productivity is decreased by drainage operations. Decreases in total productivity and standing biomass are attributed to the diversion of energy flow from below the

Table 23. Energetics of cypress forests in the Caloosahatchee River/Big Cypress watershed.

Rate	Pond cypress		Scrub cypress	Bald cypress	Mixed swamp
	d*	ud*			
Total net productivity (g/m^2/day)	2.7(2)	3.1-6.3(1) 0.0-7.2(2)	-	-	-
Standing crop biomass (Kg/m^2)	14.6(2)	27.5(2)	-	-	-
Understory production (g/m^2/yr)	-	200(5)	-	100(5)	-
Litterfall (g/m^2/yr)	-	380-600(1,4)	100(4)	500(4)	750(4)
Decomposition rate (%/yr)	-	16(4)	-	-	21-38(4)
Accumulation rate			400-500g/m^2/yr (3) (no community type specified)		

(1) Carter et al. 1973, (2) Burns 1978, (3) Flohrschutz 1978, (4) Duever et al. 1975, (5) Duever et al. 1979

* d-drained ud-undrained

ground (root system), and to low moisture content in the soil (Burns 1978).

6.2.4 Prairies, Marshes, Sloughs, and Ponds

These four communities are discussed in one section because they are often found together. All are dominated by herbaceous vegetation along a continuous gradient of hydroperiods. The common species found among these communities are listed in Table 24.

In the north Caloosahatchee River/Big Cypress watershed these communities are generally less evident, limited by such factors as soil type, elevation, and hydroperiod. An exception is found along the margins of Lake Okeechobee east of Moore Haven, where Pesnell and Brown (1977) found 10 of 15 vegetative community types to be dominated by herbaceous vegetation (Table 25). These communities are located on land between the open waters of the lake and the developed and drained uplands southwest of Moore Haven. Because of massive regional drainage and flood control they now are relatively scarce in the upper Caloosahatchee River area (Figure 60).

Species dominance at any given location in these communities is a function of hydroperiod and soils. Using transects along a gradient of elevation (indicative of hydroperiod), Pesnell and Brown (1977) report a series of distinct optimum ranges for each dominant community. Where there is overlap in hydroperiod preference, soil type appears to determine which species is more dominant. Coastal-plain willow (*Salix caroliniana*), sand cordgrass (*Spartina bakerii*), and beakrush (*Rhynchospora tracyi*) all closely overlap in their duration of inundation, although they differ in soil affinity. Willow is found on

Table 24. Plant species dominating the dry and wet prairies, marshes and sloughs, and ponds of the Caloosahatchee River/Big Cypress watershed (adapted from Long and Lakela 1971).

INCREASING HYDROPERIOD ---->			
Dry prairies	Wet prairies	Marshes and sloughs	Ponds
Broomsedge (*Andropogon* spp.)	Muhly grass (*Muhlenbergia* spp.)	Pickerel weed (*Pontederia cordata*)	Coontail (*Ceratophyllum demersum*)
White top sedge (*Dichromea* spp.)	Love grass (*Eragrostis* spp.)	Arrowhead (*Sagittaria lancifolia*)	Bladderwort (*Utricularia subulata*)
Spartina spartinae	Sand cordgrass (*Spartina bakerii*)	Maidencane (*Panicum hemitomon*)	Floating heart (*Nymphoides aquatica*)
Palmetto (*Serenoa repens*)	Spikerush (*Eleocharis cellulosa*)	Sawgrass (*Cladium jamaicensis*)	Water lily (*Nymphaea oderata*)
Foxtail grasses (*Setaria* spp.)	Sawgrass (*Cladium jamaicensis*)		Water lettuce (*Pistia stratiotes*)
69 species[1]	172 species[1]	110 species[1]	

[1] Total number of species recorded in each environment (Long and Lakela 1971).

Table 25. Plant communities dominated by herbaceous species in Lake Okeechobee near Moore Haven (adapted from Pesnell and Brown 1977).

	Community Dominants	Comments
Bulrush	*Scirpus californicus* *Vallisneria americana* *Potamogeton illinoensis* *Eleocharis cellulosa*	Found on all soils; dominant in areas exposed to wave action
Spikerush	*Eleocharis cellulosa* *Utricularia* spp. *Sagittaria lancifolia* *Potamogeton illinoensis* *Fuirena scirpoidea* *Nymphaea odorata* *Nelumbo lutea*	Shallow, sandy soils; fairly long hydroperiod
Cattail	*Typha angustifolia* *Sagittaria lancifolia* *Pontederia lanceolata* *Salix caroliniana* *Nymphaea odorata*	Found on all soils; frequently exhibit islands of woody vegetation and open water lily sloughs
Beakrush	*Rhynchospora tracyi* *Eleocharis cellulosa* *Panicum tenerum* *Eragrostis elliotii* *Pluchea purpurascens* *Iva microcephala* *Spartina bakerii*	Shallow, sandy soils often associated with depressions in underlying bedrock
Wire-cordgrass	*Spartina bakerii* *Eleocharis cellulosa* *Centella asiatica* *Cephalanthus occidentalis*	Predominately sandy soils with varying amount of organic matter
Sawgrass	*Cladium jamaicensis* *Cephalanthus occidentalis* *Eleocharis cellulosa* *Pontederia lanceolata*	In soils with high organic content
Mixed grasses	*Panicum repens* *Cynodon dactylon* *Eleusine indica*	At higher land elevations often subject to burn and cattle grazing
Bog	*Panicum hemitomon* *Pontederia lanceolata* *Sagittaria lancifolia*	Depressions with organic substrate in normally shallow sandy soils
Water hyacinth	*Eichhornia crassippes* *Scirpus cubensis* *Ludwigia leptocarpa*	Invader of bulrush and spike rush communities
Water lily	*Nymphaea odorata* *Nelumbo lutea*	Open water sloughs, often with flocculent organic substrate in cattail or sawgrass communities

mucky, fibrous peat; sand cordgrass on peat and sand mixture; and beakrush on sandy soils low in organic content. Spikerush prefers low marl substrates; sawgrass prefers low organic (peat) soils (Craighead 1971).

When prairies and marshes dry up, the annual die-off of vegetation provides a substantial supply of kindling for prairie and marsh fires. In the more productive communities the fuel supply is generally sufficient to sustain fires that limit invasion by woody species. A possible exception is the scrub cypress community, where marsh and prairie productivity is so low that the severity of fires is low and scattered cypress tend to grow in the periphery (Duever et al. 1979).

The long-term evidence of prairie fire is difficult to detect in resilient prairie and marsh communities because annual regrowth is so rapid. Prairies and marshes are the most frequently burned terrestrial (or wetland) communities in the watershed. Annual carbon production values range from 150 g/m^2 (sedge community) to 200 g/m^2 (wet prairie community) to 320-800 g/m^2 (*Spartina* marshes) according to Duever et al. (1975).

6.2.5 Riverine Communities

This section reviews the plant communities of channelized waters and oxbows of the Caloosahatchee River/Big Cypress watershed. Between LaBelle and S-79 (Franklin Locks) there are no less than 35 oxbows off the main channel of the river. These oxbows are remnants of the prechannelized river system.

Oxbow lakes are shallow (maximum depth 1.5 to 3.0 m) and small (less than 1.0 acre to 11.6 acres). They range in length from 118 m (390 ft) to 720 m (2,370 ft). The majority are openly connected to the main channel, several are clogged by floating or emergent vegetation, and a few are blocked from the Caloosahatchee River by fill or sediment. The oxbow banks are generally steep.

The vegetation of the oxbows is divided into emergent vegetation in shallow-water areas, floating mat vegetation communities, and overhanging riverbank vegetation (Milleson 1980). The most abundant species of emergent vegetation in the Caloosahatchee River oxbow lakes are spatterdock, wild rice, and cattail. Floating mats of aquatic vegetation are usually dominated by alligator weed, floating maidencane, water lettuce, and primrose willow. Overhanging riverbank vegetation consists primarily of taro, leather fern, coastal plain willow, popash, and wax myrtle. These communities are frequently punctuated by terrestrial invaders. Some submergent macrophytes (e.g., *Najas guadalupensis*) and benthic algae inhabit their open waters. A listing of these and other species common to oxbow lakes is given in Table 26.

Sediment in oxbow lakes consists of well-decomposed, fine, particulate organic matter (mud or ooze); coarse peat and plant detritus; and less frequently, sand, shell fragments, or marl. The organic deposits vary in thickness from a few inches to several feet.

The abundance of floating mats of vegetation in oxbows indicate that there is little water current; thus, detritus derived from floating, overhanging, and emergent vegetation tends to accumulate in the sediments. The high organic load, slow water movement, highly colored water, and overhanging vegetation

Table 26. Major plant species in the Caloosahatchee River oxbow lakes (adapted from Milleson 1980).

Species	Common Name	Distribution[a]
Acrostichum sp.	Leather fern	3,2
Alternanthera philoxeroides	Alligator weed	2
Annona glabra	Pond apple	3
Carya aquatica	Water hickory	3
Cicuta mexicana	Water hemlock	3
Cladium jamaicensis	Sawgrass	1
Colocasia esculentum	Taro	3
Eichhornia crassipes	Water hyacinth	2
Fraxinus caroliniana	Popash	3
Hibiscus grandiflorus	Swamp hibiscus	3
Hydrocotyle sp.	Pennywort	2
Ludwigia peruviana	Primrose willow	2
Myrica cerifera	Wax myrtle	3,4
Nuphar advena	Spadderdock	1
Panicum hemitomon	Maidencane	1
Panicum repens	Torpedo grass	1,2
Phragmites australis	Reed	1
Pinus elliottii	Slash pine	4
Pistia stratoites	Water lettuce	2
Polygonum sp.	Smartweed	1,2
Pontederia lanceolata	Pickerelweed	1
Psidium guajava	Guava	3,4
Quercus sp.	Oaks	3,4
Sabal palmetto	Cabbage palm	3,4
Sacciolepis striata	Floating maidencane	2
Sagittaria latifolia	Arrowhead	1
Salix caroliniana	Coastal plain willow	3
Sambucus simpsonii	Florida elder	3
Schinus terebinthifolius	Brazilian pepper	3,4
Scirpus sp.	Bulrush	1,3
Taxodium distichum	Cypress	1,3,4
Typha sp.	Cattail	1
Zizania aquatica	Wild rice	1

[a] Habitat designation.
1 = Emergent, 2 = Floating, 3 = River bank, 4 = Terrestrial.

together combine to produce near anoxic conditions in oxbow waters, particularly near the bottom.

The more open water environment of the Caloosahatchee River channel has a different plant composition. Emergent and floating vegetation is rare. The more common riverbank or overhanging vegetation is limited to a few species such as taro (Colocasia esculentum), wax myrtle (Myrica cerifera), and brazilian pepper (Schinus terebinthifolius). The deep open waters of the river channel are clearly dominated by microscopic algae (i.e., Anabaena flos-aquae, Microcystis aeruginosa), which are generally more abundant in the canal than in its tributaries or oxbows.

Vegetation differences between tributaries, oxbows, and the main canal are probably due to differences of substrate, degree of meander, depth, width, and flow. Oxbow and tributary cross sections, which are not as steep, wide, or deep as the main canal, encourage terrestrial as well as emergent, floating, and overhanging vegetation. The shape of the tributaries and oxbows are the consequence of the stream's physical tendency to meander and form areas of active erosion and deposition along its course. In the varied physical environment of the meadering stream there is a diverse and complex biological system.

6.3 ESTUARINE AND SALTWATER WETLAND HABITATS

6.3.1 Salt Prairies and Marshes

In the low-sloping coastal region south of Cape Romano and southwest of the Big Cypress Swamp there is a broad transitional area that ecologically bridges the gap between marine and freshwater environments. Salinities (soil and water) range from runoff-dominated freshwater conditions on the upland, eastern side, to tidally-controlled saltwater on the seaward edges. In this region salt marshes, salt prairies, and mangrove forests dominate the plant community.

Beginning at the upland edge of the transitional area, plant species composition gradually becomes intermediate between wet prairie and freshwater marsh or slough vegetation (discussed earlier), and low salinity, salt-marsh vegetation. The major intermediate species are cordgrass, saltgrass (Distichilis spicata), glasswort (Salicornia bigelovii), and sea purslane (Sesuvium portulacastrum). Species dominance is generally determined by a combination of interrelated factors, including soil salinity range, elevation, and tides. The prickly cordgrass marsh, dominated by Spartina spartinae with patches of saltgrass, spikerush (Eleocharis cellulosa), sea purslane, and sea daisy or sea ox-eye (Borrichia spp.) inhabit low-salinity areas (0-5 ppt). Saltgrass marsh tends to be dominant in more saline areas (5-20 ppt) that are little influenced by direct tidal action. Species composition is mostly saltgrass and glasswort with patches of key grass (Monanthochloe littoralis), sea purslane, sea blite (Suaeda linearis), water hemp (Acnida cannabina), and beach carpet (Philoxerus vermicularis). At sites where drainage is limited and soil salinities are high, saltwort (Batis maritima) dominates, with localized occurrences of glasswort, sea purslane, sea blite, water hemp, and beach carpet (Carter et al. 1973, EEL 1978, Duever et al. 1979).

Tidal creeks and inlets, which are seaward of the transition zone, are environments in which salinity oscillations are greater and more frequent. On areas more elevated between the creeks and inlets where tidal inundation is relatively less intense, blackrush may grow in a vast monoculture (Craighead 1971, EEL 1978). Other common species are leather fern (Acrostichum aureum), buttonwood (Conocarpus erecta), big cordgrass (Spartina cynosuroides), coastal dropseed (Sporobolus virginicus), saltwort, and saltgrass. At times Juncus may share dominance with the sedge Fimbristylis castanea. The deep saltwater marsh, dominated by nearly pure stands of smooth cordgrass (Spartina alterniflora) is favored where high salinities, wave action, and regular tidal fluctuation prevail.

These wetland communities are much more extensive in the area south of Naples where coastal re-entrant shoreline features such as islands, bays, and lagoons dominate. Onshore and offshore topography north of Naples is just slightly steeper than to the south. This increased steepness tends to limit the width of the saline transition zone, making the boundary between freshwater and brackish environments sharper. The abundance of salt marsh and prairie communities diminishes from south to north, but mangrove forests are abundant throughout the watershed's coastline. Brown (1976) reports only minor patches of salt-marsh vegetation in 1973 from the coastal zone of Lee County. Curiously enough, no salt-marsh vegetation was reported from the same area (around Estero Bay) from surveys conducted around 1900.

In southwest Florida estuaries, black bullrush, although very productive, appears to contribute less to the detrital food chain of downstream estuaries than do mangrove forests (Heald 1971). Compared to mangrove detritus (particularly red mangrove leaves), Juncus tissues are more resistant to decomposition and subsequent microbial enrichment that fosters the community of microconsumers so important to the energy flow in southwest Florida estuaries (Odum and Heald 1972). Odum et al. (1982), however, point out that the full role of salt marsh and prairie vegetation in estuarine energy flow has not been adequately studied so conclusions concerning this subject may be premature.

Although salt marshes and prairies have a questionable role in the chemical/detrital basis of estuarine energy flow, they do provide habitat for a variety of fish and wildlife. In general, moderate- (10 to 20 ppt) to high-salinity (>20 ppt) marshes support more marine invertebrates (snails, mussels, polychaetes) than do the low-salinity (<10 ppt) marshes (Carter et al. 1973). Marshes also attract numerous wading birds (herons, egrets), other more conspicuous birds (red winged blackbird, marsh hawk), mammals (rabbits, raccoons), and reptiles (alligators, salt marsh snake). Although the contribution to estuarine energy flow is not clearly established, salt prairies and marshes provide living space in which fish and wildlife reproduce, feed, and nurture their young.

6.3.2 Mangrove Forests

Scattered buttonwood trees (Conocarpus erectus) on the downstream side of salt marshes signify the beginning of the wetlands zone dominated by forest vegetation. In addition to buttonwood, three species of mangroves, red mangrove (Rhizophora mangle), white mangrove (Laguncularia racemosa), and black mangrove (Avicennia germinans), are the dominant tree species. Mangrove forests narrow from about 16 to 19 km (10 to 12 mi) in width at the southern end of the watershed to a thin fringe along estuarine shorelines north of Naples. The most significant concentration of mangroves north of Naples are along the inner shores of Estero Bay. This south-to-north tapering correlates with an increased steepness in terrestrial and offshore slopes, a condition that accounts for the formation of sand beaches north of Marco Island.

Other salt-tolerant plants frequently associated with mangrove forests are leather fern (*Acrostichum aureum*), spanish bayonet (*Yucca aloifolia*), spider lily (*Hymenocallis latifolia*), prickly pear cactus (*Opuntia stricta*), rubber vine (*Rhabdadenia biflora*), and a variety of bromeliads. In addition, there is an assemblage of root and mud algae associated with the intertidal prop roots of red mangroves. The flora and fauna commonly found attached to the prop roots are summarized in Figure 67 (Carter et al. 1973, Odum et al. 1982).

Theories on why mangrove species associations are distributed as they are follow two complimentary trains of thought, one strictly phytosociological, based on the theory of successional relationships between associations (Davis 1940), and the other based on consideration of the environmental factors favoring species dominance and physiognomy of forest growth (Lugo and Snedaker 1974, Wharton et al. 1977).

The Davis approach (Figure 68) is an empirical summary of the major habitats of the southwest Florida coast that emphasizes the relation between mangrove zones and tides. This diagram (Figure 68) is a fair representation of plant associations

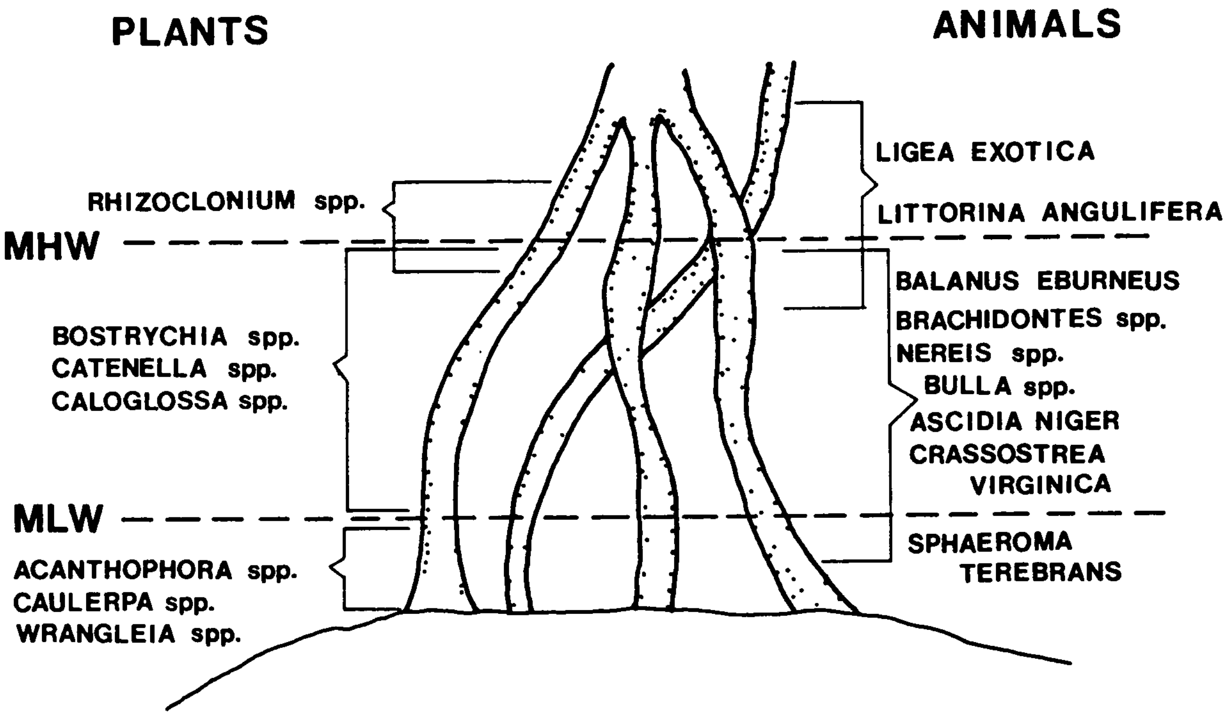


Figure 67. Mangrove prop root communities (adapted from Odum et al. 1982).

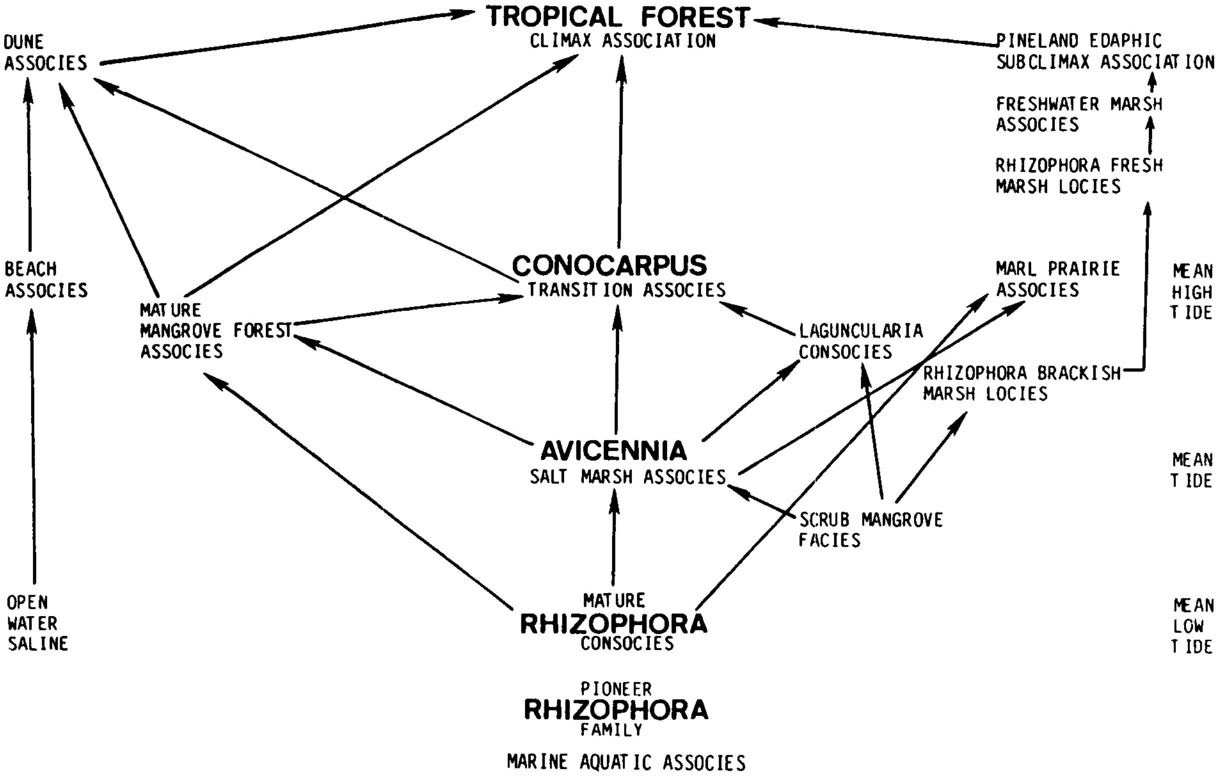


Figure 68. Mangrove community associations and forest types along the southwest coast of Florida (adapted from Davis 1940).

in the mangrove zone, but it inaccurately portrays the mangrove as a land builder that causes a succession towards the tropical forest. The current consensus is that mangroves, particularly red mangroves, are land stabilizers rather than land builders (Odum et al. 1982). Other physical forces such as sea-level fluctuation, long-term drainage patterns, and hurricanes exert the primary controlling influence on exactly where the land ends and the ocean begins. Localized environmental factors such as soil salinity, tidal flushing, and storm disturbances determine distribution patterns among mangrove plant species.

If environmental factors such as topography and hydrology were incorporated into Davis' figure, the mangrove forest types shown in Figure 69 (Lugo and Snedaker 1974, Wharton et al. 1977) would emerge. The following description of mangrove forest types was taken from these two reports.

Fringe mangrove forests are distributed along protected shorelines and are 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.

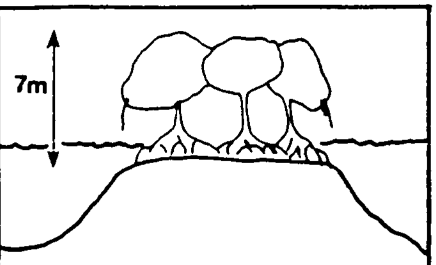
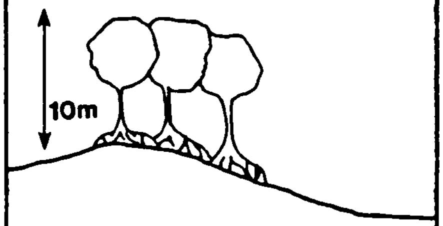
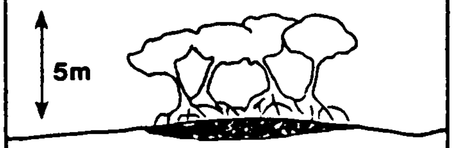
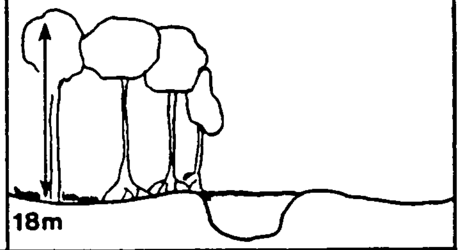
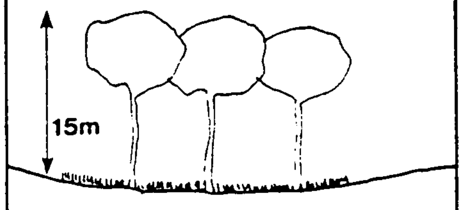
OVERWASH MANGROVE ISLANDS 1- overwashed by daily tides. 2- high rate of organic exports. 3- dominated by red mangroves but all species may be present. 4- south Florida, south coast of Puerto Rico. 5- sensitive to ocean pollution.	
FRINGE MANGROVE WETLANDS 1-line water ways. 2-high rate of organic exports. 3-dominated by red mangrove. 4-throughout south Florida, Puerto Rico and Florida's east and west coast. 5-sensitive to ocean pollution.	
SCRUB MANGROVE WETLANDS 1-on extreme environments. 2-low organic exports. 3-usually red or black mangroves. 4-southeast Florida south coast of Puerto Rico, high latitudes on west coast of Florida. 5-sensitive to further stress.	
HAMMOCK MANGROVE WETLANDS 1-on land rises in south Florida. 2-low export of organic matter. 3-all mangrove species. 4-south Florida everglades. 5-sensitive to fire and drainage.	
RIVERINE MANGROVE WETLANDS 1-along flowing waters. 2-high export of organic matter, 3-all mangrove species, reds predominate. 4-south Florida, north coast of Puerto Rico. 5-sensitive to alterations of water flow.	
BASIN MANGROVE WETLANDS 1-in depressions or areas of slow water movement. 2-high seasonal export of organic matter. 3-black mangroves predominate. 4-inland locations in south Florida and Puerto Rico. 5-sensitive to alteration of sheet flow, sea water input, and prolonged high water.	

Figure 69. Mangrove community associations and forest types along the southwest coast of Florida (adapted from Wharton et al. 1977).

Riverine forests along river and creek drainages are usually separated from the waterline by a narrow berm, yet they are flushed by daily tides. They are often fronted by fringe mangrove forests. Riverine 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. This forest type is generally overwashed by daily tides, so there is little accumulation of litter. The forest consists of fairly small, uniform trees and an absence of understory foliage, which gives it a rather symmetrical appearance when viewed from within.

Basin forests are distributed inland along drainage depressions channeling runoff toward the coast. In coastal locations red mangroves are dominant, but further inland their dominance is shared with black and white mangroves.

The dwarf forest is more or less restricted to portions of the flat, low-energy, high-salinity sites. Due to low flushing rates, high salinity and poor substrate, trees of all ages are characteristically stunted, although they may be quite old (40 yr). Some dwarf forests may also be caused by nutrient deficiencies (Lugo and Snedaker 1974).

As discussed previously, the distribution of mangrove species appears to be largely controlled by the interrelations among soil salinity, tidal flushing, storm disturbance, tidal sorting of seedlings (propagules), and interspecific competition (Odum et al. 1982). The success of the red, black, and white mangroves within the intertidal zone is possible only because their specialized physiologies are such that these basically freshwater species can thrive in a salt-rich, oxygen-poor environment (Snedaker and Brown 1982).

The physiological means by which mangrove trees tolerate salt are salt exclusion prior to uptake, salt excretion by way of salt glands at the leaf surface, succulence, and discarding of salt-laden plant parts. Salt exclusion, which is a physiological mechanism of the red mangrove, is possible because of the high negative pressures in the xylem caused by transpiration at the leaf surface. This negative pressure drives a "reverse osmosis" ultrafiltration system at the root surface, which reduces salt concentrations in tissues to about one-seventieth (1/70) that of sea water (Scholander 1968). This concentration is still 10 times that found in most terrestrial plants (Scholander et al. 1962).

Salt secretion, which is a physiological characteristic of black and white mangroves, is triggered by an enzymatic process by which salt stands remove salt at the leaf surface. Salt secreters tend to maintain sap salt concentrations about 10 times as high as salt excluders (Odum et al. 1982).

All mangrove species rely on more than one physiological process for its survival in a saline habitat. Red mangrove trees, because they cannot exclude all salt, tend to discard salt through leaves and fruit. Black and white mangroves are capable of some salt exclusion at the root surface. White mangrove trees discard salt-laden leaves under hypersaline conditions (Teas 1979, Odum et al. 1982).

Salt secreters (black and white mangrove trees) apparently tolerate higher soil salinities than the salt excluders (red mangroves). Substrate also seems to affect salinity tolerance; a moderate clay content in the soil appears to increase the tolerance of black and white mangroves to hypersaline conditions, whereas pure sand tends to reduce their tolerance (Teas 1979, Odum et al. 1982).

The sediments within which mangroves grow are frequently shifting and anaerobic; consequently, the root systems of mangroves must be adaptive as well. Examples are structural adaptations of the root system to increase stability and functional adaptations that funnel oxygen from the atmosphere to the root systems (Odum et al. 1982).

Structural stability in the red mangrove is achieved by way of conspicuous prop roots. These roots distribute what would be the basal mass of a tree growing in a stable environment over a series of small above-ground roots spread over a wider area. This horizontal spread provides greater stability than centralized trunks. Black mangroves achieve their stability through a system of shallow underground "cable" roots that radiate from the central trunk. Root systems in all Florida mangroves are shallow and have no appreciable tap roots. Judging from the relative persistence of red mangroves where wave and current energies are high, the prop roots are an effective stabilizing device.

Oxygen-funneling mechanisms of mangrove root systems are associated with two adaptations in the root system structure. The prop roots of red mangroves contain many small pores called lenticels, which at low tide allow oxygen to diffuse from the atmosphere into the plant and down to the underground roots through passages known as aerenchyma (Scholander et al. 1955). The black mangrove usually has small roots called pneumatophores growing up from the cable roots and into the atmosphere. At low tide, air diffuses from the atmosphere into the pneumatophores and down the aerenchyma. White mangroves usually have neither prop roots nor pneumatophores but do have lenticels in the lower trunk (Odum et al. 1982). Under some situations peg roots or pneumatophores may be present (Jenik 1967).

In addition to the salinity preferences and physical root-structure adaptations, the reproductive characteristics and tidal sorting of the propagules of the three species also influence species dispersion and forest type distribution. The essential differences in mangrove reproduction are flowering and fruiting, obligate dispersal time for floating propagules, and site conditions required for seed germination and growth (Table 27). The short dispersal times and obligate stranding required for black and white mangrove propagules implies that they will probably not do well in and along constantly inundated tidal creeks or basins. Red mangrove propagules, on the other hand, remain viable for some time in seawater and can establish themselves in shallow waters.

Primary productivity, litterfall, and nutrient cycling of mangroves in the Caloosahatchee River/Big Cypress watershed have been investigated by Carter et al. (1973) and Snedaker and Lugo (1973), and

Table 27. Essential differences in reproduction in Florida mangroves.

Species	Flowering	Fruiting	Days of obligate Dispersal time	Days required for root establishment	Days of viable longevity
White Mangrove	May to Aug.[1]	July to Sept.[1]	8 (5 day stranding required)	5[3]	35[3]
Black Mangrove	May to July[1]	Aug. to Nov.[1]	14 (5 day stranding required)	7[3]	110[3]
Red Mangrove	All year[2]	July to Oct.[2]	40 (establishes in shallow waters)	15[3]	365[4]

[1] Loope 1980 [2] Savage 1972 [3] Rabinowitz 1978 [4] Davis 1940

summarized by Wharton et al. (1977) and Odum et al. (1982). The last two authors list at least 19 factors that they believe influence mangrove productivity. They are as follows:

- species composition of the stand;
- age of the stand;
- presence or absence of the competing species;
- degree of herbivory;
- presence or absence of disease and parasites;
- depth of the substrate;
- substrate type;
- nutrient content of the substrate;
- nutrient content of the overlying water;
- salinity of the soil and overlying water;
- transport efficiency of oxygen to the root system;
- amount of tidal flushing;
- relative wave energy;
- presence or absence of nesting birds;
- periodicity of severe stress (hurricanes, fire);
- time since the last severe stress;
- characteristics of the ground water;
- inputs of toxic compounds or nutrients from human activities; and
- human influences such as diking, ditching, and alternating patterns of runoff.

A number of trends have been noted on mangrove forest productivity in the watershed. Although transpiration is generally low because of high negative pressure maintained in the xylem (Odum et al. 1982), wood production rates are relatively high when compared to estimates of other types of forests (Teas 1979). In terms of net primary production under optimum conditions, red mangroves rank highest, black mangroves intermediate, and white mangroves least (Lugo et al. 1975). For pioneering red mangrove stands, there is an inverse relationship between gross primary productivity (GPP) and salinity. Black and white mangroves exhibit maximum GPP at moderate salinities. The cumulative GPP for the mangrove forest exposed to increasing salinity follows a bell-shaped curve as illustrated in Figure 70 (Carter et al. 1973, Hicks and Burns 1975, Odum et al. 1982).

Mangrove forests are net accumulators of nutrients, trace elements, and heavy metals. These materials are removed from the water by the prop roots and associated algae, by sedimentation, and by filtration by the biota (e.g., oysters and barnacles) that are attached to prop roots.

Copper, chromium, iron, lead, manganese, and zinc are consistently more concentrated in the sediments of mangrove forests than in the

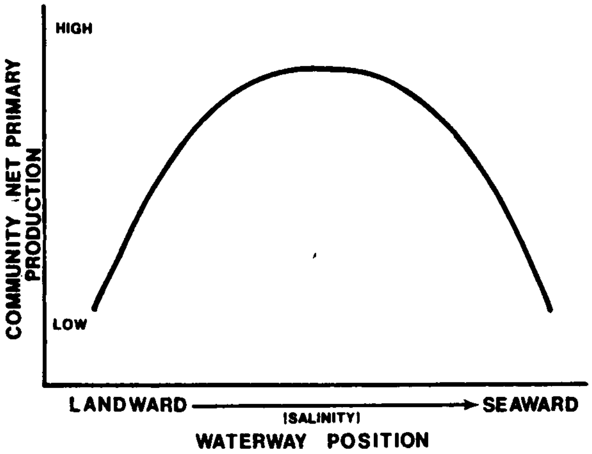


Figure 70. Mangrove community productivity as related to salinity (adapted from Odum et al. 1982).

surface waters. 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 urban-related heavy metals have been found in the mangrove environment (Horvath 1973, Mathis 1973). More importantly, mangrove tissues consistently exhibit heavy-metal concentrations much greater than sediments. It is currently unknown whether uptake into plant tissues is from sediments, the water column, or both.

Snedaker and Brown (1982) conclude that much is known about the structural aspects of mangrove biogeochemistry (i.e., chemical concentrations in various plant and animal tissues, soils, and water), but very little is known about transfer functions and uptake rates between major components (biotic and abiotic) of the mangrove community.

One of the most important and conspicuous aspects of mangrove forests is their energy contribution to downstream estuaries (Heald 1971, Odum 1971). Considering the degree of dependence of the estuarine food chain on detritus, it is important to know something about the production, export, and degradation of litter. Using the six mangrove forest type categories of Lugo and Snedaker (1974), Snedaker and Brown (1982) prepared an index of mangrove ecosystem dynamics based on leaf-litter production rates (Table 28). This index has proven to be the most reliable indicator of overall mangrove productivity.

Of all the potential sources of detritus in the watershed estuaries, mangrove debris is by far the most important. For example, about 85% of the detritus produced in wetlands surrounding the North River estuary originates from the red mangrove. Juncus and Spartina contribute little to the total available debris.

Mangrove debris either decomposes on site or is washed into the open waters by tides or freshwater inflow. In either case the debris is subjected to various forms of decomposition (Heald 1971). In general, leaves decompose faster in brackish or sea water than in freshwater or on dry land, due to more intensive grazing by small marine crustaceans, particularly amphipods.

Table 28. Leaf litter production rates of mangrove forests (adapted from Snedaker and Brown 1982).

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

The pattern of detrital decomposition also coincides with the quality of the mangrove forest structure. The larger forests usually thrive where soil salinities are well moderated by adequate freshwater and/or tidal flushing. Marginal mangrove environments are defined by areas exposed to either uniformly high or low annual salinities, excessive siltation, arid climates, and carbonate substrate, or where the tidal amplitude is small (Snedaker and Brown 1982).

Initial decomposition of freshly fallen mangrove leaves is delayed by the heavy cuticular wax. As the wax disintegrates, 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, so they decompose more slowly.

Microfloral succession on red mangrove leaves during decomposition increases the availability and nutritional value of detritus to macroconsumers (Heald 1971). The principle physical and biochemical features of this successional process are summarized in Figure 71. Mathis (1973) reports a 3- to 200-fold enrichment of iron, manganese, copper, and cadmium in various stages of decomposition of red mangrove leaves.

6.3.3 Oscillating Salinity Open Waters

The open waters of the watershed estuaries contain pelagic and benthic communities. The pelagic community is a mid-water planktonic environment, and the benthic community is either a marine grass-covered bottom or an open bottom composed of varying mixtures of sand, mud, oystershell, and bedrock (limestone outcrops). Some bedrock bottoms are known as live bottoms because of the presence of soft corals, sponges, and benthic algae (Tabb et al. 1962, Derrenbacker and Lewis 1982).

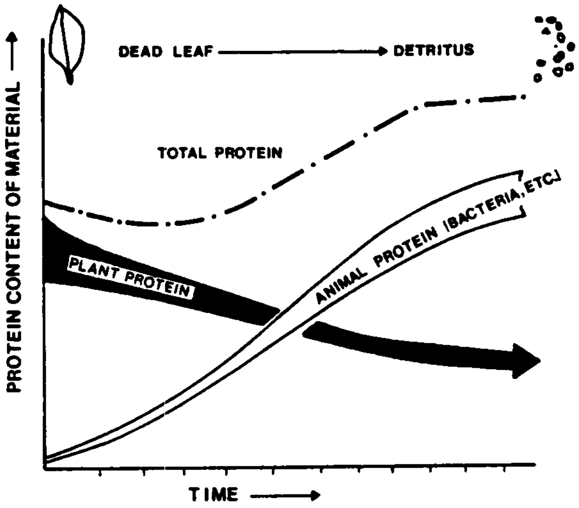


Figure 71. Protein enrichment of mangrove detritus during degradation (adapted from Heald 1971).

Because of frequent changes in physical and chemical conditions in these estuaries, it is difficult to think of benthic or pelagic communities in the same sense as terrestrial communities. As Carter et al. (1973) point out, plant communities in these coastal areas fluctuate annually and seasonally. They are strongly influenced by salinity, bottom type, water depths, and currents. It is perhaps best to view these communities, especially those furthest landward, as being in a state of flux.

Natural background factors such as tidal flushing, salinity, depth, and type of substrate influence community structure and function. Alterations in physical structure (e.g., canalization) or chemical background (e.g., agricultural development) also influence the composition and function of these coastal communities.

Benthic Communities. Seagrasses, particularly in the northern half of the Caloosahatchee River/Big Cypress watershed, thrive only in the least disturbed bays and estuaries (Zieman 1982). Relatively high turbidity and color and periodically reduced salinities may be natural factors which limit the distribution of seagrasses. Human activities such as shoreline development and canalization may also limit their distribution in the watershed. In contrast, in areas north of Tampa Bay and south of the Everglades, about 80% of the coastal bottoms are covered by benthic marine grasses.

Information on species composition of sea-grass beds in the Caloosahatchee River/Big Cypress watershed is available from Phillips and Springer (1960) for the Caloosahatchee River estuary and Estero Bay, Tabb et al. (1974) for Estero Bay, Yokel (1975) for Rookery Bay, and Carter et al. (1973) for Fahka Union and Fahkahatchee Bays.

In all, 7 species of rooted vascular plants and 46 taxa of algae, many of which are epiphytic on the seagrasses, are reported from the area's grassbeds. In low-salinity lagoons and lakes (<5 ppt), basically freshwater vascular plants such as pondweed (*Potamogeton* sp.), tapegrass (*Vallisneria americana*), marine naiad (*Najas marina*), and algae such as *Chara* sp. are most abundant. In mid-salinity (10 to 20 ppt) lakes and lagoons, widgeongrass (*Ruppia maritima*) is most prominent. Grassbeds in open-water estuaries are characteristically composed of a mixture of marine grasses, such as turtle grass (*Thalassia testudinum*), Cuban shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiformis*) and *Halophila* sp. Algal taxa collected from the area by Phillips and Springer (1960) are listed in Table 29.

Despite their limited areal coverage, marine seagrass meadows

Table 29. Algal species collected in the watershed (adapted from Phillips and Springer 1960).

FAMILY AND SPECIES	ATTACHED	REMARKS
MYXOPHYCEA		
Lyngbya semiplena	Yes	On *Diplanthera*
Mastigocoleus testarum	Yes	In shells
CHLOROPHYCEAE		
Chaetomorpha brachygona	No	Entangled in *Diplanthera*
Chaetomorpha linum	No	
Cladophoropsis membranacea	Yes	On shells
Enteromorpha flexuosa	Yes	
Enteromorpha sp.	Yes	On *Syringodium*; young sporelangs
Rhizoclonium kerneri	Yes	On *Lophesiphenia scopulorum*
PHAEOPHYCEAE		
Dictyota cervicornis	No	
Dictyota dichotoma	No	
Ectocarpus subcorymbosus	Yes	On *Syringodium*, with gametangia
Ectocarpus sp.	Yes	On *Thalassia*, *Syringodium*, *Diplanthera*, and *Gracilaria verrucosa*; sterile, may float
Giffordia duchassaigniana	Yes	On a log; with gametangia
Giffordia mitchellae	Yes	On *Thalassia*; with gametangia
Myrionema strangulans	Yes	On *Thalassia*
Rosenvingea intricata	Yes	On *Thalassia*
Sargassum filipendula	No	
RHODOPHYCEAE		
Acanthophora muscoides	No	
Acanthophora spicifera	No	
Acrochaetium sargassi	Yes	On *Thalassia*
Acrochaetium sp.	Yes	On *Syringodium* and *Acanthophora muscoides*
Agardhiella tenera	Yes	On a shell; cystocarpic
Callithamnion halliae	Yes	
Ceramium byssoideum	Yes	On shells
Ceramium tenuissimum	Yes	On *Diplanthera*
Champia parvula	Yes	On *Syringodium*
Chondria tenuissima		
Erythrocladia subintegra	Yes	On *Callithamnion halliac*
Erythrotrichia carnea	Yes	On *Syringodium*
Eucheuma acanthocladum		
Fosliella lejoisii	Yes	On *Thalassia*
Geniotrichum alsidii	Yes	On *Lophosiphonia scopulorum* and *Acanthophora muscoides*
Gracilaria blodgettii		
Gracilaria foliifera	Yes	On shells
Gracilaria verrucosa		Some plants cystocarpic
Hypnea cervicornis		
Hypnea cornuta		
Hypnea musciformis		
Lomentaria baileyana		Tetrasporic
Lophosiphonia scopulorum	Yes	On shells; tetrasporic
Polysiphonia binneyi	Yes	On *Thalassia*; antheridial, cystocarpic
Polysiphonia howei	Yes	
Polysiphonia macrocarpa	Yes	On shell
Polysiphonia ramentacea	Yes	On *Thalassia*; tetrasporic
Spyridia filamentosa		

are one of the most productive communities in estuaries and are a vital habitat for fish and wildlife (Zieman 1982). For example, in Estero Bay seagrasses accounted for about 5,000 kg of carbon, which is 26% of its total annual autochthonous carbon (Charlotte Harbor Resource Planning and Management Task Force 1980). In the Caloosahatchee River estuary, where seagrasses are relatively scarce, they only account for about 6% of the total annual carbon production. In terms of total community metabolism, depth-specific measurements suggest that the benthic macroflora and microflora may account for as much as 65% to 85% of the metabolism in shallow waters such as Estero Bay (SWFRPC 1977, Estevez 1981). In addition, the export of severed or uprooted seagrass blades (detritus) has been noted by Zieman (1982) as a potentially important source of organic matter for offshore waters. More locally, seagrass detritus is essential to beach/dune and sea wrack communities. Washed-up seagrass detritus comprises a major portion of the shoreline substrate upon which many insects, crustaceans, shorebirds, and other wildlife feed and reproduce.

Seasonal variations in the standing crop of marine grasses, red macroalgae, and green filamentous algae differed according to the bottom substrate in Fahka Union and Fahkahatchee Bays (Carter et al. 1973). The sand-mud substrate of Fahkahatchee Bay supported the richest concentrations of seagrass and red macroalgal biomass in the two bays. From July to September the biomass of grasses and algae sharply increased on this substrate in Fahkahatchee Bay, but in Fahka Union Bay the standing crop of seagrasses on the same bottom type declined. Standing crops of green filamentous algae on sand-mud declined in Fahkahatchee Bay and were nonexistent in Fahka Union.

In contrast, the mud-sand substrates of Fahka Union Bay supported a phenomenal growth of red macroalgae, some seagrasses, and green filamentous algae, but only minor biomass production was apparent in Fahkahatchee Bay on the same substrate. Shell bottoms in the two bays were the least productive of all three substrates (sand-mud, mud-sand, shell). In general, standing crops of green filamentous algae peaked in January and declined significantly in the summer months whereas the reverse was true for red macroalgae and seagrasses. Benthic macroalgae and filamentous green algae appear to dominate the bottom vegetation of Fahka Union Bay, whereas seagrasses are dominant in Fahkahatchee Bay.

Reasons for the differences in plant species composition, dominance, productivity, and seasonal variation between the two bays are difficult to unravel. Carter et al. (1973) suggest a variety of causes which probably act in combination to effect and maintain the differences. These causal factors are especially interesting, since they shed light on the many mechanisms which regulate species composition and growth. The physical and chemical differences in the two bays include nutrient loading (quantity and pattern), salinity regime and turnover time, sediment composition, depth and bottom topography, and sediment chemistry. Differences in these factors must be examined in terms of the physiology and adaptation of the plants that dominate the two bays.

Seasonal and annual nutrient loading to Fahka Union Bay is greater than to Fahkahatchee Bay.

Upstream channelization shunts more nutrients into Fahka Union Bay on an area basis than to undisturbed Fahkahatchee Bay. Channelization increases both total and peak loading as well as providing a regular input during the dry season when natural drainage would be extremely low. The dry season corresponds to the time of year when seagrasses die back and algae reach their peak concentrations in both bays. Carter et al. (1973) hypothesize that this dieback of seagrasses and continuous nutrient load may give the algae an initial growth advantage in Fahka Union Bay. In addition, algae (which extract their nutrients from the water rather than from the sediment, as seagrasses do) may be better adapted to exploiting bursts of nutrient loading than rooted vegetation. Such an advantage may be maintained by higher turbidities, which inhibit light penetration and the growth of seagrasses.

Other factors that control benthic plant composition are sediment chemistry and sediment composition. Increased nutrient inflow to Fahka Union Bay is also accompanied by increased loads of organic matter and heavy metals from oxidized and leached upland soils. Once in the estuary, the materials tend to be absorbed by the particulate matter, settle out of the water column, and concentrate in bottom sediments (Horvath 1973, Harriss et al. 1972). Carter et al. (1973) document higher sediment concentrations of nickel, zinc, lead, cadmium, and copper in Fahka Union Bay than in Fahkahatchee Bay. Perhaps because of differences in salinity gradient and flushing rate of the water column, heavy metal concentrations in the water columns of the two bays display opposite trends, i.e., concentrations are higher in Fahkahatchee Bay than Fahka Union Bay. The difference may favor algae in Fahka Union Bay because algae obtain their nutrition from the water column, and seagrasses, which draw most of their nutrition from sediments, are exposed to slightly higher concentrations of toxic metals (Carter et al. 1973). In addition, the substrate of Fahka Union contains relatively more of the mud-sand type of bottom than Fahkahatchee, possibly due to increased organic loading and subsequent sedimentation. This may lead to poorer growth conditions for seagrasses by creating a more shifting substrate than would exist under less organic conditions.

Seagrasses are known to support a wide variety of aquatic organisms. They provide food for a number of grazers such as pinfish (Lagodon rhomboides), sea urchin (Diadema antillarum), and sea turtles (Chelonia mydas); and epiphytic algae. The algae may constitute an even greater source of food to marine and estuarine grazers than seagrass itself (Zieman 1982).

Although numerous references have been made to the open bottom of estuaries as a substrate for primary production by benthic microalgae (Hicks 1979, Estevez et al. 1981, Odum et al. 1982), little is known about species composition and seasonal variation. Hicks (1979) and Carpenter and van de Kreeke (1975) report benthic metabolism data that clearly show considerable production (and more respiration) in the open bottoms of estuaries. The Marco Island Development canals have exhibited benthic oxygen production rates from 0 to 0.10 $g/m^2/hr$ (Carpenter and van de Kreeke 1975). In a variety of locations within Naples Bay (canal berms, troughs, open bay) Hicks (1979) reported little difference in benthic production between stations of similar depth. As depth increased, the light penetration and oxygen production decreased sharply. In contrast, benthic respiration rates varied little as a function of either location or depth. Benthic metabolism data from Naples Bay are summarized in Table 30.

Plankton. Two distinct plant transitions between Chokoloskee Bay on the south and the Caloosahatchee River estuary on the north, are of considerable importance to estuaries of the watershed. The transitions are the narrowing areal extent of mangrove forest vegetation (Figure 60) and the patchy abundance of seagrass beds (Zieman 1982). The first of these transitions is important because it suggests that mangrove detritus, which plays such a fundamental role in estuarine energy flow in the south (Odum and Heald 1972), is found in smaller quantities in estuaries to the north. A decreased presence of the mangrove and seagrass communities indicates a shift toward plankton community dominance.

Numerous studies on the plankton of estuaries, particularly on metabolic rates, were reported by Balough et al. (1977), Carpenter and van de Kreeke (1975), ESE (1978a, 1978b), Hicks (1979). Information on species composition is scarce except in metabolic studies (ESE 1978a, 1978b). The four estuaries sampled for plankton composition and metabolism were Estero Bay, Wiggins Bay, Naples Bay, and Chokoloskee Bay (ESE 1978a, 1978b). Chlorophyll *a* and metabolism data from three of the estuaries sampled in 1977 are summarized in Tables 31 and 32. In addition, an independent study has been conducted on community metabolism in Naples Bay (Hicks 1979).

Table 31. Chlorophyll *a* in Big Cypress estuaries at high and low tides during selected months in 1977 (adapted from ESE 1978a).

	Chlorophyll *a* (mg/m^3)					
	April		June		Sept	
Estuary	High	Low	High	Low	High	Low
Wiggins Pass	1.72	3.19	----	6.51	4.84	5.76
Naples Bay	4.91	6.26	----	16.58	4.42	6.02
Chokoloskee	3.32	3.04	----	11.58	9.11	13.68

Table 30. Benthic metabolism in Naples Bay (adapted from Hicks 1979).

		Metabolism (gm O_2/m^2/day)[b]		
Station	Parameter[a]	Spring	Summer	Fall
Canal Berms	GPP	0.58 ± 0.49	0.92 ± 0.67	0.87 ± 0.47
	R	0.70 ± 0.65	1.37 ± 0.87	1.08 ± 0.36
	P/R	1.06 ± 0.84	0.76 ± 0.34	0.76 ± 0.31
Canal Troughs	GPP	0.38 ± 0.52	0.28 ± 0.24	0.42 ± 0.30
	R	0.86 ± 0.47	0.91 ± 0.64	1.76 ± 1.05
	P/R	0.77 ± 1.02	0.35 ± 0.24	0.27 ± 0.18

[a] GPP = gross primary production P/R = GPP to R ratio

[b] all data represent mean values R = respiration

Table 32. Plankton metabolism estimates for estuaries of the Big Cypress watershed (adapted from ESE 1978a).

		Metabolism (gm $O_2/m^2/day$)[b]		
Estuary	Parameter[a]	April	June	September
	GPP	2.78	3.73	1.71
Wiggins Pass	R	0.14	2.03	1.11
	P/R	19.7	1.91	1.53
	GPP	8.76	4.51	0.35
Naples Bay	R	3.58	1.11	0.30
	P/R	4.91	3.80	2.91
	GPP	2.30	1.28	1.30
Chokoloskee Bay	R	1.06	1.39	0.57
	P/R	2.16	1.44	1.91

[a] GPP = gross primary production, R = respiration, P/R = ratio of GPP to R
[b] all data represent mean values

In Wiggins Bay downstream from the Cocohatchee River Canal, diatoms are the dominant life form (cells/ml) during both wet and dry seasons. Diatoms contributed as much as 76.3% of the cell numbers in the spring but only 57% in the fall. Skeletonema costatum was particularly abundant in the April samples, but in September the species composition was more balanced, consisting largely of Thallasiosira, Thallasionema, Cyclotella, and Cylindrotheca in addition to Skeletonema. Dinoflagellates exhibit a similar trend. Peridinium were rare in April, and common in September as were the algae Ceratium and Prorocentrum. Diatoms were most abundant in the spring, followed by cryptomonads and microflagellates. In the fall, microflagellates were found only in one concentrated patch.

Concentrations of chlorophyll a are higher at low tide than at high tide, largely because of dilution by incoming seawater. Although there is little difference in cell numbers between the spring and fall samples, seasonal differences in chlorophyll a concentrations suggest that there may be some difference in the physiological state of the plankton. Metabolism data show higher gross primary productivity and a high P/R ratio during April than at other times of the year, suggesting that the photosynthetic efficiency in the spring plankton is greater than in the fall. This also coincides with peak annual solar radiation (see Chapter 3).

In Chokoloskee Bay, seasonal trends in species composition of plankton are similar to those in Wiggins Bay. Diatoms comprise about 70% of the cell numbers in April and 68% in September. Skeletonema costatum and Chaetocerous wighami are the primary species in April whereas species of Thallasiosira and Cylindrotheca as well as Skeletonema are abundant in the fall. Dinoflagellates were a very minor component of the phytoplankton in the spring, but were more numerous in the fall. In contrast to Wiggins Bay, metabolic and biomass indicators in Chokoloskee Bay showed September and

April P/R ratios to be about equal whereas chlorophyll *a* concentrations increased 3- to 4-fold. Apparently in this estuary the photosynthetic efficiency declines in September.

In Naples Bay, trends in species composition, biomass, and metabolic rates are considerably different from those from Wiggins Bay and Chokoloskee Bay. Here biomass and cell numbers actually declined between April and September. At the same time the biomass and cell numbers of phytoplankton in Naples Bay were much higher than the other two bays, even though chlorophyll *a* concentrations were lower than in Chokoloskee Bay in September. Metabolic rates were high in April, when flushing is minimal. In addition to the background trends in diatom and dinoflagellate abundance mentioned for the other bays, Naples Bay supported an extensive microflagellate community that ESE (1978a) believes were the most abundant phytoplankton in terms of cell numbers. Also reported from Naples Bay were blue green algae such as *Oscillatoria* sp. as well as one bloom of dinoflagellates (*Peridinium*) at one station in September.

Differences between the plankton composition and metabolism of Naples Bay and Wiggins and Chokoloskee Bays are probably caused by differences in urban/industrial development. For example, upstream flow control tends to exaggerate seasonal salinity fluctuation, which brings about high-salinity low-flushing conditions in the dry season and pulsing freshwater conditions in the wet season. Meanwhile, nutrient- and organic-laden sewage and stormwater inflow stimulate algal and microbial metabolism, particularly during the long dry season. Within the bay, shoreline development removes the moderating influence of mangroves on nutrient loading, and canals create abnormal bottom topography that restricts flushing in remote finger canals. Microflagellates are most benefited by a combination of rapidly changing flows and high nutrients.

In sharp contrast to the data of ESE (1978a) on plankton in the open waters of Naples Bay, the waters of Gordon River and canals peripheral to the bay exhibit a "respiration-dominated" metabolism. The P/R ratios of plankton metabolism range between 0.3 and 0.8 in the spring; 0.1 to 0.5 in the summer, when temperatures are highest; and 0.2 and 0.9 in the fall. The combined plankton and benthic metabolism of Naples Bay canals are summarized in Figure 72. Indications are that total metabolism peaks from June through September when water flow and temperature are generally their highest. Nonetheless, the restricted flushing, depth alterations, and nutrient loading associated with the canal environment creates a respiration excess at all times.

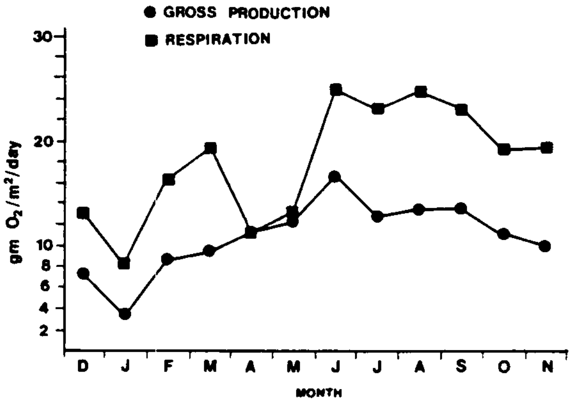


Figure 72. Monthly trends in gross production and respiration in Naples Bay canals (adapted from Hicks 1979).

6.3.4 Beach, Dune, Sea Wrack, and Coastal Strand

The increased offshore slopes from Marco Island north are conducive to the building of sand beaches and barrier islands. The beaches and barrier islands are extremely complex and dynamic. They occupy a very sharp transition zone that ranges from open marine conditions on the seaward side to well-drained sandy terrestrial conditions shoreward, frequently within distances of only 1 to 2 meters (3 to 6 ft). The islands are regularly exposed to physical and chemical extremes such as high winds, salt spray, storm surges, rains, ceaselessly pounding waves, and intense heat and drought.

A profile of a typical beach community is given in Figure 73. The profile is a composite from several authors (Ingle 1962, Collard and D'Asaro 1973, Riedl and McMahan 1974, Carlton 1977). The terrestrial community is dominated by familiar pioneer beach species such as sea oats (Uniola paniculata), and seasonal invasions of railroad vine (Ipomoea pes-capre), beach bean (Canvalia maritima), and sandspur (Cenchrus incertus). Further upland at Wiggins Pass, Carlton (1977) reports two strand communities, one dominated by cabbage palm (Sabal palmetto) and the other by Australian pine (Casuarina equisetifolia). Common weedy species associated with Casuarina include spurge (Chaemaesyce hirta), tick trefoil (Desmodium canuum), smutgrass (Sporobolus poiretti), and beggar tick (Bidens pilosa). Understory species associated with the cabbage palms include golden polypody fern (Phlebodium aureum), poison ivy (Toxicodendrum radicans spp. radicans), and shoestring fern (Vittaria lineata). Other common herbs and shrubs are the dayflower (Commelina diffusa),

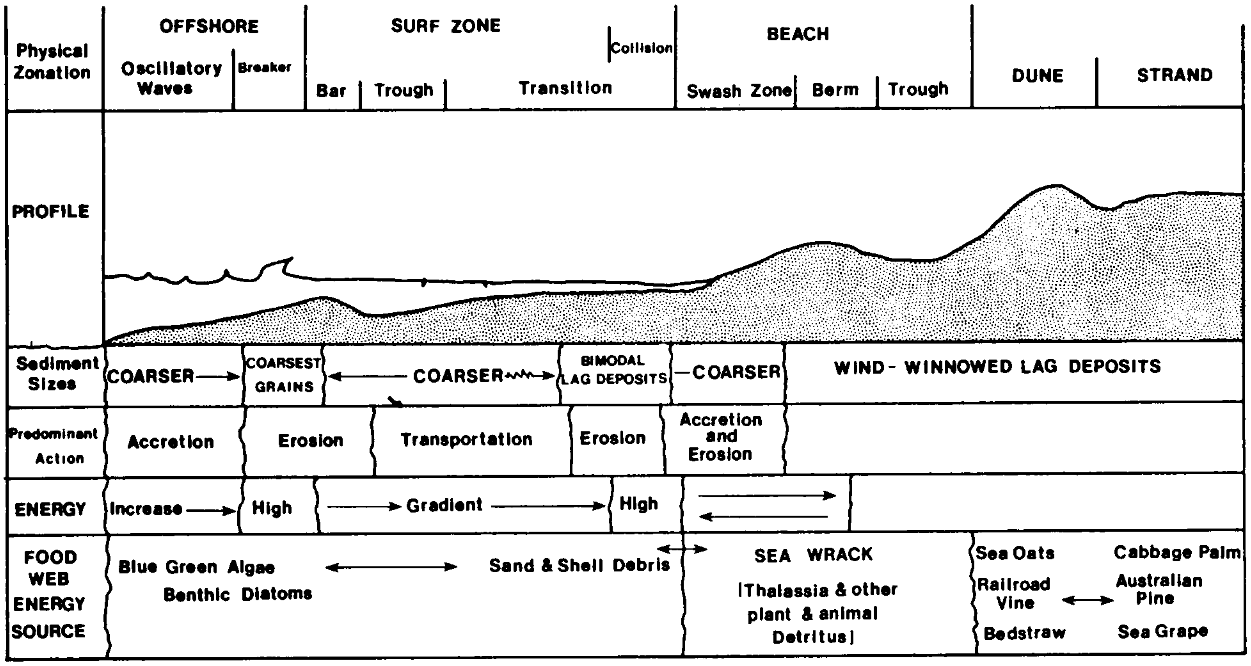


Figure 73. A high-energy beach community, showing major zones relating to sand motion (adapted from Riedl and McMahan 1974).

bedstraw (*Galium hispidulum*), and spiderwort (*Tradescantia ohiensis*). Nearer to the pass, species such as century plant (*Agave americana*), coin vine (*Dalbergia ecastophyllum*), spanish bayonet (*Yucca aloifolia*), and Brazilian pepper (*Schinus terebinthifolius*) are reported. Other common dune/strand plants are seven-year apple (*Casasia clusiifolia*), ernodia (*Ernodia littoralis*), shrub verbana (*Lantana camara*), and bay cedar (*Suriana maritima*).

Where sand is plentiful and wind and wave energy high, the transition from beach to strand may include one or more dunes and intermediate troughs. Such environments frequently support a characteristic vegetation composed of such species as saw palmetto (*Serenoa repens*) and Chapman's and twin live-oak (*Quercus chapmanii*, *Q. geminata*) according to Cooley (1955). This area is referred to as the "scrub" zone by Kurz (1942), because of its similarity to scrub oak growing on relict sand dunes in interior central Florida.

The sea wrack zone is probably the most familiar habitat of the beach strand community profile. Virtually no emergent vegetation grows there for very long because of the frequent turnover of the zone by wind- and storm-related tides and waves. Nonetheless, this zone supports a healthy fauna based on the regular input of seaweed and marine animal debris deposited by waves (Rabkin and Rabkin 1978).

Ecological data on the inhabitants and dynamics of the submerged high energy beach environment in the Caloosahatchee River/Big Cypress watershed have not been reported. General information describing similar communities elsewhere in the Gulf can be found in Riedl and McMahan (1974) and Collard and D'Asaro (1973). Based on these summaries, the fauna of the submerged high-energy beach probably depends only slightly on autotrophic production from benthic blue-green algae and diatoms. The characteristic grazers of the beach probably glean bacteria from sand particles and interstitial spaces. Although phytoplankton may be a component of the organic substrate upon which this detrital food chain is based, the high energy and turbid waters of the environment suggest that allocthonous energy sources are probably more important in the total energy budget.

6.4 DISTURBED COMMUNITIES

As man develops the land to serve his needs, the species composition and abundance of plant communities change. The changes may encompass wholesale replacement of one community (such as a pinelands forest) with one more suited to human economy (such as a citrus grove), or more subtle change such as the inadvertent introduction of exotic species via drainage canals.

Human disturbances bring about fundamental changes in habitat types and their interrelationships. For example, if the soil profile is changed or soil cover removed, the soil arthropod community is also changed. The new soil structure may be less likely to protect burrowing amphibians from dessication during drought, and important water and nutrient holding capacity may be lost, causing physiological stress for the remaining vegetation.

For discussion purposes, disturbed communities are divided into exotic invaders (exotics introduced by man, e.g., cajeput tree), agricultural communities, urban/industrial communities, and canal communities.

Disturbed communities such as agricultural land, urban-industrial developments, and channelized streams create new physical/chemical background conditions that modify ecological succession and fish and wildlife production. In principle at least, human activities function as analogs of natural modifiers of community succession. Disturbed-community modifiers differ from their natural counterparts in the following ways:

(1) Historical persistence (most human influence has occurred only in the past 100 years).

(2) Frequency (unlike hurricanes, floods, or fire which are acute but only periodic events, human influence is often continuous and chronic).

(3) Spatial coverage (the spread of development activities usually follows a radiating pattern from preexisting disturbances with little regard for existing vegetation or soils. In contrast, natural communities are more strongly modified by existing conditions).

(4) Human influence (may introduce new exotic species and accelerate the spread of endemic as well as exotic species which creates new species associations of unknown fish and wildlife value).

(5) Environmental changes induced by man (almost always involve long-term operation and maintenance costs as well as initial startup costs. The choice to incur these costs is a social process and must be balanced by human society against the benefits derived from the altered communities).

(6) Local ecological changes initiated by man (frequently motivated by events, needs, and processes far removed from the disturbance, e.g., fertilizer needs in the Soviet Union could cause disturbances in Polk County pine flatwoods (phosphate mining), and oil extracted from the Big Cypress watershed may be refined and consumed outside the State).

6.4.1 Exotic Plant Communities

Although most agricultural crops and ornamental plants are exotic species, this section reports only exotics that survive and spread in the wild. The cultivation of crops is a disturbance discussed in section 6.4.2, and ornamentals are included in section 6.4.3 as a component of urban-industrial development.

Exotics that survive and spread in the wild are common in south Florida and comprise about 16 percent of the species (Long 1974). Duever et al. (1979) list over 250 exotic plant species for the Big Cypress National Preserve. These authors believe that south Florida is particularly vulnerable to invasion by exotics because the area is geologically young, somewhat island-like, and squarely located at the interface of temperate and tropical climates, and it is subject to intensive and rapid alterations by man.

The geological youth of the area implies that the flora has had relatively little time to reach an advanced condition of homeostasis; so that the process of evolutionary adaptation is still in a relatively early stage. In addition to south Florida's young geologic age, the peninsula is geographically isolated from other land masses with similar climate. These conditions support a flora with a small number of species compared to other areas of subtropical America. Many of the species that comprise the climax hardwood hammocks of south Florida are typically second-growth colonizers elsewhere in tropical America, a fact that Duever et al. (1979) claim attests to the immaturity of the flora.

The reduced number of preadapted colonizers in south Florida causes both temperate and tropical species to occupy habitats to which they are not particularly well adapted. For example, in south Florida deciduous temperate plants must form new foilage during the spring drought, and tropical species are sometimes subject to killing or damaging frosts; consequently, Duever et al. (1979) hypothesize that native south Florida species do not utilize the environment to its fullest, which permits certain invaders to become established.

The establishment of new plants is assisted by urban/industrial development in south Florida. Drainage, agriculture, and logging, as examples, leave bare ground open to new colonizers and create new habitats with altered hydroperiods, fire frequencies, and soil types. The importation of ornamentals from all over the world provides a vast new seed pool for colonization. Some of the tropical fruits and vegetables introduced into south Florida for agricultural purposes are growing in the wild.

Of the total number of exotic plants in south Florida, only a few are a threat to native communities. In the Big Cypress National Preserve Duever et al. (1979) identified five species that warrant attention: (1) cajeput (Melaleuca quinquinervia), (2) Australian pine (Casuarina spp.), (3) Brazilian pepper (Schinus terebinthifolius), (4) water hyacinth (Eichornia crassippes), and (5) hydrilla (Hydrilla verticilata). These five plants are also of concern in the rest of south and central Florida (SFWMD 1980).

Cajeput. Melaleuca quinquinervia, cajeput, or punk tree, is one of several species of Melaleuca grown and used in south Florida as an ornamental. Of these only M. quinquinervia has become naturalized and spread into the wild. This species is native to coastal Australia where the monsoonal climate closely mimics the alternating wet and dry seasons of south Florida. Its preferred substrate in Australia is acid, sandy soils that are frequently high in sulfides. The trees grow in thick monocultures behind brackish coastal swamps and along riverbanks up to 16 km (10 mi) inland. In terms of its natural distribution in Australia, cajeput is reminiscent of buttonwood (Conocarpus erectus) in the American tropics.

In the Caloosahatchee River/Big Cypress watershed and south Florida in general, cajeput is largely restricted to disturbed sites such as roadsides, drained areas (farms, urban developments), or sites with altered soils, e.g., from mining and farming (Capehart et al. 1977). Although there is much public concern over the apparent spread of cajeput, Duever et al. (1979) contend that this is somewhat unjustified; most people see only the roadsides and disturbed areas where this plant is most abundant, but in one area of Lee County where cajeput appears predominant, it only comprises about 0.4% of the land cover. Possible overconcern also may have been caused by the rapid spread of this tree in only a short period of time. It may well be that the spread of the species from disturbed roadsides, for example, is slowed considerably by natural vegetation. Yet in Lee County where the species was first introduced in about 1910, the trees are slowly inching into the natural habitats. The cajeput is filling a vacant niche that is being widened and made even more pervasive by the building of roads, the dredging of canals, increased farming, and urban development.

The cajeput flowers in late fall and early winter when relatively few animal vectors are available for seed dispersal. The seeds (anywhere from 17,000 to 34,000 per gram) are streamlined, unwinged, and may be stored in scrotinous capsules on the tree for a number of years without any loss of viability (Meskimen 1962, Myers 1975). Trees 10 m (33 ft) tall may conceivably store over 20 million seeds, all of which may be released almost simultaneously by the right stimuli. Woodall (1978, 1982) and Duever et al. (1979) conclude that the Melaleuca seed generally falls in an area immediately adjacent to the source tree. Wind dispersion plays a minor role in seed distribution although strong winds have been observed to carry seed for more than a kilometer (Schroeder and Browder 1979).

Seed release is either one of low intensity and long duration, or one of high intensity and short duration (Woodall 1982). The first insures a continuing supply of fresh seeds on the ground "which allows the species to exploit all reproduction opportunities - no matter how short in duration." The second form of release is keyed to catastrophic events, e.g., fires, which cause the simultaneous release of several years' accumulated seed production. This massive seed release helps to maintain the cajeput community during a period of possible seed tree mortality or suppressed reproduction.

Stands of cajeput thin themselves in their competition for light. Nearly all the leaves are at the top, and the understory is little more than stems or trunks. When a fire strikes, the flame is quickly transferred to the crown, which spares the spongy bark and triggers the release of seed capsules. The seeds find a nearly perfect germination site in adjacent newly burned areas.

Frost and logging create nearly as desirable a condition for the spread of cajeput as fire does. Massive amounts of seed may be triggered by frost or logging, but their chance for survival is much less.

The most critical factor in Melaleuca germination is desiccation of the seeds (Myers 1975). With adequate moisture, seeds will germinate within three days, but, anaerobic conditions inhibit it (Duever et al. 1979). Open, water-logged soils, such as might occur during the wet season after a burn, are ideal for this species to get started. Seeds are known to germinate under water a few centimeters deep if sufficient dissolved oxygen is available.

Melaleuca also possesses specialized mechanisms for thriving in areas periodically inundated and anaerobic. The most notable of these adaptations is its tendency to produce adventitious roots from virtually any plant surface in contact with the water. A fibrous sheath of these water roots may surround the base of the trunk up to the high-water mark. Large tufts or clumps of these roots may form from underground roots some distance from the main tree, similar to the knees of cypress trees (Duever et al. 1979). Also, seeds that fall into seasonal wetlands may survive inundation for as long as 5 months (Myers 1975, 1976).

One of the more convincing arguments in favor of the vacant niche or habitat theory was reported by Duever et al. (1978). They believe that there is a "vacant" hydroperiod range in southwest Florida between 155 and 224 days where no single distinct plant community dominates. More specifically, there are no tree dominated plant communities between hydroperiods of 113 and 245, so it is possible that cajeput may be moving into an underutilized ecotone between those of the wet cypress swamp and dry pinelands.

Some authors believe that the site requirements of cabbage palm (Sabal palmetto) are similar to those of cajeput, particularly since the cabbage palm can reproduce in cajeput stands (Woodall 1978). These two species are similar in their adaptations to the south Florida extremes of fire, flooding, and drought (Myers 1978), but cajeput is more persistent. Further draining of the Fahkahatchee cypress strand is of some ecological concern as it may help the cajeput become established in the Big Cypress National Preserve (BCNP).

Australian Pine. Three species of the genus Casuarina (Australian pine) flourish in south Florida (Long and Lakela 1971) and in the Caloosahatchee River/Big Cypress watershed (Duever et al. 1979, SFWMD 1980). The species that causes the most concern, particularly in coastal areas, is C. equisetifolia. The other two species, C. cunninghamia and C. glauca, are much less of a problem in south Florida because of their failure to reproduce in abundance.

Australian pine (which is actually an evergreen angiosperm, not a true pine) normally grows in dense monospecific stands on relatively high, dry soils. The trees may grow as high as 15 to 20 m (50 to 65 ft). The leaves are tiny, scale-like, and whorled at each joint on wiry, pale green, drooping branches. Seeds are produced in small cones in C. equisetifolia, whereas C. cunninghamia reproduces vegetatively from root sprouts. The other species, C. glauca, is relatively scarce, at least in BCNP, because of the isolation of the male and female trees (Duever et al. 1979).

Casuarina spp. were introduced into south Florida as ornamentals and windbreaks along roads, canals, and baysides. In the watershed they are particularly thick and obvious along Tamiami Trail and Canal from the Dade County line to 40 Mile Bend near Monroe, Florida. Because of their relative sensitivity to frequent fire or long hydroperiods, they tend to thrive only where they are protected from such stresses. High canal banks, berms, and coastal areas are examples of ideal locations for the Australian pine.

Brazilian Pepper. Brazilian pepper (Schinus terebinthifolius) a native of Brazil, was introduced into Florida at numerous locations around the turn of the century. The plant is dioecious, and usually grows in thick monocultures to an average height of about 3 m (10 ft). The females bear white flowers in late summer. The fruit, which becomes mature as red berries in November, has led some people to refer to Brazilian pepper as Florida holly.

Although Brazilian pepper generally abounds as a monoculture on disturbed sites such as abandoned farm fields, spoilbanks, or roadsides, scattered individuals are found in pinelands, hammocks, prairies, and even mangroves (Duever et al. 1979).

Brazilian pepper exhibits most of the characteristics of an early successional shrub species, namely intolerance of low light, an abundant and readily dispersed seed, rapid growth, and fast recovery after frost, fire, and hurricanes (Duever et al. 1979). The pollen is spread by insects, particularly bees, which make use of the flowers during late summer when other sources of nectar are scarce. The plant reproduces by seed, by root sprouting after fire or frost defoliation, and by sending shoots and runners into nearby disturbed areas. The fruits are consumed by a variety of wildlife such as wintering robins, opossums, raccoons, and others that contribute to the dispersal of seeds (Ewel et al. 1976).

Water Hyacinth. Water hyacinth (Eichhornia crassipes) is a floating aquatic plant that flourishes in a wide variety of physical and chemical conditions. It grows in waters with a pH between 4 and 10 SU. It can withstand near-freezing temperatures and survive water temperatures as high as 34°C (Bock 1966, Haller and Sutton 1973, Morris 1974). In full sunlight, hyacinth grows very fast, but at low light intensities it does poorly. It grows on seasonally inundated wetlands, although the rhizomes must maintain a high water content to survive and grow (Penfound and Earle 1948).

Like Brazilian pepper, water hyacinth originates from Brazil although it has now spread throughout tropical and subtropical America. It reproduces largely by vegetative sprouting, and, to a much lesser extent, by seed.

The distribution of water hyacinth tends to be more closely linked to canals than to natural waters where there is more shade. It is generally found in open, relatively shallow canals such as the Tamiami Canal (Duever et al. 1979), the Golden Gate canals (Tabb et al. 1976), tributaries to the Caloosahatchee River (SFWMD 1980), and many other locations such as along lakeshores (Pesnell and Brown 1977). Hyacinths interfere with the drainage of canals and there is evidence that evapotranspiration rates of hyacinth mats may reach 3 to 4 times the rate of open water evaporation. The effects of clogging and increased evapotranspiration may negate each other to some extent in the overall hydrologic budget (Timmer and Weldon 1967, Kelleher 1976, Duever et al. 1979). Hyacinth mats are frequently used by wading birds and other vertebrates as a source of food and cover. Crowder (1974) claims that this plant supports an abundance of insects and other invertebrates that are an important component of the aquatic food web.

Hydrilla. Hydrilla verticillata (hydrilla or Florida elodea), is a member of the Hydrocharitacea family and originates from central Africa. Only female plants have been introduced into the U.S., so reproduction by seed propagation has never been observed in this country. Introduction into Florida is a fairly recent phenomenon (1960) although the species is now common in many canals, where it tends to be interspersed with other species.

The lack of seed reproduction is more than compensated for by its four means of vegetative reproduction (Haller 1977):

(1) apical fragments with leaf whorl that may develop into new plants,
(2) axillary buds (turions) may develop on floating plants, drop to the bottom and sprout,
(3) sprouts may develop from nodes on stolons and rhizomes,
(4) tubers may develop on the ends of rhizomes embedded in the hydrosoil.

Unlike the hyacinth, hydrilla cannot grow in areas that are not fully watered year round. An exception to this is the hydrilla tuber which, once embedded in the soil can survive drought, ice cover, and chemical sprays. Also unlike hyacinths, the hydrilla grows well in full as well as reduced (1%) sunlight. Like the hyacinth, the hydrilla's growth rate is often phenomenal.

At least four canal sites in the BCNP - along U.S. 41 (Tamiami Canal), Turner River Road, State Road 837 north, and parallel to U.S. 41 and Birdon Road in the southwest corner of the preserve - support hydrilla interspersed with stands of cattail (Typha latifolia), water hyacinth (Eichhornia crassippes), and ludwigia (Ludwigia spp.) (Duever et al. 1979). Hydrilla has also established itself in Lake Hicpochee and Lake Trafford, north BCNP (SFWMD 1980). Deep Lake and Halfway Pond apparently are not suitable for hydrilla: Deep Lake because of its deep, pitlike bottom morphology, and Halfway Pond because of its seasonal drying.

There are mixed opinions on the fish and wildlife value of hydrilla in south Florida. Lake Trafford, prior to 1960, had no rooted vegetation and was noted as a poor bass fishing spot. Today, ten years after being infested with hydrilla, the lake supports a sizable bass population and is well known for its fishing (Duever et al. 1979). In central Florida lakes, however, hydrilla usually is associated with stunted fish populations comprising an excess of small forage fish and a few large predators (Haller 1977). Other wildlife users of hydrilla include the American coot (Fulica americana) and the ring-necked duck (Aythya collaris), which are reported to feed (perhaps extensively) on its plant parts.

Since the hydrilla plant effectively clogs canals, it also tends to accelerate sediment buildup and ultimately its own demise. At times hydrilla mats become so dense that terrestrial vegetation may actually colonize them.

Because hydrilla mats interfere with canal drainage and recreation, typical chemical and physical controls have been tried. The results have been unsatisfactory because of the high cost of chemicals and the rapid regeneration of plants. In addition to herbicides such as diquat and copper sulfate and mechanical removal, much attention has been focused on the potential of the grass carp or white amur (Ctenopharyngodon idella) for partial control (Kilgen and Smitherman 1971, Michewicz et al. 1972, Terrell and Fox 1975, Beach et al. 1976). The grass carp is believed to readily ingest hydrilla and other soft macrophytes. Its usefulness is still under study (Duever et al. 1979).

6.4.2 Agricultural Communities

Farming always involves continual alterations of the land. Over a year's time an agricultural area may be plowed, planted, fertilized, sprayed, drained, irrigated, and harvested; consequently, the plant community is greatly altered by factors outside the bounds of "natural" background conditions. The monospecific nature of agriculture is also suboptimal for a balanced mixture of fish and wildlife.

Agriculture in the Caloosahatchee River/Big Cypress watershed is primarily concerned with cattle production (pasture), citrus crops (groves), and vegetable crops, in that order (ESE 1978a). Farming is a much more important feature of the Caloosahatchee River watershed than of the Big Cypress watershed. In the half of the Caloosahatchee River watershed east of LaBelle, urban land accounts for only 1% to 5%; forest, swamps, and prairie make up 40% to 80%; and agriculture accounts for 20% to 60%. The Big Cypress National Preserve (BCNP) supports 259 cattle-grazing operations that use 60,720 acres (24,583 ha) of land (Duever et al. 1979). Ninety-three percent of the cattle grazing takes place on two sites. Other agriculture, mostly north of the BCNP, includes tomato, watermelon, and cucumber farming near Ochopee, and beekeeping along the Barron River Canal, SR29, and the Tamiami Trail.

The effect of agricultural operations on vegetation and fish and wildlife depend to a large extent upon the type of crops, management practices, and the cumulative regional intensity of agriculture. Obviously, the result of converting pine-palmetto forest to improved pasture is different from converting it to an orange grove or to a tomato field. There may also be quite substantial differences between heavily and lightly grazed pastures, between different citrus groves (based on age of the orchard and pruning schedule), and between differently cultivated fields (based on the type of crop and the fertilizer and pesticide schedules used).

Rather large areas of intense cultivation interspersed with natural lands present unique problems for the fish and wildlife. Large agricultural areas create discontinuities between species populations, eliminate breeding sites, and reduce population numbers and gene flow below critical levels necessary for population maintenance. Other factors affecting plants, fish, and wildlife are canalization and streamside alterations, changes in regional drainage and runoff characteristics, and the introduction of pesticides into soils and water. The effects of individual developments may be small, but their cumulative effects can be especially dangerous to endemic species when advanced farming techniques (e.g., drainage control and pesticide application) become an integral part of land use.

In pasturelands, overgrazing is common where cattle congregate, such as around high-quality forage, near supplemental feeding stations, on dry uplands during the wet season, and around water holes during the dry season (Duever et al. 1979). In the Corkscrew Swamp Audubon Sanctuary, grazing has been responsible for removing so much of the dry litter that repeated attempts at controlled burning fail for lack of fuel (Duever et al. 1976). In some hammocks virtually all of the understory vegetation has been destroyed or consumed and all small trees killed by grazing cattle. In some marshes subjected to grazing, 70% to 80% of the live biomass may be consumed. Grazing generally has an effect similar, at least in pinelands, to that of ground fire. Overgrazing decreases the diversity of the plant community, limits shrub invasion, and promotes grasses (Hilmon and Lewis 1962, Hughes 1974).

The artificial hydroperiod and repeated soil disturbances associated with conventional crop farming in south Florida invite the invasion of exotics such as cajeput and Brazilian pepper. The location of farms near major roads, canals, and minor urban centers assures an abundance of disturbed sites where exotics may spread. Construction of ditches and canal banks essentially creates two new sites, one high and dry, the other permanently wet, where before there was a single site with seasonal inundations. Instead of species characteristic of the diverse background condition (e.g., dry prairie), other species such as Brazilian pepper or hydrilla can become dominant.

Citrus groves are another example of an altered natural community. A typical grove is planted in clean-cut rows for easy access by farm workers and to maximize the use of sunlight, water, nutrients. The trees are generally managed so that all are of similar age and size. Understory vegetation is usually completely lacking except for some grasses. The groves are managed (by physical and chemical controls) to maximize production of the trees and minimize competition, predation, parasitism, and disease.

6.4.3 Urban-Industrial Communities

Human influence on the vegetation of urban areas is both complex and variable depending on the area and the intensity of development. Part of a community may be completely obliterated by urban structures such as roadways and buildings, whereas another portion (such as a park) may be altered only slightly.

Urban-industrial communities are generally divided into light, medium, and heavy residential, commercial, and industrial categories. For our purposes these categories of disturbed lands also include communities along the roads, railroads, and transmission lines, that are essential to urban-industrial complexes.

Often the areas of greatest topographic relief include spoil sites for fill obtained from borrow canals. The canals serve as drainage swales to lower the water tables and receive highway runoff, and as a source of fill for road construction. Railroad rights-of-way are similar to highways, in constituting narrow paths of high relief between major urban centers. They differ from roads in that canals are less frequently associated with them. They also tend to be narrower than paved roads.

The vegetation along power transmission lines is much like an early succession field. The annual cutting of vegetation establishes early succession and fast growing shrubs and grasses, the same as for controlled burning or wildfire. Since tolerance to fire is not a factor where vegetation is held in check by mechanical mowing, species intolerant to fire may become an important part of the community.

The Caloosahatchee River/Big Cypress watershed contains relatively few major urban centers. Among the larger of these are Fort Myers (and north Fort Myers), Naples, Marco Island, and Cape Coral (Figure 1). Lee County has the fastest growing population in the state. Other semiurban centers in the watershed are LaBelle, Denard, Lehigh Acres, Moore Haven, Bonita Springs, Immokalee, Goodno, Golden Gate Estates, Everglades City, Chokoloskee, Naples Park, Estero, Fort Myers Beach, and Ochopee.

Some of the urban areas in the watershed have caused considerable environmental controversy over land development plans. The most notable are described in the following paragraphs.

The Estero Bay estuaries development controversy went all the way to the U.S. Supreme Court for a final decision. This proposed development would have converted much of the mangrove wetland surrounding Estero Bay into medium residential land use (SWFRPC 1980).

The Marco Island development involved extensive dredge and fill of mangrove shorelines and barrier islands. Initiated before 1970, it has converted most of the uplands, beaches, and mangroves on Marco Island into a plush resort.

The Golden Gate/Remuda Ranch Grants development plans were significantly slowed and altered to insure proper environmental safeguards and human services.

The Cape Coral development has induced saline contamination of shallow aquifers, affected water quality, and caused serious aquatic weed problems over a 103-square-mile area just north of the mouth of the Caloosahatchee River estuary (SWFRPC 1980). Major industrial sites, outside of light industries associated with urban areas, include oil fields scattered throughout Collier, Lee, and Hendry Counties (Figure 3) and fossil fuel power plants at Fort Myers.

The changes in vegetation brought about by urban development are best viewed in terms of a shift in local plant selection. In a natural setting, plant community structure is largely determined by those species that survive best under prevailing physical/chemical background conditions. Community associations in the Caloosahatchee River/Big Cypress watershed that appear to have dominated the natural setting where major urban centers are now located are given in Table 33. Species composition and other structural-functional attributes of these communities was reported earlier in this chapter. The general categories of structural and functional changes that occur in natural communities in response to the gross changes brought on by urbanization are given in Table 34. Information is lacking on the long-term impact of converting major fractions of natural communities into urban areas.

To some degree the columns in Table 34 represent a complex stimulus-response process characterized by considerable overlap between many of the categories. For instance, it is clear that the gross changes in the structure and function of plant communities caused by economic development may be divided into two essential and interrelated stages as suggested in column 1 of Table 34. Stage 1 is the onset of construction during which the associated secondary responses dominate. Stage 2 is the lifetime of the structure used and maintained by urban dwellers.

Although many of the environmental impacts of the two stages are similar, they often differ in form

Table 33. Plant communities affected by major urban centers in the Caloosahatchee River/Big Cypress watershed.

Urban Center Area	Communities Affected	Source
Ft. Myers	Pinelands, marshes and sloughs, hammocks, cypress	Brown (1976)
Naples	Grassy scrub, dry pinelands, mangrove	Browder et al. (1973)
Marco Island	Beach and dune, pinelands, hammocks, mangrove	Browder et al. (1973)
Cape Coral	Pinelands, marshes and sloughs	Brown (1976)
Golden Gate	Cypress, pinelands, hammocks, prairies, marshes and sloughs	Tabb et al. (1976)

(i.e., how they are implemented) and intensity. Construction generally requires heavy equipment and much energy expenditure. The environmental impacts of using the structure arise from the actions of individuals expending only minor amounts of energy. One impact is acute, the other is chronic. Initial construction must be followed by maintenance or the site will be reinvaded by exotic and native vegetation. A similar overlap is apparent in the secondary structural/functional changes brought on by other activities, such as the discharge of wastes. The initial impacts of discharge from one-time construction activities may be more devastating to aquatic communities than daily discharges that continue to feed the community.

6.4.4 Canals

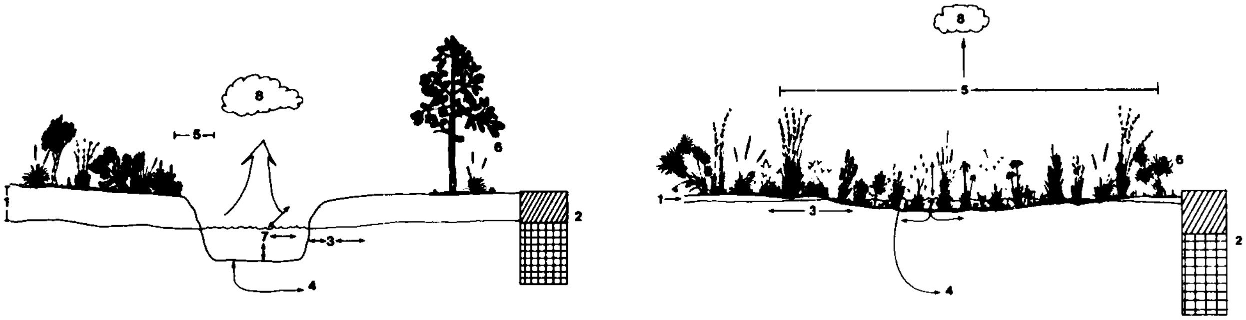
Major canal systems are fairly common in the Caloosahatchee River/Big Cypress watershed. The most prominent example is along the northern reaches of the Caloosahatchee River, where the river and many of its tributaries are ditched and channelized for drainage and irrigation. The City of Cape Coral, located at the mouth of the Caloosahatchee River, is characterized by an extensive network of canals that have destroyed or bisected mangroves, salt marshes and prairies, pinelands, grassy scrub (dry prairies), and freshwater marshes and sloughs. In 1973 the dominant communities in the disturbed area were grassy scrub (dry prairie), lakes (impounded), and freshwater and saline canals (Brown 1976). To the south, in the upland areas near Naples, lies one of the largest canal drainage systems in Florida. The two systems, the Golden Gate Estates and Remuda Ranch Grants canals, cut through areas once dominated by cypress strands, grassy scrub, freshwater marshes and sloughs, and salt marsh and mangroves (Carter et al. 1973, Browder et al. 1976). In and around Naples Bay, canals and seawalls replaced mangroves as the dominant shoreline feature (Collier County Conservancy 1979). On Marco Island, channelization has also replaced a large portion of the diffuse (and sometimes nonexistent) drainage network of this barrier island/coastal swamp system. On the southern and eastern edge of the Big Cypress watershed, three borrow canals were dug along major roadways. These are the Barron River Canal (with State Road

Table 34. Structural and functional changes in natural communities caused by urbanization.

Gross Structural/Functional Changes	Secondary Structural/Functional Changes
Structure	
1. Construction and maintenance of urban-industrial component parts (roads, offices, houses, parking lots, etc.)	a) Direct killing of overstory, understory, or other natural vegetation and wildlife: affects local microclimatic factors such as temperature, humidity, and incident light; may also influence runoff, erosion, subsequent species composition, and soil structure.
	b) Change in local topography for construction or landscaping purposes: affects runoff, recharge; erosion creates new microhabitats such as canals or high dry conditions, and even new soil types.
	c) Removal of forest litter or soil duff layer: affects cation exchange capacity of soils, thus quality and quantity of runoff; affects soil nutrient and water holding capacity; constitutes a loss of productive microhabitat for soil building organisms and wildlife that is trophically dependent on them.
Function	
2. Daily activities involved in construction and maintenance of urban metabolism.	d) Active artificial wildlife selection 1) Introduction of dogs, cats, other pets and livestock. 2) Elimination of predators, varmits, "pest" insects,"dangerous" spiders, "slimy" lizards, venomous snakes (pesticides, trapping, etc.).
	e) Passive artificial wildlife selection 1) Changes in substrate (1. above) cause microhabitat destruction, affects narrow niche species more than generalists. 2) Urban noise and pollutant levels interfere with species communication, sensory processes 3) Habitat discontinuity increases likelihood of population isolation, affects birth rate, death rate, and gene flow. 4) Road kills affect birth and death rates directly and indirectly. 5) Trophic web consequences of both active and passive wildlife selection factors.
	f) Discharge of urban stormwater, sewage or industrial waste products (including air pollution) 1) changes water quantity relationships such as peak flows, flow frequencies, tidal exchange factors, etc. as drainage diversion and dredging activities increase; affects substrate and species composition through both initial construction and maintenance. 2) changes water quality relationships; introduces nutrients, toxins, and aquatic weeds at levels and frequencies not previously encountered.

29), the Turner River Canal (with Turner River Road), and the Tamiami Canal (with U.S. 41, Tamiami Trail).

A schematic illustration of the impact of canals on ground- and surface-water hydrology and terrestrial and aquatic habitat structure is given in Figure 74. Water quality and quantity impacts of channelization were discussed in Chapter 4. Most of the environmental impacts on community structure have been mentioned previously in the sections on riverine communities, exotic



PARAMETER OR PROCESS	IMPACT	REFERENCE
1 Groundwater Table Fluctuations	Canals lower depth to groundwater table; seasonal fluctuations dampened or shifted generally to lower lows and lower highs.	Klein et al. (1970), McCoy (1964), Carter et al. (1973)
2 Penetration into subsurface strata	Canals may penetrate into deeper (aquifer) strata below surficial sediments; aquifer drainage is facilitated, water quality affected.	Klein et al. (1970), McCoy (1964), Carter et al. (1973)
3 Groundwater flow gradient	By lowering water table, seasonal recharge, discharge cycle disrupted thus hydroperiods change, availability of soil moisture changes, saline waters intrade.	Klein et al. (1970), McCoy (1964), Carter et al. (1973)
4 Water storage and exchange	Stored groundwater may be discharged or tidal exchange factor increased, thus changing extremes of drought/flood and background water quality.	Van de Kreeke (1979), Hicks (1979), Carter et al. (1973) SWFRPC (1980)
5 Shallow water habitat and fish and wildlife	Area of wetland habitat decreases, replaced by upland deep water habitats; shallow water dependent wildlife have less habitat, deep water and upland dependent species favored, aquatic weeds favored.	Duever et al. (1979), Brown (1974), Lehman (1976)
6 Terrestrial vegetation and wildlife	Shift from xeric to mesic conditions, promotes fire and early succession communities, invasion by exotics. Wildife also shifts according to available habitat and other factors.	Brown (1974) Lehman (1976)
7 Water quality	Turbidity, color, dissolved oxygen, pH, conductivity, inorganic ions, metals and other parameters may change with depth, groundwater drainage, sediment removal of canals.	Carter et al. (1973) Hicks (1979), SWFRPC (1980)
8 Evapotranspiration	Wetland habitat loss, excess discharge, lower soil moisture, lower water table, increased depth and storage in open canal reservoirs change the nature and magnitude of ET.	

Figure 74. The effects of canal development on hydrology and habitat structure.

species, and agricultural and urban-industrial communities.

The preeminent environmental effect of channelization is to change the local topography. Undulating, low-sloping land surfaces including broad expanses of shallow wetland are usually converted into systems having more distinct boundaries between land and water. Naturally this results in a narrower band of surface area and more sharply fluctuating water levels.

Some freshwater canals (e.g., Golden Gate Estates Canals) support lush growths of aquatic weeds (Joyce Environmental Consultants 1975) while others (e.g., Cape Coral) do not. One major difference may be the nature of the respective canal substrates and the surrounding land-use practices. Golden Gate Estates canals are downstream from a drainage system that still has considerable natural vegetation. Cape Coral canals, on the other hand, are cut into limestone and have essentially no natural surface drainage upstream. Currently there is little urban development in Cape Coral to generate stormwater pollution, and the aquatic vegetation is under control. Nutrient-loading differences between the two canal systems may account for some of the differences in plant species composition (M. Lehman; personal commentation). A list of the aquatic weeds common in canals of the watershed are given in Table 35.

Table 35. Aquatic plants found in the waterways of central and northern Collier County (adapted from Joyce Environmental Consultants 1975).

Species Number	Common Name	Scientific Name
0	Alligatorweed	*Alternanthera philoxeroides*
1	Azolla	*Azolla caroliniana*
2	Sea Myrtle	*Baccharis halimifolia*
3	Bacopa	*Bacopa caroliniana*
4	Bidens	*Bidens cernua*
5	Cabomba	*Cabomba caroliniana*
6	Ferns	*Centella repanda*
7	Buttonbush	*Cephalanthus occidentalis*
8	Coontail	*Ceratophyllum demersum*
9	Chara	*Chara* spp.
10	Dayflower	*Commelina communis*
11	Sedge	*Cyperus strigosus*
12	Barnyard Grass	*Echinochloa crusgalli*
13	Hyacinth	*Eichhornia crassipes*
14	Slender Spikerush	*Eleocharis acicularis*
15	Hydrilla	*Hydrilla verticillata*
16	Hydrocotyle	*Hydrocotyle umbellata*
17	Needlerush	*Juncus roemerianus*
18	Cutgrass	*Leersia hexandra*
19	Duckweed	*Lemna minor*
20	Frogbit	*Limnobium spongia*
21	Ludwigia	*Ludwigia palustris*
22	Primrose Willow	*Ludwigia peruviana*
23	Wax Myrtle	*Myrica cerifera*
24	Broadleaf Milfoil	*Myriophyllum heterophyllum*
25	Southern Naiad	*Najas guadalupensis*
26	Waterlily	*Nymphaea odorate*
27	Maidencane	*Panicum hemitomon*
28	Paragrass	*Panicum purpurascens*
29	Torpedograss	*Panicum repens*
30	Common Reed	*Phragmites communis*
31	Waterlettuce	*Pistia stratioties*
32	Smartweed	*Polygonium* spp.
33	Pickerelweed	*Pontederia lanceolata*
34	Pondweed	*Potamogeton illinoeni*
35	Swamp Dock	*Rumex verticillatus*
36	Sagittaria	*Sagittaria isoetiformis*
37	Sagittaria	*Sagittaria lancifolia*
38	Arrowhead	*Sagittaria* spp.
39	Willow	*Salix* spp.
40	Brazilian Pepper Tree	*Schinus terebinthifolius*
41	Cattail	*Typha* spp.
42	Bladderwort	*Utricularia foliosa*
43	Wolffia	*Wolffia columbiana*

CHAPTER 7
FAUNA

7.1 INTRODUCTION

Ordinarily, an animal species can use only a few habitats in a given geographic area. Major factors that regulate habitat use and geographic range are the behavior, physiology, and anatomy of the species; competitive, trophic, and symbiotic interactions with other species, and forces (both random and systematic) that influence species dispersion. Such restrictions may be broad, as in the case of the common crow, which prospers in a wide variety of settings over a vast geographic area; or narrow, as in the case of the mangrove terrapin, which is found in only one habitat and only in the near tropics of the western hemisphere. Knowledge of the animal species in particular habitats is fundamental to understanding and managing fish and wildlife resources; consequently, the major thrust of the following discussion is on the fauna of the Caloosahatchee River/Big Cypress watershed. Detailed descriptions of species-habitat relations, were considered to be beyond the scope of this report. Literature that gives more detailed information on local fish and wildlife and their habitats is cited.

7.2 INVERTEBRATES

7.2.1 Terrestrial and Wetland Invertebrates

Little is known about the ecology of the invertebrates in this watershed. Studies by Ross and Jones (1979) and Milleson (1980) list invertebrates (primarily aquatic) identified at sites along the Caloosahatchee River and in Lake Trafford. Ross and Jones (1979) summarize data collected from 1974 to 1978 at three Caloosahatchee River stations and one station in the littoral zone of Lake Trafford. Differences between two collecting methods (natural versus artificial substrate) were examined, and temporal variations in species diversity and biotic index are described. Milleson (1980), compared the benthic faunas of seven Caloosahatchee River oxbow lakes in respect to species density and composition in the various sedimentary and hydraulic conditions.

In the Caloosahatchee River upstream from Franklin Lock, seasonal diversity of species composition was apparent on natural substrates. Diversity peaked in winter and spring and reached its minimum in summer. Differences in seasonal distribution were attributed to a combination of low oxygen and low salinity induced by lock operations, high instream metabolic rates, and the instream allocthonous organic matter. Unlike the seasonal trends in natural substrate samples, the artificial substrate diversity showed no clear seasonal trend (Moore Haven Station). Some of the discrepancies between natural and artificial substrates may be attributed to sampling bias.

Milleson (1980) reported 28 species of benthic organisms from seven Caloosahatchee River oxbow lakes. Three species, *Tubifex tubifex* (Annelida, Tubificidae), *Gammarus fasciatus* (Amphipoda, Gammaridae), and *Chaoborus punctipennis* (Diptera, Culicidae) were found in all seven lakes. Collectively, these three species accounted for 88% of the total numbers of individuals. Cyathura polita (Isopoda, Anthuridae), Corbicula leana (Pelecypoda, Corbiculidae), Ablabesmyia cinctipes (Diptera, Chironomidae), and Polypedilum halteri (Diptera, Chironomidae) were the four next most abundant species.

Tubifex tubifex, Gammaris fasciatus, and Cyathura polita are scavengers that feed on algae, vegetation, and plant detritus (Milleson 1980). Ablabesmyia cinctipes, Polypedilum halteri, and Chaoborus punctipennis are primarily predators that feed on rotifers and microcrustacea. C. punctipennis often feeds extensively on Tubifex tubifex. Corbicula is a filter-feeding pelecypod that would not be expected in great abundance in fine, organic sediments that dominate the oxbow lake bottoms, and instead prefers sandy bottoms and moving water.

The average density of benthic macrofauna in six oxbows ranged from 201 individuals/m^2 to 692/m^2, and averaged 365/m^2. In the seventh oxbow lake the density averaged 848/m^2. Of this total, however, 53% of the individuals collected were Chaoborus punctipennis.

7.2.2 Marine and Estuarine Invertebrates

Marine and estuarine invertebrates are either pelagic (as members of the plankton) or benthic (bottom dwellers), or both. Those that use both habitats are meroplankton; they move between the plankton and benthos as a function of diurnal activity or part of their life history. Major studies on invertebrates are listed below.

(1) Caloosahatchee River estuary: Gunter and Hall (1965) and Applied Biology (1976).
(2) Estero Bay area: Tabb et al. (1974) and ESE (1978b).
(3) Wiggins Pass: ESE (1978b).
(4) Naples Bay: ESE (1978b) and Yokel (1979).
(5) Rookery Bay: Yokel (1975).
(6) Fahka Union and Fahkahatchee Bays: Carter et al. (1973).
(7) Chokoloskee Bay: ESE (1978b).
(8) Offshore waters: Lindall et al. (1973).

Authors of some of these studies (Gunter and Hall 1965 and Yokel 1975) could not clearly differentiate between planktonic and benthic components because of the sampling technique employed (trawls). General characteristics of planktonic and benthic communities are described by Hopkins (1973) and Collard and D'Asaro (1973).

Zooplankton. The most systematic study of the true zooplankton of the area's estuaries (excluding icthyoplankton) is that of ESE (1978b). Four estuarine systems; Estero Bay, Wiggins Bay, Naples Bay and Chokoloskee Bay, were sampled during the dry season (April 1977) and the wet season (September 1977). Individuals were identified to species where possible, and counted and weighed. Only one sample (wet season) was taken in Estero Bay.

Zooplankton numbers and biomass were lowest in the dry season. Station-to-station variations were less pronounced under dry, high-salinity conditions than during wet, low-salinity conditions. Averages were not very meaningful because of the large variation between stations in each estuary.

The variations in species composition, numbers, and biomass under different physical/chemical conditions were difficult to explain. Salinity, although significantly different between seasons, did not explain station-to-station differences in biomass or numbers within the same estuary. Temperature correlated more precisely with seasonal differences in numbers and biomass, but did little to explain station-to-station differences.

The general seasonal trends in plankton numbers and biomass (Figure 75) are similar to those described by Hopkins (1973) for other estuaries of the eastern Gulf of Mexico. Salinity and temperature generally explain only a fraction of the variation in numbers and biomass of zooplankton. Water temperature probably is most influential. Other factors often are seasonal composition of the plankton and predator-prey relationships. Seasonal concentrations of meroplankton, which represent the larvae of benthic or epibenthic invertebrates, may greatly influence the concentration and composition of plankton. Large variations in numbers and biomass may also arise from the transitory nature of the estuarine environment. In addition to the growth and decline of a population in response to the scarcity of food and predators, the total community is in constant physical motion. This movement is due to the zooplankton's own mobility (primarily vertical), as well as that caused by wind and tidal currents. The sampling of such a dynamic process at indiscrete intervals and locations is likely to produce an incomplete and perhaps confusing picture of spatial and temporal patterns.

Qualitatively, copepods constitute a major year-round fraction of the zooplankton of Estero, Wiggins, Naples and Chokoloskee Bays. Acartia tonsa, a calanoid, was the dominant copepod observed. Paracalanus parvus, another calanoid copepod, was also frequently encountered. Less frequent, though a significant contributor to the copepod group, was

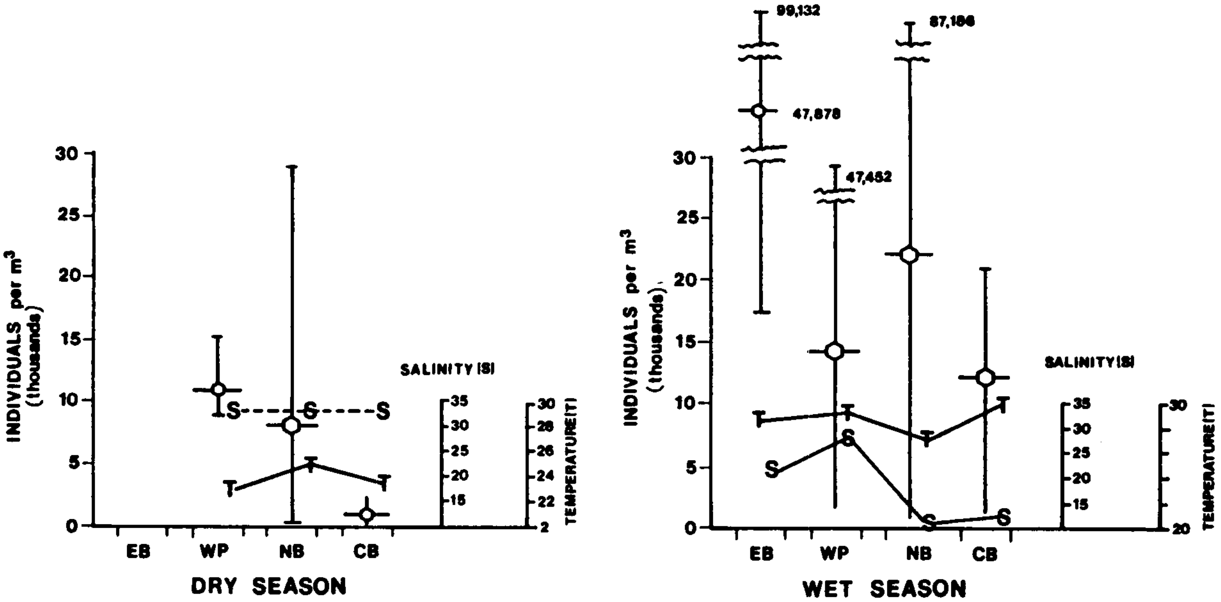


Figure 75. Seasonal trends in plankton numbers and biomass (adapted from ESE 1978a, 1978b).

the harpacticoid Euterpina acutifrons, which was more abundant in April than September, and the cyclopoid Oithona sp., which was more frequent in September than April. Juvenile copepods (nauplii) and meroplankton were relatively abundant in all samples. Gastropod (snail) larvae account for the greatest percentage of the meroplankton community at Chokoloskee Bay. Generally, barnacle (cirripidea) and snail (gastropoda) larvae were common in all three estuaries (excluding Estero Bay). Crab larvae were less abundant. At Wiggins Pass, cirriped (barnacle) nauplii were the most abundant meroplankters. This was generally the case for Naples Bay, except at a few stations where pelecypod (bivalve) larvae were dominant.

Microzooplankton, although numerous at times, were relatively scarce in the samples because the mesh size of the net was too large (Hopkins 1973). Other sampling variables (e.g., time, depth, and speed) also biased the species composition of the samples.

Benthos. Variation within the estuarine and marine benthic invertebrate community is primarily controlled by substrate (grain size and composition) and salinity. Other major factors that influence community composition are water temperature, plant cover, disruptions (either natural, e.g., hurricanes, or man-made, e.g., dredge and fill), predator-prey interactions, and food availability. Information on species composition and biomass of benthic communities is relatively plentiful in the watershed's estuaries, but distinct communities and gradients between them are difficult to define because of sampling inadequacies and errors and the dynamic nature of benthic communities.

As components of the benthos, many infauna and epifauna ingest bacteria-laden sediment and detritus and upgrade the organic matter into higher levels of the estuarine food web. Although seldom quantified, this reprocessing also has side benefits for planktonic metabolism and water quality. By concentrating bacteria, which have a relatively high ratio of surface area to volume, into a multicellular organism with a lower ratio, the net metabolic rate is slowed. A given amount of organic matter in the form of polychaetes, for example, typically consumes less oxygen per unit of time than the same amount of microbial biomass.

In addition to the direct biological effect on the oxygen balance, estuarine benthic fauna also exert biological effects through their physical activities. By feeding, burrowing, pumping, and filtration, the fauna physically rework the sediments. As in terrestrial soils, such bioturbation induces a much greater movement of chemicals and gases (e.g., oxygen between the bottom substrates and the water column). One factor that controls the level of bioturbation is the amount of dissolved oxygen (DO) at the sediment-water interface. Benthic fauna and other aerobic decomposers (e.g., bacteria) consume oxygen in direct proportion to their metabolic rate and numbers. As the DO drops, fewer aerobic species are able to survive and those that do may flourish because of the reduced competition for food and space. As the DO approaches zero, the few remaining aerobic species die, and any further decomposition is accomplished at a much lower rate by anaerobic microbes.

Benthic fauna also affect the cycling of other chemical elements in the estuary. The adsorption of certain heavy metals by particulate matter increases as the conductivity (salinity) of the water increases (Horvath 1973). Heavy metals are also concentrated in the degradation of red mangrove leaves (Mathis 1973). It is not surprising, therefore, that heavy metal concentrations in the sediments of some estuaries are generally higher than in overlying waters (Carter et al. 1973).

The concentration of elements in the sediments benefits the estuary by helping to conserve materials necessary for metabolism and also helps keep the concentration of potential toxins in the water column at extremely low levels. On the other hand, the presence of higher concentrations in the sediments does not necessarily mean that the materials are either removed from circulation or detoxified. Rather, their point of entry into estuarine metabolism is in the benthos rather than the water column. For the benthos, prevailing physical/chemical conditions such as the uptake and release of elements by benthic organisms dictate whether such substances are buried, exported, or shunted into higher levels of the food chain.

Substrate differences that most clearly delineate benthic communities from one another are the hard and soft bottom, and the inter-tidal and submerged bottoms. For example, where salinities are similar, the exposed prop roots of mangroves support an invertebrate fauna similar to that of the shell-based intertidal oyster reef. The communities along the mud to mud/sand to sand substrate, although different from the intertidal communities, are hard to distinguish from one another (Carter et al. 1973). Salinity also has a major effect on the species composition of the benthos. For example, in the upper end of the Caloosahatchee estuary, larval insects comprise anywhere from 0.1% to 92.4% of the benthic fauna (Applied Biology 1976), but at the lower end of the estuary, the marine benthic fauna are nearly devoid of larval insects (Gunter and Hall 1965). The number of benthic species at any one location increases with seasonal increases in salinity. A more obscure change occurs in species composition and abundance from the vast "middle-ground" area between San Carlos Bay and Franklin Locks where salinity fluctuates greatly. The following subsection describes the substrate communities and the factors affecting abundance.

Intertidal Communities. The intertidal community consists primarily of the prop-root associates of red mangroves (Figure 76), and the oyster reef (Figure 77). A third community, which Odum et al. (1982) include with the prop-root associates, is the intertidal mud flats (Figure 76). The inclusion of the intertidal mud flat with the prop-root associates is based on the observation that many of the prop-root species feed on flooded and exposed mud flats. Although not as extensively documented, oyster reef fauna behave in much the same way. A fourth community, the seawall, exhibits a fauna similar to but slightly different from that of mangrove prop roots (Courtenay 1975). In addition to the connection

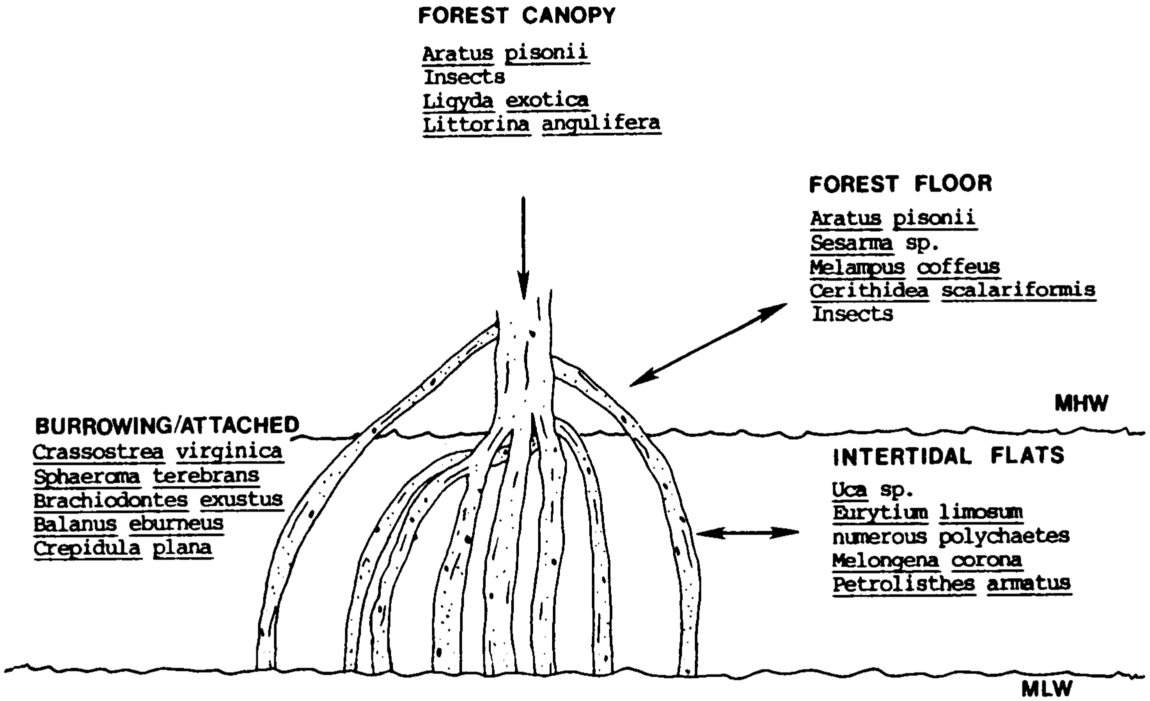


Figure 76. Representative benthic invertebrates living among mangrove prop roots.

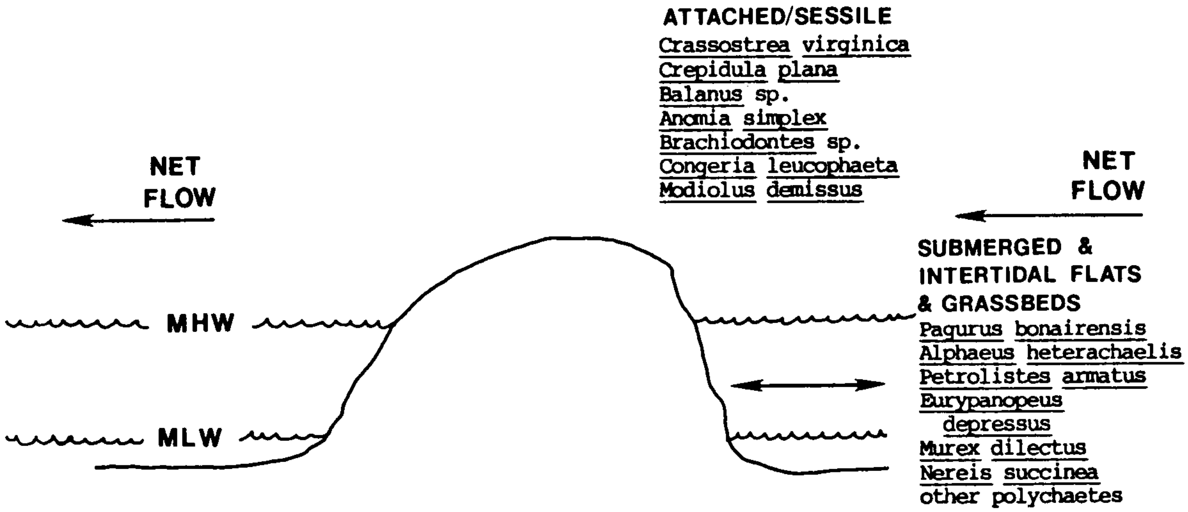


Figure 77. Representative benthic invertebrates living among oyster reefs (adapted from Tabb et al. 1974).

between prop-root dwellers and intertidal flats, Odum et al. (1982) describe similarities between prop-root dwellers and those that occupy the mangrove-forest canopy and floor. The latter, however, tend to be dominated by nematodes, insects, insect larvae, polychaetes, harpacticoid copepods, isopods, and amphipods - clearly a mixture of terrestrial and marine forms.

The temporal and spatial variation in species composition among communities are largely dependent on salinity, DO, substrate, flow and tides. One consistent trend noted with regard to salinity is a relative decrease in the diversity of invertebrates on prop roots at the head ends of mangrove creeks (Wanless et al. 1975, Weinstein et al. 1977). Presumably the low oxygen, low salinity, and finer sediments there inhibit the colonization of certain species. Benthic fauna also decrease along this same salinity gradient within mangrove-lined creeks. Lower faunal diversities were reported from canals where mangroves had been replaced by seawalls. Major species found only on mangrove roots and not on seawalls are: Turitella sp., Melongena corona, Anachis semiplicata, Bulla striata, Hypselodoris sp., Arca imbricata, Carditamera floridana, Pseudoirus typica, and Martesia striata.

Submerged Bottoms. Decapod crustaceans comprise one of the most important groups of invertebrates that characterize the estuarine floor (Gunter and Hall 1965, Carter et al. 1973, ESE 1978b). Grass shrimp (Paleomonetes intermedius, P. paludosus, P. pugio), pink shrimp (Penaeus duorarum), Periclimenes americanus, Periclimenes longicaudatus, Hippolyte pleuriocantha, Toxuma carolinese, and Rhithropanopeus harrissi, are major primary consumers of vascular plant material, periphyton, and detritus. Grass shrimp, pink shrimp, swimming crabs (family Portunidae), mud crabs (family Xanthidae), Rhithropanopeus, and other decopods are major foods of many sport and commercial fishes. Yokel (1975) and Carter et al. (1973) reported 33 species of decapods in samples from Fahkahatchee, Fahka Union, and Rookery Bays. Table 36 lists these crustaceans and their numerical distribution in Fahkahatchee and Fahka Union Bays. In Rookery Bay the five most abundant decapods were more numerous at sites vegetated with seagrasses or benthic algae than at unvegetated sites (Yokel 1975).

The abundance of the five major decapod species in Rookery Bay was best correlated to plant biomass, water temperature, salinity, and the red tide (Yokel 1975). Nonetheless, these factors explained relatively little about the station-to-station and seasonal variation. These variations suggested that the subtle aspects of the biology and adaptation of each species were probably more important in explaining variations in abundance and distribution than gross environmental measures.

Two particularly important penaeids from a commercial standpoint are the pink shrimp (Penaeus duorarum) and the stone crab (Menippe mercenaria). Because of their commercial importance and as representatives of the decapod benthic fauna, their role in southwest Florida's estuarine ecology is described in some detail. Both species are good examples of the important connections between coastal waters and estuaries.

Table 36. Numbers of decapod crustaceans collected in various habitats in Ten Thousand Islands, Florida, 1972 (adapted from Carter et al. 1973).

Family and Species	Habitat (1) A	B	C	D	E	F
Penaeidae						
Penaeus duorarum	355	357	1655	522		
Palaemonidae						
Periclimenes longicaudatus	2	5	246	14		
Periclimenes americanus	3	9	42	6		
Leander paulensis	32	8	8	1		
Palaemonetes paludosus						24
Palaemonetes vulgaris	15	6	14	58		
Palaemonetes intermedius	21	91	1430	162		
Palaemonetes pugio	1	2	26	12		
Alpheidae						
Alpheus normanni	1			8		
Alpheus heterochaelis		1	5	5		
Hippolytidae						
Thor floridanus			4			
Hippolyte pleuracantha		45	422	134		
Tozeuma carolinense		57	365	114		
Astacidae						
Procambarus alleni						514
Porcellanidae						
Petrolisthes armatus		2	8	7		
Porcellana sayana					2	
Paguridae						
Paguristes spp.		2	9	33		
Pagurus longicarpus			[a]	[a]		
Pagurus bonairensis	[a]	[a]	[a]	[a]	[a]	
Portunidae						
Portunus sayi	2	2	6			
Portunus gibbesii	2	7	2			
Callinectes sapidus	27	22	12	24		
Callinectes ornatus	5	14	11	25		
Xanthidae						
Menippe mercenaria			1		1	
Rhithropanopeus harrisii					1	
Neopanope texana	23	161	70	221		
Eurypanopeus depressus		1	7	15		
Panopeus herbstii		1				
Goneplacidae						
Eucratopsis crassimanus					1	
Grapsidae						
Aratus pisonii					8	
Ocypodidae						
Uca rapax					10	
Uca pugilator					51	
Majidae						
Libinia dubia	12	17	38	42		

[a] Numerical data on *Pagurus* spp. were only recorded from a few collections.

(1) Habitat designations were as follows: Fahka Union Bay (A); Fahkahatchee Bay - West (B), - North (C), - East (D); other estuarine areas (E); and freshwater sites (F).

Most of the commercial shrimping in southwest Florida focuses around the Tortugas and Sanibel shrimping grounds northwest of Key West and off Sanibel Island to the northwest of the Caloosahatchee River. Due to the great economic value of this resource, a significant amount of research has been conducted over the years on shrimp ecology and population dynamics. After 1954, when new markets developed for smaller sized shrimp, the question arose as to how to best manage the Tortugas shrimp grounds for sustained optimum yield (Iversen and Idyll 1959). Costello and Allen (1966) have determined that shrimp from area estuaries also utilize the Sanibel grounds off Cape Romano (Figure 78).

Intensive sampling and analysis of the shrimp population of the Tortugas grounds in the mid-fifties revealed that the smaller shrimp tend to inhabit shallower waters than the larger shrimp. In an attempt to prevent excessive exploitation of the shrimp population, a "controlled area" or refuge near Key West was declared off limits to commercial fishing. This area is the shallower portion of the Tortugas nursery grounds and the area surrounding the Marquesas Keys (Ingle et al. 1959).

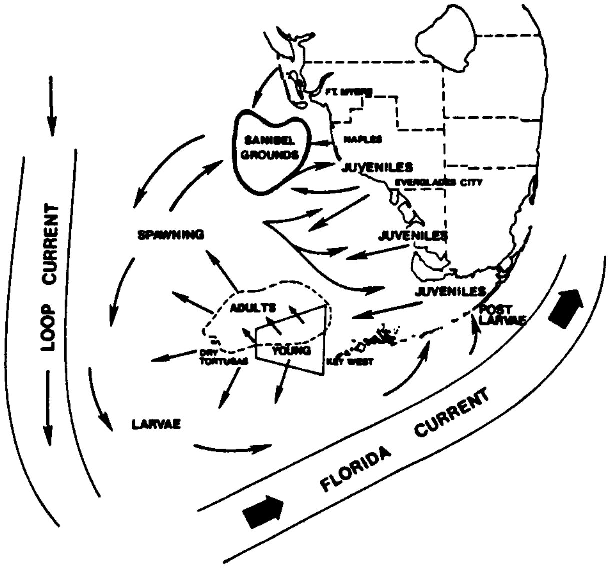


Figure 78. Simplified model of shrimp migratory patterns in south Florida.

Predicting the timing and abundance of shrimp on the Tortugas shrimping grounds is of primary importance in making management recommendations to protect the fishery; consequently, research has been focused on understanding the growth and migratory patterns of the pink shrimp and the factors that control their seasonal and yearly fluctuations. Although there are still information gaps, a simplified model of the pink shrimp life cycle and migratory patterns off southwest Florida is given in Figure 78. The following discussion describes one loop in the model's cycle. Since most of the information available pertains to the Tortugas grounds, the focus is on this geographic area. Some of the general findings are also applicable to the Sanibel grounds as well.

The various sizes and ages of shrimp are rather broadly dispersed throughout the Tortugas shrimping grounds, but the smaller, younger shrimp tend to congregate in shallower waters along the south/southeast boundary of the grounds (Iverson et al. 1960). The smaller shrimp are believed to be the year's early recruits from the estuarine nursery. There is also an increase of shrimp size north from Key West irrespective of depth increase. Controlled release and recovery of shrimp over the Tortugas grounds confirms that there is a general northwesterly movement but this is by no means always true (Iverson and Jones 1961). An average migration rate (in any direction) of about 8 km/day (5 mi/day) is reported. Numbers of shrimp at the surface and middepth generally decrease from midnight to midday and increase from midday to midnight (Roessler et al. 1969).

Female pink shrimp on the Tortugas grounds tend to grow faster and ultimately, larger than male shrimp (Iverson and Idyll 1960). The effect of seasonal changes in water temperature on the growth of pink shrimp is believed to be relatively small. Iverson and Jones (1961) report that, in cage experiments, growth during the warm months is not significantly greater than during the cooler months. Indeed the high summer temperatures appear to slow the growth of shrimp.

The gradual movement of older, larger adults into deeper waters is believed to correspond to the onset of spawning in the pink shrimp. Female shrimp can reproduce when they reach about 90 mm (3.5 inches) in length (Ingle et al. 1959). Shrimp spawn year round in the warm south Florida waters, although there is distinct temperature amplification. Spawning peaks in the spring and summer were apparently triggered by changes in bottom water temperatures (Roessler et al. 1969, Jones et al. 1970). Water temperatures are fairly constant all year in the Tortugas shrimping grounds, although Iverson and Idyll (1960) note that a thermocline may develop during the summer. The thermocline is generally a short-lived phenomenon because strong winds keep the water mixed. The occasional thermocline may help to explain the sporadic nature of summer spawning peaks noted by Roessler et al. (1969). Shrimp spawn most actively when water temperatures are between 27° and 30.8°C (81° and 87°F).

Spawning is generally restricted to waters deeper than 6 fathoms (11 m or 36 ft). There is also some indication that spawning is greater during the waning moon phases. An average annual production of 87 x 10^{11} protozoea larvae/year is estimated by Roessler et al. (1969). Average survival rates ranging from

74% to 98% (mean = 80.4%) per day are estimated for larval stages of pink shrimp (Munro et al. 1968, Jones et al. 1970, Roessler et al. 1969).

The numbers and biomass of pink shrimp in estuaries of the Ten Thousand Islands area reach a seasonal peak in June and July (Carter et al. 1973, Yokel 1975). A second peak is reported by Carter et al. (1973) in November in Fahkahatchee and Fahka Union Bays (Figure 79).

Early nauplii and young protozoea stages are believed to remain close to the bottom, but second and third protozoea and mysis stages often migrate vertically, a behavior that may greatly enhance their chances to drift with prevailing surface and bottom water movements in the nursery grounds.

Larvae may take one of two routes to reach estuarine nursery areas (Figure 78). The first and least known route involves direct travel across the shallow shelf toward the Ten Thousand Islands, Whitewater Bay, and Florida Bay. In taking this route, plankton larvae must traverse waters with complex and sometimes contrary currents. Nonetheless, Jones et al. (1970) reported finding numerous post-larvae moving in that direction.

The second route is somewhat less direct, but probably more energy efficient for the larvae. This migration is a fortuitous coupling of the planktonic life style with locally cycling currents: larvae are swept southwestward by prevailing surface and bottom currents. Further south, as these currents are increasingly influenced by the Florida Current, the larvae are swept northeastward along the outer banks of the coral reef tract, developing into post-larvae as they go. By the time they reach the post-larval stage they begin to enter Florida

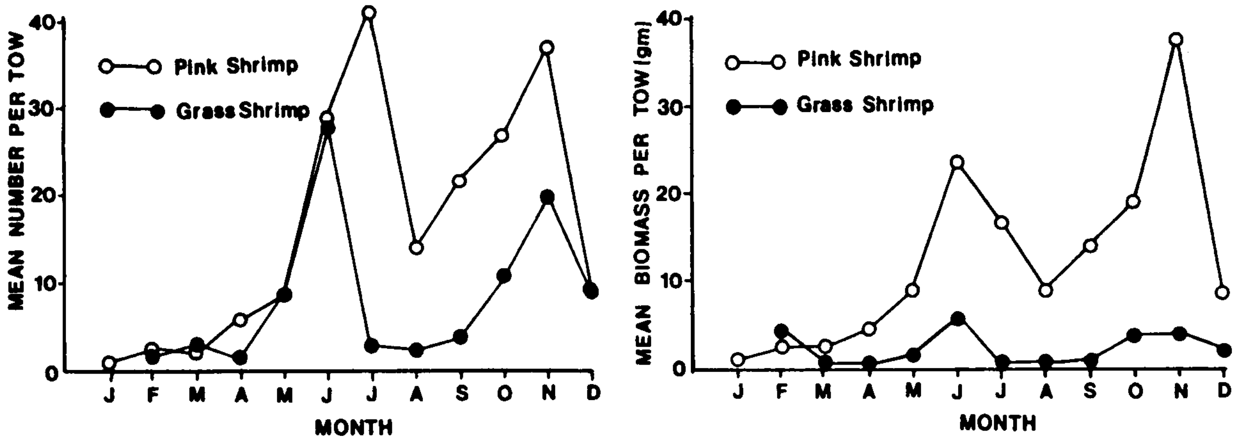


Figure 79. Numbers and biomass of pink shrimp (Penaeus duorarum) and grass shrimp (Palaemonetes spp.) taken from combined catches of surface and otter trawls in Fahka Union and Fahkahatchee Bays, 1972 (adapted from Yokel 1975).

Bay on incoming tides through the channels between the Keys (Allen et al. 1980). The correlation between seawater temperatures and post-larval abundance in one such channel in the upper Keys is shown in Figure 80. Seasonal abundance peaks from May through August or September. Superimposed on this pattern (Allen et al. 1980) is seasonal variation in the depth at which shrimp post-larvae abound (Table 37). During peak seasonal abundance the shrimp tend to concentrate near the surface, but as they become scarce, the greatest numbers are found at mid-depth.

Apparently one of the more important factors controlling the migration of shrimp is their response to ambient conditions as a function of life stage. The post-larvae entering 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).

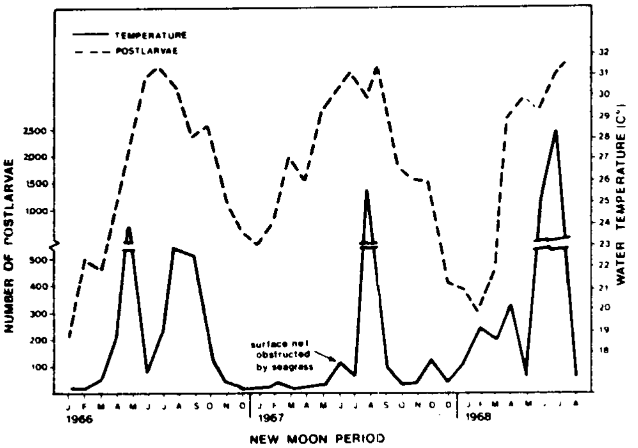


Figure 80. Abundance of post-larval shrimp at Whale Harbor Channel in the upper Keys (adapted from Allen et al. 1980).

Table 37. Seasonal variation in pink shrimp post-larvae with depth (adapted from Allen et al. 1980).

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

A number of authors acknowledge seasonal correlation between nearshore salinity and freshwater inflow and post-larval and juvenile shrimp abundance. Increased intertidal habitat created by seasonal water-level fluctuation in Florida Bay is one of the more important factors contributing to the survival of young post-larvae (Allen et al. 1980). Another factor that must certainly be involved is the tremendous seasonal pulse of detritus in nearshore waters; still another may be protection from aquatic predators that can't tolerate low salinity.

The biology of the stone crab (Menippe mercenaria) has been reviewed by Bert et al. (1978). The following discussion starts with the distribution and behavior of adult crabs and proceeds through their reproductive cycle and succeeding life-history stages to adulthood.

Adult stone crabs apparently crave some sort of protective shelter, seeking out crevices on shell bottoms and oyster reefs or, more commonly, digging burrows in sand and mud. Their characteristic shelters are burrows 15 to 127 cm (6 to 50 inches) deep in Thalassia flats and along the edges of channels. In the vicinity of adequate food, burrows may be as close as 20 to 30 cm (7.9 to 11.8 inches) apart. There seems to be a distinct relationship between burrow size and crab size. No crabs less than 43.2 mm (1.7 inches) in carapace width (cw) are found in burrows, and younger adults 43 to 74 mm (1.7 to 2.9 inches) cw tend to excavate rather short, straight burrows. In contrast, burrows of larger stone crabs of 76.2 mm (3.0 inches) cw are dug obliquely into the sediment, are deeper, and are oriented perpendicular to the direction of water flow (McRae 1950, Powell and Gunter 1968, Bender 1971). The burrows provide mating chambers, and areas for food storage (Bert et al. 1978), and protect molting females from predators and cold.

The distribution of adult stone crabs is based largely on directional movements that are probably a behavioral function and nondirectional movements related to environmental changes. Directional movements include seasonal mass migrations involving primarily one sex or one size class. As a group, male stone crabs seem to live farther offshore than females, which are year-round residents of shallow seagrass flats. Both sexes move closer inshore at certain times of the year. Sexually maturing females move inshore in early summer, and males migrate inshore in the fall to mate with molting females. Stone crabs tolerate wide fluctuations in salinity (Karandeyeva and Silva 1973). Mass movement of crabs of different size groups may also help reduce intraspecific competition and cannibalism.

Nondirectional movements refers to distribution that shows no consistent pattern in time or space. This type of movement may be caused by a temporary increase in food abundance, a strong showing of spawning females, or a decrease in larval predators. Water-quality disturbances such as abnormal turbulence from storms may provoke movements or influence food supplies. Such disturbances are reported to have a beneficial effect on fishing because highest catches usually follow "northers" which raise turbidity and lower water temperatures. Apparently stone crabs move in response to these conditions, seeking shelter in deeper, less turbid, and warmer waters, making them more vulnerable to the fishing.

Stone crabs are carnivores that feed on all kinds of shellfish, including members of their own species. The powerful claws of the crab serve as a shellcracker and a protective device against potential predators. Some of the marine animals that feed on adult stone crabs are octopus, sea turtles, and the Florida horse conch *Pleuroplora gigantea* (Bert et al. 1978).

Adult stone crabs molt infrequently with a minimum 6-month intermolt period. Some researchers believe that stone crabs reach a terminal size beyond which no molting or growth takes place. Temperature and salinity are regarded as major external factors controlling the growth rate of crabs. Sexual activity also influences growth and molting, particularly in the female. Growth in males is not affected by this activity, so they tend to be larger than females (Noe 1967, Cheung 1969, Savage 1971).

The reproductive cycle of the stone crab under natural conditions is not well documented. Crabs apparently spawn in summer and fall in the north (around Cedar Keys), but in the south (Everglades-Florida Bay) they spawn year round (Bender 1971, Bert et al. 1978). The number of eggs produced is directly proportional to the size of the female, ranging from 160,000 to 350,000 (Noe 1967). Females reach sexual maturity around 33.7 mm (1.3 inches) carapace width and may eventually reach 110 to 120 mm (4.3 to 4.7 inches).

Spawning behavior is described by Binford (1913) as follows:

> *When a female is ready to lay eggs, she assumes an upright position and holds the abdomen out from her body so that it and the exopods of the abdominal appendages form a basket into which the eggs are run. They there become attached to the hairs of the endopods of the appendages and pass through the embryonic stages of their development, which requires nine to thirteen days. The eggs then hatch and the larvae escape. The female then cleans off the egg shells and their stalks from the hairs of the pleopods and, after one day to three weeks, she spawns again. Eight days is a very common length for the period between the hatching of one batch of eggs and the spawning of the next.*

Cheung (1969) estimates that an average of 4.5 spawns may take place between molts of the female.

Molting and mating by female crabs take place soon after spawning stops (Noe 1967, Bender 1971). The reproductive cycle of the female tends to inhibit growth and molting, consequently females in the north tend to molt only in the cooler months of November through May. Growth of females may therefore be slow, inhibited by cooler water temperatures in the winter (Savage 1971) and ovarian development in the summer (Cheung 1969). A single mating of stone crabs provides enough spermatazoa (stored by the female) for as many as thirteen spawnings (Cheung 1969).

Unlike the pink shrimp, stone crab larvae do not depend on nearby estuaries as nursery grounds. Maximum growth and survival of crab larvae occurs in warm (30°C or 86°F) full-strength sea water (30-35 ppt). Adult females may try to move into this kind of environment to spawn, but where the shelf is extremely broad this may not be possible (Bender 1971). Larvae that hatch on the shelf are apt to be exposed to salinities and temperatures that are too high for optimal survival. Larvae and juveniles in the Everglades National Park may be mostly recruited from offshore, due to the high mortality of locally spawned larvae (Bert et al. 1978). The metamorphosis from hatching to true crab form takes around 6 weeks (Ong and Costlow 1970).

Even as zoea and megalops, stone crab larvae are carnivous, feeding on smaller planktonic animals. As zoea they tend to remain near the surface, but as megalops they drop toward the bottom, perhaps in search of a place to settle. During this phase, predation is high.

Authors disagree about the distribution and movement of juvenile stone crabs. Some investigators (Hay and Shore 1918) claim that the juveniles move inshore to warm bays and estuaries, whereas others claim they generally stay in deeper waters than those populated by adults (Williams 1965, Bender 1971). For reasons that are not at all clear, the salinity range tolerated by stone crabs in the north appears broader than that reported in the south.

Juvenile stone crabs do not burrow, but seek out shelter in the form of empty shells, oyster reefs, rock outcroppings, and seagrasses. Juvenile stone crabs feed on polychaetes, small bivalves, oyster drills, and epizooic fauna of seagrass blades (Bert et al. 1978). Major predators of juvenile crabs are the mud crab, Neopanope texana, and bottom-feeding fishes of the Serranidae family, such as the grouper and black sea bass.

Before leaving the subject of decapods, it is interesting to briefly contrast the life history and environmental preferences of the stone crab and the blue crab (Callinectes sapidus). Within broad boundaries the blue crab and stone crab are similar species. Migratory patterns of both involve movement to warmer waters as water temperatures change with the seasons. Larval development and trophic preferences are similar, although stone crabs appear to be more singularly carnivorous.

The one overriding difference between the two species of crab is a geographic one. The blue crab lives much closer to shore than the stone crab at the same life stage. Blue crabs frequently inhabit shallow, murky tidal creeks during the summer, but stone crabs are found more often in shallow grass beds, where water conditions are relatively stable. Management should consider that these two similar species coexist over a broad geographic area by utilizing, at least partially, different habitats at different times. Other aspects of the two species and their mutual environment which may contribute to their use of a common resource are differences in reproductive timing and fecundity, behavioral characteristics that favor greater survival at all life stages, relative intensities of predation, osmoregulatory capabilities, and trophic differences.

Other important benthic invertebrates in the southwest Florida estuaries are the isopods, amphipods, mollusks, echinoderms, and polychaetes (Carter et al. 1973; Evink 1974; Yokel 1975, 1979; ESE 1978b). Two studies in particular analyzed the characteristics of the entire benthic community. Yokel (1979) divided the Naples Bay community into recurrent groups and other indices, which provided a basis for comparing sampled sites within the bay system as well as with control sites in Dollar Bay. Evink (1974) compared benthic community diversities and species composition in a channelized (Fahka Union Bay) and a "natural" estuarine system (Fahkahatchee Bay).

In Naples Bay 13 recurrent groups of benthic fauna (Table 38) were identified from monthly samples collected at 38 stations. These groups consist of animals (or taxa) that tended to be found with one another. These groups apparently react to similar physical, chemical, and biological factors and distribute themselves accordingly.

Analysis of spatial and temporal distributions of recurrent groups revealed a variety of benthic environments in Naples Bay. These environments were ranked by the frequency of recurrent groups (Table 39). The higher the average number of recurrent groups the more "useful" the habitat to the total community. Two other measures of benthic

Table 38. Recurrent groups of benthic fauna in Naples Bay (adapted from Yokel 1979).

Recurrent Group	Season	Control Station	Lower Bay	Canal Begins	Trib. Station	Canal Troughs	Gordon River
Group 1 Nemertea (Phylum) Sabellidae (Polychaeta) Capitellidae (Polychaeta) Gammaridae (Crustacea) *Tellina versicolor* (Mollusca) Spionidae (Polychaeta) Phyllodocidae (Polychaeta) Lumbrinereidae (Polychaeta) Cirratulidae (Polychaeta) Orbiniidae (Polychaeta)	Year round, some oscillation peak in fall	X	X	X	X	X	X
Group 2 *Abra aequalis* (Mollusca) Maldanidae (Polychaeta) *Parvalucina multilineata* (Mollusca) *Macoma tenta* (Mollusca) Sigalionidae (Polychaeta)		X	X		X		
Group 3 *Crassostrea virginica* (Mollusca) *Balanus eburneus* (Crustacea) *Eurypanopeus depressus* (Crustacea)	Year round with peak in fall	X		X			
Group 4 Nematoda (Phylum) Parergodrilidae (Polychaeta) Nereidae (Polychaeta)	Year round, peaks in fall months	X	X	X	X	X	X
Group 5 Terebellidae (Polychaeta) Sipunculida (Phylum) Glyceridae (Polychaeta)	Year round, peaks from December to April	X	X	X		X	X
Group 6 *Asthaenothaerus hemphilli* (Mollusca) *Cyclinella tenuis* (Mollusca)	July through November	X	X	X		X	
Group 7 *Gastrochaena hians* (Mollusca) Polyplacophora (Mollusca)	Low frequency from February to November	X	X	X			
Group 8 Mysidacea (Crustacea) Cumacea (Crustacea)	Highs in May, July, November	X	X	X			X
Group 9 *Lithophaga bisulcata* (Mollusca) *Crepidula aculeata* (Mollusca)	Narrow range of suitable salinity and substrate	X					
Group 10 *Jaspidella blanesi* (Mollusca) *Nucula aegeenis* (Mollusca)	Year round at low levels	X	X			X	
Group 11 *Branchiostoma caribeaum* (Chordata) *Tagelus divisus* (Mollusca)	Year round at low levels	X	X	X			
Group 12 *Diplodonta* sp. (Mollusca) Owenidae (Polychaeta)	Heavy in summer	X	X	X		X	
Group 13 Trichobranchidae (Polychaeta) *Corbula* sp. (Mollusca)	Peaks in summer may be absent in winter	X	X	X		X	

Table 39. Benthic habitat ranking in Naples Bay based on average number of recurrent groups, abundance and diversity of fauna (adapted from Yokel 1979).

Sampling area	Average number recurring groups per station	Average density per station	Average diversity per station
Control Station	70.5 (1)	7536 (1)	2.80 (1)
Lower Bay	39.4 (2)	5477 (2)	2.33 (2)
Canal Berms	31.2 (3)	1892 (3)	2.32 (3)
Trib. Sta.	16.5 (4)	2068 (3)	1.99 (4)
Canal Troughs	14.5 (5)	1682 (5)	1.41 (6)
Gordon River	8.7 (6)	1023 (6)	1.77 (5)

numbers in parenthesis refer to ranking within column

community structure, animal density and diversity, showed similar trends in ranking of environments. The control station in Dollar Bay ranked as the most useful and supported nearly twice as many recurrent groups as the best location in Naples Bay. In Naples Bay, usefulness declined from a peak in the lower bay to the tributary stations to a low in the Gordon River. Within the canals, the berms were clearly more useful than the deeper troughs (Table 40) although there was another definite gradient extending out of the canals as well. Both canal berm and trough benthic environments declined in usefulness toward the upper ends of canals.

Table 40. Benthic habitat ranking of canal troughs and berms based on average number of recurrent groups, abundance and diversity of fauna (adapted from Yokel 1979).

Sampling area	Position	Average number of recurring groups per station	Average density per station	Average diversity per station
Canal Trough	Bay	45.3 (1)	558 (1)	2.48 (1)
	Mouth	28.2 (2)	255 (2)	2.06 (2)
	Middle	9.5 (3)	137 (3)	1.33 (3)
	End	2.7 (4)	28 (4)	0.84 (4)
Canal Berm	Mouth	43.5 (1)	198 (1)	2.55 (1)
	Mid	30.2 (2)	198 (1)	2.38 (2)
	End	20.0 (3)	120 (3)	2.05 (3)

numbers in parenthesis refer to ranking within column

In Fahka Union and Fahkahatchee Bays, Evink (1974) described differences in the benthic community diversity and biomass of the two bays (Table 41). Slightly lower diversities were reported from Fahka Union Bay and considerably lower average biomass was found on mud, sand, and shell substrates. High diversities of benthic invertebrates were apparent in both estuaries in March and August. Low diversities in December probably better reflect the true resident populations.

The three major ecological differences between the two bay systems that may account for differences in benthic invertebrate composition and abundance are salinity, plant cover, and sediment composition. The abundance and density of pink shrimp, blue crab, and grass shrimp was greater in Fahkahatchee Bay (Table 41).

7.3 FISHES

7.3.1 Freshwater Fishes

The freshwater fishes of the Caloosahatchee River/Big Cypress watershed are a mix of northern freshwater species, marine species, and exotics.

In addition to southward movement of some freshwater fish species, marine invasions are biogeographically limited by the location of the peninsula within the Carolinian and near-tropical marine provinces. The third factor influencing the composition of the freshwater fauna is considered a function of recent rather than geological history, or biogeographic origins.

According to Kushlan and Lodge (1974), the freshwater fauna of south Florida consists of 108 species of fishes from 34 families

Table 41. Differences in benthic community structure and species composition between Fahka Union and Fahkahatchee Bays (adapted from Evink 1974).

	Composition by Number (%)		Composition by Biomass (%)	Biomass (Avg. gm dry wgt/m^2)	Diversity Index
FAHKA UNION BAY					
Amphipoda	65	*Alpheus* spp.	13		
Polychaeta	15	*Tellina* spp.	17		
Palaemonetes spp.	7	*Crassostrea virginica*	15		
Isopoda	4	Xanthids (crabs)	11	mud 1.78 ± 0.78	H = 0.67
Tellina spp.	2	Polychaeta	6	sand 1.80 ± 1.10	E = 0.39
Alpheus spp.	1	*Palaemonetes* spp.	6	shell 2.37 ± 1.70	
Crassostrea virginica	1	Amphipoda	3		
Xanthids (crabs)	<1	*Penaeus* spp.	1		
Penaeus spp.	<1	Isopoda	1		
Mysids	<1	*Callinectes sapidus*	<1		
Callinectes sapidus	<1	Mysids	<1		
FAHKAHATCHEE BAY					
Amphipoda	17	Xanthids (crabs)	21		
Palaemonetes spp.	11	*Palaemonetes* spp.	18		
Polychaeta	7	*Alpheus* spp.	8		
Isopoda	4	*Tellina* spp.	7	mud 2.60 ± 0.65	H = 0.85
Tellina spp.	2	*Penaeus* spp.	5	sand 2.92 ± 1.89	E = 0.49
Alpheus spp.	1	*Callinectes sapidus*	4	shell 2.79 ± 0.97	
Penaeus spp.	1	Polychaeta	5		
Ostracoda	1	Ascidiacea	1		
Xanthids (crabs)	<1	Amphipoda	1		
Ascidiacea	<1	Isopoda	<1		
Callinectes sapidus	<1	Ostracoda	<1		

(Table 42). A number of the species listed may not actually be found in the watershed because the list includes all species from all habitats in southern Florida. Some species may be restricted to the coastal canals of southeastern Florida. There is an apparent biogeographic difference between eastern and western south Florida that affects the localized distribution of selected species (Kushlan and Lodge 1974); however, a general paucity of systematic studies of the freshwater fishes makes it difficult to delineate species distribution.

Among the principally marine species that may be found in freshwater, many are recognized as estuarine inhabitants. In south Florida, where land slopes are low and rainfall seasonal, the estuarine transition zone is both broad and seasonally mobile. This creates a zone where the salinity gradient is spread out over a relatively wide area. In addition, the background salinity of inland waters is frequently in the oligohaline (or near oligohaline) range due to contact with residual salts from past invasions by shallow seas (Odum 1953). These factors, i.e., distance to seawater over an extended gradient and high residual chlorinities, are believed to facilitate the invasion of freshwaters by euryhaline marine species (Odum 1953). Another factor which may aid such invasions is the high concentration of calcium (Ca^{++}) in Florida freshwaters (Hulet et al. 1967). High levels of Ca^{++} inhibit salt loss and water gain in marine fishes, which helps them osmoregulate in less saline environments.

Some principally marine species such as the tarpon (*Megalops atlantica*), American eel (*Anguilla rostrata*), and mullet (*Mugil* spp.) occasionally move far inland via canals and rivers, whereas others such as the croaker (*Micropogon undulatus*), red drum (*Sciaenops ocellata*),

Table 42. Freshwater fishes of southern Florida (adapted from Kushlan and Lodge 1974).

LEPISOSTIDAE (PRIMARY)

Longnose gar
(*Lepisosteus osseus*)
Florida gar
(*L. platyrhincus*)

AMIIDAE (PRIMARY)

Bowfin
(*Amia calva*)

ESOCIDAE (PRIMARY)

Redfin pickerel
(*Esox americanus*)
Chain pickerel
(*E. niger*)

CYPRINIDAE (PRIMARY)

Redeye chub
(*Hybopsis harperi*)
Golden shiner
(*Notemigonus crysoleucas*)
Iron color shiner
(*Notropis chalybaeus*)
Pugnose minnow
(*Notropis emiliae*)
Coastal shiner
(*N. petersoni*)
Taillight shiner
(*N. maculatus*)

ICTALURIDAE (PRIMARY)

White Catfish
(*Ictalurus catus*)
Yellow bullhead
(*I. natalis*)
Brown bullhead
(*I. nebulosus*)

CYPRINODONTIDAE (SECONDARY)

Sheepshead minnow
(*Cyprinodon variegatus*)
Goldspotted killifish
(*Floridichthys carpio*)
Golden topminnow
(*Fundulus chrysotus*)
Banded topminnow
(*F. cingulatus*)
Marsh killifish
(*F. confluentus*)
Seminole killifish
(*F. seminolis*)
Flagfish
(*Jordanella floridae*)
Bluefin killifish
(*Lucania goodei*)
Rainwater killifish
(*L. parva*)

POECILIIDAE (SECONDARY)

Pike killifish
(*Belonesox belizanus*)
Mosquito fish
(*Gambusia affinis*)
Least killifish
(*Heterandria formosa*)
Sailfin molly
(*Poecilia latipinna*)
Green swordtail
(*Xiphophorus helleri*)
Variable platyfish
(*X. variatus*)
Channel catfish
(*I. punctatus*)
Tadpole madtom
(*Noturus gyrinus*)
Speckled madtom
(*N. leptacanthus*)

CATOSTOMIDAE (PRIMARY)

Lake chubsucker
(*Erimyzon sucetta*)

CENTRARCHIDAE (PRIMARY)

Everglades pygmy sunfish
(*Elassoma evergladei*)
Bluespotted sunfish
(*Enneacanthus gloriosus*)
Warmouth
(*Lepomis gulosus*)
Bluegill
(*L. macrochirus*)
Dollar sunfish
(*L. marginatus*)
Redear sunfish
(*L. microlophus*)
Spotted sunfish
(*L. punctatus*)
Largemouth bass
(*Micropterus salmoides*)
Black crappie
(*Pomoxis nigromaculatus*)

PERCIDAE (PRIMARY)

Swamp darter
(*Etheostoma fusiforme*)

APHREDODERIDAE (PRIMARY)

Pirate perch
(*Aphredoderus sayanus*)

CLARIIDAE (SECONDARY)

Walking catfish
(*Clarias batrachus*)

CICHLIDAE (SECONDARY)

Oscar
(*Astronotus ocellatus*)
Black acara
(*Cichlasoma bimaculatum*)
Convict cichlid
(*C. nigrofasciatum*)
Jack dempsey
(*C. octofasciatum*)
Jewelfish
(*Hemichromis bimaculatus*)
Mozambique tilapia
(*T. mossambica*)

ATHERINIDAE (PERIPHERAL)

Brook silverside
(*Labidesthes sicculus*)

CLUPEIDAE (PERIPHERAL)

Gizzard Shad
(*Dorosoma cepedianum*)
Threadfin Shad
(*D. petenense*)

and ladyfish (*Elops saurus*) are rarely found in oligohaline waters, at least in south Florida.

Since the marine species in the Caloosahatchee River/Big Cypress watershed tend to concentrate in the estuaries, this discussion is focused on freshwater species listed in Table 42. Because of the transitional nature of fauna in brackish waters, there is some overlap between the discussions of freshwater and marine fishes.

Of the 34 families of freshwater fishes of south Florida, only ten are obligatory freshwater families: the gars (Lepisostideae), the bowfin (Amiidae), the pickerels (Esocidae), the shiners (Cyprinidae), the suckers (Catostomidae), the catfishes (Ictaluridae), the sunfishes (Centrachidae), the perches (Percidae), the Loricaridae, and the

Aphredoderidae. Of these families only the first eight are reported in the watershed (Kushlan and Lodge 1974). Three families that have only secondary relationships with freshwater also contribute an abundance of species to the fauna. These are the killifishes (Cyprinodontidae), the live bearers (Poecilidae), and the Cichlids (Cichlidae). These three families contribute 7, 3, and 6 species to the south Florida fauna, respectively. The tropical Cichlidae, however, tend to be much more prevalent on the east coast, where they are periodically released or escape from aquaria into extensive canal networks. Two families classified as peripheral to freshwater, the Clupeidae and the Atherinidae, contribute 2 and 1 species, respectively.

Freshwater fishes occupy at least nine different habitats common to the watershed. These include ponds, lakes, streams, canals, cypress domes and strands, marshes, prairies, river channels, and oxbows. These habitats may be broken down even further based on seasonal factors such as deep marsh and shallow marsh, and seasonal or permanent ponds. Water quality, flora, and topographic distinctions of similar sites may also influence site suitability for certain species; for example, whether a stream flows into mangrove or cypress swamps; whether a pond is associated with a marsh or a cypress dome; whether cattails or overhanging trees dominate an oxbow lake; and whether canals are deep with steep banks or shallow with sloping banks. Representative species of each of the eight major freshwater families are discussed first in terms of general habitat preferences and other ecological characteristics, followed by a discussion of the secondary and peripheral families to the freshwater habitats of the watershed.

Lepisostidae. The gars are represented by two species, the longnose gar (Lepisosteus osseus) and the far more common Florida gar (L. platyrhincus). The Florida gar lives in nearly all aquatic habitats such as lakes, canals, marsh sloughs, ponds, cypress swamps, and even wet prairies during prolonged high water. During high water, they may even move into the mangrove swamps (Kushlan and Lodge 1974, Odum et al. 1982). The longnose gar appears to be restricted to Lake Okeechobee. Hunt (1960) reports that the Florida gar may reach concentrations of 80.1 kg (178 lb) per acre in shallow canals, making it second only to the bowfin in biomass per acre and first in numbers of individuals per acre. The gar possesses an air bladder that retains a wide connection to the pharynx. This bladder is an essential part of their respiratory system, allowing them to live in oxygen-starved, stagnant waters. The gar feeds on a variety of living and dead animal matter, especially fish (Eddy 1969). They constitute a major portion of the diet of the American alligator (Alligator mississippiensis), (Fogarty 1974). A particularly useful adaptation of the gar is the toxicity of its eggs to warm-blooded vertebrates (Eddy 1969).

Amiidae. The bowfin (Amia calva) constitutes a major portion of the standing crop of fish in shallow canals (approximately 598 kg/hectare or 534 lb/acre), according to Hunt (1960). This species is noted for its adaptability to fluctuating water levels such as those in the Big Cypress watershed. Like the gar it is a widespread species that occupies a variety of habitats from shallow marshes to canals to oxbow lakes (Kushlan and Lodge 1974, SFWMD 1980). During extreme droughts adult bowfin burrow into the moist peat soils and apparently are capable of entering a state of prolonged aestivation to survive dry conditions (Dineen 1974).

In addition, the bowfin (or freshwater dogfish) retains a connection between the air bladder and the pharynx which enables it to use the air bladder as a respiratory organ. In stagnant waters where low oxygen may be limiting for other fishes, bowfin can rise to the surface to take in air. They feed primarily on small crustaceans and fishes.

Esocidae. Two species, the redfin pickerel (Esox americanus) and the chain pickerel (E. niger), represent this family in south Florida. From all indications these two species exist in a variety of the study area's habitats such as shallow marshes, lake margins, and canals, although neither species has yet been reported from marshes in the study area (Dineen 1968, Kushlan and Lodge 1974, Crowder 1974). In contrast, estimates of standing crop in four habitats in Lake Okeechobee show considerable numbers of chain pickerel in this habitat (Ager 1971). Others (Dineen 1968, Kushlan and Lodge 1974, Duever et al. 1979) have reported E. niger in the conservation areas to the west, the Tamiami Canal, and the Everglades National Park surrounding the study area. Thus it seems likely that at least the chain pickerel exists within the study area.

Like all members of the pike family, the chain and redfin pickerel are voracious carnivores, consuming almost any fish small enough to eat. Of the two, the redfin is smaller, reaching a maximum size of about 0.3 m (12 inches). The chain pickerel may reach 0.6 m (24 inches).

Cyprinidae. The five major species of minnows are the golden shiner (Notemigonus crysoleucas), the ironcolor shiner (Notropus calybaeus), the pugnose minnow (Notropus emiliae), the taillight shiner (Notropus maculatus), and the coastal shiner (Notropus petersonii). Two of these species (N. calybaeus and N. emiliae) are reported only in Lake Okeechobee, whereas the other three are common throughout south Florida. The largest of the five is the golden shiner, which may reach 22-25 cm (9-10 inches) in length.

As a group, the minnows play a key role in the transfer of energy and materials within aquatic ecosystems. As omnivores they consume vegetation, detritus, and microscopic animal life; they are preyed upon by a wide variety of important predators including other fish, mammals, and reptiles. Minnows are not especially well adapted to fluctuating water conditions and tend to be among the species most rapidly eliminated during fish kills (Kushlan 1974).

Catostomidae. The sucker family (Catostomidae) is represented by one species, the lake chubsucker (Erimyzon succetta). This species is widely distributed in freshwater mangrove swamps, canals, ponds, sawgrass marshs, wet prairies, and cypress sloughs and ponds (Kushlan and Lodge 1974). The lake chubsucker is omnivorous, feeding on plant and animal matter gleaned largely from bottom sediments.

Ictaluridae. The freshwater catfish (Ictaluridae) in south Florida are the white catfish (Ictalurus catus), the yellow bullhead (Ictalurus natalis), the brown bullhead (Ictalurus nebulosus), the channel catfish (Ictalurus punctatus), the tadpole madtom (Noturus gyrinus), and the speckled madtom (Noturus leptacanthus). The sea catfish (Arius felis) and gafftopsail (Bagre marinus) belong to the family Ariidae, and are principally marine species.

Members of the catfish family are usually omnivorous and nocturnal, feeding on a variety of animal and vegetable matter that they locate with their barbels. Because of this habit, they tend to do well in murky or colored water in which visual prey selection is difficult. The white catfish and channel catfish are most frequently found in open waters (Lake Okeechobee) and channels (Caloosahatchee River). The smaller bullheads and madtoms are found in these habitats as well as shallow ponds, sloughs, and mangrove swamps (Kushlan and Lodge 1974).

The Ictaluridae prefer deep waters, which may be one factor that helps them survive periodic droughts. Kushlan (1974) points out that the yellow bullhead's blood hemoglobin exhibits a high affinity for oxygen and a small Bohr effect (i.e., the ability to unload O_2 to tissues when CO_2 partial pressure is high). These fishes generally spawn in spring or early summer by depositing their eggs in a depression or cavity. After hatching, the male guards and cares for the young for several weeks.

Centrarchidae. The freshwater sunfish family consists of the Everglades pygmy sunfish (Elassoma evergladei), the blue spotted sunfish (Enneacanthus gloriosus), the warmouth (Lepomis gulosus), the bluegill (L. macrechirus), the dollar sunfish (L. marginatus), the redear sunfish (L. punctatus), the largemouth bass (Micropterus salmoides), and the black crappie (Pomoxis nigromaculatus). Many of these species are popular sport fish.

Generally speaking, the sunfishes are predators of other small fishes, crustaceans, insects, and benthic organisms. They thrive in heavily vegetated ponds, canal margins, and sloughs where prey tend to concentrate. The sunfishes adapt to fluctuating water levels by retreating into deeper waters; consequently, during droughts, bass and sunfish concentrate in shrinking canals and water holes. Of the nine species of centrachids, the Everglades pygmy sunfish is the most divergent. About 3.8 cm (1.5 inches) long, it lives almost exclusively on or near the bottom.

Percidae. The swamp darter (Etheostoma fusiforme) is the only south Florida representative of this family. It is a small, common bottom-dwelling fish reported from Lake Okeechobee to the Big Cypress swamp (Kushlan and Lodge 1974). Like all Percidae it is highly predaceaous, feeding on small insects and crustaceans (Eddy 1969).

Cyprinodontidae. Cyprinodonts and Poeciliads, which are not obligatory freshwater families but secondary invaders, are represented by 11 species. Of seven species of fish that Dineen (1972) believes make the Everglades "tick", five are from these two families. Seven species of Cyprinodonts and three species of Poeciliads are native to south Florida.

Members of the killifish family found in the watershed are the sheepshead minnow (Cyprinodon variegatus), the golden topminnow (Fundulus chysotus), the banded topminnow (F. cingulatus), the marsh killifish (F. confluentus), the seminole killifish (F. seminolis), the flagfish (Jordanella floridae), and the bluefin killifish (Lucania goodei). Killifish are generally euryhaline and adapt well to fluctuating water levels. Because of their small size they live in shallow waters and may even invade underground channels in bedrock limestone during low water. The upturned mouths of many of the killifishes can be used to extract oxygen from the thin surface layers of shallow ponds when deeper waters are devoid of oxygen (Carr 1973, Kushlan 1974a).

The killifishes are a fundamental ecological link between primary producers and trophically higher fish and wildlife species. Their diet consists of a mixture of plant and animal tissue ranging from periphyton to insect larvae. Killifish are preyed upon by sport fishes such as sunfish and bass, and wading birds such as woodstork and white ibis. They rapidly invade newly flooded marshes, prairies, and marginal wetlands, where they become a new source of food.

Poeciliadae. The topminnows or live bearers are represented by the ubiquitous mosquito fish (Gambusia affinis), the least killifish (Heterandria formosa), and the sailfin molly (Poecilia latipinna). The mosquito fish and sailfin molly are euryhaline and occupy a range of habitats from lake margins to salt marshes. The least killifish is abundant in shallow marshes, prairies, and freshwater pockets within mangrove swamps. They seldom inhabit brackish waters. According to Kushlan and Lodge (1974), this species prefers thick emergent or submerged vegetation.

Topminnows feed primarily on small insects, crustaceans, and attached periphyton. They protect their eggs from dessication by internal fertilization and development. The female carries the developing eggs until they hatch and the young emerge alive.

Atherinidae. The silversides are a family peripheral to freshwaters. The brook silverside (Labidesthes sicculus) prefers freshwater and inhabits open canals, clearwater ponds, and deep cypress sloughs from Lake Okeechobee and the Caloosahatchee River south to the southern Everglades (Kushlan and Lodge 1974). The tidewater silverside, Menidia beryllinia, is an important estuarine prey species.

Clupeidae. The herring family is also peripheral to freshwaters. Only two of four species live principally in freshwater. They are the gizzard shad (Dorosoma cepedianum) and the threadfin shad (D. petenense). These fish tend to flourish in canals, rivers, channels, and open waters where they feed on plankton and algae. Although considered freshwater species, they may frequent brackish waters as well.

Community Dynamics. Factors affecting the composition of the freshwater fish community in southwest Florida are fluctuating water levels, predation, geographic location, and habitat alteration.

When water levels remain high for an extended time, larger predatory fish move into refuges previously safe from carnivores, and the smaller fish disperse into the new shallows (Kushlan 1976a). The increased habitat space permits the expansion of the fish population. As water levels drop, many fish return to deeper waters such as shallow depressions, wet season ponds, alligator holes, sloughs, and channels. Continued decreases in water levels concentrate physical, chemical and biological materials and may eventually cause a fish kill or feeding frenzy. Fish kills are caused by an increased concentration of nutrients that stimulate algal blooms and subsequent decomposition of the plankton biomass depletes the dissolved oxygen. Another cause of fish kills is when soupy organic ooze (muck) in marshes and swamps, suspended by high waters, concentrates into a water/mud mixture and suffocates fish by lowering the DO or clogging the gill filaments (Crowder 1974). A feeding frenzy occurs in response to an increased density of prey which allows easy and heavy predation by fish, birds, turtles and alligators. The predation does not usually endanger the fish population as much as a fish kill. Kushlan (1974a, 1976a) examined the effects of the fish kill and the feeding frenzy on the fish population's biomass and diversity in the watershed. A mixture of wading birds was the dominant predator of a feeding frenzy that consumed about 75% of the fish biomass but did not eliminate any species. A fish kill caused by low oxygen, on the other hand, destroyed 93% of the fish (biomass) and eliminated 20 of 26 species from the local population (Kushlan 1976a).

In addition to fluctuating water levels and predator-prey interactions, fish community composition differs geographically. To the south, aquatic habitats are primarily "natural" and include dwarf cypress ponds, seasonal marshes and wet prairies, bald cypress strands, ponds, and sloughs. To the north, canals such as those in Golden Gate Estates are prevalent. Usually these canals are relatively shallow and heavily vegetated with aquatic plants. Compared to natural waters further south, these canals have longer hydroperiods, different plant composition, and a difference in water quality; consequently, the fish species and abundance are different. Even further north, strands such as those in Corkscrew Swamp, as well as Lake Trafford and Deep Lake, are different and support a somewhat different fish composition. Also, to the north of the watershed, aquatic habitats are agricultural canals, oxbows, river channels, and residential canals, many of which are intensively maintained for irrigation, flood control, navigation, and public water supply. They exhibit another set of physical/chemical characteristics and a different fish community.

The fourth major factor affecting fish composition and abundance is habitat alteration. Destruction of littoral zones, plant removal, channel dredging, contaminated runoff from agricultural lands and urban centers, and the drawdown of shallow aquifers are major examples of habitat alteration. Habitat alterations may also be affected indirectly by opening undisturbed waters to invasion by exotic plants and fishes. Roadside ditches provide a convenient corridor for transporting species across former obstacles. In at least one case, the introduction of a new species was profitable. Lake Trafford was once noted for poor fishing, but soon after it became infested with a healthy growth of hydrilla the abundance of large-mouth bass increased sharply (SFWMD 1980). Most other examples of habitat alteration are negative. In the Caloosahatchee River, there is little chance of establishing a viable freshwater fishery because of the magnitude and persistence of habitat alteration (Ogilvie 1965).

Intentional and accidental introductions of new fish species has changed the fish populations in the watershed. One particular example of change is the potential competition between members of the native sunfish family (Centrarchidae) and the generally tropical family Cichlidae (Kushlan and Lodge 1974). The latter, which are aquarium fish that have escaped, are the oscar (Astronotus ocellatus), the black acara (Cichlasoma bimaculatum), the jack dempsey (C. octofasciatum), the convict cichlid (C. nigrofasciatum), the fire mouth (C. mecki), and the jewelfish (Hemichromis bimaculatus). One cichlid, the tilapia (Tilopia mossambica), is being cultivated on fish farms for profit in Hendry County (M. Edemoff, personal communication). Kushlan and Lodge (1974) characterize their concern over the spread and impact of the cichlids as follows:

> *Six of the species of exotic fish currently established in southern Florida are members of the tropical secondary freshwater family Cichlidae, a highly diversified group considered to be in many ways the ecological counterpart of the centrarchids. Members of this family are generally well adapted for survival in the Everglades and Big Cypress Swamp due to their ability to withstand drought, their highly developed system of parental care and their general aggressiveness. The Centrarchidae on the other hand comprise a primary freshwater family which reaches the extreme of its range in southern Florida in habitats characterized by seasonal drought to which the family is poorly adapted (Kushlan 1974a). It is anticipated that the spread of cichlids will be at the expense of the native centrarchids. The range expansion of Cichlasoma bimaculatium, already widespread throughout southern Florida, was aided by its tolerance of brackish water and its use of the extensive canal system of the interior. The future of both the exotic and native fish fauna of southern Florida should be a matter of concern.*

7.3.2 Estuarine and Marine Fishes

Marine and estuarine fishes of southwest Florida have been grouped into four community types based on salinity, detritus and substrate (Odum et al. 1982). These are black mangrove basin forest, riverine fringing community, estuarine bay fringing community and oceanic bay fringing community. Representative species for each of the four communities and characteristics that define each community are given in Figure 81.

The euryhaline killifishes (Cyprinodontidae) and livebearers (Poeciliidae) are the dominant fishes of the black mangrove forest. The waters there are shallow and the mud substrate is high in hydrogen sulfide and low in dissolved oxygen (0 to 2 mg/l). The survival of these fish in such waters is dependent upon their high tolerance to low oxygen concentrations, their efficient osmoregulatory system, and their type of parental care (e.g., live bearing). Other important fishes of mangroves are the mosquitofish, marsh killifish, sheepshead minnow, sailfin molly, flagfish, and rainwater killifish.

One of the distinguishing characteristics of these fish is that they complete their life cycles in the same waters. As a group, they represent an important trophic link for many other fish and wildlife. Locally they are top carnivores, but they also feed on mangrove detritus and algae. During high water, fishes of the mangrove community may move downstream where they become the prey of larger fishes such as snook, tarpon, ladyfish, Florida gar, and mangrove snapper. During low water they tend to concentrate in receding pools and ponds where wading birds

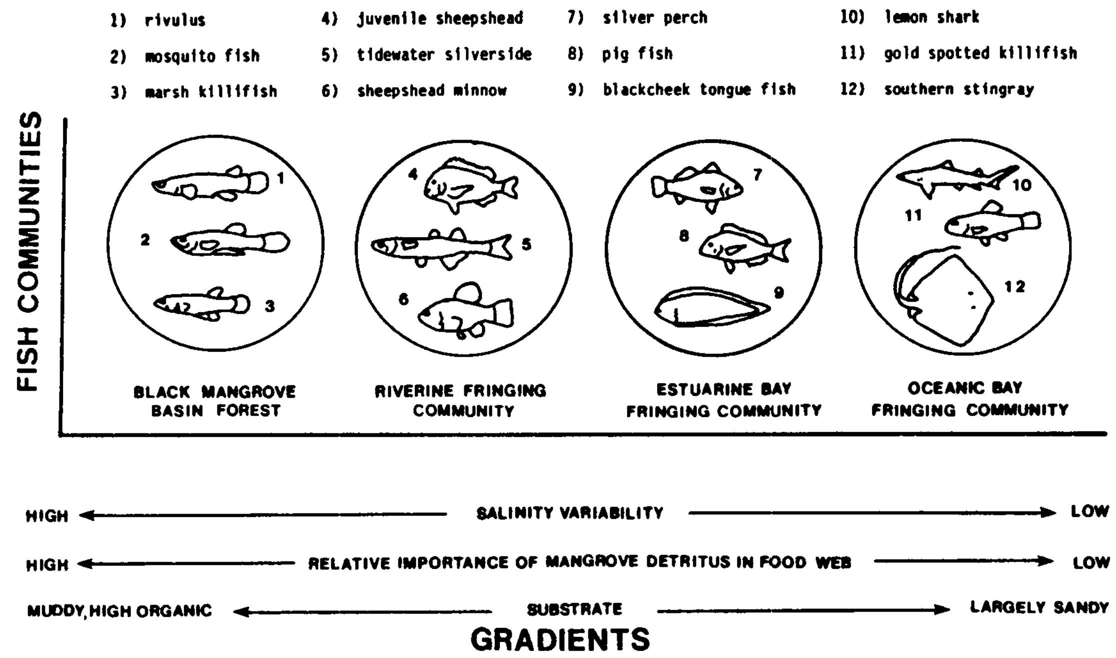


Figure 81. Continuum of mangrove environments and associated fish communities (adapted from Odum et al. 1982).

such as herons, egrets, white ibis, and woodstork feed on them.

The riverine fringing community supports a larger number and wider variety of fish species than the mangrove basin forest community. Seasonal changes in the environment, based largely on freshwater inflow and tidal movement, create conditions that support a wide spectrum of fish species during one or more stages in their life cycles (Odum et al. 1982).

During the wet season, the influx of freshwater in the riverine community attracts a number of freshwater fishes from upstream marshes and sloughs. The Florida gar, several members of the centrarchid family such as the sunfishes and the largemouth bass, the yellow bullhead, the tadpole madtom, the bluefin killifish, and the rivulus are the major species recruited (Odum et al. 1982).

During the dry season (December through May), when freshwater inflow is lowest, higher salinities force freshwater fishes farther upstream and attract marine and brackish-water fishes into tidal streams and rivers. Major invaders are the needlefishes (family Belonidae), stingrays (Dasyatidae), jacks (Carangidae), and barracuda (*Sphyraena barracuda*). Low freshwater inflow along with cool winter temperatures cause the lined sole (*Achirus lineatus*), the hogchoker (*Trinectes maculatus*), the bighead searobin (*Prionotus salmonicolor*), and the striped mullet (*Mugil cephalus*) to move offshore into warmer waters.

In addition to temperature- and salinity-induced fluctuations in fish species composition and abundance, the tidal streams and rivers are nursery grounds to the larvae and juveniles of numerous marine and brackish-water species that spawn further offshore. Larval recruitment generally peaks during late spring and early summer when the salinity of relatively large areas of the estuary are low. It is believed that fluctuating salinities are important to the survival of many larval and juvenile forms by providing a degree of protection from less euryhaline predators. As they grow, the young fish tend to move downstream to higher salinity waters. Another important contributing factor to the basic productivity of tidal streams and rivers is the large quantity of detritus, particularly in late spring when freshwater runoff peaks.

Fish species that commonly spend at least a portion of their life cycles in the mangrove-lined tidal streams and rivers include the killifishes, livebearers, silversides, mojarras, tarpon, snook, snappers, sea catfishes, gobies, porgys, mullet, drums, and anchovies.

The estuarine-bay fringing community is essentially the open estuarine waters associated with a shoreline fringe of mangroves (e.g. Fahkahatchee and Fahka Union Bays, Caloosahatchee River estuary and Naples Bay). The major environmental difference between the estuarine-bay fringing community and the riverine fringing community is the degree of salinity fluctuation. In the bays salinities tend to fluctuate less (freshwater inflow is less direct or less significant), and are more saline than in the rivers. True freshwater forms are rare in the estuarine bay and marine species are more common. The bays also provide seagrass beds, benthic algae, and oyster reefs for food and shelter, which are not available in the tidal rivers.

Estuarine-bay fringing communities are made up of benthic fish, and the mid and upper pelagic water fishes. Dominant families of bottom dwellers are the drums (Sciaenidae), porgys (Sparidae), grunts (Pomadasyidae), mojarras (Gerreidae), snappers (Lutjanidae), and mullet (Mugilidae). Less dominant are the pipefish (Syngnathidae), flounder (Bothidae), sole (Soleidae), searobin (Triglidae), and toadfish (Batrachoididae) families. Fish that are more pelagic are anchovies (Engraulidae), herrings (Clupeidae), and needlefishes (Belonidae). Dominant species of the benthic fauna include the common pinfish (*Lagodon rhomboides*), the silver perch (*Bairdiella chrysura*), the pigfish (*Orthopristis chrysoptera*), and the mojarras (*Eucinostomus gula* and *E. argenteus*). Among the pelagic fish, the dominant species are the bay and striped anchovies *Anchoa mitchilli* and *A. hepsetus*, and the yellowfin and scaled sardines *Brevoortia smithi* and *Harengula pensacolae*.

A summary of relative fish-species abundance from six estuarine bays in the Caloosahatchee River/Big Cypress watershed is given in Table 43. Despite differences in relative species abundance, virtually all the bay communities are dominated by large numbers of only a few species. The twenty-nine species listed accounted for 82% to 96% of all individuals captured. Three species accounted for well over 50% of the fish in the samples, although composition varied from bay to bay.

In addition to significant "between bay" and "between year" differences in species composition and relative abundances, fish populations also vary seasonally as well as spatially within a single estuary. The best documented example of such variation is presented by Yokel (1979) for Naples Bay. This example is particularly appropriate since it comes from an estuary subjected to many of the more common forms of man-induced alterations such as upstream flow control, finger-fill canal construction, seawall construction, shoreline development, sewage disposal, and nonpoint-source runoff. As development pressures intensify along the coast, these alterations are likely to infringe on other estuaries as well.

The bay system is divided into the Gordon River, the lower bay, the canals, the tributary waterways, and a control station in Dollar Bay. Midwater fishes (adults and juveniles) as well as ichthyoplankton were identified and enumerated.

Among the midwater fishes, three recurrent groups were identified. Group 1 consisted of species common to nearly all estuaries of the area, the bay anchovy, striped anchovy, yellowfin menhaden, and silver perch. Group 2 consisted of the dusky anchovy, Atlantic thread herring, and scaled sardine. The last two fish were common to other area estuaries but the dusky anchovy was reported only from Naples Bay.

Table 43. Relative fish species abundance for six estuarine bays within the study area.

Species	Bay System					
	Caloosahatchee[1]	Naples[2]	Rookery[3]	Marco Island[4]	Fahka Union[5]	Fahkahatchee[5]
Pinfish (*Lagodon rhomboides*)	0.7	-	42.0	22.0	1.9	55.8
Bay Anchovy (*Anchoa mitchilli*)	14.1	48.9	-	0.6	-	0.3
Striped Anchovy (*Anchoa hepsetus*)	4.9	7.4	-	-	4.4	-
Dusky Anchovy (*Anchoa lyolepis*)	-	4.5	-	-	-	-
Spotfin Mojarra (*Eucinostomus argentus*)	1.8	-	-	5.4	13.6	23.0
Silver Jenny (*Eucinostomus gula*)	2.1	-	-	26.5	26.4	9.3
Striped Mullet (*Mugil cephalus*)	14.2	-	-	-	0.6	0.2
Yellowfin Sardine (*Brevoortia smithi*)	0.1	21.7	-	-	15.2	0.1
Tidewater Silverside (*Menidia beryllina*)	24.7	-	-	-	-	-
Naked Goby (*Gobiosoma bosci*)	trace	10.3	-	-	-	0.1
Code Goby (*Gobiosoma robustum*)	-	-	-	2.5	4.7	5.2
Silver Perch (*Bairdiella chrysura*)	-	-	2.0	2.0	0.6	12.8
Pigfish (*Orthopristis chyrsoptera*)	-	-	10.0	20.3	-	1.1
Sea Catfish (*Arius felis*)	4.6	-	-	-	1.6	-
Spotted Seatrout (*Cynoscion nebulosus*)	-	-	-	-	0.1	1.1
Sand Seatrout (*Cynoscion arenarius*)	0.8	-	-	-	-	-
Spot (*Leiostomus xanthurus*)	4.1	-	-	-	-	-
Scaled Sardine (*Harengula pensacolae*)	2.5	0.5	-	-	-	0.1
Redfish (*Sciaenops ocellata*)	1.7	-	-	-	-	-
Lane Snapper (*Lutjanus synagris*)	-	-	1.4	3.6	-	-
Grey Snapper (*Lutjanus griseus*)	-	-	-	0.4	0.6	0.3
Croaker (*Micropogon undulatus*)	2.2	-	-	-	-	-
Gulf Pipefish (*Sygnathus scovelli*)	-	-	-	2.1	3.8	2.5
Gulf Toadfish (*Opsanus beta*)	trace	-	-	-	-	2.0
Lined Sole (*Achirus lineatus*)	trace	-	-	1.0	0.9	0.1
White Grunt (*Haemulon plumieri*)	-	-	-	1.2		
Blackcheeked Torquefish (*Symphurus plagiusa*)	trace	-	-	1.9	2.7	0.6
Atlantic Thread Herring (*Opisthonema oglinum*)	-	-	-	-	-	0.5
Hogchoker (*Trinectes maculatus*)	3.3	-	-	-	-	-
TOTAL PERCENT	81.8	93.3	88.0	89.5	96.1	95.1

SOURCE

[1] Gunter and Hall 1963
[2] Yokel 1979
[3] Yokel 1975
[4] Weinstein et al. 1974
[5] Carter et al. 1973

Group 3 consisted of the fringed flounder (*Etropus crossotus*) and porcupine fishes of the family Diodontidae. The frequency of occurrence of these recurrent groups is summarized in Table 44. The ichthyoplankton in seven recurrent groups (Table 45) reflect a generally more diverse group of estuarine dependent fishes.

In addition to these data on recurrent groups, a summary and ranking of locations within the bay are given in Table 46. Tables 44 to 46 show patterns of abundance of fish in the estuary.

The pattern of spawning in estuarine-dependent fishes is first reflected by the abundance of larvae. Fish of recurrent Group 1 apparently spawn in the estuary at about the same time (December through March). In contrast, fish of recurrent Group 2 spawn offshore from May to December, and the larvae immigrate into the estuary from January to April. Based on the appearance of fish larvae, Groups 5 and 6 spawn from June through October. Groups 3 and 7 are relatively scarce and are not as important as the other groups to the estuarine fish fauna.

The recurrent group ranking, and relative diversity and density of the fishes in Table 46 is a summary of the seasonal abundance of midwater fishes and ichthyoplankton in Naples Bay. The abundance of fishes was highest in the lower bay and control stations and lowest in the Gordon River. In contrast, average densities have an inverse relationship with diversity and habitat use. For example, canal stations and the Gordon River tributary rank higher in average fish abundance than the lower bay or control stations, having high numbers of only a few species such as menhaden and anchovies that prefer low salinities, whereas other less euryhaline species are rare or absent.

The oceanic-bay fringing community, exemplified by Florida Bay, is a shallow bay of nearly uniform oceanic salinities, clear waters, and sandy bottoms (Odum et al.

Table 44. Seasonal occurrences of midwater fish groups in Naples Bay (adapted from Yokel 1979).

Species	Salinity (ppt)	Seasonal Occurrence	Station Occurrence[1]	Total Occurrences[1]
GROUP 1				
Anchoa mitchelli	4 - 30	Feb. - Nov. Highest in May - Sept.	16/17	89/187
Anchoa hepsetus				
Brevoortia smithi				
Bairdiella chrysura				
GROUP 2				
Anchoa lyolepis	10 - 15	High in March - May again in October	16/17	73/187
Opisthonema oglinum				
Harengula pensacolae				
GROUP 3				
Etropus corrotus	Unknown (probably >30)	January only	1/17	1/187
Diodontidae				

[1] refers to frequency of occurrence over maximum possible occurrences

Table 45. Seasonal occurrences of icthyoplankton in Naples Bay (adapted from Yokel 1979).

Species	Salinity (ppt)	Highest Seasonal Occurrence[1]	Station Occurrence[1]	Total Occurrences[1]
GROUP 1 *Anchoa mitchilli* *Anchoa* sp. *Gobiosoma bosci* *Gobiosoma* sp. *Microgobius gulosus*	1 - 30	April - November	17/17	102/187
GROUP 2 *Brevoortia* sp. *Orthopristis chyrsoptera* *Lagodon rhomboides* *Leiostomus xanthurus*	0 - 30	January - April	17/17	39/187
GROUP 3 *Albula vulpes* *Chaetodipterus faber* *Sphoeroides* sp.	unknown	August	1/17	1/187
GROUP 4 *Gobiesox* sp. *Hypsoblennius hentzi*	0 - 30	August - April	16/17	57/187
GROUP 5 *Cynoscion nebulosus* *C. arenarius*	1 - 30	June - October	14/17	32/187
GROUP 6 *Symphurus plagiusa*	1 - 30	August - October	13/17	18/187
GROUP 7 *Lucania parva* *Lepomis* sp.	0 - <1	July	1/17	1/187

[1]refers to frequency of occurrence over maximum possible number of occurrences

Table 46. Ranking of recurrent groups of midwater fishes and ichthyoplankton in Naples Bay (adapted from Yokel 1979).

	Area	Average number recurrent groups per station	Average catch per station	Average monthly diversity per station
Midwater Fishes	Control Station	12 (1)	2,048(5)	1.02 (1)
	Lower Bay	10.5 (2)	2,119(4)	0.92 (2)
	Canal Station	10.4 (3)	5,105(2)	0.66 (4)
	Tributary Station	8.5 (4)	5,766(1)	0.67 (3)
	Gordon River	4.5 (5)	4,110(3)	0.63 (5)
Ichthyo-plankton	Lower Bay	17.0 (1)	2,474(5)	1.59 (1)
	Control Station	17.0 (2)	3,726(4)	1.49 (2)
	Canal Station	15.6 (3)	4,764(2)	1.37 (3)
	Tributary Station	12.5 (4)	4,577(3)	1.31 (4)
	Gordon River	7.5 (5)	8,043(1)	1.06 (5)

number in parenthesis refers to ranking within column

1982). Because of its proximity to open ocean it has greater species diversity than any of the four fish communities. In the Caloosahatchee River/Big Cypress watershed these conditions are not clearly met by any body of water, except possibly by Gullivan Bay and the area in the lee of Sanibel Island off Estero Bay. At these locations the substrate is sandy and salinities are uniformly high, but the waters are relatively dark due to organic matter in terrestrial runoff. Because of the lack of a clear distinction between these "bays" and the Gulf, and also to a general lack of information on fishes in these areas, they are considered a part of the offshore ecosystem and are not discussed here.

7.3.3 Endangered Species

Four species of fish listed by Gilbert (1978) as threatened, rare, or of special concern are reported for the Caloosahatchee River/Big Cypress watershed (Table 47). Of these four, only the rivulus (*Rivulus marmoratus*) has been provisionally included in the south Florida fauna (Kushlan and Lodge 1974). All four have been reported from areas both north and south of the watershed; however, their presence in their preferred habitat is not confirmed, but only projected. For all four, the primary range is further south, in the tropics and the Carribean.

7.4 AMPHIBIANS AND REPTILES

Nine amphibian and reptile habitats in the Big Cypress National Preserve (BCNP) are listed in Table 48 (Duever et al. 1979). Although the authors concern themselves only with the fauna of the BCNP, their compendium of information on species abundance and utilization is the most thorough region-wide information available. For this reason we provisionally use their information to include the entire watershed, although this will surely result in some inaccuracies and omissions.

Table 47. Endangered, threatened, rare, or special concern species of fishes found in the Caloosahatchee River/Big Cypress watershed (adapted from Gilbert 1978).

Species	Status	Habitat
Rivulus (*Rivulus marmoratus*)	Threatened	Mangroves, salt marshes mosquito ditches
Opossum pipefish (*Oostethis lineatus*)	Rare	Freshwaters, brackish waters, usually associated with dense vegetation.
Mountain mullet (*Agonostomus monticola*)	Rare	Freshwater to estuarine, probably catadromous.
River Goby (*Awaous tojasica*)	Rare	Small to large streams, with clean water, slow to moderate current.

Table 48. Habitat importance to amphibian and reptile species in the Big Cypress watershed (adapted from Duever et al. 1979).

	HABITAT								
Common Name (Species Name)	Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes
Two-toed Amphiuma (*Amphiuma means*)			1	2	2	1			
Greater Siren (*Siren lacertina*)			1	2	2	2			
Everglades Dwarf Siren (*Pseudobranchus striatus belli*)			1	2	2	2			
Peninsula Newt (*Notophthalmus viridescens piaropicola*)			1	2	2	1			
Southern Toad (*Bufo terrestris*)	2F	3F	2B	1B	2B	2B			
Oak Toad (*Bufo quercicus*)	3F	2F	2B			2B			
Florida Cricket Frog (*Acris gryllus dorsalis*)			1	1	2	3			
Green Treefrog (*Hyla cinerea*)	1F	2F	2	3	3	2			
Barking Treefrog (*Hyla gratiosa*)	2F	2F	2B		2B	2B			
Pine Woods Treefrog (*Hyla femoralis*)	3F	1F	1B	1	1B	2B			
Squirrel Treefrog (*Hyla squirella*)	3F	3F	2	2	1	2			
Little Grass Frog (*Limnaoedus ocularis*)			2	2	2	3			
Florida Chorus Frog (*Pseudacris nigrita verrucosa*)			2	2	2	1			
Eastern Narrow-mouth Toad (*Gastrophryne carolinensis*)	1F	1F	2B			3			
Southern Leopard Frog (*Rana utricularia*)	1F	1F	2	2	3	3			
Pig Frog (*Rana grylio*)			1	2	3	1			
Florida Gopher Frog (*Rana areolata aesopus*)	1				3B	3B			
American Crocodile (*Crocodylus acutus*)							4		
American Alligator (*Alligator mississipiensis*)			2	3	3	1	1		
Florida Snapping Turtle (*Chelydra serpentina osceola* spp.)			2	3	3	2			
Stinkpot (*Sternotherus odoratus*)			1	2	3	1			
Florida Mud Turtle (*Kinosternon subrubrum steindachneri*)			1	1	3	2		1	
Striped Mud Turtle (*Kinosternon bauri*)			2	3	1	1			
Florida Box Turtle (*Terrapene carolina bauri*)	3	3				1F			
Diamondback Terrapin (*Malaclemys terrapin macrospilota*)							3	2	3
Florida Redbellied Turtle (*Chrysemys nelsoni*)			1	3	3	1			
Florida Chicken Turtle (*Deirochelys r. chrysea* spp.)			1	2F	3	3			
Gopher Tortoise (*Gopherus polyphemus*)	4						2		
Florida Soft-shelled Turtle (*Trionyx ferox*)			1	3	3	1			
Green Anole (*Anolis carolinensis carolinensis*)	2	2	2	2	2	2	2	2	2
Six-lined Racerunner (*Cnemidophorus sexlineatus sexlineatus*)	4						3		
Florida Scrub Lizard (*Sceloporus woodi*)	1								
Ground Skink (*Scincella lateralis*)	3	2					2		
Southeastern Five-Lined Skink (*Eumeces inexpectatus*)	2	3	2	3			1		
Eastern Glass Lizard (*Ophisaurus ventralis*)	3	1				1			
Slender Glass Lizard (*Ophisaurus attenuatus*)	3	1				1	2		
Florida Green Water Snake (*Natrix cyclopion floridana*)			1	2	3	2			
Florida Banded Water Snake (*N. fasciata pictiventris*)			1	2	2	1			

(continued)

Table 48 (Concluded).

Common Name (Species Name)	HABITAT Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes
Mangrove Water Snake (*Natrix fasciata compressicauda*)							3	2	3
South Florida Black Swamp Snake (*Seminatrix pygaea*)			1	2	3	2	2		
Striped Swamp Snake (*Liodytes alleni*)				1	2	2			
Florida Brown Snake (*Storeria dekayi vicia*)	1	3			1				
Eastern Garter Snake (*Thamnophis sirtalis sirtalis*)	1	1	1	1	2	2			
South Florida Ribbon Snake (*Thamnophis sauritus sauritus*)		2	2	2	2	2	1	1	1
Eastern Hognose Snake (*Heterodon nasicus*)	3	2					2		
Southern Ringneck Snake (*Diadophis punctatus punctatus*)	1	3		1			1		
Eastern Mud Snake (*Farancia abacura*)			2	3	3				
Southern Black Racer (*Coluber constrictor priapus*)	2	2	1	1	1	2	2		
Everglades Racer (*Coluber constrictor paludicola*)	2	2	1	1	1	2	2		
Eastern Coachwhip (*Masticophis flagellum flagellum*)	4						2		
Rough Green Snake (*Opheodrys aestivus*)	1	2	1	2	2	2	1	1	1
Eastern Indigo Snake (*Drymarchon corais couperi*)	3	2	1			1	2		
Corn Snake (*Elaphe guttata guttata*)	3	2					2		
Yellow Rat Snake (*Elaphe obsoleta quadrivittata*)	2	3	2	3			2		
Everglades Rat Snake (*Elaphe obsoleta rossalleni*)	2	3	2	3			1	2	
Florida Kingsnake (*Lampropeltis getulus floridana*)	1	1	2			1	2	1	
Scarlet Kingsnake (*Lampropeltis triangulum elapsoides*)	4	1						2	
Scarlet Snake (*Cemophora coccinea*)	3	2						2	
Florida Cottonmouth (*Agkistrodon piscivorus conanti*)		1	2	3		2	1	1	1
Dusky Pygmy Rattlesnake (*Sistrurus miliarius barbouri*)	3	2					2F	1	
Eastern Diamondback Rattlesnake (*Crotalus adamanteus*)	3	1						2	
Eastern Coral Snake (*Micrurus fulvius fulvius*)	3	2						2	
Atlantic Hawksbill (*Eretmochelys imbricata imbricata*)		Occasionally in Estuarine and Coastal Waters							
Atlantic Ridley (*Lepidochelys kempii*)		Occasionally in Estuarine and Coastal Waters							
Atlantic Loggerhead (*Caretta caretta caretta*)		Occasionally in Estaurine and Coastal Waters							
Atlantic Green Turtle (*Chelonia mydas mydas*)		Occasionally in Estuarine and Coastal Waters							
Atlantic Leatherback (*Dermochelys coriacea*)		Occasionally in Estuarine and Coastal Waters							

1 = Habitat rarely used.
2 = Habitat commonly used.
3 = Habitat heavily used (elimination of habitat could reduce species population in the general area).
4 = Habitat critical for continuation of species in the general area.
Blank column - Habitat probably not used.
F = Feeding habitat only, B = Breeding habitat only.
No letter - Habitat used for both breeding and feeding.

The herptilian fauna of the Caloosahatchee River/Big Cypress watershed has been studied by Duellman and Schwartz (1958) and more recently by Crowder (1974). Other significant studies and summaries of watershed herptiles include Carr and Goin (1955) and Conant (1975). The latter work contains a rough approximation of species distribution. According to Crowder (1974), the relative distribution and abundance of herptiles has been greatly affected by massive habitat alterations in south Florida. The destruction of trees and islands, hydroperiod alterations, and agricultural and urban development favor the spread of some herptilian species while restricting the range and survival of others.

Amphibians in the watershed include nine species of frogs, three species of toads (order Anura) and four species of salamanders (order Caudata). All are freshwater forms and are almost exclusively upland in habitat preference.

The three orders of reptiles in the watershed are the Crocodylia, the Testudines (turtles), and the Squamata (scaled reptiles). The latter is divided into two suborders, the snakes (Serpentes) and the lizards (Lacertilia). The most common reptiles in the Caloosahatchee River/Big Cypress watershed are the snakes (30 species), the turtles (16 species), and the lizards (8 species).

All but three of the 30 species of snakes belong to the family Colubridae. Particularly abundant are those snakes with an affinity for water. Five species of water snakes (genus *Natrix*), two species of swamp snakes, and a variety of others that possess a broad habitat tolerance are reported. The poisonous eastern coral snake (*Micrurus fulvius fulvius*) is one of the more conspicuous members of this family. Other poisonous snakes are water moccasins, dusky pygmy rattlers, and eastern diamondback rattlers, all of which belong to the family Viperidae.

Lizards are represented by four families, the Iguanidae, the Teeidae, the Scincidae, and the Anguidae. The common anole (*Anolis carolinensis carolinensis*) and the rare Florida scrub lizard (*Sceloperus woodi*) are members of the Iguanidae. The fast moving sixlined racerunner is the only member of the family Teeidae. The three species of skinks (Scincidae) in the watershed are southeastern fivelined skink, the ground skink, and the mole skink. The glass lizards (Anguidae) are represented by three species, the eastern glass lizard, which is predominantly a wetland dweller, and the slender glass lizard and island glass lizard, both of which prefer dry grasslands and pine woods.

Freshwater turtles consist of three species of mud turtles (family Kinosternidae), five species of the family Emydidae, and one soft-shell turtle (family Trionychidae). The one brackish-water turtle is the mangrove terrapin (*Malaclemys terrapin rhizopharum*). The larger freshwater turtles are the Florida snapper (*Chelydra serpentina osceola*) (family Chelydridae) and the gopher tortoise (*Gopherus polyphemus*) of the family Testudinae. The largest turtles, the sea turtles, are found in estuarine waters or along the beaches. The five species in southwest Florida are the Atlantic green (*Cholonia mydas mydas*), the Atlantic hawksbill (*Eretmochelys imbricata imbricata*), the Atlantic ridley (*Lepidochelys kenipii*), the Atlantic loggarhead (*Caretta caretta caretta*), and the Atlantic leatherback (*Dermochelys coriacea*). The first four of these species belong to the family Chelonidae; the last one belongs to the family Dermochelyidae.

In all, 16 amphibians and 48 reptiles are listed in Table 48 for the watershed. This compares to 17 amphibians and 56 reptiles reported in the lower Everglades (Schomer and Drew 1982). Thirty-two of these species (all reptiles) frequent coastal and brackish water habitats; sixteen species exclusively prefer terrestrial or freshwater habitats. Only six species, the diamondback terrapin, the crocodile, and four marine turtles, live exclusively in coastal habitats.

The Florida Committee on Rare and Endangered Animals (1978) lists 10 species of amphibians and reptiles that are endangered, threatened, rare, or of special concern in the Caloosahatchee River/Big Cypress watershed (Table 49). Conspicuous on this list are all five sea turtles. Commercial exploitation of adults in the Caribbean Sea, high egg mortality rates on Florida and other beaches, and entanglement or entrapment in nets are prime contributors to the decline of these species.

7.5 BIRDS

Birds in the watershed are grouped into six guilds based on general similarities in habital preference (Odum et al. 1982). The guilds are as follows:

(1) forest-dwelling arboreal birds,
(2) wading birds,
(3) floating and diving water birds,
(4) birds of prey,
(5) probing shorebirds, and
(6) aerially searching birds.

These guilds are discussed here because they are more useful than

Table 49. Endangered, threatened, rare, and special-concern amphibian and reptile species in the Caloosahatchee River/Big Cypress watershed (adapted from McDiarmid 1978).

Common Name	Scientific Name	Status
Atlantic hawksbill	Eretmochelys imbricata imbricata	Endangered[1,3]
Atlantic green turtle	Chelonia mydas mydas	Endangered[3]
Atlantic ridley	Lepidochelys kempii	Endangered[1,3]
Florida gopher frog	Rana areolata aesopus	Threatened[3]
Gopher tortoise	Gopherus polyphemus	Threatened[4]
Atlantic loggerhead	Caretta caretta caretta	Threatened[4]
Mangrove terrapin	Malaclemys terrapin rhizophorarum	Rare
Atlantic leatherback	Dermochelys coriacea	Rare[1]
Florida scrub lizard	Sceloporus woodi	Rare
American alligator	Alligator mississippiensis	Special concern[1,2,4]
Eastern indigo snake	Drymarchon corais couperi	Special concern[2,4]

[1] Listed as Endangered and Threatened Wildlife and Plants, U.S. Dept. of Interior Fish and Wildlife Service. Fed. Register, Vol. 42, No. 135:36431, 1977.
[2] Listed as Threatened in above publication.
[3] Listed as Endangered in Wildlife Code, Florida Game and Freshwater Fish Commission. Effective July 1977.
[4] Listed as Threatened in above publications.

Robertson and Kushlan's (1974) broad delineation between land birds and water birds.

7.5.1 Arboreal Birds

Arboreal guilds are forest dwellers, some of which may also frequent the forest edge and other inland habitats such as wet prairies, sawgrass marshes, urban environments, and agricultural lands. This guild of birds consists largely of the perching birds (order Passeriformes) and members of the orders Galliformes (wild turkey, northern bobwhite), Columbiformes (pigeons and doves), Cuculiformes (cuckoos and anis), Caprimulgiformes (goatsuckers, i.e., nighthawks, chuck-wills-widow), Apodiformes (swifts and hummingbirds), and Piciformes (woodpeckers).

An accurate listing of the species of this guild in southwest Florida is difficult to obtain. Robertson (1953) and Robertson and Kushlan (1974) have compiled and reviewed data for the entire south Florida peninsula. The latter review summarizes a considerable data base compiled by numerous scientists, as well as amateur bird watchers, and gives many useful observations and hypotheses on the ecology and biogeography of land birds yet the raw data are not presented on specific sitings in south Florida. Duever et al. (1979) list 41 arboreal and terrestrial species that breed in the Big Cypress National Preserve (Table 50) and 15 that do not breed there (Table 51). They note that

Table 50. Habitat use and importance to breeding arboreal birds in the watershed (adapted from Duever et al. 1979).

	Habitat								
Species	Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes
Mourning Dove (*Zenaida macroura*)	3	2				1F			
Common Ground Dove (*Columbina passerina*)	3	2	1F						
Mangrove Cuckoo (*Coccyzus minor*)		1					4		
Yellow-billed Cuckoo (*Coccyzus americanus*)		2	2	2					
Chuck-will's-Widow (*Caprimulgus carolinensis*)	2F4B	2F1B	2F	1	2F	2F	1F		
Common Nighthawk (*Chordeiles minor*)	2F4B	2F1B	2F		2F	2	2F	2F	2F
Ruby-throated Hummingbird (*Archilochus colubris*)	2	1	1	2			1F		
Northern Flicker (*Colaptes auratus*)	3	2	1	1					
Pileated Woodpecker (*Dryocopus pileatus*)	2	2	2	2			1		
Red-bellied Woodpecker (*Melanerpes carolinus*)	2	2	2	2			2		
Redcockaded Woodpecker (*Dendrocopos borealis*)	4								
Downy Woodpecker (*Dendrocopos pubescens*)	3	1	1	2					
Eastern Kingbird (*Tyrannus tyrannus*)	2	1B	1	2					
Gray Kingbird (*Tyrannus dominicensis*)							4		

(continued)

Table 50 (Concluded).

Species	Habitat Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes
Great Crested Flycatcher (*Myiarchus crinitus*)	1	1	1	3					
Purple Martin (*Progne subis*)	2F4B	2F	2F	2F	2F	2F	2F	2F	2F
Blue Jay (*Cyanocitta cristata*)	2	2	1	1					
American Crow (*Corvus brachyrhynchos*)	3	1	1			1			
Fish Crow (*Corvus ossifragus*)	2	2					2F	1F	1F
Tufted Titmouse (*Parus bicolor*)	1	2	2	2			1		
Brown-headed Nuthatch (*Sitta pusilla*)	4								
Carolina Wren (*Thryothorus ludovicianus*)	2	2	2	2	2		1		
Northern Mockingbird (*Mimus polyglottos*)	3		2						
Brown Thrasher (*Toxostoma rufum*)	3		2						
Eastern Bluebird (*Sialia sialis*)	4								
Blue-gray Gnatcatcher (*Polioptila caerulea*)	1	1	2	2	2				
Loggerhead Shrike (*Lanius ludovicianus*)	3		2	1F					
White-eyed Vireo (*Vireo griseus*)	1	1	2	1	2		2		
Prothonotary Warbler (*Protonotaria citrea*)			1	2	2				
Northern Parula (*Parula americana*)	2		2	2				1F	
Common Yellowthroat (*Geothlypis trichas*)	1F		1F	1	3	2	1	1	1
Pine Warbler (*Dendroica pinus*)	3			2					
Eastern Meadowlark (*Sturnella magna*)	4				1	1	2		
Redwinged Blackbird (*Agelaius phoeniceus*)			1		3	2		2	
Common Grackle (*Quiscalus quiscula*)	2	2	2	2	1	1			
Great-tailed Grackle (*Cassidix mexicanus*)	1F		2F		2F3B	2		2F1B	
Northern Cardinal (*Cardinalis cardinalis*)	2	2	1	2			1		
Rufous-sided Towhee (*Pipilo erythrophthalmus*)	3	2					1		
Bachman's Sparrow (*Aimophila aestivalis*)	4								
Northern Bobwhite (*Colinus virginianus*)	3	1							
Wild Turkey (*Meleagris gallopavo*)	3	2	2F						

1 = Habitat rarely used.
2 = Habitat commonly used.
3 = Habitat heavily used (elimination of habitat could reduce species population in the general area.)
4 = Habitat critical for continuation of species in the general area.
Blank column - Habitat probably not used.
B = Breeding habitat only.
F = Feeding habitat only.
No letter - Habitat used for both breeding and feeding.

Table 51. Habitat use and importance to nonbreeding arboreal birds (adapted from Duever et al. 1979).

	Habitat								
Species	Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes
Smooth-billed Ani (*Crotophaga Ani*)	2	2		2	1	1			
Whip-poor-will (*Caprimulgus vociferus*)	2	2	2	2	2	2	2	2	2
Yellow-bellied Sapsucker (*Sphyrapicus varius*)	2	2	2	2					
Hairy Woodpecker (*Picoides villosus*)	3		1	1			1		
Eastern Phoebe (*Sayornis phoebe*)	2		2	2	1		2		
Tree Swallow (*Tachycineta bicolor*)	2	2	2	2	2	2	2	2	2
Marsh Wren (*Cistothorus palustris*)					3	3		2	2
Sedge Wren (*Cistothorus platensis*)					2	2		1	1
Gray Catbird (*Dumetella carolinensis*)	2	2	1	2			1		
American Robin (*Turdus migratorius*)	2	2	2	2			2		
Cedar Waxwing (*Bombycilla cedrorum*)	2	2	2	2					
Solitary Vireo (*Vireo solitarius*)	1	2	1	2			1		
Migrating Warblers	2	2	2	2	2	1	2	1	1
Rusty Blackbird (*Euphagus carolinus*)			2	3					
Painted Bunting (*Passerina ciris*)	3	1							
Upland Sparrows	3	2							
Swamp Sparrow (*Melospiza georgiana*)				2	2	1		1	1

No letter - Habitat used for both breeding and feeding.
Blank column - Habitat probably not used.
1 = Habitat rarely used.
2 = Habitat commonly used.
3 = Habitat heavily used (elimination of habitat could reduce species population in the general area).
4 = Habitat critical for continuation of species in the general area.

despite input from the most knowledgeable of local ornithologists, the list is preliminary, which is at least partially confirmed by noting many minor inconsistencies between the above references and that of the South Florida Research Center (SFRC 1980). From inland habitats (exclusive of mangroves and pinelands) in the nearby east Everglades, SFRC (1980) lists 101 species that use the area at some time of the year. A list of 71 species that utilize the Florida mangrove was prepared by Odum et al. (1982), but much of the area is north or east of southwest Florida. Despite these limitations many general observations are possible on this guild of birds.

The arboreal birds of the Caloosahatchee River/Big Cypress watershed consists of a core of about 35 to 40 species of year-round residents. Other species in the watershed are grouped as winter residents, summer residents, and migrants. About 60% of bird species reported in south Florida are migratory (Robertson and Kushlan 1974).

Historically and ecologically, the south Florida peninsula is a relatively unfavorable area for the proliferation of arboreal birds. In addition to the areal paucity of true upland terrestrial habitats, the area is generally regarded as climatically unstable, in the long-term geological sense. These two factors, along with the relative isolation of the peninsula, are believed to be the major reasons for a low diversity of arboreal fauna in south Florida. Robertson and Kushlan (1974) summarize the situation 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.*

The "unfavorable climatic trend" refers to the sea-level fluctuations of the Pleistocene era that alternately drained and flooded the south Florida peninsula.

This trend is graphically expressed in Figure 82, which shows 30 to 50 species of arboreal birds breed in southwest Florida. Farther north as many as 65 to 70 breeding species are observed. This north-south trend is especially pronounced with passerine birds, whereas the number of nonpasserine species compares fairly well to other locations within the same latitudes.

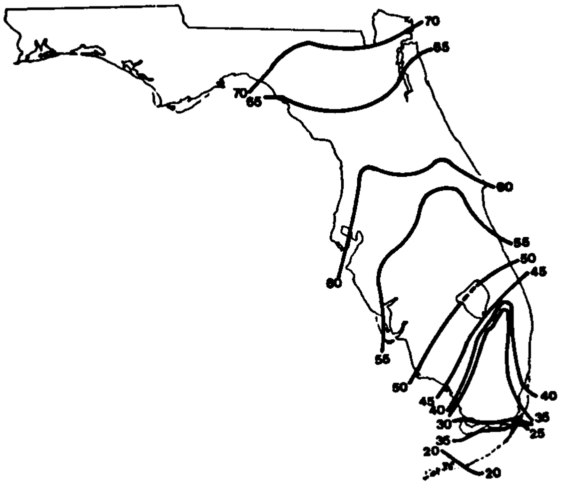


Figure 82. Numbers of species of breeding land birds in the Florida peninsula (adapted from Robertson and Kushlan 1974).

Although the previous numbers of breeding arboreal birds in southwest Florida are similar to the list of Duever et al. (1979), they do not describe the seasonal variation of species composition and abundance as listed in Table 50 and illustrated in Figure 83. According to Figure 83, the number of arboreal birds is lowest in the summer when most of

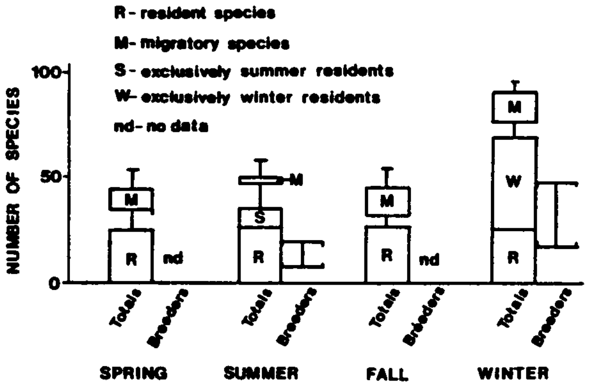


Figure 83. Seasonal habitat use by birds of various species (adapted from Robertson and Kushlan 1974).

the 27 migratory species are far north. The number of species breeding during the summer is about 30% to 60% fewer than in the winter. Noteworthy among the eight resident breeders are the common nighthawk (Chordeiles minor) and the eastern kingbird (Tyrannus tyrannus). The numbers of species and individuals are lowest in the summer.

In winter, the number of species and numerical abundance increase significantly. SFRC (1980) lists 44 species of winter residents. In the fall and spring, migrant populations are probably intermediate in numbers of species and abundance.

With regard to habitat use by both the communities, most used by resident and migratory species are pinelands, mangrove forests, and cypress or mixed-swamp forests. This habitat selection is probably a function of food supply (primarily insects, berries, and seeds) and structural diversity.

7.5.2 Wading Birds

Twenty-three species of wading birds, mostly herons (order Ciconiiformes), and some cranes and their allies (order Gruiformes), comprise this group (Table 52), but only eighteen species breed in southwest Florida (Duever et al. 1979).

Wading birds are not particularly abundant in the interior wetlands of south Florida. Only 15 species have been reported there compared to 26 species reported for nearby Cuba. The difference is partly explained by a historically unreliable freshwater wetland habitat that responded to sea-level fluctuations of the Pleistocene era. In contrast, the area of saltwater and brackish wetlands have been much more constant. Robertson and Kushlan (1974) speculate that this area is probably best used 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.

In the last 150 years, wading bird numbers have fluctuated widely due to a combination of factors, some natural and some human induced. In 1870 south Florida supported a population of approximately 2,500,000 wading birds (Robertson and Kushlan 1974). By the early 1900's the population had been reduced to about 500,000, mostly by plume hunters. Another generally less important factor was early coastal development which eliminated some nesting habitat. The species that probably suffered the most from plume hunting was the roseate spoonbill (Ajaia ajaja). Although it is listed in Table 52 as a resident, its distribution in south Florida is limited to Florida Bay.

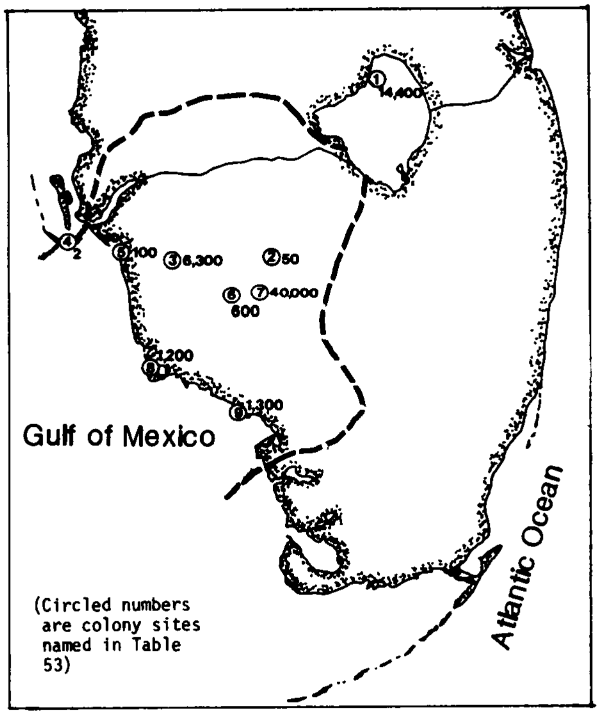
When commercial hunting, primarily for bird plumes, was banned, the wading bird populations increased to about 1,200,000 birds by 1935. In the background, however, the agricultural and urban development of south Florida was beginning in earnest. Within a matter of 25 years, as water control structures were built and lands drained, crops planted, and coastal cities constructed, large areas of wading bird habitat were altered. By 1960 only about 300,000 wading birds remained in south Florida. More recently, the population has stabilized near 125,000 birds (Robertson and Kushlan 1974, Kushlan and White 1977).

Table 52. Habitat use and importance to wading birds (adapted from Duever et al. 1979).

	HABITAT									
Species	Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes	Food Source
Reddish Egret* (*Egretta rufescens*)							3	3		Fish
American Bittern* (*Botaurus lentiginosus*)				1	3	1				Crayfish, frogs
Roseate Spoonbill* (*Ajaia ajaja*)							3	3	1	Shrimp, fish, aquatic insects
Virginia Rail* (*Rallus limicola*)					3	2		1		Berries, insects
Sora* (*Porzana carolina*)					3	2		1		Insects
Great Egret (*Casmerodius albus*)			2F	2	2F3B	2F1B	2	2F	1F	Fish
Snowy Egret (*Egretta thula*)			1	1F	2F4B	2F	2	2F	1F	Fish
Cattle Egret (*Bubulcus ibis*)	3F			1B	3B	2	3B	1	1	Fish, insects
Great Blue Heron (*Ardea herodias*)			2F1B	2	2	2F1B	2	2F	1F	Fish
Little Blue Heron (*Egretta caerulea*)			2	2	2F3B	2F1B	2B	2F	1F	Fish
Tricolored Heron (*Egretta tricolor*)			1	1F	2F3B		2	2F		Fish
Green-backed Heron (*Butorides striatus*)			1	2	2F3B	1	2	2F		Fish
Black-crowned Night-Heron (*Nycticorax nycticorax*)			1F	2	2F3B	1F	1	1F		Fish, crustaceans, frogs, mice
Yellow-crowned Night-Heron (*Nycticorax violaceus*)			1	2	2	1F	2	1F		Fish, crayfish, crabs
Least Bittern (*Ixobrychus exilis*)					4		1F	1F		Fish
Wood Stork (*Mycteria americana*)			2F	1F3B	2F	1F	2	2F		Fish
Glossy Ibis (*Plegadis falcinellus*)					3		1	3F		Fish
White Ibis (*Eudocimus albus*)			2F1B	1	3		2	3F	1F	Fish, crabs, frogs
Sandhill Crane (*Grus canadensis*)					2	3		2		Roots, rhizones of Cyperus and Sagittaria
Limpkin (*Aramus guarauna*)				1	3	1				Snails
Black Rail (*Laterallus jamaicensis*)					1	1		3	3	Insects
Clapper Rail (*Rallus longirostris*)							1	3	3	Insects
King Rail (*Rallus elegans*)					4					Crustaceans, insects

*Non-breeding
1 = Habitat rarely used.
2 = Habitat commonly used.
3 = Habitat heavily used (elimination of habitat could reduce species population in the general area).
4 = Habitat critical for propagation of the species in the general area.
Blank column - Habitat probably not used.
B = Breeding habitat only.
F = Feeding habitat only.
No letter - Habitat used for both breeding and feeding.

In 1974, eight colonies of wading-bird sites (Figure 84) supported approximately 25,000 nests (Table 53) in the Caloosahatchee River/Big Cypress watershed (Kushlan and White 1977). Inland the white ibis (*Eudocimus albus*) is the most numerous wader, followed by the cattle egret (*Bubulcus ibus*), the wood stork (*Mycteria americana*), the great egret (*Casmerodius albus*), the snowy egret (*Leucophyx thula*), and the little blue heron (*Egretta caerulea*). In contrast to other areas of Florida, wading birds much prefer freshwater wetlands to brackish-water wetlands. About 95% of the nests are in freshwater wetlands of the Caloosahatchee River/Big Cypress watershed. In brackish-water sites



(Circled numbers are colony sites named in Table 53)

Figure 84. Number of wading birds at colony sites active in 1974-1975 (adapted from Kushlan and White 1977).

the Louisiana or Tricolored heron (*Egretta tricolor*) is the most abundant species, followed by the cattle egret and the great egret. Other species are the great blue heron (*Ardea herodias*), the little blue heron, the snowy egret, and the black-crowned night heron (*Nycticorax nycticorax*).

The colony sites used by wading birds in the Caloosahatchee River/ Big Cypress watershed are delineated in Table 54. These figures are subject to considerable error because the location of nesting sites varies from year to year (Kushlan and White 1977).

Breeding wading birds in south Florida use freshwater wetlands when conditions there are right for feeding and reproduction (Robertson and Kushlan 1974). In drought or flood years wading birds tend to colonize the more stable and productive mangroves (Odum et al. 1982).

Canals drastically shrink or replace the shallow ponds, marshes, wet prairies, and sloughs that produce large populations of small fish and crayfish fed on by wading birds. The newer habitat, canals, is usually too steep sided and deep to be used by wading birds; thus a vital feeding habitat is removed from the watershed.

Table 53. Colony sites and number of wading bird nests in southern Florida, September 1974 to August 1975 (adapted from Kushlan and White 1977).

Colony Site[1]	Colony Location	Month of Nesting	White Ibis	Wood Stork	Great Blue Heron	Great Egret	Snowy Egret	Little Blue Heron	Tricolored Heron	Cattle Egret	Other Wading Bird Species
2. Sadie Cypress	Big Cypress Swamp	XII		27							
3. Corkscrew	Big Cypress Swamp	XII		3,000		150					
4. Tarpon Bay	Sanibel Island	V			1						
5. Estero Bay	Estero	III			1	2	8	2	27	12	B
6. Sunniland Grade	Big Cypress Swamp	IX				300					
7. Okaloacoochee	Big Cypress Swamp	IX	12,000			125	150	25		8,000	
8. Big Marco Pass	Marco Island	I,III,VI				28	29	7	278	274	
9. Chokoloskee	Everglades Nat'l Park	III,VI				252			416	3	
	Totals		12,000	3,027	2	857	187	34	721	8,289	

[1] Colony sites are shown in Figure 84
B - Black crowned night-heron

Table 54. Seasonality of nesting by wading birds and associated species in south Florida (adapted from Odum et al. 1982).

	Months											
Species	S	O	N	D	J	F	M	A	M	J	J	A
White Ibis	—	—	—	—			—	—	—	—	—	—
Wood Stork				—	—	—	—					
Roseate Spoonbill			—	—	—	—	—	—				
Great Blue/White Heron			—	—	—	—	—	—	—	—		
Great Egret	—	—	—	—	—	—	—	—	—	—	—	—
Little Blue Heron							—	—	—	—	—	—
Cattle Egret	—	—	—				—	—	—	—	—	—
Double-crested Cormorant	—	—	—	—	—	—	—	—	—	—	—	—
Brown Pelican				—	—	—	—	—	—	—	—	—

Hydrologic conditions also affect the seasonal distribution and abundance of wading birds. During the wet season, water levels may be too high to favor wading birds. If water levels remain high, the fish disperse into the marshes and wet prairies and are more difficult for the wading birds to catch (Kushlan 1976b). It also stimulates competition from bass, sunfish, pickerel, and other large predators. High waters also may cause an excessive buildup of a soupy ooze in the marshes. As water levels drop (caused by the dry season or unseasonable drought) the accumulated ooze creates a water/mud mixture that may kill fish by depleting the dissolved oxygen and clogging gill filaments, even when water levels do not appear to be dangerously low (Crowder 1974).

Detailed studies on the ecology of wading birds are scarce. Two species, the wood stork (Kahl 1964, Kushlan et al. 1975, Ogden et al. 1976) and the white ibis (Kushlan 1974b, 1976a, 1977a, 1977b, 1979) are the most extensively studied. For a brief review of the ecology, life history, and status of these species refer to Kale (1978). In addition to a brief summary of each species, numerous references containing detailed ecological information are listed.

7.5.3 Floating and Diving Water Birds

Seventeen species of floating and diving water birds which utilize the aquatic habitats of the Big Cypress National Preserve are listed in Table 55 (Duever et al. 1979). This list is incomplete because it omits the green-winged teal (Anas crecca), ruddy duck (Oxyura jamaicensis), hooded merganser (Lophodytes cucullatus), horned grebe (Podiceps auritis), white pelican (Pelecanus erythrorhynchos), mallard (Anas platyrhynchos), American black duck (Anas rubripes), gadwall (Anas strepera), northern pintail (Anas acuta), red-head (Aythya americana), canvasback (Aythya valisneria), and bufflehead (Bucephala albeola). These species are listed as occurring in nearby areas (SFRC 1980, Odum et al. 1982) and some are certain to frequent the preserve or the watershed.

Birds of this guild come from five taxonomic orders, the pelicans

Table 55. Habitat use and importance to floating and diving birds in the Big Cypress watershed (adapted from Duever et al. 1979).

Species	Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes
Common Loon (*Gavia immer*)							2		
American Wigeon (*Anas americana*)					2				
Northern Shoveler (*Anas clypeata*)					2				
Blue-winged Teal (*Anas discors*)					3			2	1
Fulvous Whistling-Duck (*Dendrocygna bicolor*)					2				
Ring-necked Duck (*Aythya collaris*)					1			2	
Lesser Scaup (*Aythya affinis*)							2	2	
Red-breasted Merganser (*Mergus serrator*)							3	1	
American Coot (*Fulica americana*)					2		2	1	1
Pied-billed Grebe (*Podilymbus podiceps*)					4	1		1	
Brown Pelican (*Pelecanus occidentalis*)							2F4B		
Anhinga (*Anhinga anhinga*)				2	3	1			
Mottled Duck (*Anas fulvigula*)					3	1		2	1
Wood Duck (*Aix sponsa*)			1	3F4B	3F				
Common Moorhen (*Gallinula chloropus*)					3	1			
Purple Gallinule (*Porphyrula martinica*)					4				
Double Crested Cormorant (*Phalacrocorax auritus*)							3		

1 = Habitat rarely used.
2 = Habitat commonly used.
3 = Habitat heavily used (elimination of habitat could reduce species population in the general area).
4 = Habitat critical for continuation of species in the general area.
Blank column - Habitat probably not used.
B = Breeding habitat only.
F = Feeding habitat only.
No letter - Habitat used for both breeding and feeding.

and allies (Pelecaniformes), the waterfowl (Anseriformes), the cranes and their allies (Gruiformes), the loons (Gaviiformes), and the grebes (Podicipediformes). The pelicans are the brown (*Pelecanus occidentalis*) and the white (*P. erythrorhyncus*). Aside from the obvious morphologic differences between the brown and white pelican, they differ in their methods of feeding. The brown pelican dives into estuary and nearshore waters from heights averaging 10 m (30 ft) for small fish. An accomplished glider, the brown pelican frequently skims only a few inches above the surface of the water. The white pelican, on the other hand, does not dive at all, but feeds in shallow waters by scooping up fish with its large bill. Whereas brown pelicans seldom soar, the white pelicans may be seen migrating in large V-formations at great heights. The white pelican may also be found in freshwater lakes, unlike the more exclusively marine brown pelican.

Two other important members of the Pelecaniformes are the double-crested cormorant (Phalocrocorax auritus) and the anhinga (Anhinga anhinga). Both species are fish eaters that dive from the surface and swim underwater. The double-breasted cormorant prefers coastal waters, at least in the winter, and the anhinga almost exclusively prefers freshwater.

The waterfowl (family Anatidae) consist of two subfamilies and eight tribes. Two tribes of the subfamily Anserinae, the swans (tribe Cygnini), and the geese (tribe Anserini), are not included in the following discussion because of their rarity in southwest Florida.

Surface-feeding ducks (subfamily Anatinae) include the mallard, American black duck, mottled duck (Anas fulvigula), wood duck (Aix sponsa), teals, northern shoveler (Anas clypeata), American widgeon (Anas americana), gadwall, and northern pintail. These ducks do not generally dive for food but rather tip up vertically to feed on vegetation, infauna, and small fish in shallow waters. Most of these species inhabit both fresh and brackish waters, while a few (wood duck and American widgeon) prefer fresh waters. In south Florida, most of these ducks are winter residents only. The exception is the Florida duck (Anas fulvigula fulvigula), a subspecies of the mottled duck that is a permanent resident of peninsular Florida (Sprunt 1954).

Whistling ducks (tribe Dendrocygnini) are represented by the shy fulvous whistling duck (Dendrocygna bicolor). This duck feeds nocturnally upon aquatic as well as terrestrial vegetation. Like other surface-feeding ducks it does not dive but tips and feeds from the surface.

Bay ducks (tribe Aythyini) are the scaups (Aythya marila and A. affinis), redhead (A. americana), and ring-necked duck (A. collaris). These birds seem to prefer protected coastal bays and river mouths for their wintering grounds. Unlike the surface feeders, bay ducks dive beneath the water surface where they swim in search of food. Generally they eat more animal food than the surface feeders.

Stiff-tailed ducks (tribe Oxyurini) are represented, occasionally, by one species, the ruddy duck (Oxyura jamaicensis). This small, stubby duck sits rather low in the water and dives predominantly for animal food. It overwinters in Florida from late October to early May.

Mergansers (subfamily Mergini) are commonly represented in the winter by the bufflehead, the red-breasted merganser (Mergus serrator) and infrequently by the hooded merganser. The mergansers have long, thin bills, modified for seizing fish while they swim beneath the surface. The red-breasted merganser seldom visits inland water bodies, preferring the coastal waters instead.

The cranes and their allies (order Gruiformes) are represented by three of the most abundant floating and diving water birds of the Florida gulf coast, the common moorhen (Gallinula chloropus), the purple gallinule (Porphyrula martinica), and the American coot (Fulica americana). These birds, which are permanent residents, exhibit characteristics somewhat intermediate between wading birds and floating birds. It is not uncommon to see gallinules and coots feeding along the edges of shallow waters, sometimes wading, sometimes floating but most often they dive for food. Their diet consists of a mixture of aquatic insects, benthic infauna, and vegetation. The common moorhen and purple gallinule tend to prefer freshwaters during the nesting season, but move to brackish waters in the winter.

Another resident floating and diving water bird is the pied-billed grebe (order Podicipediformes, Podilymbus podiceps), a small bird that prefers shallow freshwater and rarely inhabits brackish waters. An accomplished swimmer and rather poor flyer, it frequently escapes danger by diving. The grebe nests from mid-April to September. In the winter, increased numbers of birds indicate that there are some immigrants. An exclusive carnivore, the diet of the pied-billed grebe consists of 50% fish and crayfish and 50% insects (Sprunt 1954).

The last group of floating and diving birds is the family Gaviidae (loons), represented by the common loon (Gavia immer). Arriving in late October or early November and departing by April or May, common loons spend most of their time in coastal bays. Loons spend nearly all of their time in the water where they feed exclusively on fish. The loon often swims very low in the water, giving its head and neck a roughly S-shaped profile. Just before diving the loon leaps upward to gain momentum as it lunges under the surface.

7.5.4 Birds of Prey

Nineteen species of birds from two orders comprise the members of this guild in the watershed (Table 56). Fifteen species of the order Falconiformes (hawks, eagles, and vultures) are included in this group, along with four species of owls (order Strigiformes). Odum et al. (1982) added two species, the merlin (Falco columbarius) and Swainson's hawk (Buteo swainsoni), as users of Florida's mangrove zone.

In terms of habitat utilization these birds follow a continuum ranging from extremely broad to extremely narrow, and exclusively forest to exclusively marsh, and exclusively coastal to exclusively inland. Prominent among those with broad habitat preferences are the vultures (family Cathartidae) represented by the turkey vulture (Cathartes aura) and the black vulture (Coragyps atratus). Their seemingly effortless soaring takes them over virtually all habitats (except urban areas) in search of carrion. Although they spend much of their time cleaning up road kills, they are seldom struck by vehicles. The turkey vulture is more abundant than the black vulture.

Another species that frequently associates with vultures in south Florida, is the caracara (Caracara cheriway). This subtropical bird, a member of the family Falconidae, has the greater part of its range farther west in Mexico and Central America. Like the vultures, it feeds on carrion and tends to restrict itself to open prairies, agricultural lands, and scrub habitats.

Another group of predatory birds (the Accipitridae family) prefer upland and coastal marsh

Table 56. Habitat use and importance to birds of prey in the Big Cypress watershed (adapted from Duever et al. 1979).

	Habitat								
Species	Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes
Everglades Kite (*Rostrhamus sociabilis plumbeus*)					2	1			
Cooper's Hawk (*Accipiter cooperii*)	2	2	2	2					
Sharp-shinned Hawk (*Accipiter striatus*)	2	2	2	2	2	2	2	2	2
Northern Harrier (*Circus cyaneus*)					2	2		2	2
Broad-winged Hawk (*Buteo platypterus*)	2	2		2			1		
Peregrine Falcon (*Falco peregrinus*)	1				1	2	2	2	1
American Kestrel (*Falco sparverius paulus*)	3				2	2			
Magnificent Frigatebird (*Fregata magnificens*)							3F		
Turkey Vulture (*Cathartes aura*)	2F3B	2	2	2	2F	2F	1F	1F	1F
Black Vulture (*Coragyps atratus*)	2F3B	2	2	2	2F	2F	1F	1F	1F
American Swallow-tailed Kite (*Elanoides forficatus*)	3	2	2	3	1F	1F	3		
Red-tailed Hawk (*Buteo jamaicensis*)	2	2F1B	2F	2F1B	1F	2F			
Red-shouldered Hawk (*Buteo lineatus*)	2	2	2	2	2F	2F	1		
Short-tailed Hawk (*Buteo brachyurus*)	2	1F	2	2	2F	2F	1F2B		
Bald Eagle (*Haliaeetus leucocephalus*)	2		1B		1F		3	2F	2F
Osprey (*Pandion haliaetus*)	1B		1B				2F4B	2F	2F
Eastern Screech-Owl (*Otus asio*)	3	2		1					
Great Horned Owl (*Bubo virginianus*)	2	2	2	2	2F	2F	1		
Common Barn-Owl (*Tyto alba*)	1	2F1B	1	2		1F			
Barred Owl (*Strix varia*)	1	2	2	2	2F	2F			

1 = Habitat rarely used.
2 = Habitat commonly used.
3 = Habitat heavily used (elimination of habitat could reduce species population in the general area).
4 = Habitat critical for continuation of species in the general area.
Blank column - Habitat probably not used.
B = Breeding habitat only.
F = Feeding habitat only.
No letter - Habitat used for both breeding and feeding.

habitats. The four members are the American swallow-tailed kite (*Elanoides forficatus*), the red-tailed hawk (*Buteo jamaicensis*), the red-shouldered hawk (*B. lineatus*), and the short-tailed hawk (*B. brachynrus*). All are primarily forest dwellers, preferring to nest in cypress, pine, or oak trees. The largest of the four, the red-tailed hawk, dines predominantly upon small mammals (meadow mice), reptiles, insects, and crawfish. Small birds make up another 10% of its diet. As its prey suggests, this bird is a frequent visitor to upland prairies and marshes as well as forests. The American swallow-tailed kite prefers semiprairie country, a combination of prairies, open pine glades, and cypress. Its food, primarily snakes, lizards, dragonflies, and grasshoppers, is taken on the wing. The relatively small red-shouldered hawk is the most abundant and widely distributed of the four. Its diet consists of small mammals, snakes, lizards, frogs, and insects. The short-tailed hawk, although a resident and breeder in Florida, is relatively uncommon. The greater part of its range is located in Central and South America.

A third group of predatory birds restricts itself to a narrower range of upland habitats. This group includes the Coopers hawk and the broad-winged hawk, which appear to prefer upland forests; the Kestrel, which appears to prefer open uplands; and the Everglades kite, (Rostrhamus sociabilis plumbeus) which uses wet prairies and sawgrass marshes exclusively. All but the Everglades kite are considered uncommon throughout all of Florida. The American kestrel (Falco sparverius), and the broad-winged hawk (Buteo platypterus) rely heavily upon insects as prey, while the Cooper's hawk (Accipiter cooperii) preys on smaller birds, mammals, and reptiles. The Everglades kite feeds almost exclusively upon the apple snail (Pomacea sp.) that is found in abundance in sawgrass marshes.

The fourth group includes two species that prefer open areas in both marine and freshwater settings. The northern harrier or marsh hawk (Circus cyaneus) is common in salt marshes and to a lesser extent in upland freshwater marshes. It feeds primarily on rodents, mice, rabbits, particularly cotton rats (Sigmodon hispidus), and to some extent on birds such as the clapper rail and bob white quail. The other member of this group is the merlin (Falco columbarius) or eastern pigeon hawk, an uncommon, usually winter-only resident. The merlin is primarily a bird-eating hawk, taking shorebirds, pigeons, doves, and flickers, as well as insects and small mammals.

A fifth group contains two members, the sharp-shinned hawk (Accipiter striatus) and the peregrine falcon (Falco peregrinus), which are also bird-eating hawks. These birds prefer coastal habitats, but utilize freshwater marshes and sloughs. Both are occasional winter residents.

The sixth group includes two species, the osprey (Pandion haliaetus) and the bald eagle (Haliaeetus leucocephalus), which prefer coastal habitats. The origin of this preference, which is clearly stronger for the osprey than the eagle, is their dependence on fish. The osprey is a striking and efficient predator, snatching fish from the water surface with its feet. The eagle fishes in the same manner, but is better known for its habit of robbing the osprey of its prey. The larger eagles generally harass flying ospreys until the latter drop their prey. The eagles then catch the fish, sometimes in midair, and leave the ospreys without their food.

The owls are represented by four almost exlusively forest-dwelling species that only occasionally wander over marshes and prairies looking for prey. All are well adapted to forest hunting with large sensitive ears and eyes, and the gift of silent flight. The smaller eastern screech owl (Otus asio) tends to be more restricted to upland woods than the other three species. The long legs of the common barn owl (Tyto alba) are useful in capturing prey in marshes and prairies. The larger barred (Strix varia) and great horned owls (Bubo virginianus) are more commonly known to use wet hammock and swamp forest habitats. Although it does not appear in Table 56, the burrowing owl (Athena cunicularia) is sometimes observed in the northern portion of the watershed (Kale 1978). All owls are top carnivores that feed on a combination of small mammals, amphibians and reptiles, and occasionally even large insects.

7.5.5 Shorebirds

A combination of factors, i.e., preference for coastal habitats and similarity in mode of feeding (probing being dominant), sets the shorebird guild apart from other groups. Nonetheless, some birds of this guild exhibit significant variations in their mode of feeding, placing them somewhere between the waders and probers. Examples are the greater yellowlegs (Tringa melanoleuca), American avocet (Recurvirostra americana), and clapper rail (Rallus longirostris). Although most of the shorebird guild frequent shorelines or estuary habitats while in the watershed, others do not (Table 57). In southwest Florida, a majority of the shorebirds either overwinter or are migrating transients.

Five members of this guild, namely the clapper rail, king rail (Rallus elegans), Virginia rail (Rallus limicola), sora (Porzana carolina), and black rail (Laterallus jamaicensis), belong to the order Gruiformes. The remaining birds all belong to the order Charadriiformes, which includes the oyster catchers (family Haematopodidae), the plovers (family Charadriidae), the sandpipers, the turnstones and surfbirds (family Scolopacidae), and the avocets (family Recurvirostridae).

Among probing shore birds, morphological differences in bill length and structure determine their ultimate food source (Recher 1966, Green 1968). These differences are believed to reduce competition between species by functionally partitioning the infaunal food resources. Other factors, such as feeding behavior, flexibility in diet, and the use of other habitats also contribute to this partitioning. Peterson and Peterson (1979) distinguish between surface-searching and shallow-probing shorebirds, and the deep-probing shorebirds. This delineation is based on fundamental differences in feeding habits and diets.

Shallow probers are generally opportunistic feeders, taking whatever prey is available in greatest numbers; consequently, their diets may vary widely depending upon their location. From experiments conducted elsewhere along the coast (Schneider 1978) it can be assumed that shallow probers have at least some effect on the composition and abundance of intertidal and beach fauna. Since many of these birds are either winter residents or migrants, their predatory effect is probably greater in winter than at other times of the year.

In addition to morphological differences, the shallow probers also differ among themselves with regard to their feeding habits. Some, such as the probers and smaller sandpipers, feed by sight, commonly preying upon surface fauna in sea wrack or sand. Others such as the semipalmated sandpiper (Calidris

Table 57. Habitat use and importance to probing shorebirds in the Big Cypress watershed (adapted from Odum et al. 1982).

Common Name (Latin Name)	Abundance	Season of Occurrence[a]	Food Habits	Habitat Preferences
Order Gruiformes				
King Rail (*Rallus elegans*)	Common	Yr	Beetles, grass-hoppers, aquatic bugs	Marshes, mangroves
Clapper Rail (*Rallus longirostris*)	Uncommon-common	Yr	Crabs, shrimp	Saltmarsh, mangroves
Virginia Rail (*Rallus limicola*)	Rare	W	Beetles, snails spiders, berries	Marshes, mangroves
Sora (*Porzana carolina*)	Uncommon to locally abundant	W	Insects, seeds of emergent aquatic plants	Marshes, mangroves
Black Rail (*Laterallus jamaicensis*)	Rare	W	Beetles, snails, seeds	Dry fields, salt marshes
Order Charadrifoimes				
Family Charadridae				
Semipalmated Plover (*Charadrius semipalmatus*)	Locally common	W,T	Crustaceans, insects, mollusks worms	Beaches, inland fields, mudflats, sandbars
Wilson's Plover (*Charadrius wilsonia*)	Locally common	Yr	Crabs, shrimp, crayfish	Beaches, mudflats
Piping Plover (*Charadrius melodus*)	Common	W,T	Crustaceans, mollusks	Beaches, coastal mudflats
Cuban Snowy Plover (*Charadrius alexandrinus tenuirostris*)		Yr	Crustaceans, mollusks	Beaches, mudflats
Killdeer (*Charadrius vociferus*)		Yr	Insects	Beaches, lake shores, fields, prairies
Black-bellied Plover (*Pluvialis squatarola*)	Common	Yr	Crabs, mollusks small fish, worms, insects	Beaches, lake shores,
Family Scolopacidae				
Least Sandpiper (*Calidris minutilla*)	Common	W,T	Pupae of beetles and flies	Beaches, mudflats, inland ponds, marshes
Short-billed Dowitcher (*Limnodromus griseus*)	Common	W,T to Yr	Mollusks, crustaceans	Beaches, marshes, chiefly coastal but some inland
Long-billed Dowitcher (*Limnodromus scolopaceus*)	Uncommon	W	Aquatic insects, mollusks, beetles, flies, worms	Beaches, marshes, chiefly coastal but some inland
Stilt Sandpiper (*Calidris himantopus*)	Rare-uncommon	W,T	Chironomids	Tidal bays, sounds, interior ponds, marshes
Semipalmated Sandpiper (*Calidris pusilla*)	Common-abundant	W,T	Mollusks, insects	Beaches, mudflats, marshes
Western Sandpiper (*Calidris mauri*)	Common-abundant	W,T	Chironomids	Beaches, mudflats, marshes
Ruddy Turnstone (*Arenaria interpres*)	Common	Yr	Insects, crustaceans, mollusks	Beaches, marshes, mudflats
Common Snipe (*Gallinago gallinago*)	Uncommon	W,T	Mollusks, insects, worms	Mangroves, meadows, shortgrass marshes
Long-billed Curlew (*Numenius americanus*)	Rare-uncommon	W, T	Crustaceans, insects	Marshes, mudflats, beaches, mangroves
Whimbrel (*Numenius phaeopus*)	Uncommon Uncommon	W,T W,T	Mollusks, crustaceans, worms, insects	Marshes, mangroves, beaches, mudflats
Spotted Sandpiper (*Actitis macularia*)	Abundant	W,T - Yr	Mollusks, crustaceans	Rivers, ponds, sloughs, canals, beaches, mudflats

(continued)

Table 57 (Concluded).

Common Name (Latin Name)	Abundance	Season of Occurrence[a]	Food Habits	Habitat Preferences
Solitary Sandpiper (Tringa solitaria)	Common	W,T	Crustaceans, small frogs, aquatic insects	Upland swamps, wet meadows, ponds, creeks
Willet (Catoptrophorus semipalmatus)	Common	Yr	Crabs, crayfishes killifishes	Beaches, mudflats, mangroves
Greater Yellowlegs (Tringa melanoleuca)	Common	W,T	Fishes, crabs, crustaceans	Beaches, mudflats
Lesser Yellowlegs (Tringa flavipes)	Common	W,T	Snails, mollusks, crabs	Beaches, mudflats
Red Knot (Calidris canutus)	Uncommon	W,T	Marine worms, crustaceans	Beaches, mudflats
Dunlin (Calidris alpina)	Common	W	Marine worms, mollusks	Beaches, mudflats
White-rumped Sandpiper (Calidris fuscicollis)	Rare	T	Chironomids, snails, some seeds	Beaches, marshes, salt and fresh
Marbled Godwit (Limosa fedoa)	Rare-common	W	Crustaceans, seeds of emergent aquatic plants, mollusks	Mudflats, sandflats
American Woodcock (Scolopax minor)		Yr	Earthworms, cutworms, grasshoppers, mayflies	Upland forests
Pectoral Sandpiper (Calidris melanotos)	Uncommon-common	S,F,T	Crickets, grasshoppers, insects	Grasslands, freshwater marshes
Purple Sandpiper (Calidris maritima)	Rare	W,T		Beach, rock, jetties
Sanderling (Calidris alba)	Common	W,T - Yr	Mollusks, crustaceans, sandfleas, marine worms	Beaches
Family Recurvirostidae				
American Avocet (Recurvirostra americana)	Uncommon	W,T	Marine worms, aquatic insects, tubers	Fresh and Salt water marshes mudflats
Black-necked Stilt (Himantopus mexicanus)	Common	S	Aquatic beetles	Mudflats, coastal and inland marshes, lake and pond margins
Family Haematopodidae				
American Oystercatcher (Haematopus palliatus)	Rare	S,T	Oysters, other mollusks	Mudflats, beaches, oysterbars

[a] Yr = year round resident
S = Summer resident
W = Winter resident
T = Transient, present during spring and fall migrations

pusilla) and sanderling (C. alba) feed by probing in the substrate. Their bills are intricately innervated with sensory nerves that facilitate prey location and capture. Prey selection may also play a role in resource partitioning by minimizing spatial overlap between species. Certain species such as the ruddy turnstone (Arenaria interpres) tend to prefer hard substrates that support their favorite prey. Others such as the clapper rail stick to the high portions of salt marshes and only occasionally venture out onto mudflats at low tide.

Two species, the long-billed (Limnodromus scolopaceus) and the short-billed dowitcher (L. griseus), belong somewhere between the shallow- and deep-probing categories. Although their bills are long, they frequently feed more like the shallow probers than the deep probers. Another species, the

American oystercatcher (*Haematopus polliatus*), feeds when possible on oysters and other large mollusks. For this reason it is hard to place the oystercatcher in either category.

The deep-probing shorebirds include such species as the willet (*Catoptrophorus semipalmatus*), the marbled godwit (*Limosa fedoa*), and the long-billed curlew (*Numenius americanus*). Their anatomical equipment is suited for reaching deeper into the sediment to obtain a different food source. Their generally greater size also allows them to take larger prey. The most common deep prober in the beach environment is clearly the willet. This bird often exhibits aggressive behavior toward other probing shorebirds, frequently causing them to forfeit their prey.

7.5.6 Aerially Searching Birds

Although the birds of this guild (Table 58) are largely estuarine, many of them frequent a variety of other habitats as well. One species, the belted kingfisher (*Ceryle alcyon*), prefers freshwater wetland habitats. Of the gulls, the ringbilled gull (*Larus delawarensis*) is most commonly found inland. The herring (*L. argentatus*), laughing (*L. atricilla*), and Bonaparte's gulls (*L. philadelphia*) tend to be strictly coastal and venture only occasionally to inland lakes, agricultural fields, or dump sites. The terns as a group tend to restrict themselves to coastal habitats. Some, like Forsters tern (*Sterna forsteri*), are regularly reported from Lake Okeechobee, but coastal embayments, marsh and mangrove ponds, and offshore waters are preferred. The black skimmer (*Rhychops niger*), probably because of its unique fishing tactics, tends to prefer large bodies of calm inland and coastal waters. When skimming is not possible, the bird has been known to wade and probe for small fishes in shallow pools. The fish crow (*Corvus ossifragus*), tends to prefer estuarine over freshwater habitats.

Birds of this guild are either piscivorous or omnivorous. The acrobatic terns are the fish eaters of this guild and hover 20 to 30 m (66 to 98 ft) above the water in search of surface-feeding fishes. When prey is sighted they make a spectacular dive into the water. Prey selectivity is probably a function of the size of the bird and the available fish. The Caspian tern (*Sterna caspia*), the largest tern, has been known to take mullet, menhaden, and sardines. Smaller birds such as the least tern (*S. antillarum*), select smaller fish. Fish is also heavily favored as food by the belted kingfisher, which may be seen perching on cypress branches or on power lines above roadside ditches. When the kingfisher locates a likely prey it dives down into the water in a manner similar to that of terns. The black skimmer, because of its unique anatomy and mode of feeding, is also dependent almost exclusively upon a fish diet.

Omnivory is common among the gulls. They make use of beaches, mudflats, open bays, offshore waters, inland lakes, fields, marshes, and even urban settings. One of their most conspicuous centers of congregation is at garbage dumps. Along the coast their diet consists of fish, insects, and other small marine fauna. Inland, they feed on soil arthropods, possibly earthworms and, at landfills, on garbage. The use of inland habitats for food and shelter by gulls is seasonal in nature and associated with adverse weather.

Three of the four gull species listed in Table 58 - ringbilled gull, Bonaparte's gull, and the herring gull - overwinter in southwest Florida. Although the laughing gull is the only true year- round resident gull, it apparently does not nest in the Caloosahatchee River/Big Cypress watershed.

Probably the most omnivorous bird of this guild is the fish crow, which belongs to this guild because of its predilection for searching for eggs and exposed young in rookeries of herons, ibises, and other seabirds. Other foods are small fishes, crabs, shrimp, mollusks, and numerous types of wild fruit including palmetto berries, dogwood, sour gum, red bay, and others. Even turtle eggs are sometimes consumed.

The Florida Committee on Rare and Endangered Plants and Animals (Kale 1978) lists 44 taxa of birds from the Caloosahatchee River/Big Cypress watershed (Table 59). This list includes all of the wading

Table 58. Habitat use and importance to aerially searching birds in the Big Cypress watershed (adapted from Odum et al. 1982).

Common Name (Latin Name)	Abundance	Season of Occurrence[a]	Food Habits	Habitat Preferences
Herring Gull (*Larus argentatus*)	Uncommon	W	Fish, mollusks, crustaceans	Beaches, mudflats, bays, offshore coasts
Ring-billed Gull (*Larus delawarensis*)	Common	W,T	Fish, insects mollusks	Beaches,mudflats, bays, offshore coasts,inland lakes
Laughing Gull (*Larus atricilla*)	Common	Yr	Fish, shrimp, crabs	Beaches, mudflats, bays, offshore coasts
Bonaparte's Gull (*Larus philadelphia*)	Uncommon	W	Fish, insects	Beaches, mudflats, bays, offshore coasts
Gull-billed Tern (*Sterna nilotica*)	Uncommon	Yr	Grasshoppers, dragonflies, crabs	
Forster's Tern (*Sterna fosteri*)	Uncommon-common	W	Fish	Offshore coasts, mudflats, bays, lakes, ponds
Common Tern (*Sterna hirundo*)	Uncommon	W	Fish	Offshore coast, mudflats, bays, marsh ponds
Least Tern (*Sterna antillarum*)	Common	S	Fish	Offshore coasts, mudflats, bays, marsh ponds
Royal Tern (*Sterna maxima*)	Common	W,T	Fish	Offshore coasts, mudflats, bays, marsh ponds
Sandwich Tern (*Sterna sandvicensis*)	Uncommon	Yr	Fish	Offshore coasts, mudflats, bays, marsh ponds
Caspian Tern (*Sterna caspia*)	Uncommon	W	Fish	Offshore coasts, mudflats, bays, marsh ponds
Black Skimmer (*Rynchops niger*)	Common	Yr	Fish	Estuarine bays, pools
Belted Kingfisher (*Ceryle alcyon*)	Common	Yr	Fish, Berries	Marshes, sloughs, mudflats, shallow waters, roadsides
Fish Crow (*Corvus ossifragus*)	Common	Yr	Fish, crabs, shrimp, mollusks, eggs, berries	Anywhere, preferably near water

[a]Yr = year round resident
S = Summer resident
W = Winter resident
T = Transient, present during spring and fall migrations

Table 59. Endangered, threatened, rare, and special concern species of birds in the Caloosahatchee River/Big Cypress watershed (adapted from Kale 1978).

ENDANGERED SPECIES

- Wood Stork[3]
  (*Mycteria americana*
- Florida Everglade Kite[1,3]
  (*Rostrhamus sociabilis plumbeus*)
- Peregrine Falcon[1,3]
  (*Falco peregrinus*)
- Cuban Snowy Plover[3]
  (*Charadrius alexandrinus tenuirostris*)
- Ivory-Billed Woodpecker[1,3]
  (*Campephilus principalis*)
- Red-Cockaded Woodpecker[1,3]
  (*Picoides borealis*)
- Florida Grasshopper Sparrow[3]
  (*Ammodramus savannarum floridanus*)
- Cape Sable Seaside Sparrow[1,3]
  (*Ammospiza maritima mirabilis*)

THREATENED SPECIES

- Eastern Brown Pelican[1,4]
  (*Pelecanus occidentalis carolinensis*)
- Rothchild's Magnificent Frigate-bird[4]
  (*Fregata magnificens rothschildi*)
- Southern Bald Eagle[1,4]
  (*Haliaeetus leucocephalus leucocephalus*)
- Osprey[4]
  (*Pandion haliaetus*)
- Southeastern American Kestrel[4]
  (*Falco sparverius paulus*)
- Audubon's Caracara[4]
  (*Polyborus cheriway auduboni*)
- Florida Sandhill Crane[4]
  (*Grus canadensis pratensis*)
- American Oystercatcher[4]
  (*Haematopus palliatus*)
- Least Tern[4]
  (*Sterna antillarum*)
- Florida Scrub Jay[4]
  (*Aphelocoma coerulescens coerulescens*)

RARE SPECIES

- Reddish Egret
  (*Egretta rufescens*)
- Roseate Spoonbill
  (*Ajaia ajaja*)
- Black-shouldered Kite
  (*Elanus caeruleus majusculus*)
- Short-tailed Hawk
  (*Buteo brachyurus fuliginosus*)
- Mangrove Cuckoo
  (*Coccyzus minor*)
- Black-whiskered Vireo
  (*Vireo altiloquus*)

SPECIES OF SPECIAL CONCERN

- Florida Great White Heron[4]
  (*Ardea herodias occidentalis*)
- Great Egret[5]
  (*Casmerodius albus*)
- Little Blue Heron[5]
  (*Egretta caerulea*)
- Snowy Egret[5]
  (*Egretta thula*)
- Tricolored Heron[5]
  (*Egretta tricolor*)
- Black-crowned Night-Heron[5]
  (*Nycticorax nycticorax*)
- Least Bittern[5]
  (*Ixobrychus exilis*)
- Yellow-crowned Night-Heron
  (*Nycticorax violaceus*)
- Glossy Ibis[5]
  (*Plegadis falcinellus*)
- White Ibis[5]
  (*Eudocimus albus*)
- Coopers Hawk
  (*Accipiter cooperii*)
- Limpkin[5]
  (*Aramus guarauna*)
- Piping Plover
  (*Charadrius melodus*)
- Royal Tern
  (*Sterna maxima*)
- Sandwich Tern
  (*Sterna sandvicensis*)
- Black Skimmer
  (*Rynchops niger*)
- Florida Burrowing Owl
  (*Athene cunicularia floridana*)
- Southern Hairy Woodpecker
  (*Picoides villosus auduboni*)
- Marian's Marsh Wren
  (*Cistothorus palustris marianae*)
- Florida Prairie Warbler
  (*Dendroica discolor paludicola*)
- American Avocet
  (*Recurvirostra americana*)

STATUS UNDETERMINED

- Merlin
  (*Falco columbarius*)
- Florida Clapper Rail
  (*Rallus longirostris scottii*)
- Black Rail
  (*Laterallus jamaicensis*)

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[1] Listed as Endangered in *Endangered and Threatened Wildlife and Plants*. U.S. Dept. of Interior, Fish and Wildlife Service. Federal Register, Vol. 42, No. 135, July 14, 1977: 36420-36431.

[2] Listed as Threatened in above publication.

[3] Listed as Endangered in Wildlife Code, Florida Game and Fresh Water Fish Comm. Effective July , 1977.

[4] Listed as Threatened in above publication.

[5] These species are not considered individually endangered. They are included because their wetlands habitat is considered to be of special concern, and of the highest priority for preservation.

birds plus a number of species that depend on beaches and coastal wetlands. Cumulative habitat alterations are one of the primary reasons for the decline of many of these species. Two other factors that may be responsible for the decline of some species are their naturally limited range within the state and their specialized habitat requirements. The Florida scrub jay and the everglades kite are two good examples. Their inflexible set of food and habitat requirements make them especially vulnerable to habitat alterations.

7.6 MAMMALS

Thirty-four species of land mammals have been identified or projected to be found in the Caloosahatchee River/Big Cypress watershed (Table 60). The list is compiled from a number of sources including Burt and Grossenheider (1964), Duever et al. (1979), SFRC (1980), and Odum et al. (1982). For some species, habitat occurrence is left blank or marked with an "X" to indicate their presence only. Further designation is not possible because of the scarcity of information.

Table 60. Habitat use and importance to land mammals in the Caloosahatchee River/Big Cypress watershed (adapted from Duever et al. 1979).

	Habitat									
Species	Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes	Food Source
Carnivores										
Florida Panther (*Felis concolor*)	3	2	1F	2		1F	1			Deer, rabbits, mice, birds
Bobcat (*Lynx rufus*)	2	2	1F	2		1F	2			Rabbits, squirrels, birds
Mink (*Mustela vison*)			1F	2	1	1				Small mammals, fish, frogs, snakes,
Gray Fox (*Urocyon cinereoargenteus*)	4			1F	1F	1F				Small mammals, birds
Striped Skunk (*Mephitis mephitis*)	3	1	1F			1F				Bird eggs, young frogs, mice, larger invertebrates
Eastern Spotted Skunk (*Spilogale putorius*)	3	2				1F	1			Mice birds, eggs, insects, carrion (some vegetable matter)
River Otter (*Lutra canadensis*)			1	2	2	1	1	1		Crayfish, fish, mussels, young alligators
Domestic Dog (*Canis domesticus*)										
Long-tailed Weasel (*Mustela frenata*)	2	2	1	1						Small mammals
Domestic Cat (*Felis catus*)										
Short-tailed Shrew (*Blarina brevicauda*)	2	3	1	2	1	1				Insects, worms, snails, young mice
Least Shrew (*Cryptotis parva*)	2	2	1	1	1	2				Insects, worms, snails
Insectivores										
Eastern Yellow Bat (*Lasiurus intermedius*)	2									Insects, nocturnally on the wing
Evening Bat (*Nycticrius humeralis*)	2	2F	2F	2F1B	2F	2F	2F	2F	2F	Insects, nocturnally on the wing
Brazilian Free-tailed Bat (*Tadarida brasiliensis*)										Insects, nocturnally on the wing
Southeastern Big-eared Bat (*Plecotus rafinesquii*)										Insects, nocturnally on the wing
Herbivores										
White-tailed Deer (*Odocoileus virginianus*)	3	2	1F	2	1F	2F				Emergent aquatic vegetation, grasses
Marsh Rabbit (*Sylvilagus palustris*)		1	2	2	2	2	1	1	1	Emergent aquatic vegetation, grasses, rhizomes and bulbs
Eastern Cottontail (*Sylvilagus floridanus*)	3	2								Vegetation as above, bark and twigs
Marsh Rice Rat (*Oryzomys palustris*)	2	2F			2	2				Green vegetation, seeds

(continued)

Table 60 (Concluded).

Species	Habitat Pine Forest	Hammock Forest	Cypress Forest	Mixed Swamp Forest	Inland Marshes, Ponds, Sloughs	Prairies	Coastal Forest	Coastal Marshes	Saltwater Prairies or Marshes	Food Source
Eastern Gray Squirrel (*Sciurius caroliniensis*)	1	3	2	3						Nuts, seeds, fungi, fruits, cambium
Mangrove Fox Squirrel (*Sciurius niger avicennia*)	3	1	1	3			1			Nuts, fruits, seeds, fungi, twigs, berries
Omnivores										
Black Bear (*Ursus americanus*)	2	2	2	2		1F	1	2		Berries, nuts, tubers, insects, eggs, larvae, small mammals, honey, carrion, garbage
Raccoon (*Procyon lotor*)	2	2	2	2	1	1F	2	1	1	Crayfish, frogs, fish fruit, seeds, insect eggs.
Virginia Opossum (*Didelphis virginiana*)	2	2	1	2	1	1F	2	1F	1	Fruits, berries, insects, frogs, snakes, small birds, mammals, and eggs
Wild Hog (*Sus scrofa*)	2	2	2F		2F	2F				Berries, nuts, grubs insects, tubers, snakes.
Nine-banded Armadillo (*Dasypus novemcinctus*)	3	3								Insects, berries, fruits, bird eggs, snake eggs.
Round-tailed Muskrat (*Neofiber alleni*)					4	1				Water plants, crayfish
Black Rat (*Rattus rattus*)										Insects, garbage, vegetable matter
Hispid Cotton Rat (*Sigmodon hispidus*)	2	2	1F	1F	2	2	1	1F	1F	Vegetable matter, bird eggs.
Cotton Mouse (*Peromyscus gossypinus*)	3	2	1	2		1F	1	1F		Seeds, insects
House Mouse (*Mus musculus*)										Anything edible.
Eastern Mole (*Scalopus aquaticus*)										Worms, insects, vegetable matter.
Southern Flying Squirrel (*Glaucomys volans*)										Nuts, berries, bird eggs, seeds, insects

1 = Habitat rarely used.
2 = Habitat commonly used.
3 = Habitat heavily used (elimination of habitat could reduce species population in the general area).
4 = Habitat critical for continuation of species in the general area.
Blank column - Habitat probably not used.
B = Breeding habitat only.
F = Feeding habitat only.
No letter - Habitat used for both breeding and feeding.

The 34 species in Table 60 represent 69% of the 49 mammalian species recognized in Florida (Layne 1978). Virtually all of the species listed are of North America origin. This extension of a temperate fauna into the subtropics accompanies what appears to be an extensive differentiation of some species populations into several races. Such differentiation is believed to result from the frequent isolation of populations and subsequent genetic drift during fluctuating sea levels of the late Pleistocene era (Layne 1974, 1978) rather than adaptation resulting from invasion into unexploited subtropical habitats. Although listed under their genus and species names, some of the mammals in Table 60 are considered subspecies endemic to south or peninsular Florida. These include the mangrove fox squirrel (sub-species *avicennia*), the Florida panther (sub-species *coryi*), the black bear (sub-species *floridanus*), the longtailed weasel (sub-species *peninsulae*), the everglades mink (sub-species *lutensis*), and the shorttailed shrew (sub-species *shermani*).

In addition to land mammals, eight species of aquatic and marine species are also considered part of the total mammalian fauna (Table 61). Only two of these species, the manatee (*Trichechus manatus*) and the bottlenose dolphin (*Tursiops truncatus*),

Table 61. Aquatic and marine mammals found in the Caloosahatchee River/ Big Cypress watershed (adapted from Caldwell and Caldwell 1973, and Schmidly 1981).

West Indian Manatee	*Trichechus manatus latirostris*
Atlantic Bottlenose Dolphin	*Tursiops truncatus*
Atlantic Spotted Dolphin	*Stenella plagiodon*
Minke Whale	*Balaenoptera acutorostrata*
Short-finned Pilot Whale	*Globicephala macrorhyncha*
Sperm Whale	*Physeter catodon*
California Sea Lion	*Zalophus californianus*
Killer Whale	*Orcinus orca*
Antillean Beaked Whale	*Mesoplodan europaeus*
False Killer Whale	*Pseudorca crassidens*
*Humpback Whale	*Megaptera noraeangliae*
*Striped Dolphin	*Stenella coeruleoalba*

*sighted about 40 miles (65 Km) offshore of the watershed.

are seen with any regularity. The manatee frequents both fresh and estuarine waters. Factors that determine whether a particular site is suitable for manatee use are the availability of vascular aquatic vegetation, proximity to channels at least 2 m (7 ft) deep, recourse to warm waters during cold snaps, and a source of freshwater. Sightings in the watershed include the Caloosahatchee River and Fahka Union Canal (Layne 1978). The manatee is a strict herbivore with no known predators. It is apparent that cold weather, shoreline development, pollution, and injuries from boat propellors limit the survival of manatees in Florida.

The bottlenosed dolphin is strictly marine and only seldom visits estuarine waters.

Nine taxa of mammals from the watershed which are either endangered, threatened, rare, of special concern, or status undetermined are listed in Table 62 (Layne 1978). Included are four of the larger mammals, the panther, the black bear, and two species of the genus *Mustela*. These four taxa generally thrive only in unimpeded open areas that support a mixture of aquatic and terrestrial habitats. The present watershed remains as one of the few locations in Florida where large areas are relatively undisturbed and the habitats are suitable for their survival.

Table 62. Endangered, threatened, rare, and special-concern species of mammals in the Caloosahatchee River/ Big Cypress watersheds (adapted from Layne 1978).

	Status
Mangrove Fox Squirrel[2] *Sciurus niger avicennia*	E
Florida Panther[1,2] *Felis concolor coryi*	E
Florida Black Bear[3] *Ursus americanus floridanus*	T
Everglades Mink[3] *Mustela vison evergladensis*	T
West Indian Manatee *Trichechus manatus latirostrus*	T
Florida Weasel *Mustela frenata peninsulae*	R
Round-tailed Muskrat *Neofiber alleni*	SSC
Sherman Short-tailed Shrew *Blarina brevicauda shermani*	UD
Pine Island Rice Rat *Oryzomys palustris planirostris*	UD
Insular Cotton Rat *Sigmodon hispidus insulicola*	UD

[1] Listed as Endangered by the U.S. Dept. of Interior as of July 1977.
[2] Listed as Endangered in the Wildlife Code, Florida Game and Freshwater Fish Commission as of July 1977.
[3] Listed as Threatened in the Wildlife Code, Florida Game and Freshwater Fish Commission as of July 1977.

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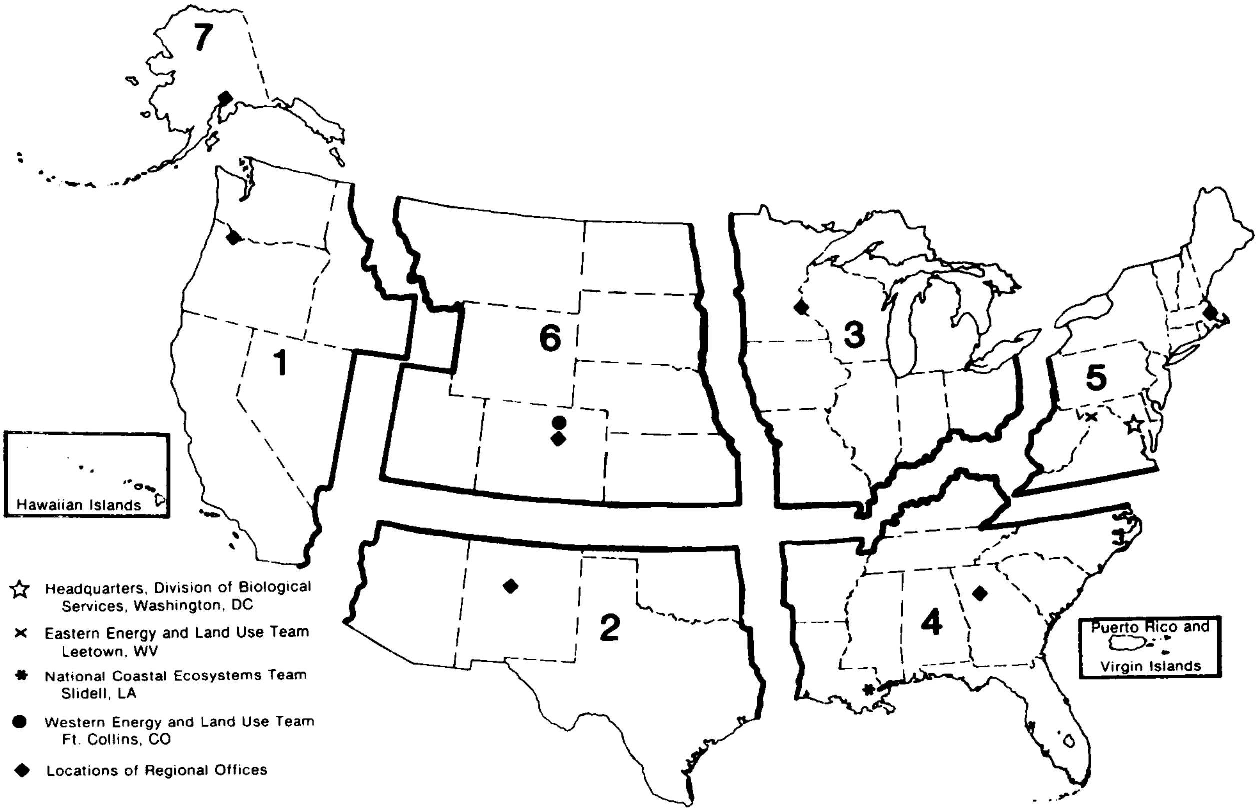

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