FINAL TECHNICAL REPORT
VOLUME 1 OF 2

BIOLOGICAL RESOURCES OF THE INDIAN RIVER LAGOON

INDIAN RIVER LAGOON NATIONAL ESTUARY PROGRAM MELBOURNE, FLORIDA

Prepared By:
Woodward-Clyde Consultants
Marshall McCully & Associates, Inc.
Natural Systems Analysts, Inc.

Prepared For:
Indian River Lagoon National Estuary Program
1900 South Harbor City Boulevard - Suite 109
Melbourne, Florida 32901-4749
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Woodward-Clyde

Woodward-Clyde Consultants
9950 Princess Palm Avenue, Suite 232
Tampa, Florida 33619

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INTERNATIONAL SYSTEM (SI METRIC)/ U.S. CUSTOMARY CONVERSION TABLES

TO CONVERT FROM	TO	MUTLIPLY BY
LENGTH		
centimeters	inches	0.3937
inches	centimeters	2.5400
feet	meters	0.3048
meters	feet	3.2808
kilometers	meters	1.0×10^3
	feet	$3.280\ 84 \times 10^3$
	miles	0.621 37
miles	kilometers	1.609 34
AREA		
acres	hectares	0.404 69
	square feet	4.356×10^4
	square kilometers (km^2)	.00404
	square miles	.00156
hectares	square meters	1.0×10^4
	acres	2.471
square kilometers	hectares	100.0
	acres	274.105 38
	square miles (mi^2)	0.3861
square miles	hectares	258.998 81
	square kilometers (km^2)	2.589 99
	square feet	$2.787\ 84 \times 10^7$
	acres	640.0
VOLUME		
liters	cubic feet	0.035 31
	gallons	0.264 17
gallons	liters	3.785 41
	cubic feet	0.133 68
cubic feet	cubic meters (m^3)	$28.316\ 85 \times 10^{-3}$
	gallons (gal)	7.480 52
	acre-feet (acre-ft)	$22.956\ 84 \times 10^{-6}$
cubic yards	cubic meters	0.764 55
	cubic feet	27.0

INTERNATIONAL SYSTEM (SI METRIC)/
U.S. CUSTOMARY CONVERSION TABLES, Continued

TO CONVERT FROM	TO	MUTLIPLY BY
VOLUME		
cubic meters	gallons cubic feet cubic yards acre-feet	264.1721 35.314 67 1.307 95 8.107×10^{-4}
acre-feet	cubic feet gallons	43.560×10^{3} 325.8514×10^{3}
TEMPERATURE		
	degrees Celsius (C) (t_c)	$t_c = (t_f - 32)/1.8 =$ $t_k - 273.15$
	degrees Fahrenheit (F)	$t_f = t_c/1.8 + 32$
VELOCITY		
kilometers per hour	meters per second miles per hour	0.277 78 0.621 47
miles per hour	kilometers per hour meters per second	1.609 34 0.447 04
FORCE		
kilograms	pounds (lbs)	2.2046
MASS		
pounds (avdp)	kilograms	0.453 59
VOLUME PER UNIT TIME FLOW		
cubic feet per second	cubic meters per second (m^3/s) gallons per minute (gal/min) acre-feet per day (acre-ft/d) cubic feet per minute (ft^3/min)	0.028 32 448.831 17 1.983 47 60.0
gallons per minute	cubic meters per second cubic feet per second (ft^3/s) acre-feet per day	0.631×10^{-4} 2.228×10^{-3} 4.4192×10^{-3}
acre-feet per day	cubic meters per second cubic feet per second	0.014 28 0.504 17

1.0 INTRODUCTION

An estuary is classically defined as a semi-enclosed body of water with free connections to the open sea but measurably diluted by freshwater (Pritchard, 1967). The Indian River Lagoon can be defined by this statement but encompasses much more. It is biologically unique due to a combination of climatological and physiographic features which occur nowhere else. The latitudinal gradient within the Lagoon region represents a major biogeographical transition zone between warm-temperate and subtropical to tropical areas (Gilmore, 1977), which helps to create a rich diversity of habitats and biological communities. The latitudinal patterns and biotic diversity are represented in many different groups such as fish (Gilmore, 1977) and epifauna associated with seagrasses (Virnstein, et al., 1984), with major differences in species composition between the north and south ends of the Lagoon (Gilmore, et al., 1983), as well as between the Lagoon and other coastal areas short distances to the north and south (Virnstein, 1990).

Biological diversity is high within the Lagoon: approximately 1,800 species have been identified in the Lagoon itself. A gradient of environmental conditions from inlets and freshwater drainage systems, and a variety of landforms and substrates ranging from mucky sediments to hard sandy bottoms also contribute to the diversity of habitats and communities (Gilmore, et al., 1981; Virnstein, et al., 1983; Nelson, 1994: Winston, 1994; Rice, et al., 1994). This estuarine ecosystem supports one of the most productive aquatic faunas within the continental United States (Gilmore, 1985). The submerged aquatic vegetation (SAV) community of seagrasses and algae provides one of the most diverse and productive coastal habitats, with the highest seagrass diversity of any estuary in the United States. The shallow areas of the Lagoon historically contained vast meadows of lush seagrasses, and although most of these remain, some losses have occurred over the last 50 years.

Adjacent upland and freshwater wetlands parallel much of the 155 miles of the Lagoon, interacting with communities in the Lagoon ecosystem. Intertidal mangrove swamps border the shallow waters of the Lagoon, with prop roots and pneumatophores providing habitat for millions of small fishes and shellfish. Small islands, serving as wildlife refuges, occur throughout the system.

Man-made and altered habitats have had positive and negative impacts on habitat diversity in the Lagoon region. In many cases, the increase of human development and activity has resulted in habitat losses and in fragmentation and degradation of remaining habitats and natural communities. However, in some cases, man-induced changes have provided new habitats such as spoil islands that have to some extent replaced other habitat for wading and shore birds that has been lost through other actions of man. Wading birds also may continue to thrive in some of the man-made mosquito impoundments that have been created in most of the salt marshes in the system (Swain, et al., 1992), although the impoundments have destroyed essential habitat for some other species (Gilmore, et al., 1990).

The condition of the Lagoon system can be implied by the condition of these biotic communities (Virnstein, 1987). Changes and impacts observed in communities such as seagrass meadows may allow insights into trends in the health of the Lagoon such as changes in water clarity, sediment or muck deposition, and nutrient inputs. The impacts or responses may suggest options for management action to enhance or protect the quality of the Lagoon ecosystem. It must be recognized that human development along the Lagoon is now a part of the functional ecosystem surrounding the Lagoon, and that the condition of the biota will also be dependent upon its ability to adapt to this present and future condition, as well as to the success of humans in providing current and future environmental conditions that will protect and enhance the biota.

The intent of this report is to summarize and discuss existing information on the biological resources of the Lagoon. The existing information includes data from extensive past efforts of scientists and conservationists, as well as new information that has been developed in recent studies on the Lagoon. The review is intended to cover material published through July 1993, although it has been possible to insert a few more recent references.

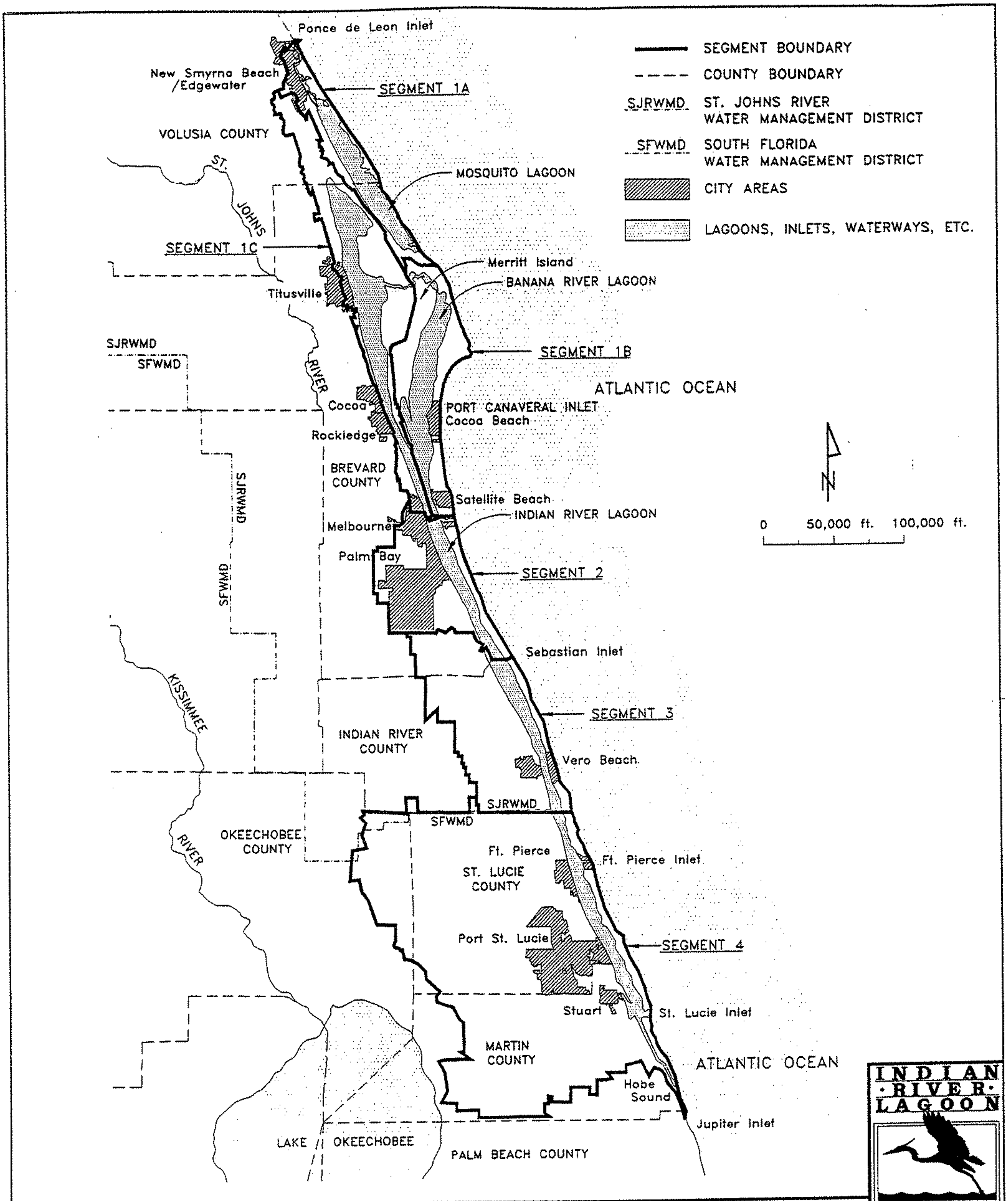
1.1 DEFINITION OF THE INDIAN RIVER LAGOON SYSTEM

This report is produced for the Indian River Lagoon National Estuary Program (IRLNEP). This program uses the term Indian River Lagoon to include the entire estuarine region of Florida's east coast from Ponce de Leon Inlet near New Smyrna Beach to Jupiter Inlet. This area is comprised of several water bodies which have natural or man-made connections. In this report, the terms "Indian River Lagoon complex," "Lagoon," and "IRL" are used interchangeably to refer to the aggregate of these water bodies including the Indian River Lagoon, Banana River, Mosquito Lagoon, and Hobe Sound. Mosquito Lagoon forms the northernmost segment between Ponce Inlet and Cape Canaveral. Banana River is located east of the Indian River Lagoon and south of Cape Canaveral, and Hobe Sound encompasses the southern end of the Indian River Lagoon between St. Lucie and Jupiter Inlets. The term "Indian River Lagoon system" includes the Lagoon complex and the entire watershed emptying into the Banana River, Indian River Lagoon, Mosquito Lagoon, and Hobe Sound. The Indian River Lagoon proper extends from Turnbull Creek in Volusia County south to Jupiter Inlet in Palm Beach County.

This report is one of a series of Technical Reports documenting existing conditions and trends throughout the Indian River Lagoon system, supporting the IRLNEP Characterization Report. The Indian River Lagoon complex and associated watershed has been broken into six geographical segments based on hydrologic, hydrodynamic, and political factors. The methods for this segmentation have been described in the companion volume in this series entitled "Physical Features of the Indian River Lagoon". Figures 1-1 and 1-2 show the six segments and major landmarks of the Indian River Lagoon system.

1.2 ORGANIZATION AND OBJECTIVES

This report is organized with two major areas of emphasis. The first is a discussion of the biotic communities that characterize the Indian River Lagoon system, and includes Sections 2.0, 3.0 and 4.0, which are included in Volume 1 of this report. The biotic communities are the assemblages of plants and animals that characterize specific environments. The combination of the effects of major biotic components (e.g., dominant plants) and abiotic environmental conditions defines habitats within these environments. These discussions describe the flora (plants), fauna (animals), and important environmental variables that characterize these habitats and communities. Section 2.0 describes the upland and freshwater communities and habitats that occur in the Indian River Lagoon system in the immediate vicinity of the Lagoon. These habitats are outside of the marine areas of the Lagoon, but they have an influence on the condition of the Lagoon. These peripheral habitats support numerous animals that also use the Lagoon.



•Woodward–Clyde Consultants •Marshall McCully & Associates •Natural Systems Analysts	DRAWING NO.: INDIAN10.DWG DATE: 7-5-94	FIGURE 1–1 MAP OF INDIAN RIVER LAGOON SYSTEM AND WATERSHED SHOWING SEGMENTS

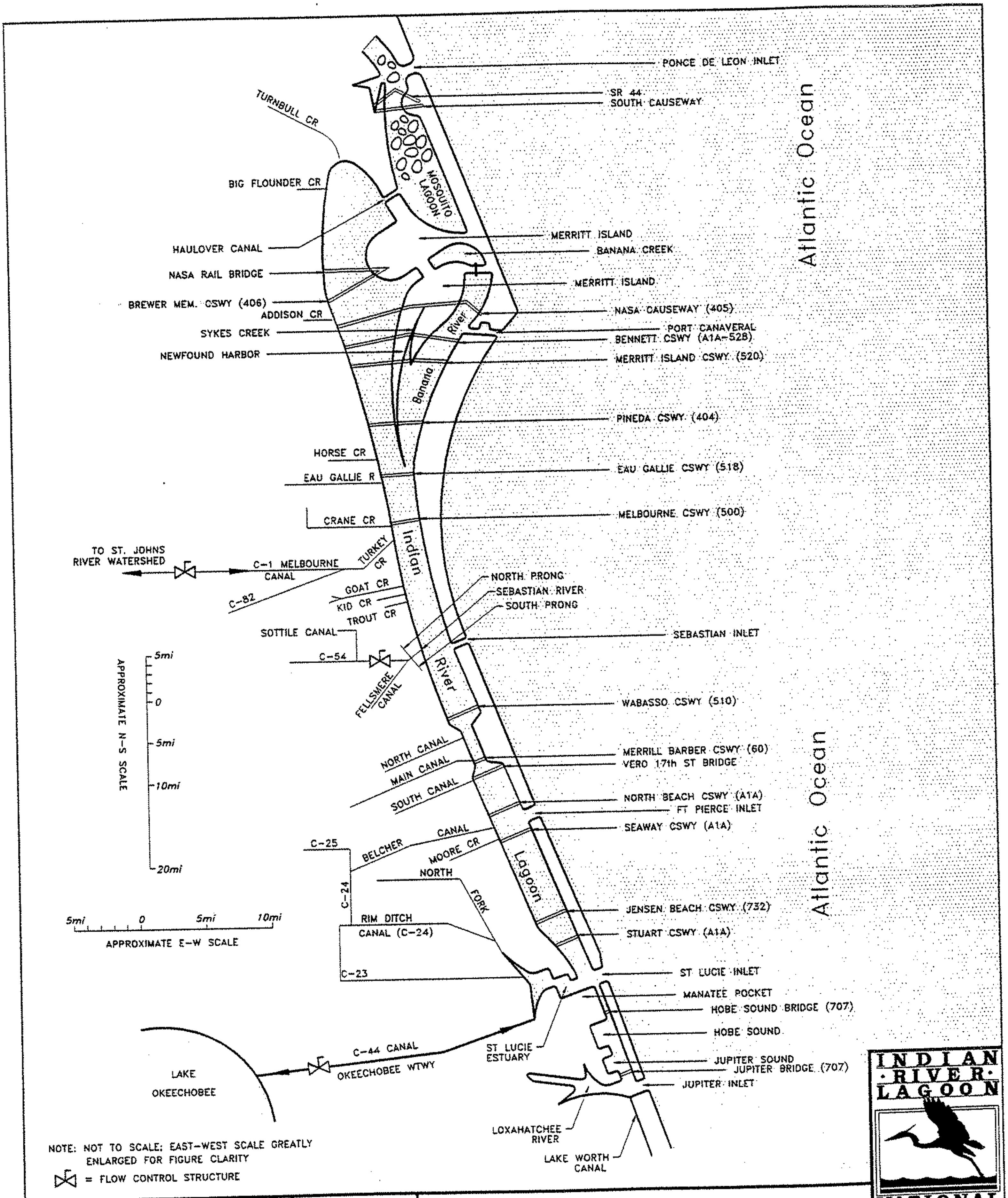


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FIGURE 1-2 MAJOR LANDMARKS OF THE INDIAN RIVER LAGOON SYSTEM

Section 3.0 describes the intertidal communities of the Indian River Lagoon complex. Intertidal communities occur between the highest and lowest limits of the tidal waters. Because the Indian River Lagoon complex is a lagoon type of estuary (Stowe, 1979), it is influenced both by tides and by non-tidal changes in water level such as higher water levels due to freshwater runoff from the watershed. The major natural intertidal habitats in the Lagoon are salt marshes and mangrove forests. Impounding these habitats for mosquito control has altered their functions significantly and created a substantially different habitat. Mosquito impoundment habitats are also discussed in this section.

Communities which occur predominantly in the subtidal or submerged portions of the Lagoon are covered in Section 4.0. These communities include those of the seagrass bed habitats, open water columns, and unvegetated bottoms. Section 5.0 contains more detailed discussion of important fishes and shellfish resources of the Lagoon.

Sections 6.0 through 10.0 comprise Volume 2 of the report. Volume 2 contains more detailed discussion of important wildlife resources of the Lagoon, such as the benthic macroinvertebrates, amphibians, reptiles, birds, and mammals. Major species which directly and indirectly utilize the Lagoon are described, as well as the threatened and endangered wildlife of the Indian River Lagoon system. Conclusions and the references for both volumes are included in Volume 2.

2.0 UPLAND AND FRESHWATER COMMUNITIES AND HABITATS WITHIN THE INDIAN RIVER LAGOON REGION

2.1 UPLAND COMMUNITIES ADJACENT TO THE INDIAN RIVER LAGOON

Prior to the encroachment of modern human civilization, the majority of upland communities adjacent to the Indian River Lagoon included vast stands of longleaf pine forest, pine flatwoods, and oak scrub maritime forest. These communities supported a wide variety of flora and fauna that utilized the Lagoon as foraging areas and nesting areas and/or for reproductive success. Most of the adjacent uplands have since been disconnected from the Lagoon ecosystem by man-made physical features such as U.S. Highway 1, located on the western shore of the Indian River Lagoon, and U.S. Highway A1A, which borders much of the eastern shoreline of the Indian River Lagoon and Banana River. Additionally, the citrus boom years of the early 1900s led to the demise of many natural upland community areas as land was cleared to create thousands of acres of citrus. Separation of these uplands from the Indian River Lagoon has fragmented the natural communities of Lagoon flora and fauna.

Upland ecosystems adjacent to the Lagoon can be separated into several distinctive communities associated with the coastal geology of eastern Florida. From the northern extent of the Indian River Lagoon to the southern end, a wide variety of plant communities is found, including maritime forest, hardwood hammock, coastal scrub, longleaf pine forest, and pine flatwoods.

In their native condition, the upland communities west of the Indian River Lagoon complex consist of upland pine forests and oak scrub grading into salt marshes and/or mangrove communities at the upper edge of the intertidal zone. Salt marshes and/or mangroves extend from the lower end of the intertidal zone and continue to above the high water mark on either side of the Lagoon. On the eastern or barrier island side of the Lagoon, a vegetative and topographic change occurs at the high water mark with maritime forest continuing until a point where coastal strand and dunes begin. The coastal strand occurs where the salt spray and wind from the Atlantic naturally stunts growth of vegetation. Coastal strand changes into the high dune and beach communities adjacent to the ocean.

In addition to change along topographic gradients, upland communities adjacent to the Lagoon also exhibit latitudinal variation in community composition. For example, live oak (*Quercus virginiana*) dominates the maritime forests in the northern part of the system. However, live oak starts to diminish in this community south of Cape Canaveral at the 38.7° F (12° C) isotherm of the January average daily temperature (Tomlinson, 1980) where temperate flora is replaced by sub-tropical and tropical flora such as gumbo limbo (*Bursera simaurba*), strangler fig (*Ficus aurea*), inkwood (*Exothea paniculata*), wild coffee (*Psychotria undata*) and wild tamarind (*Lysiloma latisiliqua*) of West Indian nature. Johnson and Barbour (1990) divided these coastal communities into the Northeast Coast vegetation north of Cape Canaveral and the Southeast Coast vegetation from Cape Canaveral southward. Davis (1943) put the northern limit of his "South Florida flora" at St. Lucie County. It has been reported that the tree canopies in all of the remaining natural coastal hardwood hammocks south of the Indian River Lagoon basin are dominated by tropical species (Richardson, 1977), while those in the vicinity of Ft. Pierce and Sebastian Inlet have a mixture of tropical and temperate species (Johnson and Barbour, 1990).

2.1.1 Barrier Island Coastal Communities

The upland communities on the barrier islands east of the Lagoon are maritime oak forest (also known as maritime hardwood hammock) and coastal scrub. The maritime forests occur on old stabilized dunes on the barrier islands. Floral species commonly encountered in the maritime forest habitat include live oak, saw palmetto (*Serenoa repens*), red bay (*Persea borbonia*), southern magnolia (*Magnolia grandiflora*), and cabbage palm (*Sabal palmetto*) in the area north of Cape Canaveral. South of Cape Canaveral, West Indian species such as nakedwood (*Myrcianthes fragrans*) occur. Common understory species include marlberry (*Ardisia escallonioides*), myrsine (*Rapanea guianensus*), wax myrtle (*Myrica cerifera*), and winged sumac (*Rhus copallina*) (Johnson and Barbour, 1990).

Most hardwood hammocks in the portion of the system north of Sebastian Inlet are transitional between swamps and upland forests such as the maritime forests. These hammocks are limited in extent and generally consist of cabbage palm hammocks and mixed oak-cabbage palm hammocks (Edward E. Clark Engineers, 1991). Southern red cedar (*Juniperus silicicola*), pignut hickory (*Carya glabra*), American elm (*Ulmus americana*), and laurel oak (*Quercus laurifolia*) occur in scattered locations.

In the southern portion of the region (approximately beginning at Sebastian Inlet), hammocks are generally termed tropical hardwood hammocks. These are islands or small stands in depressions or on limestone outcrops raised in relation to surrounding land surfaces (Craighead, 1974). Vegetation in tropical hardwood hammocks is dominated by tropical species, but relicts of temperate flora persist from the last glaciation. In addition to gumbo limbo, prominent tropical species include sea grape (*Cocoloba uvifera*), pigeon plum (*Cocoloba diversifolia*), mastic (*Mastichodendron foetidissimum*), myrsine (*Rapanea punctata*), wild lime (*Zanthoxylum fagara*) and several species of tropical palms (Richardson, et al., 1992; US Fish & Wildlife Service, 1992). The hardwood hammocks are very fire-resistant compared to the scrub and flatwood communities which they often border (Craighead, 1974).

In the Blowing Rocks Preserve near Jupiter, lower elevation sites are reported to support "low hammocks" consisting of more temperate species (Richardson, 1977; Richardson, et al., 1992). These low hammocks are analogous to most of the hardwood hammocks reported for the area north of Sebastian Inlet.

Coastal scrub represents the second major upland community on the barrier islands, occurring mainly on arid, well-drained sand dune areas. Significant areas of scrub are generally confined to the Merritt Island National Wildlife Refuge (MINWR) in Brevard County and to Jonathan Dickinson State Park in Martin County, with a few remnant patches on private lands on Merritt Island and other scattered locations throughout the region. Canopy species are dominated by evergreen oaks, primarily myrtle oak (*Quercus myrtifolia*) and Chapman oak (*Q. chapmanii*). The zones between the coastal dunes and the oak scrub or maritime hammocks sometimes contain a palmetto scrub or oak/saw palmetto scrub community (Austin and Coleman-Marois, 1977; Breininger and Schmalzer, 1990; Schmalzer and Hinkle, 1991).

These coastal communities have largely been eliminated from the barrier islands. Johnson and Barbour (1990) indicate that only eight significant areas of natural barrier island vegetation occur along the Indian River Lagoon and that all but one of these is publicly owned. Less than 40% of the island chain retains natural vegetation except for the federally owned lands in Volusia and Brevard Counties. Real estate development has been responsible for most of this habitat loss. However, natural events such as hurricanes also may damage coastal habitats. Prior to development, storms tended to form or alter the natural features in a continuing evolution of the Indian River Lagoon system. In some areas, this process might damage existing features, while new features were created in another area. As humans attempt to stabilize the Indian River Lagoon system by stabilizing inlets and barrier islands, the balance between natural creation and destruction becomes shifted toward the more destructive phase (Godfrey and Godfrey, 1976).

2.1.2 Mainland Communities

Although the hardwood hammocks are most noticeable on the barrier island chain, they also are present on the mainland side of the Lagoon complex. In the same manner, many of the communities described here as mainland communities also occur on the barrier islands to some extent. The largest concentration of these communities on the islands is within the Kennedy Space Center (KSC) and Merritt Island National Wildlife Refuge (MINWR).

On the western shore of the Indian River Lagoon, upland communities include oak scrub, slash pine flatwoods, and scattered areas of sand pine scrub. The oak scrub communities are similar to those on the barrier island and generally are confined to the small remnant dunes comprising parts of the Atlantic Coastal Ridge. These scrubs may be more diverse than those on the barrier islands and include such understory and herbaceous species as saw palmetto, rusty lyonia (*Lyonia ferruginea*), and Florida rosemary (*Ceratiola ericoides*). Myrtle oak, Chapman oak, and sand live oak (*Q. geminata*) are the dominant species of this community (Myers, 1990).

Sand pine scrubs are similar in nature to oak scrubs. However, sand pine (*Pinus clausa*) forms the dominant tree species (Myers, 1990). This community occurs on well-drained sandy ridges of the Atlantic Coastal Ridge and the interior ridge systems (Davis, 1967; Laessle, 1968). It is adapted to frequent fires, low nutrient regimes, and water stress conditions (Monk, 1966a; Abrahamson, 1984a). The largest concentrations of sand pine scrub are adjacent to Hobe and Jupiter Sounds around Hobe Sound National Wildlife Refuge and Jonathon Dickinson State Park in southern Martin County. This type is well-represented west of Titusville and Cocoa and near the Savannas State Reserve between Ft. Pierce and Jensen Beach, but is not abundant elsewhere near to the Lagoon.

The most prevalent upland community type west of the Indian River Lagoon is pine flatwoods. Most of the flatwoods in the Indian River Lagoon system are dominated by slash pine (*Pinus elliottii*), although some areas of longleaf pine (*Pinus palustris*) occur on soils with better drainage. Common understory species include gallberry (*Ilex glabra*), saw palmetto, tar flower (*Befaria racemosa*), and wax myrtle. Scrubby flatwoods intermediate in nature between pine flatwoods and scrub communities also occur in the region (Abrahamson and Hartnett, 1990).

Numerous wildlife reside within these upland communities adjacent to the Lagoon which also forage or use the Indian River Lagoon during part of their life history. Urbanization has disrupted the native fauna by introducing domestic cats which prey upon small mammals, or stimulating increased populations of scavengers such as raccoons which out-compete other native wildlife species. The scrub and flatwoods communities are essential habitat for such threatened or endagered species as the Florida scrub jay, red-cockaded woodpecker, Florida mouse, and gopher tortoise.

2.2 FRESHWATER SYSTEMS

Numerous freshwater wetlands and streams are found adjacent to or connected directly to the Lagoon system. Although not directly a part of the Lagoon, adjacent wetland communities are a vital component for the biodiversity of the Lagoon. These wetlands are protected by federal and state law because of their functions in maintaining water quality and in filtering harmful substances before they can reach sensitive waters such as the Indian River Lagoon.

2.2.1 Freshwater Wetlands

Freshwater wetlands consist of swamps and marshes. These wetlands develop in locations where the ground surface is sufficiently saturated or flooded for enough of the growing season to support wetland plants. The hydroperiod (duration of the saturated period), and depth of flooding are the primary factors controlling the types of vegetation and communities that develop. Other factors may include the soil type and amount of organic matter present, frequency of fire, and water chemisty (Ewel, 1984).

Swamps along the banks of streams and rivers are generally riverine swamps where hydroperiod is usually short, restricted to periods following rainfall events (Ewel, 1990). In areas where groundwater or surface runoff are the primary sources of water, and water flow from or through the wetland is limited, stillwater swamps develop (Ewel, 1990).

Swamp habitats are very limited in the Indian River Lagoon watershed and are mainly confined to the bands of riverine swamp along major rivers such as the Sebastian River. Bald cypress (*Taxodium distichum*), red maple (*Acer rubrum*), and laurel oak (*Quercus laurifolia*) are major species along these wetland edges of the rivers and streams.

The largest single expanse of swamp in the watershed is Turnbull Hammock, bordering Turnbull Creek at the north end of Indian River Lagoon. This community grades into upland hammock at the upper end of the watershed, but in the lower end has zones typical of a blackwater floodplain forest type of riverine swamp or a hydric hammock type of stillwater swamp (Wharton, et al., 1982; Ewel, 1990). In blackwater swamps and stillwater swamps such as cypress domes and shrub swamps, the lack of water movement often affects the water chemistry, resulting in lower dissolved oxygen and lower pH (greater acidity)(Dierberg and Brezonik, 1984; Spangler, 1984), which in turn may reduce the rate of decomposition of organic matter and increase the tannin content of the water (Dierberg and Brezonik, 1984). When large storm events flush water from these swamps into streams, the resulting water often is highly colored and acidic (because of the tannin content) and low in disssolved oxygen. Nutrient cycling may be very slow in acidic swamps, allowing nutrients to remain bound in the organic matter lying on the ground surface. Flushing of such detritus into the Lagoon may result in high short-term nutrient loading (Brown, et al., 1984). This water may have short term negative impacts on the Lagoon when it reaches the Lagoon. Swamps may also have positive effects on the water quality of the Lagoon by absorping excess nutrients from upland runoff before it reaches the Lagoon (Sloey, et al., 1978).

Although there are numerous freshwater marshes in the watershed, they also are fairly poorly represented in the Indian River Lagoon watershed in comparison to the region to the west. There are no large marsh expanses like there are in the St. Johns River basin. Most of the individual marshes are less than five acres in size.

The factors influencing the ecology and functions of freshwater marshes are similar to those for swamps, with hydroperiod being the primary controlling factor (Pesnell and Brown, 1977; Duever, et al., 1978). Fire and temperature are also important factors controlling species occurrence, productivity, and sucession in marshes (Craighead, 1971; VanArman and Goodrick, 1979; Duever, et al., 1986; Lowe, 1986; Schmalzer and Hinkle, 1991).

Many of the marshes that occur close to the Lagoon are found in swales and depressions between dunes and dune ridges. These are small, linear marshes or freshwater swales that generally extend from north to south. They occur on sandy soils supported by a high groundwater table and by water percolating laterally from the adjacent dunes. The most extensive marshes of this type include approximately 10,500 acres (ac) [4,251 hectares (ha)] in MINWR and Kennedy Space Center (Edward E. Clark Engineers, 1991). Other areas are west of Cocoa and in the Savannas State Reserve area south of Fort Pierce (FDNR, n.d.). Vegetation is dominated by maidencane (*Panicum hemitomon*), sawgrass (*Cladium jamaicense*), beardgrass (*Andropogon* spp.), sand cordgrass (*Spartina bakeri*), or St. John's wort (*Hypericum* spp.).

Another major natural marsh type in the watershed is the flatwoods marsh or prairie (Kushlan, 1990). This type is characterized by generally round depressions within poorly drained flatwoods communities. Although most of the marshes were naturally isolated from other water bodies, many have subsequently been connected to the surface water drainage system by man-made ditches. Ditching has reduced their effectiveness in attenuating storm flows to the Lagoon, and has also reduced the wildlife values for most of these marshes. These may grade into pine flatwoods through poorly drained cabbage palm savannas or wet prairies (Edward E. Clark Engineers, 1991). Sand cordgrass, black needlerush (*Juncus roemerianus*), soft rush (*J. effusus*), and fimbristylis (*Fimbristylis* spp.) often occur in the transitional zones leading to salt marshes. Much of the land adjacent to Indian River Lagoon, particularly north of the St. Lucie River and north of Titusville appear to have consisted of these transitional savannas in aerial photographs from the 1940s (Fletcher, 1993). Most such savannas have since disappeared due to drainage and filling.

The freshwater communities adjacent to the Indian River Lagoon system are important biological systems which contribute valuable cover, foraging ground and reproductive habitats for many wildlife species that utilize the Lagoon and freshwater bodies as part of their ecological life history.

Avian species that utilize the Indian River Lagoon system often use freshwater communities as foraging areas and nesting/roosting areas (Breininger, 1990; Breininger and Smith, 1992). Many crustaceans and fish are adapted to the transition zone created by the mixing of Indian River Lagoon waters and freshwater systems which connect to the Indian River Lagoon. Submerged aquatic vegetation such as seagrasses also adapt to transitional changes. Such species as *Ruppia maritima* are found in salinities far less than other SAV species that are distributed throughout the Lagoon.

2.2.2 Lotic Systems

Various freshwater discharge points are scattered throughout the Lagoon. These lotic (flowing water) systems include natural rivers, creeks, and man-made drainage canals. Because of the small watershed of the northern Indian River Lagoon region and the low elevations throughout, rivers and streams are not prevalent in that portion. Of the 40 principal rivers and canals of Florida listed by Nordlie (1990), only the St. Lucie Canal/River discharges to the Indian River Lagoon. This list did not include the Sebastian River which also should be considered as one of the major waterways. The major brackish and freshwater sources that discharge to the Indian River Lagoon in each segment shown in Figure 1-2 are:

Segment 1B -Banana River

- Sykes Creek

Segment 1C -North Indian River Lagoon

- Turnbull Creek
- Big Flounder Creek
- Addison Creek
- Horse Creek

Segment 2 - North Central Indian River Lagoon

- Eau Gallie River
- Crane Creek
- Turkey Creek (Includes C-1,C-82 Canal)
- Goat Creek
- Kid Creek
- Trout Creek

Segment 3 - South Central Indian River Lagoon

- Sebastian River (includes Sottile, C-54 and Fellsmere Canals)
- North Canal
- Main Canal
- South Canal

Segment 4 - South Indian River Lagoon

- C-25 Canal
- Moore Creek
- St. Lucie River (includes North St. Lucie River, C-23-C-24 Canals, Bessy Creek, Danforth Creek, C-44 Canal, Krueger Creek, Frazier Creek, and Manatee Creek)

No major streams or creeks discharge into Mosquito Lagoon (Segment 1A).

Most of the streams or rivers in the region are of the "swamp-and-bog type," described by Beck (1965) as being acidic, highly colored, sluggish streams with low gradients and silty bottoms. Others, such as Sykes Creek and Big Flounder Creek, are predominantly brackish for most of their length and offer limited freshwater habitat.

Several of these waters, such as the Sebastian River, have extensive vegetated littoral zones which provide habitat for reptile, amphibian, and bird species such as the American alligator, little blue heron, and great blue heron. Most of the canals and many of the dredged creeks have very little emergent littoral vegetation. However, the open water zones can support large fish populations as described in Section 5.0.

Increased nutrient and sediment loadings have contributed to a probable decrease in the abundance and diversity of aquatic species in many of these waterways. Natural waterways for which sufficient data exists to show that water quality has been significantly degraded or that the creek bottom has been altered by various sediments include Big Flounder Creek, Trout Creek, the Eau Gallie River, Crane Creek, Turkey Creek, Horse Creek, Kid Creek, and the St. Lucie River (see "Water and Sediment Quality and Loading Assessment" Technical Report volumes).

2.3 EXOTIC SPECIES

In their natural state, the coastal communities were capable of recovering from natural and non-natural disturbances. However, exotic plant and animal species have become prominent on the barrier islands and spoil islands. When areas are disturbed, these species invade and prevent native species from becoming re-established. Many of the exotic species are West Indian or tropical in origin. As such, they are vulnerable to freezes, leaving occasional windows of opportunity for re-establishment of native species.

Australian pine (*Casuarina equisetifolia*) is one of the frost and fire sensitive species that has become dominant in much of the elevated upland hammock and forest areas south of Cape Canaveral, where it forms pure stands and excludes native species. It has been extensively planted as a wind break and along roadsides since the 1920s (Alexander and Crook, 1974).

Many of the Australian pines north of Sebastian Inlet were killed by recent freezes and have been replaced by Brazilian pepper (*Schinus terebinthefolius*), another tropical exotic species that invades both upland and wetland areas (Day, 1993). Brazilian pepper is salt tolerant and tends to invade mangrove forests that have been disturbed by ditching or diking. Seeds are spread by birds so that dispersal can occur over long distances. This species was not abundant as late as the 1950s (Alexander and Crook, 1974) but is today the most intrusive and abundant of the exotic species throughout almost all of the region.

Punk tree or cajeput (*Melaleuca quinquenervia*) is another exotic tree species from Australia that has invaded natural communities of the south half of peninsular Florida. This species primarily invades freshwater swamps and marshes where the natural vegetation has been disturbed by fire, reduction of the hydroperiod, or clearing (Myers, 1983).

It has been estimated that about 10% of the plant species on the Blowing Rocks Preserve on Jupiter Island consist of exotics (Richardson, et al., 1992). Australian pine and lather leaf (*Colubrina asiatica*) have been reported as serious management problems at the preserve (Richardson, et al., 1992).

Other exotic species that have been documented as replacing native flora are the climbing fern (*Lygodium microphyllum*) and calophyllum (*Calophyllum inophyllum*). Calophyllum has been documented as replacing native tropical hammock vegetation on Indian mounds in the Hobe Sound National Wildlife Refuge (Alexander and Crook, 1974).

2.4 OTHER THREATS

Natural events such as hurricanes and fires may alter natural communities in the region, even to the point of eliminating individual stands or habitats. The shoreline of Florida has been estimated to be eroding or receding at average rates of 1 to 2 ft (0.3 to 0.6 m) per year (Doyle, et al. 1984; Pilkey, et al., 1984) as a result of shoreline currents and storms. However, the natural communities have developed in response to these natural forces. Fires are essential for maintaining many scrub habitats (Schmalzer and Hinkle, 1984), and natural habitats have a natural degree of resiliency and adaptation as conditions change.

However, conversion of natural land types to urban or agricultural development not only removes the existing community but precludes recovery of the community for the period that the man-induced use is present. In 1990, approximately 44% of the original upland and wetlands habitat remained in the Indian River Lagoon watershed, with the rest converted to urban and agricultural land uses (see "Uses of the Lagoon" Technical Report volume for additional information). The amount of uplands and wetlands in natural land cover types such as maritime forests and pine flatwoods is predicted to decline by an additional 17% in the period from 1990 to 2010 (see "Uses of the Lagoon" Technical Report volume).

In addition, fragmentation of the habitats reduces the potential for recruitment or replacement of plants or animals in areas that have been damaged. Fragmentation also may restrict the use of factors such as fires for maintaining natural habitats (Myers, 1989).

2.5 LAND ACQUISITION AND PRESERVATION

Numerous federal, state, and local programs have been initiated to acquire lands along the Indian River Lagoon complex to protect and preserve upland and wetland habitats. Many involve interactive agreements and funding among different levels of government. Table 2-1 lists major land holdings of public ownership as of 1993 devoted primarily to preservation along the Lagoon complex.

The federal government has the largest conservation holdings in the Indian River Lagoon system. However, the only imminent increase in federal holdings is likely to be an addition to the Pelican Island National Wildlife Refuge (Whitmore, 1993). Four state parks are significant resources, but no immediate change in their status appears likely.

Most active acquisition and preservation programs are being implemented using State of Florida funding resources. Several programs have been established by Florida Statutes for acquiring preservation lands. These include the Save Our Rivers (SOR) program which was formed in 1981. It is administered by the water management districts through the Strategic Land Acquisition Plans and funded by the Water Management Lands Trust Fund. Funding for this program is secure through documentary tax stamp revenues (Calleson and Draper, 1992). Lands in the Indian River Lagoon system that have been at least partially acquired through the Water Management Lands Trust Fund include:

- Turnbull-Scottsmoor Marsh Conservation Area - Volusia County
- Canaveral Marshes Conservation Area - Brevard County
- South Indian River Project Area - Indian River County
- Savannas State Reserve - St. Lucie County
- North Fork St. Lucie River - St. Lucie County
- South Fork St. Lucie River - St. Lucie County

TABLE 2-1

SIGNIFICANT CONSERVATION AND PRESERVATION AREAS WITHIN THE INDIAN RIVER LAGOON WATERSHED

AREA NAME	COUNTY	SEGMENT
National Parks and Seashores		
Canaveral National Seashore	Volusia, Brevard	1A
National Wildlife Refuges/Wilderness Areas		
Merritt Island National Wildlife Refuge	Brevard	1A,1B,1C
Pelican Island National Wildlife Refuge	Indian River	3
Hobe Sound National Wildlife Refuge	Martin	4
Pelican Island Wilderness Area	Indian River	3
State Parks		
Sebastian Inlet State Park	Brevard, Indian River	2,3
Pepper Beach State Park	St. Lucie	4
Ft. Pierce Inlet State Park	St. Lucie	4
St. Lucie Inlet State Park	Martin	4
Jonathon Dickinson State Park	Martin	4
Reserves and Conservation Areas		
Turnbull-Scottsmoor Marsh Conservation Area	Volusia	1A
Enchanted Forest	Brevard	1A
Kabbord Sanctuary	Brevard	1A
Maritime Hammock Sanctuary	Brevard	1B
Malabar Scrub	Brevard	2
Canaveral Marshes Conservation Area	Brevard	1C
South Indian River Project Area	Indian River, St. Lucie	3,4
Jack Island State Preserve	St. Lucie	4
Savannas State Reserve	St. Lucie	4
South Fork St. Lucie River	Martin	4
Blowing Rocks Preserve	Martin	4
Aquatic Preserves		
Mosquito Lagoon	Volusia, Brevard	1A
Banana River	Brevard	1B
Malabar to Vero Beach	Brevard, Indian River	2,3
Vero Beach to Ft. Pierce	Indian River, St. Lucie	3,4
Jensen Beach to Jupiter Inlet	St. Lucie, Martin	4
North Fork - St. Lucie River	Martin	4

Sources: Brevard County, n.d.
FDNR, 1991a
Richardson, et al., 1992
SJRWMD, 1991
Virnstein, 1987a
U.S. FWS, n.d., 1992

A second program is the Preservation 2000 (P-2000) program, established in 1990 to purchase lands needed to protect natural resources. A major portion (30%) of this funding program is administered by the water management districts primarily to protect or recharge groundwater (SJRWMD, 1991). Other programs which administer P-2000 funding for other types of land acquisition are the Florida Department of Community Affairs (FDCA), Florida Department of Environmental Protection (FDEP) Division of Recreation and Parks, FDEP Roads to Trails program, Florida Department of Forestry, and the Florida Game and Fresh Water Fish Commission (FGFWFC). The combined funding for these programs is less than that administered through the water management districts. Funding for this program has not been secure and the status of this program is uncertain.

A third state program is the Conservation and Recreational Lands (CARL) program, which obtains recommendations for regionally significant recreational or conservation lands from local government units. The state prioritizes these lands and helps arrange for purchase based on funding, priority, and imminent need. Among the properties in the Indian River Lagoon region listed on the 1993 Priority Acquisition list are the Archie Carr Sea Turtle Refuge, Valkaria Scrub Jay Refugia, Sebastian Creek, North Indian River, and the maritime hammock initiative sites in Brevard County.

About half of the P-2000 funding is dedicated to the CARL program. CARL funds are administered as matching funds with local sources. For example, Brevard County maintains an Environmentally Endangered Lands Program funded by county bonds. Four properties totalling 1,261 ac (510 ha) have been purchased by this program, and several other acquisitions are planned. Purchased properties are the Enchanted Forest CARL Project, Kabboord Sanctuary, Maritime Hammock Sanctuary, and the Malabar Scrub (Brevard County, 1993).

Similar local programs exist throughout the region, as well as numerous programs administered or supported by non-profit organizations and foundations. Spoil islands associated with the Lagoon are also accorded some management implemented by the Florida Department of Environmental Protection and Florida Inland Navigation District, and mosquito impoundmends are managed by the county mosquito control districts and MINWR.

Although not upland communities, there are six portions (Table 2-1) of the Indian River Lagoon complex which have been designated as Aquatic Preserves under the Florida Aquatic Preserve Act (Chapter 258, F.S.).

2.6 FINDINGS AND RECOMMENDATIONS FOR ADJACENT COMMUNITIES

The principal natural upland communities on the barrier islands of the Lagoon system are the maritime forest, tropical and temperate hardwood hammocks, and coastal scrubs which have a distinct tropical influence as far north as Cape Canaveral. On the mainland side, oak and sandpine scrub and pine flatwoods are also present. Drainage, development, and road construction have caused the loss of as much as 56% of the original natural upland and wetland communities. This development also has fragmented most of the remaining habitats and isolated them from the Lagoon, lowering their functional values and connections for the Lagoon complex. The primary remaining tracts are in publicly owned lands and preserves, including the three National Wildlife Refuges and Canaveral National Seashore.

Freshwater wetland communities are dominated by marsh systems, with swamps being significantly represented only along major rivers such as the Sebastian River and in headwater swamps best represented by Turnbull Hammock. There are no major stream systems in the Mosquito Lagoon watershed (Segment 1A). Many of the natural streams have degraded water quality. The Water and Sediment Quality Technical Report findings indicate that water quality in many of the freshwater lotic tributaries is worse than in the Lagoon itself, and habitat value may be correspondingly degraded. Drainage of large expanses of freshwater wetlands has been described in the Uses of the Lagoon Technical Report. These losses have further reduced the amount of freshwater habitat in the region.

In addition to loss of habitat and water quality degradation, the major threat to adjacent habitats is invasion and replacement of native species by exotic species. Most of the important exotic species are tropical in origin, such that they are most prevalent south of Sebastian Inlet.

Australian pine is a major exotic species of the southern region, but frost sensitivity limits its expansion in northern areas. Brazilian pepper has been replacing Australian pine in many areas where Australian pine has been damaged by frosts. Brazilian pepper also invades disturbed wetlands as well as uplands, and potentially represents the greatest exotic plant species threat in the entire region. In 1950, it was hardly present, but today it is abundant and actively invading natural habitats throughout the region. Without control of this species, restoration of many communities may not be feasible.

Recent local/state agency cooperative acquisition programs, utilizing state funding sources, are the primary on-going means of acquiring additional lands. Land acquisition programs appear to be the most significant option available for conservation of these adjacent habitats. Acquisition programs also fulfill community needs for recreation, flood control, and other activities.

The common characteristic and necessity for all programs appears to be a need for funding assistance from the state or federal governments to provide the necessary impetus and resources. The P-2000 and CARL programs have been the greatest recent stimuli for acquisition programs. Future funding for the P-2000 program in particular appears to be uncertain, and loss of this program would seriously damage the land acquisition efforts of agencies along the Lagoon.

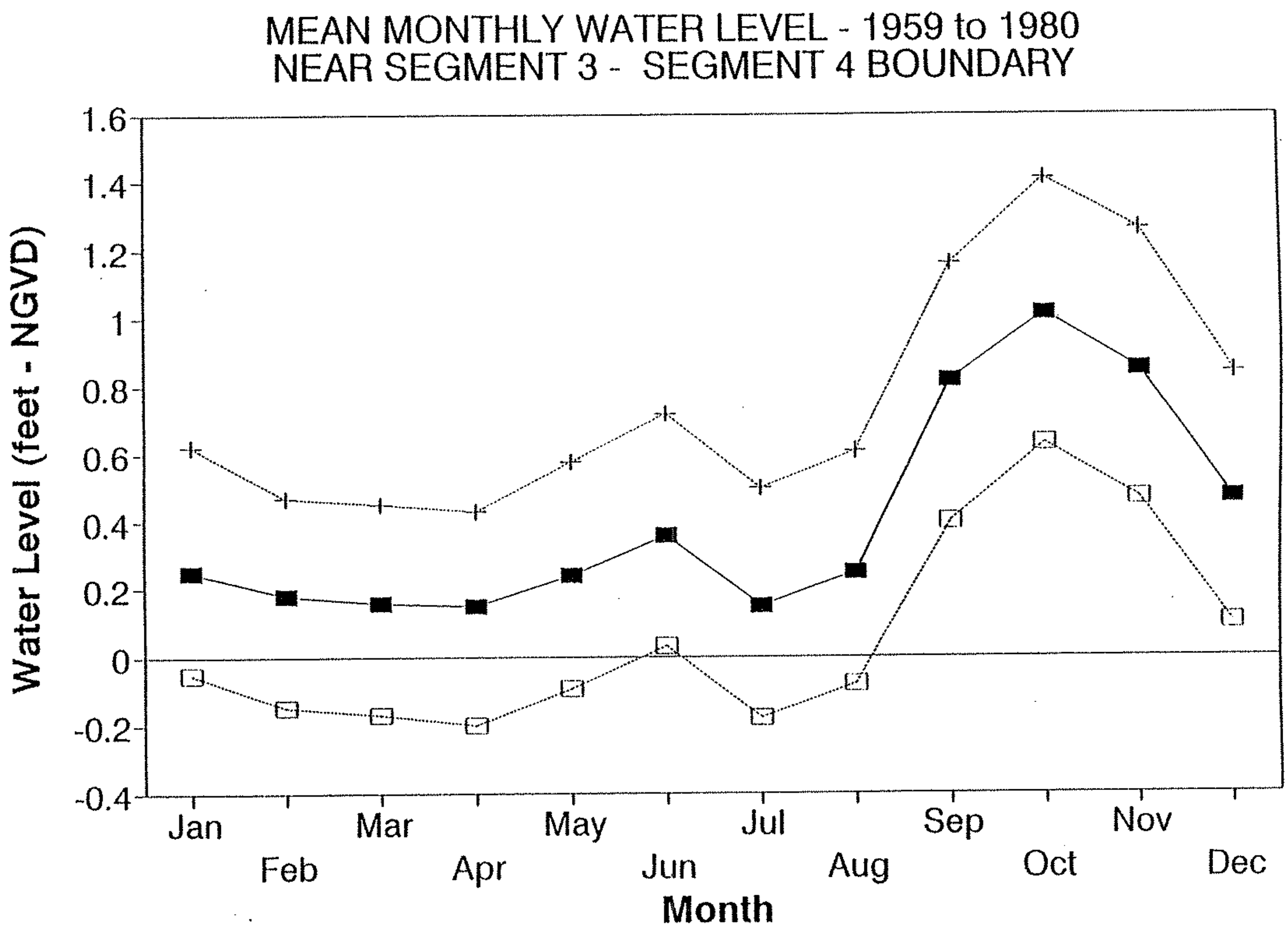
3.0 INTERTIDAL AND COASTAL COMMUNITIES AND HABITATS WITHIN THE INDIAN RIVER LAGOON

3.1 WATER LEVEL FLUCTUATIONS AND THE "INTERTIDAL" ZONE

The Indian River Lagoon is unusual among Florida estuaries in that much of the Lagoon has a narrow tidal range, often with less than a 1-foot difference between low tide and high tide. While the semi-diurnal (twice daily) tidal range at Sebastian Inlet, for example, may be about 3.1 ft (0.9 m), it decreases to about 0.2 ft (0.06 m) near the Melbourne Causeway, about 23 miles north (Dombrowski, et al., 1987). The daily fluctuation in much of Banana River, Mosquito Lagoon, and the Indian River Lagoon north of Melbourne is also usually less than 0.5 ft (0.15 m) (Smith, 1992). The pattern of water level fluctuations and how it affects conditions in the intertidal zone is important in understanding the ecology of the two primary intertidal communities of the Lagoon, the mangrove forests and the salt marshes.

Water level fluctuations on an irregular basis caused by such factors as rainfall and wind often cause larger water level changes than the tides (Smith, 1992). This condition is described in the Physical Features Technical Report in more detail. The significance of this low tidal range is that in much of the year, the high tide is insufficiently high to enter the upper zones of the intertidal zone, so that large areas of intertidal mangrove forests and salt marshes may remain above Lagoon water level for days or weeks at a time.

Another unusual feature of the Indian River Lagoon is that there is a regular seasonal increase in water level of about 1 ft (0.3 m), occurring between September and November (Smith, 1986; 1992). This seasonal increase is caused by pressure and temperature differentials originating in the Atlantic Ocean, in combination with increased freshwater runoff to the Lagoon following the heavy rainfall of the wet season (Smith, 1992). Figure 3-1 shows the water levels of the Lagoon over a typical year with the increase in water level in the autumn. Although the tidal range remains the same in this period, the increased base water level allows high tides to enter the upper zones of salt marshes and mangrove forests as well as culverted or breached impounded marshes on a regular basis during this period.



Sources: Smith, 1986
Smith, 1988.

• Woodward-Clyde Consultants
• Marshall McCully & Associates
• Natural Systems Analysis

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FIGURE 3-1 SEASONAL WATER LEVEL VARIATION IN THE INDIAN RIVER LAGOON

INDIAN RIVER LAGOON NATIONAL ESTUARY PROGRAM

These patterns of water level rise and fall are very critical in governing the ecological function and condition of the intertidal wetlands of the Indian River Lagoon complex. They also are important for an understanding of the life cycle of the salt marsh mosquitoes and the means by which these mosquitoes are controlled at their "source," by methods which are common only in the Indian River Lagoon and which have posed special problems unique to this ecosystem.

Consideration of the tidal regime was one of the criteria behind the definitions of the segments of the Lagoon shown in Figure 1-2. In the Physical Features Technical Report, Segments 1A (Mosquito Lagoon), 1B (Banana River), and 1C (North Indian River Lagoon) have been described as the "tideless sub-reach" of the Indian River Lagoon complex. In these areas particularly, the differences in water level caused by rain, wind, and other factors may be greater than tidal differences.

3.2 ESTUARINE OR INTERTIDAL WETLANDS

As pointed out above, the term "intertidal" may be somewhat of a misnomer for the salt water wetlands of the Indian River Lagoon system because other water level fluctuations completely overshadow the regular diurnal or semi-diurnal effects of the astronomical tides. The Indian River Lagoon has wetland areas which are alternately dry and inundated by salt water, and which harbor wetland species that are found in the intertidal zone of other estuaries. However, because of the lesser tidal range and more irregular patterns of inundation, the communities found around the Indian River Lagoon vary somewhat from those of other estuaries.

The two basic types of salt water wetland or "intertidal" wetland in the Lagoon are mangrove forests and salt marshes. The distribution of these habitat types is primarily on a latitudinal basis, with salt marsh dominant in the north end of the Lagoon complex and mangrove forest dominant in the south end. The zone of transition between the two types lies between Sebastian Inlet near the Indian River-Brevard County line and Oak Hill in Volusia County (Haddad and Harris, 1985).

This latitudinal gradient is caused primarily by the temperature gradient along the Lagoon and particularly by the occurrence of freezes, since mangroves are sub-tropical species that are sensitive to freezes and low temperatures (Waisel, 1972; Carlton, 1974). In areas where mangrove dominance is limited by periodic freezes, salt marsh is the dominant wetland habitat type.

The reduced tidal range also affects species composition of the salt water wetlands and has produced a community type that is intermediate in nature between these two types. This community, which is typical of the Indian River Lagoon but rare in other estuaries in Florida, has been termed a "mangrove marsh" by Lewis, et al. (1985).

Another wetland feature that is specific to the Indian River Lagoon system because of the unique nature of the intertidal zone is the presence of mosquito impoundments. These are areas in which natural salt marshes or mangrove forests have been diked to alter the hydroperiod to reduce breeding of salt marsh mosquitoes. The following sections describe the mangrove forest and salt marsh habitats, as well as the systems of mosquito control that have been developed in these habitats.

3.3 MANGROVE COMMUNITIES

Mangrove communities are an integral part of the ecosystem associated with the Indian River Lagoon. The word mangrove is derived from "mangue," Portuguese for tree, and the English word "grove" or stand of trees (Dawes, 1981). Mangrove communities or forests within the Indian River Lagoon include three species of mangroves found within the boundaries of the Indian River Lagoon and also a non-mangrove shrubby species that is commonly associated with these floral systems. These scrub and tree-like communities occur within the intertidal zone of the Lagoon.

Mangroves are found throughout the Lagoon, but are more prevalent south of Melbourne. The distribution of mangroves within the Indian River Lagoon appears to be limited by several factors including climate, water fluctuation, salinity, type of substrate, nutrient availability, and wave action (Odum, et al., 1982; Lewis, et al., 1985). Mangroves are salt tolerant, but they are also facultative halophytes (Egler, 1948), which indicates they do not require the presence of salt water or high salinity for normal growth.

3.3.1 Associated Flora

Three plant species, all in different plant families, are collectively called "mangroves" because they all have specialized morphological and physiological adaptations to saline coastal habitats. All are restricted to the mangrove forest community, and have no close relatives among the terrestrial vegetation (Tomlinson, 1986).

The red mangrove (*Rhizophora mangle*) is the most waterward of the mangroves, generally found only at elevations near or below the mean high water line. It is identified by the presence of prop roots extending from the trunk and by drop roots from the branches which may eventually develop into prop roots (Dawes, 1981; Tomlinson, 1986). It may reach heights of 75 ft (24 m) (Odum and McIvor, 1990), but rarely is larger than 35 ft (12 m) in the Indian River Lagoon. Recruitment occurs through floating pencil-shaped propagules.

The black mangrove (*Avicennia germinans*) is easily identified by the presence of pencil-sized and -shaped pneumatophores (gas exchange structures) which originate from the roots and commonly rise up to 12 in (30 cm) above the soil. Maximum height of black mangroves may be 60 ft (20 m), but they also are generally much smaller in the Lagoon. Because of the presence of salt-excreting glands on the leaf surfaces, the leaves can become encrusted with salt. Black mangroves have propagules which are lima bean-shaped and which also are dispersed by water.

The white mangrove (*Laguncularia racemosa*) is the most landwardly occurring of the three true mangrove species, ranging in height to 35 ft (12 m). In poorly aerated situations, white mangroves may develop pneumatophores or bulbous, knee-like "peg roots" rising from the base of the tree, but they generally lack the extensive root and pneumatophore system of the black mangroves or the prop roots of the red mangroves (Jenik, 1967; Tomlinson, 1986).

Buttonwood (*Conocarpus erectus*), a small shrub or tree, is a common associate of the mangroves in the intertidal zone community, but is not considered to be a "true mangrove" because it does not have the same degree of specialized adaptation as the mangrove tree species (Tomlinson, 1986). It is in the same family as the white mangrove, but lacks pneumatophores.

Smooth cordgrass (*Spartina alterniflora*) may be associated with red mangroves at or below the mean high water level. Often, other salt tolerant plant species such as saltwort (*Batis maritima*), glasswort (*Salicornia* spp.), saltmeadow cordgrass (*Spartina patens*), sea oxeye daisy (*Borrichia frutescens*), and leatherleaf fern (*Acrostichum danaeifolium*) are intermixed with mangrove species near and above the mean high water level (Ball, 1980; Richardson, et al., 1992).

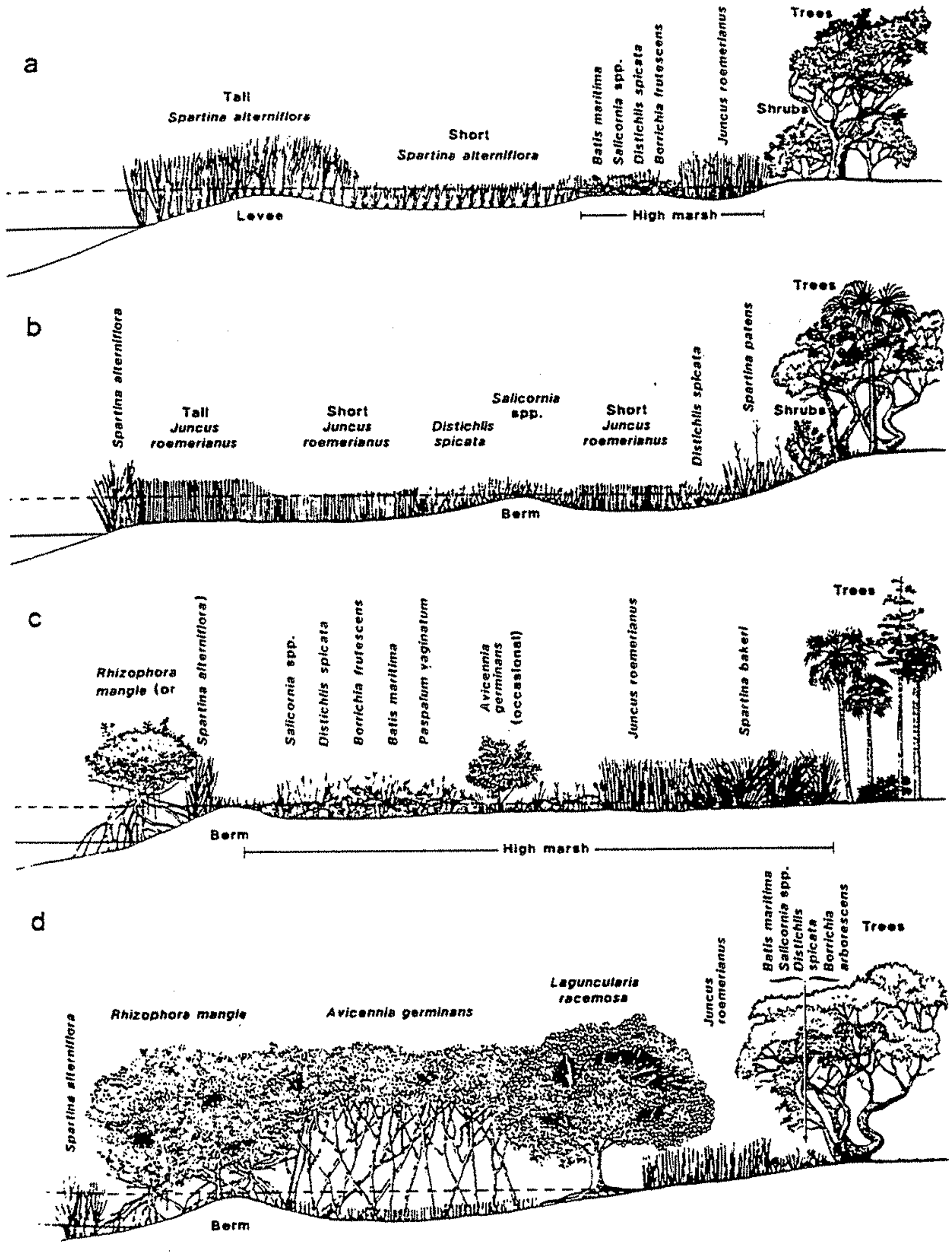
Figure 3-2 depicts a typical mangrove community associated with the southern Indian River Lagoon complex as well as typical salt marsh profiles. The distribution of species generally follows elevational gradients with red mangroves in the lowest or most waterward sites, grading into black mangrove, and then white mangrove and buttonwood in the higher locations. The degree of flooding appears to be a primary factor for the zonation of mangroves, with distribution related to the differing mechanisms and ability of root adaptations to cope with saline inundation and substrate stability (Davis, 1943; Tomlinson, 1986). However, other factors have been shown to influence zonation and distribution as well. These factors include soil water salinity (Cintron, et al., 1978), seed predation by snails and land crabs (Smith, et al., 1989), and fire (Taylor, 1981).

In many areas, the halophilic herbaceous plants constitute the majority of the plant cover, particularly above the mean high water level, with less abundant black mangroves scattered throughout. These areas with mixed shrubs and herbs have been described as "mangrove marshes" (Lewis, et al., 1985). Elevation of one such area has been reported as between -1.7 ft and +1.7 ft NGVD (O'Bryan, et al., 1990), or about 2.7 ft below to 0.7 ft above mean high tide.

3.3.2 Ecological Requirements and Adaptations

The five major natural factors affecting mangrove development are climate (temperature), salinity, water level fluctuation, nutrient availability, and substrate/wave energy regime (Odum, et al., 1982). The interaction of these factors determines the distribution and productivity of mangroves in the Indian River Lagoon.

Mangroves are sub-tropical or tropical species which are limited in distribution by temperature. They will not survive in climates where the annual average temperature is



a) Typical Northeast Florida Salt Marsh
b) Typical Northwest Florida Salt Marsh
c) Typical Indian River Lagoon "High" Salt Marsh
d) Typical Indian River Lagoon/South Florida Mangrove/High Marsh

Source: Montague & Wiegert (1990)

INDIAN RIVER LAGOON NATIONAL ESTUARY PROGRAM

• Woodward–Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysts	DRAWING NO.: DATE:	FIGURE 3-2	COMPARISON OF INDIAN RIVER SALT MARSH AND MANGROVE COMMUNITIES TO OTHER FLORIDA SYSTEMS

below 64°F (19°C) (Waisel, 1972). Temperature is undoubtedly the primary limiting factor determining mangrove geographical distribution within the Indian River Lagoon region. Although the northern limits have been reported as being as far north as Daytona Beach for red and white mangroves and St. Augustine for black mangroves (Odum, et al.,1982), they are essentially not found north of the Indian River Lagoon region.

Heavy freezes with temperatures below 30°F (0°C) for at least a 24-hour period were documented in the Indian River Lagoon region in 1957, 1962, 1977, 1983, 1985, and 1989 (Doehring and Barile, 1988; U.S. Department Commerce, 1985; 1992). These freezes killed the above-ground portions of most mangroves north of Haulover Canal and heavily damaged red and white mangroves as far south as Jupiter Inlet. All three species have historically been found in the north segment of the Indian River Lagoon, but persistent freezes since 1957 have curtailed their northern extent. Tree size individuals are currently restricted to the area south of central Brevard County. Black and white mangroves have resprouted since the 1989 freeze and are up to four feet in height as far north as the New Smyrna Beach area. Aerial photographs of Mosquito Lagoon since 1943 have shown a pattern of alternating periods of dominance between mangrove and salt marsh on the islands in the northern Lagoon. Mangroves were abundant and tall in 1974 photos following a long growing period since the 1962 freeze. In 1984, after the 1977 and 1983 freezes, salt marsh had again replaced mangrove forest as the dominant community.

Although mangroves have been reported to survive and grow under freshwater conditions (Teas, 1979), they appear to be incapable of withstanding competitive pressure from freshwater species (Tomlinson, 1986). Therefore, minimum salinities between 5 to 15 ppt appear to be necessary for development of mangrove forests (Tomlinson, 1986).

To flourish in a saline environment, mangroves require special adaptations. Morphological structures such as elaborate root systems, pneumatophores, salt-excreting foliar glands, and xerophytic succulent leaves enable mangroves to survive in the estuarine environment (Albert, 1975; Teas, 1979). Red mangroves are able to separate freshwater from salt water at the root surface, by an exclusion process that also excludes sulfide which is an element that may be high in the surface and ground water (Carlson and Yarbro, 1987). This exclusion is driven by pressure within the stem structures and transpiration at the leaf surface

(Fahn, 1979). White and black mangroves excrete excess salt by the use of salt excreting glands located on the leaf surface (Fahn, 1979).

As a result of these salt regulation mechanisms, red mangroves have been shown to occur where soil salinity is as high as 65 ppt, while white and black mangroves may grow in soil salinities above 90 ppt (Cintron, et al., 1978; Odum and McIvor, 1990). These ranges of soil salinity tolerances contribute to the zonation of mangroves and the development of the "mangrove marshes" of the Indian River Lagoon system. The extensive areas above mean high water, which are flooded and flushed only by the irregular and occasional high tides throughout most of the year, have been shown to develop salinities above 200 ppt (Gilmore, et al., 1982) restricting vegetation to a few very specialized species.

Mangrove communities, like other coastal wetlands, contribute to the removal of dissolved nutrients in runoff from adjacent upland areas (Snedaker and Lugo, 1973). Nitrogen, phosphorus, and other essential nutrients are absorbed by mangrove root systems. Lugo and Snedaker (1974) have shown that mangrove size and growth are proportional to the levels of nutrients received and that this growth may be correlated to the amount of runoff received from adjacent terrestrial sources.

This uptake of nutrients from terrestrial runoff therefore may mitigate the rate of eutrophication throughout the open water portions of the Indian River Lagoon (Carter, et al., 1973). Because development of adjacent uplands may increase runoff and concentrations of nutrients in the runoff, the productivity of mangroves in some cases may be further enhanced by human activities. Natural factors such as the presence of bird rookeries and decomposition of storm-driven vegetative detritus can also increase productivity on a localized basis (Odum and Heald, 1975a; Onuf, et al., 1977).

Growth and survival of mangroves may be influenced by other factors including hydrologic conditions. Movement of water has also been shown to be a key factor in mangrove productivity (Odum, et al., 1982). Tidal circulation is important in maintaining a supply of nutrients and dissolved oxygen to some areas as well as flushing hydrogen sulfide and salts from groundwater of mangrove forests (Snedaker, 1989).

The interaction of wave energy, substrate type, and climatic factors such as hurricanes may influence mangrove forest establishment and survival. Mangroves have specialized reproductive strategies adapted to dispersion by wave and current movement by water. Mangrove species are viviparous or cryptoviviparous, conditions which allow the embryo to germinate and begin development while still attached to the tree or prior to settling in the substrate (Rabinowitz, 1978a). The propagules, which are the "seeds" of the pre-germinated structures, have the ability to float. In coastal systems, this is a tremendous advantage over methods of seed dispersal found in other plant species. These propagules remain viable for extended periods of time, thereby allowing distribution throughout a water body. When proper sediment and hydroperiod conditions are present, the grounded propagules become established.

The prop roots of the red mangrove and extensive arrays of sub-surface roots of black mangroves not only contribute to the maintenance of suitable salt and water balances in the trees, but also are important for anchoring mangroves in soft substrates and during hurricances.

Mangroves have been noted as one of the highest net primary productive ecosystems in the world, with over 0.2 lb ft^{-2} yr^{-1} (1,000 g m^{-2} yr^{-1}) of dry matter (Odum, et al., 1992) and 0.04 oz ft^{-2} yr^{-1} (12 g m^{-2} yr^{-1}) of carbon fixation (Miller, 1972). Much of this production results in litter and leaf fall from the trees and as dieback of herbaceous plants (Odum, 1970). Estimates of the amount of annual litter fall from one acre of mangrove forest have ranged from 2.5 to 22 metric tons (Odum and Heald, 1975a; Lugo, et al., 1980). Tidal flushing can export the resulting detritus to the Lagoon, making the mangrove community a major energy source for the food web of the Lagoon.

A substantial amount of the primary production of mangrove marshes is also believed to occur on or just under the soil surface, where bacteria, fungi, and microalgae may occur. As this material dies, detritus is added to the surface, forming an organic floc (Wood, 1965; Bell, 1980). Microscopic fauna, as well as larger invertebrates and fish feed on the resulting mixture.

3.3.3 Associated Fauna

Mangrove communities provide valuable habitat for a myriad of animal life, as extensively reviewed by Odum, et al. (1982). Among the vertebrates, fishes were reported as the most diverse group (220 species), followed by birds (181 species), amphibians and reptiles (24 species), and mammals (18 species). This fauna includes many species listed as endangered, threatened, or of special concern (see Section 7.0). Animals encountered in the mangroves include both resident and transient forms.

Residents are animals that spend virtually their entire life cycle within the mangrove communities, reproducing, foraging, and hiding from predators. Many fishes and birds tend to be mangrove residents, such as the marsh killifish (*Fundulus confluentis*), the mangrove rivulus (*Rivulus marmoratus*), the wood stork (*Mycteria americana*), and the roseate spoonbill (*Ajaia ajaja*).

Transients spend only a portion (or portions) of their lifes in or near the mangroves. A key example is the popular sportfish, the common snook (*Centropomus undecimalis*), which concentrates in and around mangroves during a certain portion of their juvenile phase, move out into more open waters to mature, and then return on frequent predatory forays as adults (Gilmore, et al., 1983).

The submerged root systems of mangroves form a protected nursery habitat for dozens of other fishes, such as striped mullet (*Mugil cephalus*), tarpon (*Megalops atlanticus*), and mangrove (gray) snapper (*Lutjanus griseus*). This submerged habitat is also a common nursery for valuable crustaceans such as penaeid shrimp (*Penaeus* spp.) and spiny lobster (*Panulirus argus*).

Some researchers have indicated that the prop root habitat of red mangroves may be even more valuable to juvenile fish species on a per area basis than the seagrass beds (Lewis, et al., 1985; Thayer, et al., 1987). The prop roots of red mangroves provide habitat for many other types of invertebrates, including mangrove periwinkle snails (*Littorina angulifera*), hermit crabs (*Pagurus* spp.), numerous tunicates (sea squirts), and many polychaete worm species including fanworms (Sabellidae) (Kaplan, 1988).

Birds which use mangrove communities as foraging and/or nesting areas represent a wide variety of behavioral types (e.g., wading, floating, diving, aerial, arboreal). Many of the known rookeries scattered throughout the Lagoon system are associated with mangroves (See Section 6.2). Herons and egrets are especially prevalent, as are brown pelicans (*Pelecanus occidentalis*), white ibis (*Eudocimus albus*), and many others.

The animals of the mangrove forests and salt marshes may also play important roles in the cycling of nutrients, energy transport, and water chemistry of intertidal wetlands. Fiddler crabs (*Uca* spp.) in particular are an important part of this food web, eating and converting the detrital matter of the mangrove marsh into animal matter that is eaten by many fish and bird species (Teal, 1958, 1962). In addition, fiddler crabs may have an important role in nutrient cycling and in soil water chemistry regulation in intertidal communities (Kraeuter, 1976; Christy, 1978; Gilmore, et al., 1990). It has been estimated that fiddler crabs and snails may excavate and turn over all of the substrate of an intertidal area each year (Kraeuter, 1976), thus cycling organic matter, nutrients, and other constituents. Such action may also affect soil and soil water chemistry by altering the oxygen content of the soils.

At least six species of fiddler crabs occur in the Indian River Lagoon region (Gilmore, et al., 1990). Over 100 fiddler crab burrows per square meter have been counted in marshes or mangrove communities along the Indian River Lagoon (Gilmore, et al., 1990).

3.3.4 Community Trends

Mangrove communities within the Indian River Lagoon have been altered or lost due to man's impacts on the Lagoon. Dredging of mangrove forested areas for marina and channel/inlet creation and filling for causeways, housing developments, and recreational facilities have destroyed many mangrove areas along the shoreline of the Lagoon. One estimate (Haddad and Harris, 1985) has put such losses of mangroves in the Ft. Pierce region at 27% between 1958 and 1982.

In addition to this loss of habitat, many mangrove forests have been impacted and functionally altered by the creation of mosquito impoundments. Construction of impoundments has first resulted in some direct loss through dredging and filling to create the dikes. Creation of the diked impoundments has also altered the functions of many of these systems. Functional effects include hydrologic isolation, which results in the loss of exchange of nutrients and detrital matter between the forests and the lagoons. This isolation has also prevented many transient fish species from utilizing the mangrove community during sensitive portions of their life cycles.

Changes in hydroperiod in many impounded areas have altered the balance of mangroves and other species throughout the Lagoon complex. In some cases, the impoundments have increased water levels and allowed red mangroves a competitive advantage at the expense of black and white mangroves and high marsh herbaceous species. Although mangroves have been found to tolerate freshwater conditions, it has been shown that all species of mangroves may be killed if salinity of the impoundments is allowed to decrease significantly (Rey and Kain, 1993). In other cases, reduction in hydroperiod has caused death of mangroves and allowed exotic species such as Brazilian pepper to invade the community (Rey and Kain, 1991).

Soil salinity is also known to affect the distribution of mangrove species, with red mangrove reported to be limited to soil salinities below 65 (ppt). White and black mangroves can exist in soil salinities as high as 90 ppt (Odum and McIvor, 1990). Black and white mangroves therefore can colonize the salt flats and high marshes above the mean high tide line, while red mangrove is restricted to regularly inundated zones because of the very high soil salinities that can occur in the soils above the mean high tide line.

Implementation of recent management plans for mosquito impoundments is likely to prevent further net loss of mangrove habitat in impoundments and may enhance the functional roles of this community. In particular, the RIM (Rotational Impoundment Management) technique will restore a more natural hydroperiod, allowing mangroves to adjust to more natural tidal regimes and historical distribution patterns. One study (O'Bryan, et al., 1990) has found that black mangrove, along with glasswort and saltwort, has shown signs of re-establishment in an impounded marsh after the impoundment was re-opened and a more natural hydroperiod was established.

Mangroves are protected by Florida law. Chapter 17-321 of the Florida Administrative Code provides protection from alteration to mangrove communities (Florida Sea Grant College Program, n.d.). The intent of the law is to protect mangroves and their vital role in the economic and ecological aspects of the Lagoon by establishing a procedure for evaluating and minimizing impacts of proposed mangrove alteration. This law also includes a provision requiring private individuals to obtain a permit before they can trim or remove mangrove branches and leaves in order to gain access to, or a view of, the Lagoon.

The combination of natural stresses such as freezes and man's activities such as impounding and coastal development appear to have resulted in a net loss of mangrove habitat and productivity within the Lagoon. Haddad and Harris (1985) have documented a 76% loss of mangrove habitat through impounding between 1958 and 1982 in the portion of the Lagoon between Satellite Beach and Sebastian Inlet, as well as a 27% loss of mangrove habitat in the vicinity of Ft. Pierce. It is important to note that natural forces such as freezes affect the status and extent of the mangrove community at any given time within the Lagoon, in addition to the effects of man's activities. The alternating dominance of mangrove and salt marsh habitats within the northern portions of the Lagoon is a good example of a natural effect.

Mangroves also provide one of the most important nesting habitats for wading and water birds such as egrets and pelicans. Loss of mangroves through freezes can therefore affect the quality of bird rookeries and influence reproductive success throughout the Lagoon. It has been reported that Pelican Island was one of a very few nesting sites for brown pelicans on the Florida east coast for many years between the early and mid 1900s (Whitmore, 1993). The island may have been even more crucial for survival of the species because it was the only documented location in which pelicans nested on bare ground after freezes killed back most mangroves throughout the Lagoon.

3.4 SALT MARSH COMMUNITIES

Myers and Ewel (1990) state that approximately 10% of the herbaceous salt marshes in Florida are associated with the Indian River Lagoon complex. These intertidal communities, dominated by salt tolerant vegetation, occur sparsely within most portions of the Indian River Lagoon complex. Most of the salt marshes are concentrated around the northern ends of Indian River Lagoon and Banana River. This community type exhibits both terrestrial and marine ecosystem characteristics, interacts with other ecosystems, and has one of the highest net primary productivities of any ecosystem found worldwide.

Many of the salt marshes within the Indian River Lagoon complex vary from those found elsewhere in Florida and the southeastern United States. Differences in climatic conditions, latitudinal gradients, wave action, and topographic changes account for these special conditions. Many of the salt marshes occur within the intertidal zone of the Indian River Lagoon, but most are above the mean high water line and are referred to as high marshes (Provost, 1973). High marshes differ from low marshes in vegetation composition, tidal exchange, and other factors. Low marshes generally occur below the mean high water line.

The high marshes associated with the Indian River Lagoon complex also differ from high marshes in many other areas by having a natural berm occurring at the level of mean high water (Provost, 1973). Figure 3-2 illustrates that due to the berm, the high marshes are only inundated by wind-driven tides and during the rare times of seasonal flooding.

3.4.1 Associated Flora

A commonality of all salt marsh systems is the presence of plant zonation within the vegetative communities. The natural zonation in many Indian River Lagoon complex salt marshes includes a "low marsh" zone with red mangroves or smooth cordgrass (*Spartina alterniflora*) in the lower margins, most often continuing inland for approximately 30 ft (10 m) to the upper edge of the mean high water line. At this point, a low berm marks the boundary between the low marsh and the "high marsh." Smooth cordgrass may also be found as a narrow band at the beginning of the upland forest.

Smooth cordgrass-dominated low marsh (below the mean high water line) is much less abundant in the Indian River Lagoon than in most of the other estuaries in Florida. This low abundance is thought to be due to the unusual tidal regime of the Lagoon in which seasonal water level fluctuations and irregular rainfall events generally cause greater water level fluctuations than the diurnal tidal cycle (Provost, 1976; Montague and Wiegert, 1990). The narrow tidal range results in an extremely narrow band of Lagoon bottom that is exposed and flooded on a regular basis. As a result, the intertidal low marsh zone is limited in extent. More information on the tidal conditions of the Lagoon is provided in the Physical Features Technical Report.

The high marsh is vegetatively characterized in some locations by monotypic stands of black needlerush (*Juncus roemerianus*) combined with a mixture of glasswort, salt grass *(Distichlis spicata)*, sea oxeye, saltwort, salt jointgrass (*Paspalum vaginatum)*, and black and white mangroves. Black needlerush is prevalent in parts of the northern Indian River Lagoon near Black Point at the northern end of Merritt Island and in portions of the Banana River, especially in the headwaters of Sykes Creek on Merritt Island. Generally this species occurs where lower salinities are present due to impoundment of rainwater or from freshwater runoff. Aerial photographs indicate that it was present in the 1940s at the transition between the marshes and flatwoods west of the northern end of Indian River Lagoon. In much of the Indian River Lagoon complex, especially in the southern portions, salt meadow cordgrass (*Spartina patens*) and salt jointgrass are the principal graminoid species of the high marsh.

In areas of the Indian River Lagoon south of Sebastian Inlet, the natural occurrence of salt marsh diminishes (Provost, 1976). To the south of Wabasso, mangrove communities replace salt marsh as the dominant natural intertidal community due to a lower occurrence of killing freezes.

3.4.2 Ecological Requirements and Functions

The primary environmental factors affecting function and development in salt marshes are flood frequency and soil salinity (Eleuterius, 1984). The degree of flooding appears to be the factor which determines the relative abundance of smooth cordgrass and black needlerush in an area rather than salinity. Soil salinity may be higher in high marsh areas than in regularly flooded salt marshes, due to evaporation and concentration of the remaining salts. This evaporation leads to the development of "salt pans" where the high salinities allow only a few halophytic (salt tolerant) species to survive. Saltworts and glasswort are among the few species that can grow in these areas (Montague and Wiegert, 1990).

High marshes often occur on sandy soils with low nutrient retention, in contrast to the deep organic soils common in low marshes. Net above ground primary production of high marshes generally is much lower than in low marshes (130 to 700 g m^{-2} yr^{-1} vs 1,300 to 2,200 g m^{-2} yr^{-1}). However, unimpounded high marshes on Merritt Island have been found to have productivities between 2,000 and 2,500 g m^{-2} yr^{-1}, much higher than reported in other Florida marshes (Montague and Weigert, 1990). This high level of productivity indicates the importance of the salt marshes of the upper Indian River Lagoon in the food chain of the Lagoon.

Approximately 90% of the material produced by marsh plants is dead when consumed by animals and microorganisms (Pfeiffer and Weigert, 1981). Because of the natural berms in the Indian River Lagoon complex, much of this production is not directly exported to the Lagoon. Instead, much of the living or detrital marsh vegetation is consumed by invertebrate animals, primarily crabs and terrestrial insects in the high marshes. These, in turn, form food for birds and mammals. Rey, et al. (1991) have also reported that zooplankton biomass may be higher in the impounded marshes of the Indian River Lagoon than in other estuaries studied. Impounding salt marshes, discussed below, tends to favor those species which feed on fish and aquatic invertebrates at the expense of species which feed on terrestrial insects, plant tissue, or crabs. Salt marshes also may have a role in the nutrient cycling of the Lagoon. There are indications that an important function that occurs within the marsh habitat is the conversion of inorganic nitrogen (NO_2, NO_3) to organic nitrogen (NH_4) and the consequent export of organic nitrogen to the Lagoon (Nixon, 1980).

3.4.3 Associated Fauna

As one of the most productive ecosystems, salt marshes provide specific habitat for a wide array of wildlife ranging from invertebrates to mammals. A few of these species are found only within the salt marshes adjacent to the Indian River Lagoon complex. These intertidal communities serve as nursery and foraging areas for estuarine wildlife. Constant fluctuations in salinity, water levels, and temperature require salt marsh inhabitants, whether resident or transient, to have special adaptations. Such specializations may be morphological, physiological, or behavioral.

Terrestrial insects and arthropods constitute the primary food chain pathway from living plant material to higher animals in many salt marshes. Invertebrate species such as fiddler crabs and snails, especially the marsh periwinkle (*Littorina irrorata*) and eastern melampus (*Melampus bidentatus*), have important roles in the detrital food web of the salt marsh. These animals eat detrital material consisting of dead plants and other materials, and in turn are food for other species. As in the mangrove forests, fiddler crabs burrow into the mud substrate, recycling nutrients and providing aeration of the sediments. The eastern melampus is a prime food for several species of ducks. All of these species require uninundated conditions for at least part of the time. Thus permanent inundation of marsh ares can eliminate these critical elements of the food web.

The most readily observed species associated with salt marsh communities within the Indian River Lagoon are the numerous bird species that occur as permanent residents or migratory visitors. The diking of salt marshes for mosquito control has contributed to the creation of many large shallow ponds which harbor numerous species of fishes, primarily mosquitofish (*Gambusia affinis*), sheepshead minnows (*Cyprinodon variegatus*), and sailfin mollies (*Poecilia latipinna*) (Harrington and Harrington, 1982). Creation of such ponds led to a change in the species composition of birds utilizing the marshes. The presence of the plentiful fish population, combined with shallow protected ponds, created an ideal habitat for many of the avian species that benefitted.

In the early 1960s the U.S. Fish and Wildlife Service (FWS) provided funding to investigate the impact of impounding salt marshes on birds utilizing the existing salt marsh communities. The study focused on a comparative study of avian use of impounded and unimpounded marshes (Provost, 1967, 1969). The study revealed that seven species were not affected by impoundments, seven species were adversely impacted, and 22 species (primarily ducks, herons, and rails) benefitted from the impoundments (Kale, 1988). The dusky seaside sparrow was extirpated from the Merritt Island area by 1977 largely as a result of the loss of habitat from the creation of these impoundments (Sykes, 1980).

3.4.4 Community Trends

Numerous alterations to salt marsh communities have occurred within the Indian River Lagoon, the most prevalent being impoundment and diking as a control method for mosquitoes. As the population of central Florida expanded during the early 1950s, humans quickly found that co-inhabiting with the hordes of the salt marsh mosquito (*Aedes taeniorhynchus*) was unbearable, in addition to being a health threat. Mosquito impoundments were created as early as the 1930s, with the majority of construction occurring between 1954 and 1961 (Rey and Kain, 1991).

More than 40,000 ac (16,000 ha) of salt marshes have been altered through impoundment throughout the Lagoon (Rey and Kain, 1991), with 63% (over 25,500 ac) of these impoundments occurring in Brevard County (Montague and Wiegert, 1990) and another almost 5,000 ac (2,024 ha) in St. Lucie County (David, 1992). It is estimated that all but 5% of Brevard County marshes were impounded, although virtually all of the salt marshes in northern Brevard County and in Volusia County remained in a natural state as late as 1943 (Myers, 1990).

Diking has not been the mosquito control measure used in all salt marshes. Ditching was the first method tried and it has continued to be used as an alternative to diking in certain cases. Ditching of marshes allows tidal and rainfall water to be drained more quickly, eliminating the pockets of standing water that newly hatched mosquito larvae need to survive. Ditching was generally abandoned as a control method after the diking technique was developed. Recent development of rotary ditching equipment has revived interest in this control method in Volusia County (Brockmeyer, 1994). Many marshes remain ditched, but not diked, in the northern Mosquito Lagoon area. In other portions of the Lagoon system, ditching is generally restricted to small marsh islands.

3.5 IMPOUNDMENT OF MARSHES FOR MOSQUITO CONTROL

3.5.1 Salt Marsh Mosquitoes

Salt marsh mosquitoes (*Aedes taeniorhynchus*, *A. sollicitans*) have always been present in great abundance along the Indian River Lagoon system. In his journal describing his 1697 travels throughout the region, Jonathan Dickinson wrote of the need to cover himself in dirt to escape insect attacks and sleep at night. Although the salt marsh mosquito has not been a significant carrier of diseases, it can be such a nuisance that outdoor activities are almost impossible without mosquito control. Rogers, et al. (1962) have calculated that up to 38 million mosquito larvae can be hatched per acre (94 million ha^{-1} yr^{-1}) in suitable habitats. Provost (1960) has estimated egg densities within salt marshes at up to 2,383 eggs ft^2 (25,951 m^{-2}). Salt marsh mosquitoes can travel up to 20 miles (32 km) from their hatching sites. Thus, almost all of the breeding grounds along the Lagoon can contribute to pest problems in the urbanized portions of the watershed.

The eggs of the salt marsh mosquitoes are laid in the salt water wetlands that border the Lagoon. Because of the enormous numbers of mosquitoes hatched and the distances that can be traveled, mosquito control within the urban areas is impracticable and cost-prohibitive and requires a strategy of controlling mosquitoes at the source (breeding areas) by interference with the reproductive cycle. This source control strategy has been adapted for the Lagoon region (Provost, 1973; Carlson and Vigliano, 1985; Carlson and O'Bryan, 1988).

Salt marsh mosquitoes are terrestrial insects in the adult stage but their larval stages are aquatic; standing water must be present for development into adults. These mosquitoes lay eggs in salt marshes, mangrove forests, and other moist sites along the Lagoon. The eggs are laid when the substrate is moist but not flooded (Provost, 1977). Development of eggs into the aquatic larval stage occurs as the eggs are flooded by rains or tides. These eggs develop and remain on the surface until flooding of the substrate causes them to hatch, releasing the larvae (Haeger, 1960). Eggs cannot be deposited and/or cannot develop if substrates remain either flooded or dry for extended periods. Provost (1977) has shown that periods of 1 to 2 weeks without flooding are required for oviposition and development to hatching. This frequency equates to a tidal inundation of about 4 days per month at 1 to 2 week intervals.

In general, salt marshes develop in low areas exposed to regular tidal flooding on a daily basis. A levee of debris and shell is often created at the interface by wave action or tidal deposition, between the wetland and the upland. In most of the Indian River system, tidal ranges and effects are very low, and tide and wave energy is not sufficient to carry the materials to the upland edge of the marsh (Montague and Wiegert, 1990). In this case, the debris is deposited at the waterward edge of the wetland, forming a low levee or barrier. This barrier then prevents low amplitude tides from flooding the wetland. Except during the few weeks of seasonally high water levels from September through November, the resulting wetlands are only flooded by the highest tides or by wind driven waves and tides (Provost, 1973; Smith 1986).

In St. Lucie County for instance, mean high water is about +1.0 ft NGVD (David, 1992). The natural levees often build to this elevation, so that only above-average tides can flood the wetlands (see Figure 3-1). These tides generally occur in the period from mid-August to November or when winds and spring tides coincide to form high tides in the Lagoon.

During the autumn period the wetlands may be flooded at intervals of less than one week and thus are unsuited for mosquito egg depositing. The breeding season for mosquitoes generally runs from about mid-April through November. Thus the tidal wetlands provide breeding areas for mosquitoes from about mid-April to mid-August or September (David, 1992), and it is during this period that control at the source, by inhibition of reproduction is most effective.

3.5.2 Historical Perspective of Mosquito Control

The first attempts at salt marsh mosquito control consisted of efforts to alter the hydroperiod of marshes by ditching. The peak period for this control measure extended from about 1920 to 1950. Between 1927 and 1935, 285 miles (460 km) of mosquito ditches were constructed in St. Lucie County alone (Kakoullis, 1992; David, 1992). Although these ditches were initially successful, accumulation of debris at the mouths of the ditches and piles of spoil from ditch construction tended to block drainage and reduce effectiveness (David, 1992). Because of the excessive labor requirements and cost, ditching was generally abandoned when additional control methods were developed.

In the 1940s, pesticides such as DDT, dieldrin, and BHC became the accepted methods of control for adult mosquitoes (Rey and Kain, 1991). Diesel oil was also used by the Brevard County Mosquito Control District from the 1930s until about 1988 when a refined diesel oil called Golden Bear replaced it (Provancha, et al., 1992). However, by the late 1940s, mosquitoes were beginning to show resistance to the chemicals and effectiveness waned. Pesticide use continued until the early 1960s when it was established that DDT and other persistent chlorinated compounds were responsible for declines in many species of birds and wildlife (David, 1992; Rey and Kain, 1991). Altosid, Altosand (Altosid/sand mix), methoprene, BTI, and Florida larvicides are still used regularly in most of the counties when mosquito larval counts are exceptionally high, generally before impoundments are closed for the season in cases where abnormal water levels and high temperatures in March and early April promote early mosquito breeding, or in the autumn after natural water regimes are restored to impoundments (Rey and Kain, 1991; David, 1992, 1993; Provancha, et al., 1992).

Impounding is a method of control of mosquito reproduction that continuously floods mosquito breeding areas during the breeding season, thus preventing mosquitoes from laying eggs (Haeger, 1960; Provost, 1977). As a control measure, impoundment was first tested in 1935 and was found to be 99% successful in controlling sandflies and mosquitoes (Hull and Shields, 1943). However, it was not until after discontinuing DDT that impounding became the common method of control in the Indian River Lagoon complex.

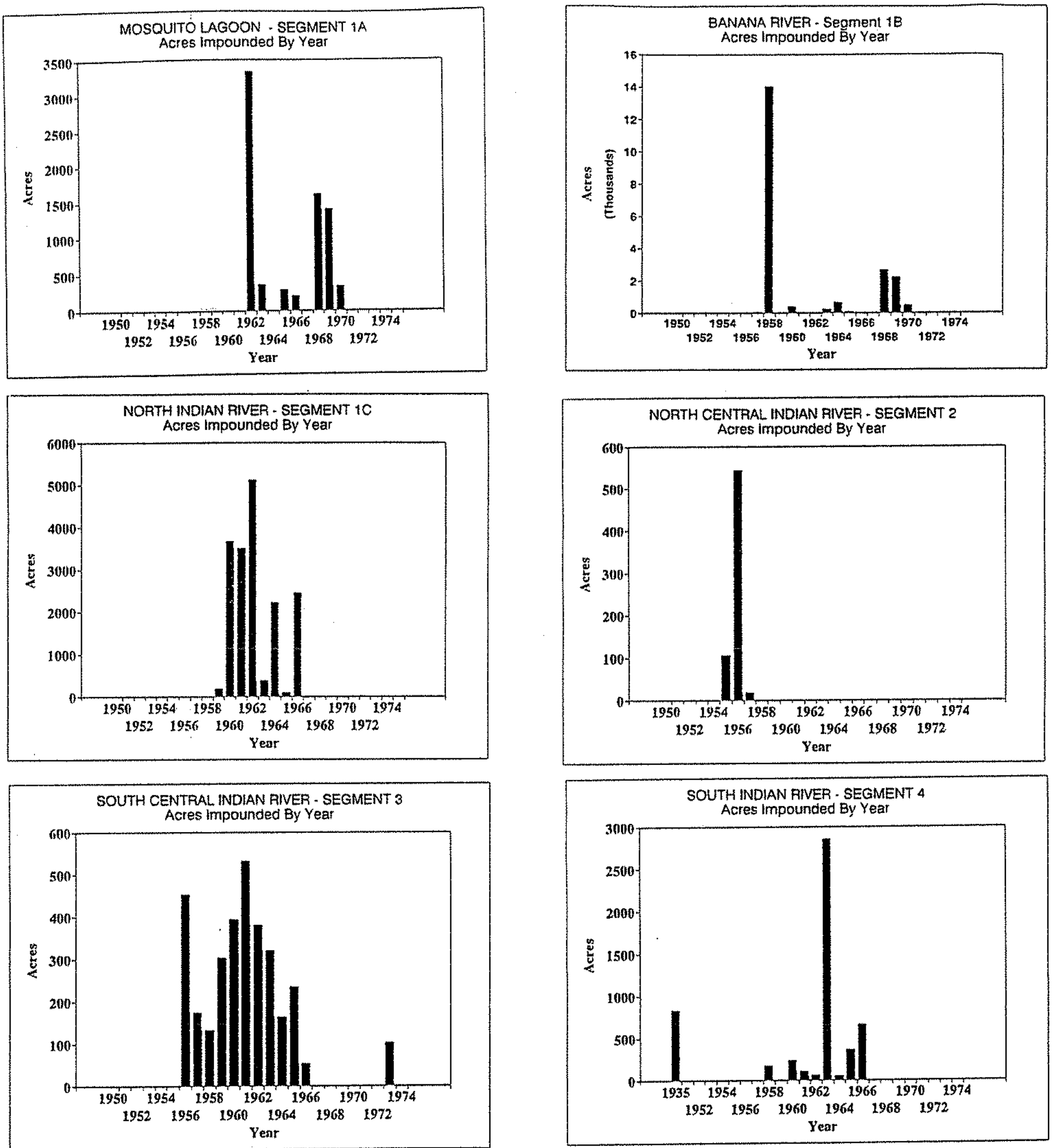
Most impoundments along the Lagoon were constructed in the period from 1957 through 1968 (Rey and Kain, 1991). Figure 3-3 shows the temporal progression in construction of these impoundments.

3.5.2 Impoundment Management Techniques

3.5.2.1 Closed Impoundments

Most impoundments were constructed by excavating ditches around the perimeters of the wetland and building dikes at the approximate mean high water line (O'Bryan, et al., 1990). Water would then be pumped into the impoundment to maintain a depth of several inches so that mosquitoes could not lay their eggs (Provost, 1967; Rey and Kain, 1991; David, 1992). This approach isolated the wetland behind the dike from the Lagoon, preventing fish and other species from moving between the Lagoon and what had once been a tidal wetland (Harrington and Harrington, 1982; Gilmore, et al., 1981). This practice also prevented the export of organic matter and nutrients from the wetland and thus isolated the Lagoon from the food chain base of the wetland.

Prolonged flooding impacted wetland vegetation which was adapted for surviving fluctuating water level conditions rather than continuous inundation. Vast areas of mangrove forest and salt marsh were killed and replaced by open water ponds (Montague and Wiegert, 1990; Rey and Kain, 1991). Permanent closure also reduced salinity in many impoundments since rainfall replaced tidal exchange as the main subsidy. In some impoundments, artesian freshwater wells were also constructed as a source of water, lowering salinity (Rey and Kain, 1991). Rey and Kain (1993) report that salinity dropped to less than 2 ppt in the Florida Oceanographic Society (FOS) Impoundment in Martin County after 20 years of virtual isolation. Since unimpounded salt marshes and mangrove marshes normally have between



Source: Data from Rey and Kain, 1991.

- Woodward–Clyde Consultants
- Marshall McCully & Associates
- Natural Systems Analysts

DRAWING NO.:

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FIGURE 3-3

ACREAGE OF MOSQUITO IMPOUNDMENTS CREATED IN EACH YEAR FOR THE SEGMENTS OF THE INDIAN RIVER LAGOON COMPLEX

INDIAN RIVER LAGOON NATIONAL ESTUARY PROGRAM

18 and 32 ppt surface water salinity and even greater soil water salinity, many salt marsh species can not adapt to the lower salinity ranges of many impoundments. In 1989, approximately 28% of impoundments were dominated by non-halophilic vegetation (Rey and Kain, 1991), reflecting the reduction of halophilic habitats.

In other impoundments, an excess of evaporation may lead to hypersaline soil and water conditions. A soil salinity of over 150 ppt has been reported from at least two studies (Harrington and Harrington, 1961; Gilmore, et al., 1982), and surface water salinity in excess of 200 ppt has also been reported (Gilmore, et al., 1982).

Implementation of seasonal management programs (closing of impoundments only during certain times of the year) has decreased the time during which impoundments were flooded to the period between mid-April and mid-September in most cases. Installation of culverts allows impoundments to be re-connected to the Lagoon at the end of the mosquito season, thus restoring a more natural hydrologic regime. Generally, the mangrove community has been able to respond favorably to this development, but salt marsh vegetation has remained sparse for longer periods (David, 1992). Some recovery of salt marshes has been reported in the Black Point area of MINWR after dikes were removed (U.S. Fish and Wildlife Service, n.d.).

In the first culvert installations, the schedules for opening the culverts were based largely on administrative requirements and annual schedules, regardless of tidal conditions (Rey and Kain, 1991, 1993; David, 1992). Often, culverts would be opened either early in autumn or not until winter when generally low water levels prevailed. When culverts were opened during the low tide or low water level conditions, large masses of water could drain from the impoundments to the Lagoon in a short time. In many cases, water from an impoundment would be released in a single event from a single discharge point, allowing a large volume of impoundment water to impact a relatively isolated area of Lagoon. This impoundment water was typically low in dissolved oxygen (DO), high in hydrogen sulfide (H_2S), high in chemical oxygen demand (COD) and biological oxygen demand (BOD), high in total suspended solids (TSS), and low in pH (Rey, et al., 1990; 1991; St. Lucie County Mosquito Control District, 1993). Release of these water masses tended to cause adverse impacts in the Lagoon, including fish kills in the vicinity of the release points. The releases

Current impoundment management practices in most areas still involve the use of larvicide sprays or briquettes to kill mosquito larvae, usually in the periods prior to (O'Bryan, et al., 1990) and just following closure (Rey and Kain, 1991). Although modern pesticides have far fewer side-effects than DDT, Best Management Practices encourage the minimal use possible of pesticides.

3.5.2.2 RIM Management

Most managing agencies now use a variation of the seasonal management approach known as Rotational Impoundment Management (RIM), which is a refinement of the seasonal management approach. Water is pumped into the impoundments in spring at the beginning of the breeding season and impoundments are reopened to tidal influence at the end of the season in September or October. However, timing of the inundation period is variable and is usually dependent on results of mosquito sampling programs in order to minimize the closed period, as well as on the state of the fall sea level rise.

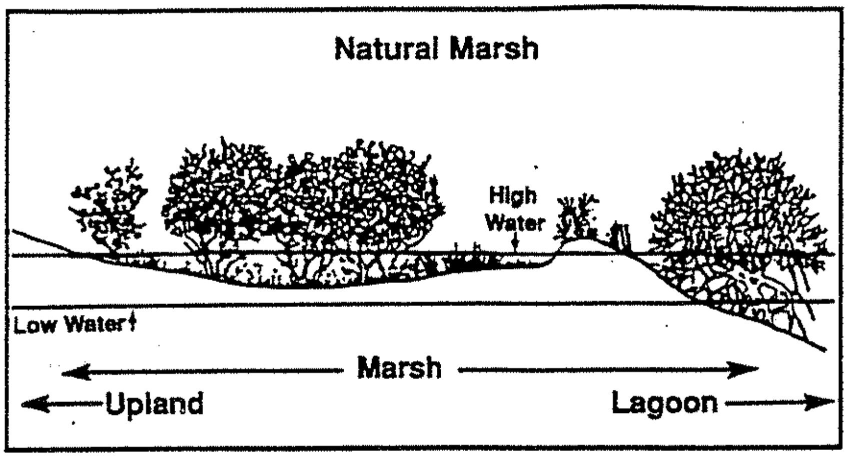
Under natural conditions in unimpounded marshes, fish are able to travel between the Lagoon and the marsh on the high tides and seasonal water level increases. The high water levels also flush the soils of the marshes, releasing and removing excess salts and H_2S, and allowing export of detritus to the food web of the Lagoon (Gilmore, et al., 1987). Installation and opening of culverts in impounded marshes duplicates to some extent these benefits. RIM management is a process by which opening of the culverts is based on the water level conditions, rather than by a fixed schedule. Culverts are opened during or just prior to the autumn sea level rise, and generally are opened during high tide periods or in a series of staged periods so that water is released gradually rather than in one "slug". The gradual release and the gradual re-mixing of Lagoon and impoundment water on high tides reduces the shock of sudden slugs of oxygen deficient or H_2S enhanced water on the biota of the Lagoon (Gilmore, et al., 1987; Rey and Kain, 1991).

Impacts to the Lagoon of these releases have been further mitigated through additional control measures. These mitigations include phased release of impoundment water over an extended period of time to reduce the concentration effect, as well as increases in the number of culverts and release points to spread discharges over a wider area (Gilmore, et al., 1987). Other methods include the use of specialized control gates or risers on culverts to time releases to high tide conditions in the Lagoon and to release the more toxic or poorer quality bottom water on a more advantageous schedule.

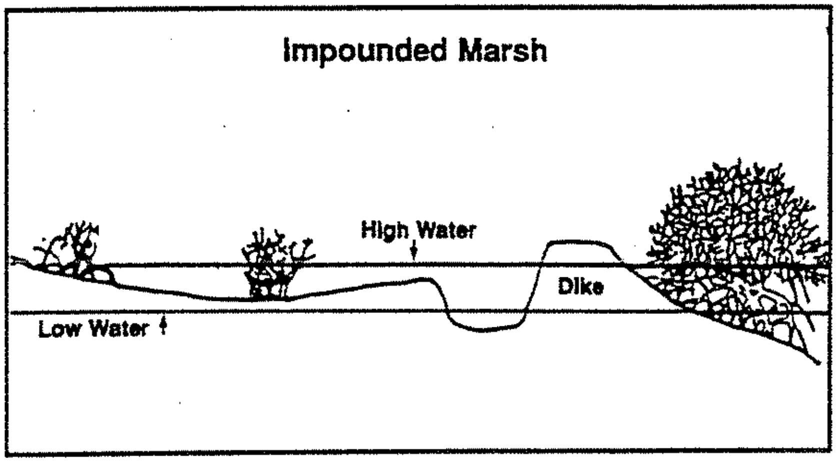
Figure 3-4 shows how these culverts reconnect impounded marsh to the Lagoon. Flapgate risers may allow water to flow in either direction within the culverts depending on the relative water levels at the ends of the culverts (Gilmore, et al., 1987; David, 1992). Flapgates allow water to flow from the Lagoon into impoundments during high water level periods while maintaining impoundment flooding and mosquito control during low water levels. This exchange restores some degree of the natural tidal interaction between the Lagoon and the wetland behind the impoundment. Modified-tidegate-wiers (MTGW's) are also being employed in some cases to prevent water levels from rising after storm events to levels which would damage vegetation (David, 1992). With these risers and weirs, water can be released from the impoundments following periods of heavy rainfall when water levels would otherwise rise to levels that would kill vegetation in the impoundments.

Presently, almost all of the managing authorities utilize a form of RIM management. The St. Lucie County Mosquito Control District (SLCMCD) has adapted a more active form of RIM management by maintaining a flow-through system in many impoundments. In this method, flapgates or open culverts may allow free exchange of fish by a continual discharge of water between the impoundment and Lagoon throughout the "closed" summer season. In addition to utilizing control structures to maintain minimum impoundment water levels, SLCMCD supplements inundation by pumping water into the impoundments throughout the summer (David, 1992). Water flows back to the Lagoon through the culverts at the same rate that it is pumped into the impoundment, maintaining constant inundation for mosquito control and circulation to reduce the development of poor water quality conditions. This method appears to have shown promise in enhancing water quality and impoundment utilization by transient open estuarine fish (David, 1992). However, it requires a continual and perpetual high level of management and commitment of management resources. Temporary or permanent interruptions of pumping may result in large adverse effects, including fish kills, so this method has not been adopted by other management authorities.

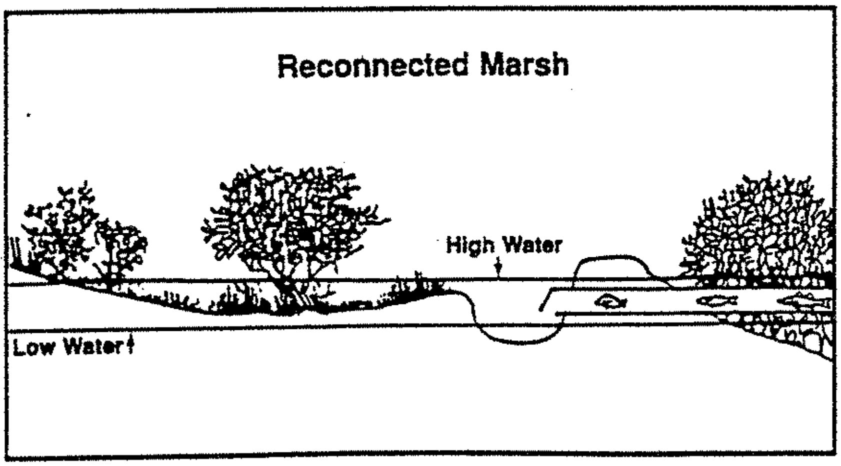
While substantial increases in transient fish populations have been reported in flow-through impoundments (David, 1992; 1993), other studies have indicated that one possible reason for utilization of marshes and impoundments by resident fish species and by juvenile transient



This is how a natural salt marsh looks. Fish and other aquatic animals find shelter and food in the marsh.



Dikes built to control mosquito breeding isolate the marsh from the lagoon and also kill vegetation.



A culvert allows fish and other aquatic animals to travel between the marshes and the lagoon.

Source: SJRWMD (1993)

- Woodward-Clyde Consultants
- Marshall McCully & Associates
- Natural Systems Analysts

DRAWING NO.:

DATE:

FIGURE 3-4 REHABILITATION OF SALT MARSH HABITAT BY CULVERT INSTALLATION

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species may be protection from larger predator fish that can not tolerate the water quality and low DO levels found in natural marshes and RIM impoundments (Peterson and Gilmore, 1988, 1991; Peterson, et al., 1991). If this is the case, then the potentially higher DO levels of the flow-through impoundments may increase predator access to the smaller fishes. Several studies have documented mortality of large transient predator species such as common snook and ladyfish under hypoxic (oxygen deficient) conditions (Peterson, et al., 1991), as well as decreases in activity (Doudoroff and Shumway, 1970; Peterson and Gilmore, 1991).

3.5.2.3 Open Impoundments

Open impoundments have permanent openings to the Lagoon through unobstructed culverts or breaching of dikes. Additional means of water level control generally need to be used in these impoundments for effective mosquito control. Volusia County Mosquito Control District has been a leader in opening impoundments and utilizing rotary ditching and Open Marsh Water Management (OMWM) to maintain mosquito control and allow transient fish utilization. In addition, Volusia County is studying impacts on the Atlantic salt marsh snake as part of its management plan (Goode, 1993), providing a future potential for managing some of its impoundments to enhance habitat for this species.

3.5.2.4 Regional or Block Management Variations

Advances in impoundment management are encouraging the multi-purpose use of impoundments. Secondary uses include enhancement of fisheries habitat, waterfowl and wading bird nesting and foraging habitat, and enhanced trophic export support to the Lagoon. A few examples of existing or potential block management techniques are included below to ilustrate potential benefits of this multi-purpose management. Block management allows certain impoundments to be recognized for their value in specific uses. A regional plan can then be developed to incorporate the best mix of these uses throughout a region. Specific block management options may include altered closing/opening schedules, periodic drawdowns during the mosquito season, flow-through pumping, and other options.

Many of the 29,584 ac (11,975 ha) within the Merritt Island National Wildlife Refuge (MINWR) are managed for the secondary purpose of providing waterfowl and wading bird habitat (Rey and Kain, 1991). Many of the MINWR impoundments used for waterfowl habitat are flooded most of the time by a system of dikes and culverts combined with rotary ditching to allow surface water consolidation and permanent ponding (Gamble, et al., 1990; Rey and Kain, 1991). The SLCMCD believes that its management system could use the impoundments for controlled rearing of fish and shellfish for stocking or commercial purposes (David, 1993).

Table 3-1 summarizes the number of impoundments under each type of management strategy as of 1991. About 26,000 ac (10,500 ha) of these are currently under some form (RIM, OMWM, or breached) of seasonal fluctuating water level or are open to the Lagoon. These impoundments have some degree of natural connection and functional value to the Lagoon, and are composed largely of native salt marsh or mangrove plants. The acreage of this group will be increasing in the next few years due to implementation of restoration and management initiatives by the operating agencies and through the auspices of the Surface Water Improvement and Management (SWIM) program.

The natural communities in the 14,968 ac (6,060 ha) of unmanaged or continually flooded closed impoundments shown in Table 3-1 have generally had the greatest alteration. These impoundments are largely unvegetated or vegetated by nuisance wetland plants (cattails), upland plants, or exotic nuisance plants (Brazilian pepper) (Rey and Kain, 1991). These unmanaged impoundments account for 36% of the total impoundment acreage in the Indian River Lagoon complex and are concentrated in Segment 1B (Banana River) and the MINWR portion of Segment 1C (North Indian River). Many of the MINWR closed and flooded standing water impoundments are being managed for waterfowl and wading bird habitat. Many of the impoundments in the Banana River watershed, however, are not providing any useful ancillary functions.

3.5.3 Management Authorities

Seven authorities as shown in Tables 3-2 and 3-3 have management responsibility over the mosquito impoundments in the Indian River Lagoon complex. Five of these are county mosquito control districts and the others are Merritt Island National Wildlife Refuge and Hobe Sound National Wildlife Refuge, which are federal government organizations.

TABLE 3-1

MANAGEMENT REGIMES OF MOSQUITO IMPOUNDMENTS IN THE INDIAN RIVER LAGOON COMPLEX BY BASIN SEGMENT[1]

MANAGEMENT REGIME	BASIN SEGMENT						
	1A-MOSQUITO LAGOON	1B-BANANA RIVER	1C-NORTH INDIAN RIVER	2-NORTH CENTRAL INDIAN RIVER	3-SOUTH CENTRAL INDIAN RIVER	4-SOUTH INDIAN RIVER[2]	REGIONAL TOTAL
Closed and Managed/ Saline Flooded Year Round	1,780[3] (10)[4]	2,000 (1)	7,281 (20)	0 (0)	1,168 (8)	446 (7)	12,675 (46)
Closed and Unmanaged/ Freshwater or Upland Regime	576 (5)	1,480 (14)	194 (3)	43 (2)	0 (0)	0 (0)	2,293 (24)
Seasonally Flooded and Managed/Culverts	4,725 (9)	2,694 (8)	7,454 (12)	240 (4)	384 (5)	0 (0)	15,497 (38)
Open/Breached or Natural Connection and OMWM Management	435 (3)	345 (1)	2,690 (8)	8 (1)	582 (12)	1,487 (22)	5,547 (47)
RIM and Pumped Flow-Through Management/ Intensive Management	0 (0)	508 (3)	0 (0)	375 (3)	1,107 (9)	3,386 (22)	5,376 (37)
TOTAL OF ALL TYPES	**7,516 (27)**	**7,027 (27)**	**17,619 (43)**	**666 (10)**	**3,241 (34)**	**5,319 (51)**	**41,388 (192)**

Source: Rey and Kain, 1991

1 = 1989 data
2 = Exclusive of Hobe Sound National Wildlife Refuge
3 = Top value is impoundment acreage of that type within the Segment or Indian River Lagoon Complex Region
4 = Value in ( ) is the number of impoundments in the group

TABLE 3-2

SUMMARY OF MOSQUITO IMPOUNDMENTS IN THE INDIAN RIVER LAGOON COMPLEX BY MANAGEMENT AUTHORITY[1]

FEATURE	MANAGEMENT AUTHORITY						
	VOLUSIA COUNTY	MINWR[2]	BREVARD COUNTY	INDIAN RIVER COUNTY	ST. LUCIE COUNTY	MARTIN COUNTY	REGIONAL TOTAL
Number of impoundments	4	76	27	34	43	8	192
Percent of region by number	2.1	39.5	14.1	17.7	22.4	4.2	100.0
Total acres	478	29,584	2,766	3,241	4,694	625	41,388
Percent of region by acreage	1.1	71.6	6.7	7.8	11.3	1.5	100.00
Number in public ownership	4 (4.2)[3] [100.0][4]	76 (80.9)[3] [100.0][4]	5 (5.3)[3] [18.5][4]	1 (1.1)[3] [2.9][4]	8 (8.5)[3] [18.6][4]	0 (0.0)[3] [0.0][4]	94 (100.0)[3] [49.0][4]
Number in private ownership[5]	0 (0.0)[3] [0.0][4]	0 (0.0)[3] [0.0][4]	22 (22.4)[3] [81.5][4]	33 (33.7)[3] [97.1][4]	35 (35.7)[3] [81.4][4]	8 (8.2)[3] [100.0][4]	98 (100.0)[3] [51.0][4]
Acres in public ownership	478 (1.5)[3] [100.0][4]	29,584 (92.3)[3] [100.0][4]	1,342 (4.2)[3] [48.5][4]	153 (0.5)[3] [4.7][4]	469 (1.5)[3] [10.0][4]	0 (0.0)[3] [0.0][4]	32,026 (100.0)[3] [77.4][4]
Acres in private ownership[5]	0 (0.0)[3] [0.0][4]	0 (0.0)[3] [0.0][4]	1,424 (15.2)[3] [51.5][4]	3,088 (33.0)[3] [95.3][4]	4,225 (45.1)[3] [90.0][4]	625 (6.7)[3] [100.0][4]	9,362 (100.0)[3] [22.6][4]

Source: Rey and Kain, 1991

1 = 1989 data
2 = Merritt Island National Wildlife Refuge
3 = Value in ( ) expresses the number as a percentage of the total of impoundments of that type within the Indian River Lagoon complex region
4 = Value in [ ] expresses the number as a percentage of total impoundments managed by that authority
5 = Category also includes all impoundments with mixed private/public ownership.

TABLE 3-3

SUMMARY OF MOSQUITO IMPOUNDMENTS IN THE INDIAN RIVER LAGOON COMPLEX BY BASIN SEGMENT[1]

FEATURE	BASIN SEGMENT						
	1A-MOSQUITO LAGOON	1B-BANANA RIVER	1C-NORTH INDIAN RIVER	2-NORTH CENTRAL INDIAN RIVER	3-SOUTH CENTRAL INDIAN RIVER	4-SOUTH INDIAN RIVER[2]	REGIONAL TOTAL
Number of impoundments	27	27	43	10	34	51	192
Percent of region by number	14.1	14.1	22.4	5.2	17.6	26.6	100.0
Total acres	7,516	7,027	17,619	666	3,241	5,319	41,388
Percent of region by acreage	18.2	17.0	42.6	1.7	7.1	13.6	100.00
Number in public ownership	27 (28.7)[3] [100.0][4]	18 (19.1)[3] [66.7][4]	40 (42.6)[3] [93.0][4]	0 (0.0)[3] [0.0][4]	1 (1.1)[3] [2.9][4]	8 (8.5)[3] [15.7][4]	94 (100.0)[3] [57.9][4]
Number in private ownership	0 (0.0)[3] [0.0][4]	9 (9.2)[3] [33.3][4]	3 (3.1)[3] [7.0][4]	10 (10.2)[3] [100.0][4]	33 (33.7)[3] [92.1][4]	43 (43.8)[3] [84.3][4]	98 (100.0)[3] [42.1][4]
Acres in public ownership	7,516 (23.5)[3] [100.0][4]	6,552 (20.5)[3] [93.2][4]	17,336 (54.0)[3] [98.4][4]	0 (0.0)[3] [0.0][4]	153 (0.5)[3] [4.7][4]	469 (1.5)[3] [8.8][4]	32,026 (100.0)[3] [81.0][4]
Acres in private ownership	0 (0.0)[3] [0.0][4]	475 (5.1)[3] [6.8][4]	283 (3.0)[3] [1.6][4]	666 (7.1)[3] [100.0][4]	3,088 (33.0)[3] [95.3][4]	4,850 (51.8)[3] [91.2][4]	9,362 (100.0)[3] [19.0][4]

Source: Rey and Kain, 1991

1 = 1989 data
2 = Exclusive of Hobe Sound National Wildlife Refuge
3 = Value in ( ) expresses the number as a percentage of the total of impoundments of that type within the Indian River Lagoon Complex Region
4 = Value in [ ] expresses the number as a percentage of total impoundments managed by that authority

Operating agencies generally require state permits from the FDEP (former Florida Department of Environmental Regulation) for dredge and fill activities and discharge from the impoundments. In addition, the former Florida Department of Natural Resources (FDNR) (now merged with FDER to create FDEP) has been involved in oversight and permitting review. A conflict of mission was present between the operators and FDNR as FDNR's mission statement called for the protection and preservation of natural resources, while the operators were charged with managing natural resources for a specific purpose that alters natural functions. The FDER/FDNR merger has resolved most conflicting mission statements, since the FDEP policy is more consistent with the operator's need to provide managed systems.

The Subcommittee on Managed Marshes (SOMM) is a state-mandated interagency subcommittee of the Florida Coordinating Council on Mosquito Control, created to coordinate research and management activities of the impoundments and to help bridge the gap between the conflicting missions. This body usually reviews all proposed projects and workplans, and a negative review by this committee usually results in FDEP permit denial and no plan implementation (O'Bryan, et al., 1990). The SOMM provides an effective mechanism for inter-agency coordination of marsh management.

Other programs which are critical to the management of mosquito impoundments include the SWIM programs and other programs administered by SJRWMD and SFWMD and the IRLNEP. These programs have provided extensive funding for implementation of actions such as purchasing culverts, pumps and aeration equipment for impoundment management Limited funding has also extended into research on environmental effects and proper management techniques.

3.5.4 Ownership

Although the impoundments are managed by the operating authorities, most of the impoundments outside of MINWR are on privately owned land. Tables 3-2 and 3-3 show the percentage of impoundment area that is in private or public ownership. All of the MINWR and Volusia County impoundments are on publicly owned lands. However, only about 50% of the impounded acreage in St. Lucie County and less than 40% in Brevard, Indian River, and Martin Counties is publicly owned. Much of the acreage indicated as private in Tables 3-2 and 3-3 is a mixture of private and public ownership within one impoundment or group of related impoundments. They are listed here as in private ownership because the private ownership limitations may apply to the entire acreage since the impoundment may be operated as a single entity. Because of the high percentage of impounded land in MINWR, 77% of total impoundment land of the region is publicly owned.

The ownership issue poses constraints on impoundment management by the counties. In many cases, privately held land is being used for the public good, and alternative uses of the land are being limited. However, other issues such as the jurisdictional wetlands status of these lands, effects of mangrove protection laws and ordinances, and other regulatory constraints complicate the determination of the value or suitability of these lands for other uses.

Most of the impounded lands have been reported as sold to private owners by the State of Florida in the 1940s and 1950s, prior to significant wetlands protection legislation (David, 1993). Many of these areas were high marsh and salt barren lands which were believed to be developable under laws at that time, but which are governed by wetlands restrictions under current laws. Many landowners have tended to view the wetland conditions on their land as having been created by impounding, thus encouraging the growth of protected species such as mangroves. In this view, the creation of wetlands and growth of protected species may restrict the owner's land use choices under current laws. Therefore, conflicts sometimes arise in determining the management options to be employed for specific impoundments, as well as complications of using public funding for improvements on private land.

3.5.5 Distribution and Extent of Impoundments

Tables 3-2 and 3-3 show the extent of mosquito impoundments associated with the Indian River Lagoon complex for each management authority and for each of the Indian River segments. Impoundments in the Lagoon complex range in size from 8 to 2,985 ac (3 to 1,208 ha), with the average size being about 200 ac (81 ha) (Rey and Kain, 1991). By far, the greatest acreage lies in the MINWR, with Brevard, Indian River, and St. Lucie Counties also containing significant amounts.

The pre-impoundment vegetative community status has not been established for all impoundments. In general, the impoundments in MINWR, northern Brevard, and Volusia County were most often herbaceous high marsh or *Spartina alterniflora* salt marsh communities prior to impoundment. Mangroves increased in dominance south of Merritt Island. Most areas in the south appear to have been irregularly inundated high marsh with large areas with salt flats and with saltwort, glasswort, and scattered black mangrove.

Table 3-4 lists cover of major vegetation groups within impoundments by region. Currently, a mixture of red mangroves and black mangroves dominates impoundments in the southern half of the Indian River Lagoon (Rey and Kain, 1991). Over 70% of the red mangrove dominated impoundments occur in St. Lucie County, and none are found north of Indian River County. Black mangroves or high mangrove marsh dominate about 16% of the impoundments in the northern complex, but unvegetated ponds and high marshes or salt flats dominated by other halophytes are the most common types of impoundments in the northern half of the complex. Open water ponds and mud flats are prevalent in many of the impoundments in MINWR due to the management options used.

3.5.6 Wildlife Habitat Values

Isolated impoundments are limited in habitat value. Prior to impoundment, the marshes had abundant fish populations, including both resident and transient species which moved in with the high tides to feed. Gilmore, et al., (1986) studied a natural tidal creek, an open impoundment, and a closed impoundment under RIM. The tidal creek was found to have a greater diversity of transient species including menhaden and bay anchovies which are sensitive to low DO levels. The RIM impoundment was found to have a greater density of fish, but diversity was restricted to a few resident species. Fish species of closed impoundments are largely restricted to a very few resident species such as the mosquito fish, sailfin molly, and sheepshead minnow (Lin and Beal, 1994), or to sunfish species where rainfall has lowered salinity (Gilmore, et al., 1990; Gilmore, 1984). Larger numbers of species are usually found in open or RIM impoundments (Gilmore, et al., 1982, 1986; Gilmore, 1987). Harrington and Harrington (1982) found that open impoundments averaged about 25 species as opposed to 5 in closed impoundments. In a SLCMCD study, Gilmore, et al. (1987) found 35 to 70 fish species in several RIM impoundments (David, 1992).

TABLE 3-4

SUMMARY OF MOSQUITO IMPOUNDMENT VEGETATIVE COMPOSITION IN THE INDIAN RIVER LAGOON COMPLEX[1]

FEATURE	COVER IN ACRES						
	VOLUSIA COUNTY	MINWR[2]	BREVARD COUNTY	INDIAN RIVER COUNTY	ST. LUCIE COUNTY	MARTIN COUNTY	REGIONAL TOTAL
Red mangrove	0 (0.0[3] [0.0][4]	0 (0.0[3] [0.0][4]	0 (0.0[3] [0.0][4]	507 (15.8)[3] [15.6][4]	2,406 (75.2[3] [51.3][4]	287 (9.0[3] [45.9][4]	3,200 (100.0[3] [8.2][4]
Other mangrove	54 (0.8)[3] [11.3][4]	3,599 (50.5)[3] [12.2][4]	681 (9.5)[3] [24.6][4]	1,438 (20.2)[3] [44.4][4]	1,114 (15.6)[3] [23.7][4]	246 (3.4)[3] [39.4][4]	7,132 (100.0)[3] [16.3][4]
Salt marsh grasses	67 (1.5)[3] [14.0][4]	4,178 (95.7)[3] [14.1][4]	118 (2.7)[3] [4.3][4]	0 (0.0)[3] [0.0][4]	1 (0.1)[3] [0.0][4]	0 (0.0)[3] [0.0][4]	4,364 (100.0)[3] [10.2][4]
Other halophytes	254 (4.2)[3] [53.1][4]	4,360 (71.9)[3] [14.8][4]	765 (12.6)[3] [27.7][4]	433 (7.1)[3] [13.4][4]	246 (4.1)[3] [5.2][4]	3 (0.1)[3] [0.5][4]	6,061 (100.0)[3] [15.0][4]
Other species	103 (0.9)[3] [21.5][4]	9,452 (86.3)[3] [31.9][4]	1,025 (9.4)[3] [37.0][4]	31 (0.3)[3] [1.0][4]	250 (2.3)[3] [5.3][4]	89 (0.8)[3] [14.2][4]	10,950 (100.0)[3] [28.1][4]
Unvegetated	0 (0.0)[3] [0.0][4]	7,995 (82.6)[3] [27.0][4]	177 (1.8)[3] [6.4][4]	832 (8.6)[3] [25.6][4]	677 (7.0)[3] [14.4][4]	0 (0.0)[3] [0.0][4]	9,681 (100.0)[3] [22.2][4]
Total area	478 (1.1)[3] [100.0][4]	29,584 (71.6)[3] [100.0][4]	2.766 (6.7)[3] [100.0][4]	3,241 (7.8)[3] [100.0][4]	4,694 (11.3)[3] [100.0][4]	625 (1.5)[3] [100.0][4]	41,388 (100.0)[3] [100.0][4]

Source: Rey and Kain, 1991

1 = 1989 data
2 = Merritt Island National Wildlife Refuge
3 = Value in ( ) expresses the number as a percentage of the total of impoundments of that type within the Indian River Lagoon Complex Region
4 = Value in [ ] expresses the number as a percentage of total impoundments managed by that authority

O'Bryan, et al. (1990) sampled the IRC #6 impoundment in Indian River County after it had been operated as a closed impoundment for 20 years. They resampled it after culverts had been installed in 1986 to allow RIM management. Fish species numbers increased from 7 to 23 within two years after connection. All of the pre-RIM species were resident, while post-RIM results included such transient species as snook, ladyfish, tarpon, and striped mullet. In addition, transient blue crabs and two species of shrimp (*Penaeus* sp.) and (*Palaemonetes* sp.) were collected only after the conversion to RIM.

Since fiddler crabs and several other important invertebrate species such as the marsh periwinkle, eastern melampus, and coffee-bean snail are predominantly air-breathing, they can not exist for long in impoundments which are inundated for several weeks of the year. Thus, many impoundments, even those under RIM management, appear to lack these important elements of the food web and organic matter recycling systems. O'Bryan, et al. (1990) have found that recolonization of flooded zones of impoundments may be slow, even after fluctuating hydroperiods are re-established.

Because of the low diversity of fish species and a lack of invertebrate species such as shrimp in some impoundedments, unmanaged isolated impounded marshes may offer poor forage habitat for wading birds. Those impoundments with standing trees can offer some nesting habitat for wading birds, and open water zones may provide habitat for waterfowl.

Several reports have indicated extensive avian and mammalian utilization of re-connected RIM impoundments (Gilmore, 1987; O'Bryan, et al., 1990; Schikorr and Swain, 1994; Smith and Breininger, 1994). Open water habitats of impoundments have been shown to be most used by wading birds (Smith and Breininger, 1994), and multiple drawdowns of water have been found to attract most wading birds (Swain, et al., 1992); Schikorr and Swain, 1994). Impoundment utilization by birds has been reported as being greatest during the spring nesting season and lowest in winter (Smith and Breininger, 1994). River otters (*Lutra canadensis*) and raccoons (*Procyon lotor*) have been reported in impoundments (O'Bryan, et al., 1990).

3.5.7 Water Quality Effects

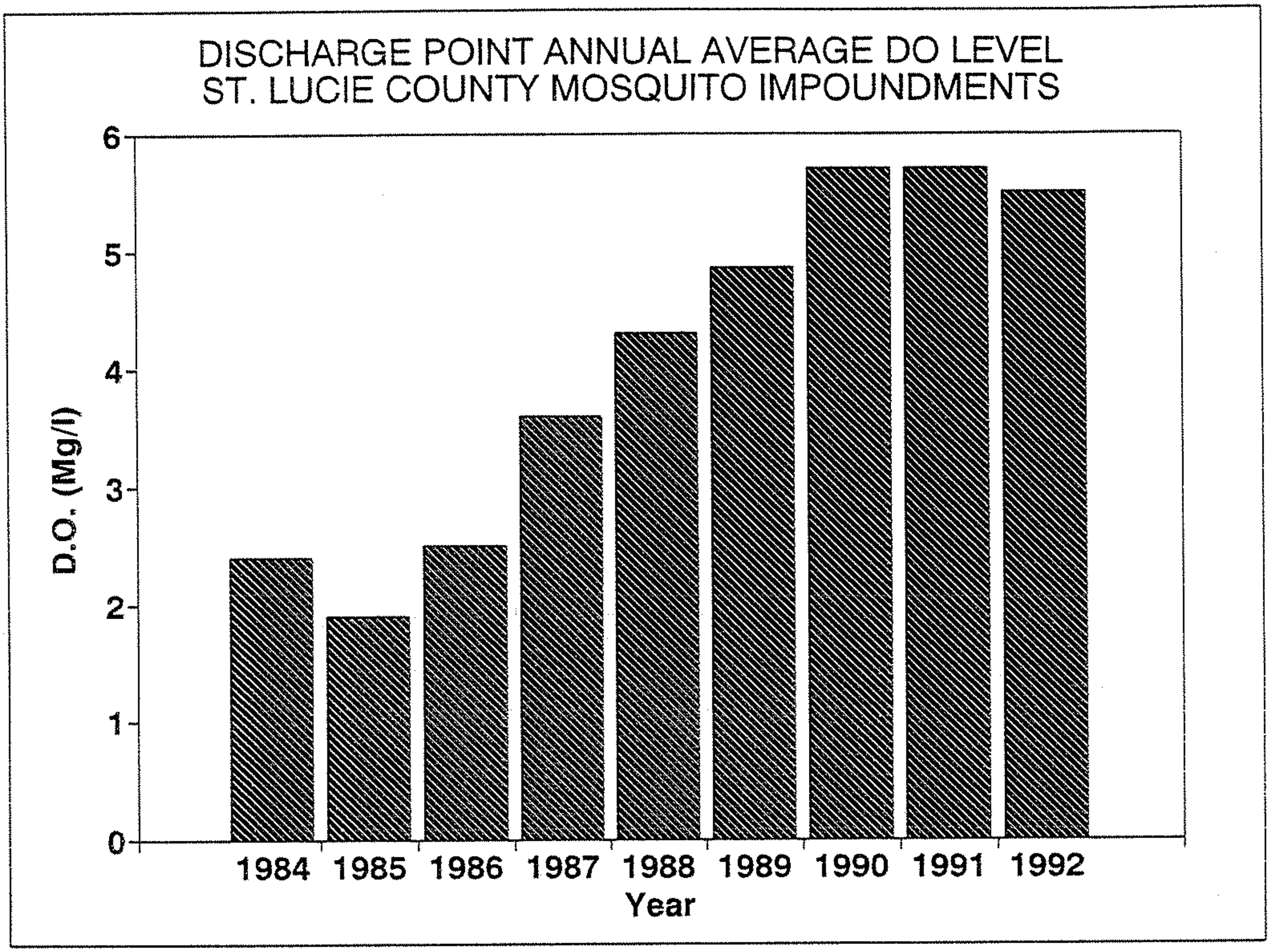
Although impoundments have been found to affect many water quality parameters, the most significant effects have been noted in the levels of dissolved oxygen (DO), salinity, temperature, and sulfur compounds. Impoundments also affect the dynamics of nutrient cycling for nitrogen, phosphorus, and carbon compounds.

Recent studies by Wang (St. Lucie County Mosquito Control District, 1993) indicate that reconnection of impoundments results in re-establishing much of the energy and nutrient linkage of the wetlands and the Lagoon without serious additional loading impacts for nitrogen, carbon, and phosphorus. The impoundments seem to provide some attenuation of peak heavy rainfall loading. This attenuation serves to alleviate widely fluctuating salinity conditions and algal blooms in the Lagoon caused by surges in nutrient-laden freshwater.

Low levels of dissolved oxygen in the waters within impoundments has in the past proven to cause stress and mortality in some transient fish species. Release of this water to the Lagoon has also resulted in fish kills (Gilmore, et al., 1982; Gilmore, et al., 1986; Rey and Gilmore, 1989). Implementation of RIM and in particular flow-through management has resulted in significant increases in DO levels in impoundments and discharges.

Figure 3-5 shows annual average DO levels for St. Lucie County discharge points with increases from 2 parts per million (ppm) to almost 6 ppm from 1984 to 1992. Over this period, SLCMCD increased its daily flow-through pumping periods by several hours and increased the number of culverts per impoundment. Perhaps more importantly, as shown in Figure 3-6, the incidence of occurrences of release of low DO (<3 ppm) levels dropped by over 90%. The data of Rey and Kain (1993) by contrast, indicates that DO levels within a typical RIM impoundment remained between 2 and 4 ppm for most stations during 1992. Gilmore, et al. (1987) found DO levels increased from 2.4 ppm in impoundments which had a ratio of one culvert per 81 ac (33 ha) to 5.8 ppm in impoundments with one culvert per 26 ac (10 ha), which may explain the variation among the results.

Severe stresses to aquatic resources have also resulted through the build-up of sulfates and hydrogen sulfide (H_2S) in impoundments. Rey and Gilmore (1989) found that the fish density and species diversity declined as sulfide levels increased, and that the levels of



Source: David, 1993.

• Woodward–Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysts	DRAWING NO.: DATE:	FIGURE 3-5	DISSOLVED OXYGEN IMPROVEMENT IN ST. LUCIE COUNTY MOSQUITO IMPOUNDMENT DISCHARGE FLOW-THROUGH WATER REGIME

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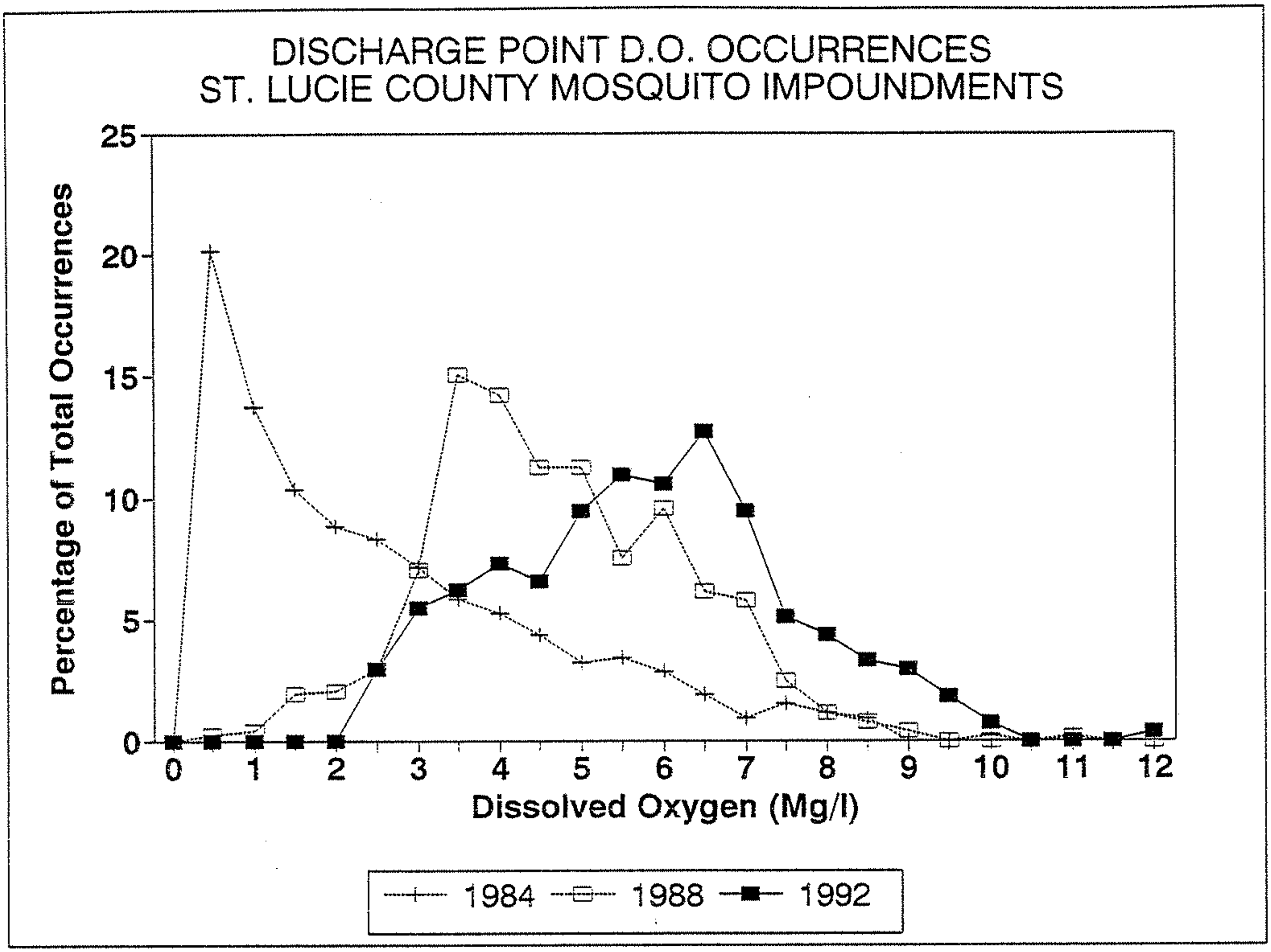

Source: David, 1993.

• Woodward–Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysts	DRAWING NO.: DATE:	FIGURE 3-6	FREQUENCY OF OCCURRENCE COMPARISON OF D.O. LEVELS IN ST. LUCIE COUNTY MOSQUITO IMPOUNDMENT DISCHARGES

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sulfide in impoundment ditches was an order of magnitude greater than in natural tidal creeks.

The high H_2S levels have been ascribed to anaerobic conditions at the water substrate interface and in the substrate pore water (Rey and Gilmore, 1989). Opening of culverts at low tide periods to discharge into the Lagoon at the end of the impounding season tended to release this bottom water without mixing. Fish mortality has also been ascribed to these H_2S releases (Rey and Gilmore, 1989). Discharging during the autumn sea level rise period has been found to increase the mixing or dispersion effects over larger areas and periods of time and thus can decrease these adverse effects, so management plans now generally specify the period of autumn sea level rise for releases or for re-opening RIM impoundments (Rey and Kain, 1991).

3.5.8 Restoration and Mitigation

Impoundments can basically be defined as closed, seasonally closed, or essentially open. Numerous research studies described above have demonstrated the benefits of restoring the open character of the impoundments. Restoration generally has involved increasing connections to the Lagoon by adding culverts and therefore increasing tidal exchange.

One partial solution to the private ownership conflict has been the designation of mosquito impoundments as wetland mitigation projects for coastal developments (O'Bryan, et al., 1990). In exchange for development impacts to some wetlands, mitigation credit may be gained through agreements to restore impoundments and grant ownership control to the operating agency. Without some form of trading value such as this, purchase of privately held impoundments may be the only means of implementing restoration efforts in many impoundments.

Management plans have been developed under the SWIM program for many impoundments in the region, although the level of management activity varies greatly for individual impoundments. Plans in St. Lucie County currently emphasize impoundments where red mangroves are established, since red mangroves have demonstrated the ability to tolerate the more constant flooding regimes generally encountered (David, 1993), although Salmela (in David, 1992) and Gilmore, et al. (1981) has indicated that black mangroves and other species appear capable of surviving under specific operating conditions. Other studies (O'Bryan, et al., 1990) have reported recovery and increases in coverage of mangrove marsh plant species, including black mangrove and glasswort, following establishment of RIM management in previously closed impoundments.

3.5.9 Current Status

When constructed in the 1950s and 1960s, most impoundments in the Indian River Lagoon complex were closed. As of 1989, approximately 36% were closed and 64% (by area) were seasonally or permanently open. Reports and 1993/94 workplans (David, 1992; Rey, et al., 1990; Rey and Kain, 1993; Virnstein and Steward, 1993) indicate that restoration work is continuing throughout the Lagoon. SWIM programs are supporting much of the restoration through funding to the county agencies for purchase of materials such as culverts and pumps.

As of 1993, only about 500 ac (607 ha) of impoundments (15%) remain unmanaged in St. Lucie County (David, 1993). The county is close to attaining its goal of the optimum ratio of one culvert for each 15 - 20 ac of impoundment. Plans have been developed to manage all but about 15% of the impounded area in the county. However, the private landowners of much of this remaining area are reluctant to allow additional restoration or construction in these areas due to loss of further landowner rights. Thus, much of this restoration may be on hold until ownership issues are settled or purchases are made.

The situation is similar in much of the rest of the Indian River Lagoon basin. New management plans are being developed by MINWR and SJRWMD for the MINWR impoundments and the impoundments in the SJRWMD area (Virnstein and Steward, 1993). However, many of these impoundments are currently being managed for wildlife habitat purposes and may not be easily reconnected to the Lagoon without a decline in existing habitat functions, such as forage or nesting potential, for one or more species. One important reason that regional or block management plans are being considered for the Lagoon complex is to coordinate management activities.

3.5.10 Future Trends

Some improvement in the ability to obtain permits allowing restoration and reconnection has been made. FDEP Division of State Lands has, in agreement with the Subcommittee on Managed Marshes, granted blanket authorization for reconnecting any impoundments that the Subcommittee and the SWIM program have recommended for reconnection.

The SWIM programs operated by SJRWMD and SFWMD are currently taking the lead in the restoration and reconnection efforts. Management plans under SWIM design and coordination are currently being finalized. The SJRWMD SWIM plan is a cooperative venture with the Florida Medical Entomology Laboratory, USFWS, and the Brevard, Volusia, and Indian River Mosquito Control Districts (SJRWMD, 1993). This plan is also being coordinated for reconnection of many of the MINWR impoundments (Virnstein and Steward, 1993). The SWIM program also has recognized that public ownership is necessary for coordinated management activity. The program includes substantial funding for purchase of privately owned impoundments over the next five years, with the remaining private impoundments in Brevard County a high priority for purchase (Virnstein and Steward, 1993).

Approximately 1,322 ac (535 ha) have been reconnected under these programs through 1992, with a goal of 5,215 ac (2,111 ha) reconnected by 1996 (SJRWMD, 1993; Virnstein and Steward, 1993). It has been reported that over 5,500 acres have been reconnected as of April, 1994 (Brockmeyer, 1994), so the program is on or ahead of schedule in this regard. Coordinated plans for rehabilitation of the MINWR impoundments were developed in 1993 (Virnstein and Steward, 1993), with the expectation that significant acreage would be connected to the upper Indian River Lagoon, Banana River, and southern Mosquito Lagoon in the near future. This restoration is expected to significantly expand potential nursery areas for fishes and will enhance productivity of the Lagoon system over the present condition, particularly in the northern portion of the complex (Segments 1A, 1B, and 1C). A financial benefit of up to $50 million to commercial and sport fisheries through enhancement of juvenile fish stocks is estimated to result from these reconnections (SJRWMD, 1993). The reconnection program may also result in some decrease of impacts to fish populations by reducing fish kills caused by release of water with low DO or high H_2S concentrations.

Water quality should continue to improve in the impoundments, but it may not be possible to readily identify or quantify the resulting water quality impacts on the Lagoon itself, because existing regional water quality programs do not have the level of resolution (based on numbers of stations and frequency of sampling) to detect such localized or event-specific effects. Most impoundment discharges have localized impacts, and water quality effects are diluted within a short distance from the discharge point. The main effect of such discharges is the cumulative effect produced by dozens of such discharges. Documentation of specific effects on the Lagoon itself can be provided by intense site-specific monitoring of impoundment discharges, but sufficient funding for extensive efforts may not be available.

Although not all problems have been overcome, the research studies indicate that great progress is possible in improving impoundments as habitats for birds and fish, increasing the energy linkage between Lagoon and impounded wetlands, and in decreasing any harmful effects of impoundment releases into the Lagoon.

3.6 SPOIL ISLAND COMMUNITIES

One of the less recognized ecological communities found within the Indian River Lagoon is the community on the numerous spoil islands located throughout the Lagoon. "Spoil islands" are not a natural component of the Indian River Lagoon complex and are best defined as man-made islands of dredged bottom material created by dredging for channels. The great majority of islands in the Indian River Lagoon complex were created as the Atlantic Intracoastal Waterway (ICWW) was created or rebuilt between 1951 and 1961, and a channel was dredged to a depth of 12 feet to become part of the ICWW (Brown-Peterson and Eames, 1990). Although a waterway throughout the Lagoon was initially constructed by the 1920s, the shallow depth of the original channel did not result in large enough amounts of spoil to create large islands. By the 1940s, much of this spoil had eroded, leaving few exposed islands. Beginning in the 1950s, additional dredging created large numbers of islands throughout the Indian River Lagoon and Mosquito Lagoon. These man-made islands range in size from less than 1.2 ac (0.5 ha) to greater than 7.5 ac (3 ha), and provide important habitat for many plant and animal species as well as serving as recreational areas for public use of the Indian River Lagoon (FDNR, 1990a; 1990b).

The deposited material consists primarily of bottom sands and mucks. The islands appear as small mounds of largely barren sand in the northern areas and become more forested in appearance along the southern portion of the Lagoon (FDNR, 1990a).

3.6.1 Distribution

There are 137 spoil islands in the Indian River Lagoon that occur sporadically along approximately 117 miles (190 km) of the Indian River from Haulover Canal in Brevard County to St. Lucie Inlet in Martin County (Brown-Peterson and Eames, 1990; FDNR, 1990a). The most numerous spoil islands are found in Indian River County with 55 islands. Second is Brevard County with 41, followed by St. Lucie with 34 and Martin County with 7 spoil islands (Brown-Peterson and Eames, 1990). More than half of these islands are located within the boundaries of the Malabar - Vero Beach Aquatic Preserve (established by the Florida Department of Natural Resources) and the Pelican Island National Wildlife Refuge.

Ownership of the spoil areas is divided among several entities. The state of Florida owns the majority (90%) of these islands, with other owners including the United States government, local governments, and private individuals. A management plan for those islands owned by the State of Florida was prepared by the Florida Department of Natural Resources, Bureau of Submerged Lands and Preserves, Division of State Lands, in 1990 (FDNR, 1990a).

In addition, about 75 spoil islands (or spoil deposits within salt marsh islands) are present in Mosquito Lagoon from Haulover Canal north to Ponce Inlet (Fletcher, 1993). Most of these are associated with the ICWW. A total of 32 spoil islands is present in the Banana River (Fletcher, 1993), none of which is associated with the ICWW. Most were created from dredging of the Canaveral Barge Canal, the Saturn Barge Canal, and privately sponsored navigation channel dredging.

Some small spoil islands are present in the southern portion of the Lagoon complex between St. Lucie and Jupiter Inlets. However, much of this portion of the waterway was constructed through uplands or adjacent to uplands. Consequently most of the spoil was deposited in upland sites or in emergent mangrove or salt marsh wetland areas rather than on submerged bottoms (Fletcher, 1993). These spoil areas therefore have little direct connection with the Lagoon.

3.6.2 Ecology

The spoil islands have evolved from barren deposits of bottom materials to thriving ecological communities which play an important role in the biodiversity exhibited throughout the Indian River Lagoon. The 1990 FDNR study indicated that a total of 467 plant and animal species ranging from fungi to marine mammals inhabited or used these islands.

As with all biological communities associated with the Indian River Lagoon complex, the latitudinal gradient permits a wide variety of temperate, sub-tropical, and tropical flora and fauna. There are distinct changes in terrestrial vegetation and marine fish species composition from north to south. It appears that species diversity increases as the islands extend southward. The lower diversity in the north has been attributed to such factors as the lack of ocean influence at the northern portion of the Indian River Lagoon, smaller size of the spoil islands, and effects of constant winds on the northern islands (a result of the greater width of the Lagoon water body in the northern portion). The transition from a temperate to a subtropical habitat also appears to occur between Sebastian Inlet and the central portion of Brevard County, effecting a change in species composition and diversity in this region.

3.6.3 Associated Flora

As with any disturbed substrate, vegetative colonization of the spoil islands occurs rapidly following spoil deposition, and is dominated by species that have rapid colonization capacity. The flora found on these spoil areas includes both upland and submerged aquatic vegetation (SAV) and varies greatly throughout the Indian River Lagoon area.

Most of the terrestrial vegetation associated with the spoils islands is exotic. In many cases, these non-native species have been strong competitors that can rapidly assume dominance over native species, especially in disturbed sites and on barren soils such as were found on the newly created spoil islands. The 1990 FDNR study concluded that exotic vegetation was found on 96% of all the spoil areas. The dominant non-native species are Australian pine and Brazilian pepper. Although exotic vegetation is most common, at least 250 native plant species are known to inhabit these islands.

A wide variety of plant life is attributed partly to the climatic changes resulting from the latitudinal changes found throughout the spoil areas. Common native plant species found throughout the region in the canopy include cabbage palm, wax myrtle, live oak, strangler fig, ironwood (*Krugiodendron ferreum*) and gumbo limbo. The shrub and herbaceous strata of these spoil areas are primarily saplings of canopy species and numerous grasses and sedges. The northern islands in Brevard County contain plant species not found on the more southern islands, and as the islands extend further to the south, the flora begins to become more West Indian in nature (FDNR, 1990a; 1990b).

Another important flora component of the spoil islands is submerged aquatic vegetation (SAV). The SAV enhances the biological diversity of the spoil banks by creating protective and foraging habitat for juvenile fishes and encrusting invertebrates such as sponges. These SAV areas were created as the dredging of bottom materials occurred, and therefore represent examples of recent primary succession on bare substrates. The temperate to subtropical gradient is also observed in SAV species associated with these islands. The most common species are shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiformi*). The more subtropical species turtle grass (*Thallasia testudium*) is found only on the southernmost islands, and is not found north of Sebastian Inlet (Virnstein, 1988).

3.6.4 Associated Fauna

In addition to creating a list of observed plant life on these spoil islands, the FDNR study also revealed that 205 invertebrate, reptile, fish, bird, and mammal species inhabit these spoils. The diversity of animal species found is attributed to the colonization of these species by patterns of dispersal such as rafting, which are indicative of classical island biogeography.

The presence of both aquatic and terrestrial invertebrates provides a valuable food source for higher animals, particularly fishes. The combination of SAV and invertebrates such as sponges, crabs, and mollusks provides ample food for juvenile fish, which in turn become food sources for other animal species such as birds and mammals. Maxwell and Kale (1974) reported 13 species of wading birds with over 2,500 breeding pairs in a rookery on one of these islands.

Although 74 different species of fish have been found associated with spoil islands, over 80% of the total number is represented by only the following eight species; spotfin mojarro (*Eucinostomus argenteus*), pinfish (*Lagodon rhomboides*), striped mullet (*Mugil cephalus*), bay anchovy (*Anchoa mitchilli*), spot (*Leiostomus xanthurus*), tidewater silverside (*Menidia peninsulae*), ladyfish (*Elops saurus*), and Gulf pipefish (*Syngnathus scovelli*) (Schooley, 1977; Brown-Peterson and Eames, 1990). The composition and structure of the spoil islands fish community has been described as similar to that of the Lagoon as a whole (Brown-Peterson and Eames, 1990), with most of the species being common or abundant Lagoon inhabitants.

The patterns of fish species around the islands may give an indication of factors affecting the fish community of the Lagoon. A large seasonality effect on these fish populations was found by Brown-Peterson and Eames (1990). In addition, distance from inlets was found to have a major effect on species composition and species richness. Species of fish which spawn offshore were most commonly found within 6 tidal cycles (based on tidal excursion distances, as defined in the Physical Features Technical Report) of inlets, while those that spawn in the Lagoon were fairly evenly distributed among all locations.

3.6.5 Community Status

In addition to providing valuable wildlife habitat, spoil islands also provide recreational areas for the human population of the region. The State of Florida has produced a management plan which designates the best use for each island under its ownership. These management designations include: conservation, passive recreation, education, active recreation and combinations thereof, and are intended to enable the islands to maintain their ecological functions through conservation, while allowing the public to enjoy these unique recreational and educational entities. The management plan will be implemented and administered by the Florida Inland Navigation District (FIND) (FDNR, 1990a), which is also responsible for maintenance of the ICWW. FIND has also supported the management studies for these islands with funding assistance.

3.7 FINDINGS AND RECOMMENDATIONS FOR INTERTIDAL AND COASTAL COMMUNITIES

Both salt marsh and mangrove communities are among the most productive in the world. In the Indian River Lagoon complex, export of productivity to the Lagoon may historically have been a major functional value of these systems, but much of the research indicates that direct export to the Lagoon may have been disrupted by impounding. These communities also have had very important functions in filtering runoff from adjacent upland areas and as habitat for many types of wildlife. Bird and fish communities in particular have permanent resident and transient components with different and sometimes conflicting ecological requirements.

Much of the salt marsh of the Indian River Lagoon complex differs from salt marshes in many regions of the world due to the presence of a berm at the outer edge of the marsh. This berm, in conjunction with the low tidal range in much of the year, naturally restricts interchange with the Lagoon and allows "high marsh" and salt pan plant species to dominate the marshes, and black and white mangroves to dominate the mangrove forests. The relative distribution of mangrove forest and salt marsh is a result of many factors, and mangroves are capable of invading salt marshes. Freezes appear to be a main factor in regulating the distribution of mangroves, and consequently of salt marshes as well.

The salt marshes and mangrove forests are breeding sites for mosquitoes, which are capable of spreading as much as 20 miles inland from the coast. Since these mosquitoes are largely incompatible with human habitation, their control has been necessary. Impounding marshes to raise water levels and prevent mosquito breeding is the primary form of control. Over 40,000 acres of salt marsh and mangrove forest have been impounded in the complex, almost half of which are located in the North Indian River Segment (1C) in Brevard County and MINWR.

Approximately 36% of the impoundments are still unmanaged or have essentially permanently raised water levels. In these impoundments, the natural marsh habitat has largely been replaced by open water or by freshwater, upland, or exotic plant species. This has resulted in a major loss of habitat and associated functions.

The current trend in impoundment management is toward Rotational Impoundment Management (RIM) or flow through systems. These management methods have restored the connection of many impoundments to the Lagoon complex and should enhance reestablishment of black and white mangroves and salt marsh plants.

The SWIM programs, county Mosquito Control Districts, Florida Medical Entomological Laboratory, and SOMM have all played important parts in developing information on management effects and in implementing RIM and other management strategies which are improving the wetlands functions of impounded marshes. Studies have shown that opening of the impoundments increases DO values, allows increased utilization of impoundments by fish, and may increase productivity within the Lagoon. The studies indicate few adverse water quality effects from managed discharges and exchanges with the Lagoon. This management trend appears to have a major beneficial impact on the biological integrity of the Indian River Lagoon complex.

Impounding may actually be proving beneficial to many wading bird and waterfowl species (Provost, 1967; Swain, et al., 1992; Schikorr and Swain, 1994), and RIM management may decrease the habitat benefits for these species. Block management to maintain some areas for specific purposes such as waterfowl habitat is believed to be an important part of regional management programs, although management for certain groups such as waterfowl may be detrimental for other functions. The MINWR is currently implementing block management, and St. Lucie County has been investigating means of enhancing habitat values for specific purposes. Managers also should recognize the needs of specific species such as the Atlantic salt marsh snake, so that management decisions do not result in the extinction that befell the dusky seaside sparrow as a result of impoundment and development activities.

One impediment to installation and management of RIM or other options was the conflicting mission statements of the mosquito control districts and FDNR. The SOMM needs to continue to provide a means of resolving any future conflicts between the operators and the FDEP, which succeeded the FDNR as a review agency for these activities.

The other major impediment for public management has been private ownership of impoundments, which has caused conflicts regarding use, liability, and funding of capital improvements for pumps and other necessary equipment. Resolution of these issues and emphasis on obtaining operating agency ownership through acquisition or mitigation/restoration agreements is of paramount importance. The SWIM programs are currently addressing these issues, and significant progress is expected within a few years.

The future of salt marsh communities within the Indian River Lagoon complex is likely to be dependent upon management activities by such groups as Mosquito Control Districts, SOMM, and the water management districts. New management goals and improved technology are allowing reconnection of impoundments to the tidal regime of the Lagoon. The reestablishment of tidal fluctuations in these areas for significant portions of the year will allow restoration of salt marshes in some areas where it has been lost through impoundment.

More than 200 spoil islands in the Indian River Lagoon complex, although not natural habitats, may provide significant habitat benefits to certain groups of species. Being man-made or disturbed habitats, they are subject to invasion by exotic species. Management of many of these islands is planned under a 1990 plan developed by FDNR.

4.0 SUBTIDAL AND MARINE COMMUNITIES AND HABITATS WITHIN THE INDIAN RIVER LAGOON

4.1 SEAGRASS AND OTHER SUBMERGED AQUATIC VEGETATION COMMUNITIES

Seagrasses are totally submerged rooted angiosperm plants with vascular systems to transport nutrients and water throughout the plant. They reproduce by seeds. Algae are more primitive plants which do not have vascular systems and do not reproduce by seed. Both seagrasses and submerged algae species may occur in large underwater meadows or beds, often in a mixture of seagrasses and algae. Together, seagrass and algae are referred to as Submerged Aquatic Vegetation (SAV).

The importance of seagrasses and other SAV in the ecological stability and productivity of estuarine ecosystems has been established in such reports as Tabb, et al. (1962), Phillips and McRoy (1980), Stoner (1980), Livingston (1982), Zieman (1982), Virnstein, et al. (1983), and Gilmore (1987), which have documented that seagrasses perform numerous functions such as stabilization of sediments, prevention of re-suspension of particulate matter, and cover and food for fish and wildlife. Of the habitats entirely confined within the Lagoon, seagrass beds support the richest fish community, in terms of both diversity of species and density (Gilmore, 1977, 1988a; Gilmore, et al., 1981, 1983; Snelson, 1983; Stoner, 1983a). In addition to being extremely productive with net productivity levels of 0.001 to 0.03 oz ft^{-2} yr^{-1} (0.5 to 10 g m^{-2}-day) of C recorded from Florida waters (McRoy and McMillan, 1977; Jensen and Gibson, 1986), seagrass beds are used by a wide range of species as feeding grounds, nurseries, and refuges from predation. Seagrass provides a substrate for epiphytic algae and food for various organisms.

Substantial research has indicated that distribution and health of seagrass and other SAV is directly related to water quality and water clarity of estuaries, and can thus be used as an estuary health indicator (Phillips, 1960; Hall, et al., 1990; Short, 1990; Funderburk, et al., 1991; Tomasko, 1992). Factors influencing seagrass and SAV growth and distribution include water depth, water clarity and availability of light, substrate, nutrient levels, salinity, temperature, and anthropogenic influences such as runoff and boating activities.

The Indian River Lagoon contains seven species of seagrasses in three families (Figure 4-1). This diversity of seagrasses is greater than that found in any other United States estuary. One of the species, Johnson's seagrass (*Halophila johnsonii*), is a rare species endemic only to the southern Indian River Lagoon region. The characteristics and zones of occurrence of each species are discussed below.

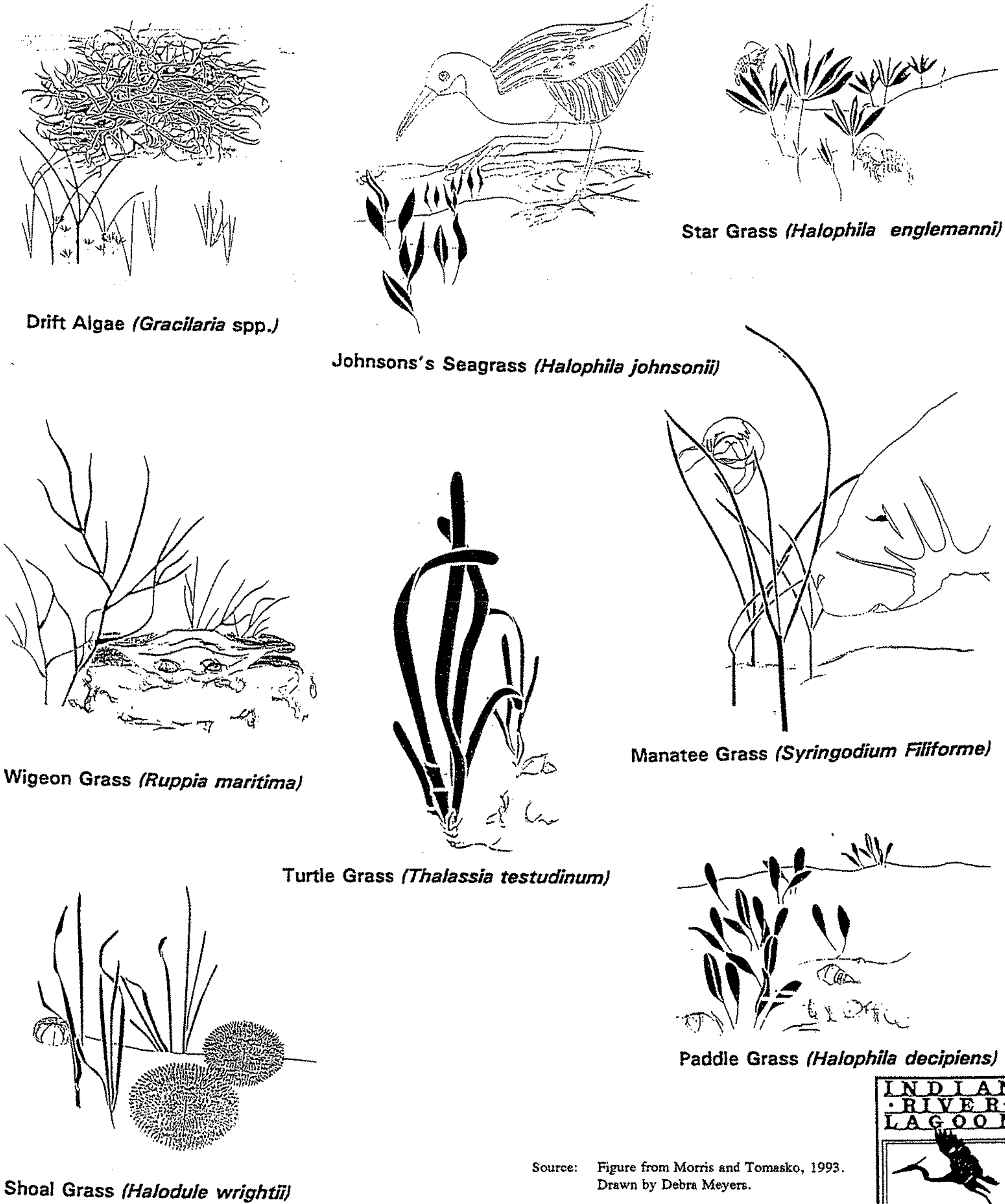
4.1.1 Species Description and Distributions

4.1.1.1 Turtle Grass (*Thalassia testudinum* Koenig.)

Turtle grass is a member of the Hydrocharitaceae or frogs-bit family, which also includes the marine genus *Halophila* as well as several common freshwater and brackish water submerged plants such as elodea (*Elodea* spp.) and hydrilla (*Hydrilla verticillata*). Turtle grass leaves are alternate, unbranched, and ribbon-like, generally from 0.4 ft to 1.3 ft (10 to 40 cm) in length, closely set on short, stout stems. Like all of the seagrasses, it is a monocot with parallel veins on the leaves. Turtle grass can be distinguished from the other seagrass species in the Indian River Lagoon by the 0.2 to 0.5 in (0.5 to 1.0 cm) width of its leaves, since none of the other species in the Lagoon have leaves of comparable width.

A perennial species, turtle grass has true unisexual flowers in the leaf axils and produces seeds in pods, although there are no records of seed production in the Lagoon. Reproduction may also be asexually through an extensive system of horizontal rhizomes just under the substrate surface.

Although turtle grass has occasionally been documented as occurring slightly north of Sebastian Inlet in the Indian River Lagoon (Virnstein and Cairns, 1986), Sebastian Inlet appears to approximate its northern limit of occurrence on the Atlantic coast. Its range extends south through the Caribbean and the Gulf of Mexico. Although turtle grass is found in much deeper water in the Caribbean, it is generally found in depths of less than 3.3 ft (1 m) in the Indian River Lagoon.



Source: Figure from Morris and Tomasko, 1993. Drawn by Debra Meyers.

INDIAN RIVER LAGOON NATIONAL ESTUARY PROGRAM

• Woodward–Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysis	DRAWING NO.: DATE:	FIGURE 4-1	PRINCIPAL SEAGRASS AND MACROALGAE SPECIES OF THE INDIAN RIVER LAGOON

4.1.1.2 Shoal Grass (*Halodule wrightii* den Hertog)

A member of the Cymodoceaceae or manatee grass family, this species was formerly known as *Diplanthera wrightii* and is often refered to by that name in older reports. Its leaves are similar to those of turtle grass, being ribbon- or strap-shaped and unbranched. However, the leaves are distinguished from turtle grass because they are rarely more than 0.1 in (0.2 cm) in width.

Flowers are borne in the leaf sheaths, but have not been reported from the Lagoon. Asexual reproduction from an extensive horizontal rhizome system appears to be the common means of reproduction in this species as well.

Shoal grass is the most widespread and abundant seagrass found in the Indian River complex, and is one of only two species found throughout the entire Indian River Lagoon complex. Its range extends as far north along the Atlantic coast as North Carolina and throughout most of the Gulf of Mexico and the Caribbean. Shoal grass is most abundant to shallow water less than 3.3 ft (1 m) in depth, and forms dense beds in water generally less than 1.6 ft (0.5 m) deep. Often, the leaf blades are may reach the water surface during low tides.

4.1.1.3 Manatee Grass (*Syringodium filiforme* (Kuetz.) Correll)

Manatee grass is the member of the Cymodoceaceae family for which the family was named, based on its older species name of *Cymodocea filiformis*. Manatee grass has long thin leaves which may reach 1.5 ft (45 cm) in length. The leaves are the only seagrass leaves in the Indian River Lagoon region which are terete or circular in cross-section. The leaves are borne on short erect stalks from the often-branched rhizomes.

Although manatee grass also spreads asexually by its horizontal rhizome system, it is believed to reproduce more readily by seed than the two previous species, with flowers borne within the leaf sheaths on branches from the main stem.

Manatee grass occurs throughout most of the Gulf of Mexico and Caribbean and north along the Atlantic coast of Florida. Mosquito Lagoon appears to be the most commonly accepted northern limit of its range. This seagrass is often found in association with turtle grass and shoal grass in the southern portions of the Lagoon and with shoal grass in the northern portions, although it appears to reach its greatest abundance in deeper water, usually between 1.7 and 5.0 ft (0.5 to 1.5 m).

4.1.1.4 Widgeon Grass (*Ruppia maritima* L.)

Widgeon grass is the only member of the Ruppiaceae family in Florida. It is similar in appearance to shoal grass, but the alternate leaves are generally slightly narrower and tapered at the ends. The flat leaves are generally about 0.05 to 0.1 in (0.1 to 0.3 cm) making them difficult to distinguish from shoal grass leaves. The stems may be branched, with many leaves from a single stem which helps to distinguish widgeon grass from other seagrasses.

Widgeon grass reproduces readily from seed produced in flowers on long-stemed inflorescences. The rhizome system is not as well developed as in the preceding species.

More tolerant of lower salinities than the other species, widgeon grass has a scattered occurrence in the Lagoon. It is the most northernly or temperate of the seagrass species of the Lagoon, being found in the northeastern United States. It is not common south of the Indian River Lagoon, but does occur along the Gulf coast of the United States.

4.1.1.5 Paddle Grass (*Halophila decipiens* Ostenfeld)

The genus *Halophila* is the only seagrass genus with more than one species represented in the Lagoon. Although dissimilar in appearance, the three species of *Halophila* in the Lagoon are most closely related to turtle grass, being in the same Hydrocharitaceae family. Paddle grass is distinguished by a bright green appearance with two opposite leaves shaped like canoe paddles at each node of the rhizome. The edges of its 1.2 to 1.6 in (3 to 4 cm) leaves are serrated, with minute teeth; it is a small plant less than 2 in (5 cm) in height.

Paddle grass is an annual species regenerating from seeds (Kenworthy, 1993). The rhizomes may extend to about 3 ft (1 m) from the parent shoot, substantially less than in turtle grass, shoal grass, or manatee grass. Paddle grass is usually found in leafy patches on soft sandy substrate only in deeper and clearer waters during the warmer months. Distribution appears to be similar to that of turtle grass, with little being known from north of Sebastian Inlet.

4.1.1.6 Star Grass (*Halophila englemanni* Asch.)

This small delicate perennial species has erect stalks, rarely as long as 0.4 ft (12 cm) in length arising from slender horizontal rhizomes. Each stalk has a whorl of 6 to 8 bright green oval to lanceolate leaves at their summits. The leaves have midribs and veins with fine teeth on the edges. It is the only *Halophila* species in the Lagoon with more than two leaves at a node.

The reproductive modes of all of the *Halophila* species in the Lagoon are not well known, but star grass appears to be a perennial species that reproduces successfully by seed. Star grass is well-distributed throughout much of the Indian River Lagoon and Banana River. It is known to occur in Mosquito Lagoon, but the extent of occurrence is not well known. Star grass grows in deeper water than most seagrasses with occurrence in water depths of over 6 ft (1.9 m) reported. It also occurs in depths as shallow as 1 ft (0.3 m)

4.1.1.7 Johnson's Seagrass (*Halophila johnsonii* Eiseman and McMillan)

Johnson's seagrass is similar in appearance to paddle grass, with leaves occurring in pairs at the tip of short stalks arising from slender rhizomes. Leaves are generally shorter (0.4 to 0.8 in) (1 to 2 cm) and narrower than leaves of paddle grass. Only female flowers have been found in this species, indicating that reproduction is limited to asexual reproduction by rhizomes (Kenworthy, 1993).

Like other species of *Halophila*, it is capable of growing in deeper water than the other four species of the Lagoon, with depths of 10 ft (3 m) reported (Kenworthy, 1993). It has also been found in very shallow water on sandy shoals where other species may not occur, indicating a possible wide tolerance of depth and light conditions, but low competitive ability (Kenworthy, 1993; Virnstein, 1994).

The range of Johnson's seagrass is believed to be limited to the east coast of Florida between Biscayne Bay and Sebastian Inlet, an area to which it is endemic. Reported occurrences appear to be most common near inlets, but information is very limited. Because of its very limited distribution, rarity within its range, and potentially limited reproductive capability, in the summer of 1993 it was put under consideration for listing as a threatened or endangered species by the U.S. Fish and Wildlife Service. The National Marine Fisheries Service of NOAA has been conducting studies to aid in determination of the life history and potential threats to this species (Kenworthy, 1993).

4.1.2 Community Description and Distribution

The term SAV often is used to refer only to underwater vascular plants such as the seagrasses, of which the preceding seven species have been estimated to cover about 32% of the Indian River Lagoon complex in 1992 (Natural Systems Analysts, 1993). However, much of the bottom of the Indian River Lagoon is also covered by macroalgae, highly varied and differentiated species of non-vascular plants. Because the extent of these algal species is so large and because these species have many characteristics similar to seagrasses, they are included as part of the SAV of Indian River Lagoon.

Because of their shallow depths [approximate mean depth 4.5 ft (1.4 m)], much of Indian River Lagoon, Banana River, Hobe Sound, and Mosquito Lagoon support SAV communities. Approximately 175,390 ac (71,008 ha) within these water bodies have depths less than 6 ft (1.8 m), which potentially could contain seagrasses (see Historical Imagery Technical Report). In addition, some macroalgae are capable of growing in virtually all depths of the Lagoon complex. In 1992, approximately 70,000 acres of seagrass and algae beds were present between Ponce Inlet and Jupiter Inlet, representing 40% of this potential habitat of less than 6 ft (1.8 m) depth (Historical Imagery Technical Report).

Not all areas may be suitable for seagrasses, even if appropriate depths are present. Like all plant species, they are adapted to certain conditions. Factors such as temperature, light, salinity, and type of substrate may all influence presence and abundance. Where conditions are appropriate, seagrasses may form an underwater meadow with dense cover. These meadow areas are generally found in water between 0.7 and 3.3 ft (0.2 and 1 m) deep on sandy or muddy sand substrates. In deeper water where there is less light or in areas where substrate or water quality conditions are not ideal, seagrasses may not be present or may occur only as scattered clumps or as plants not more than a few inches in height.

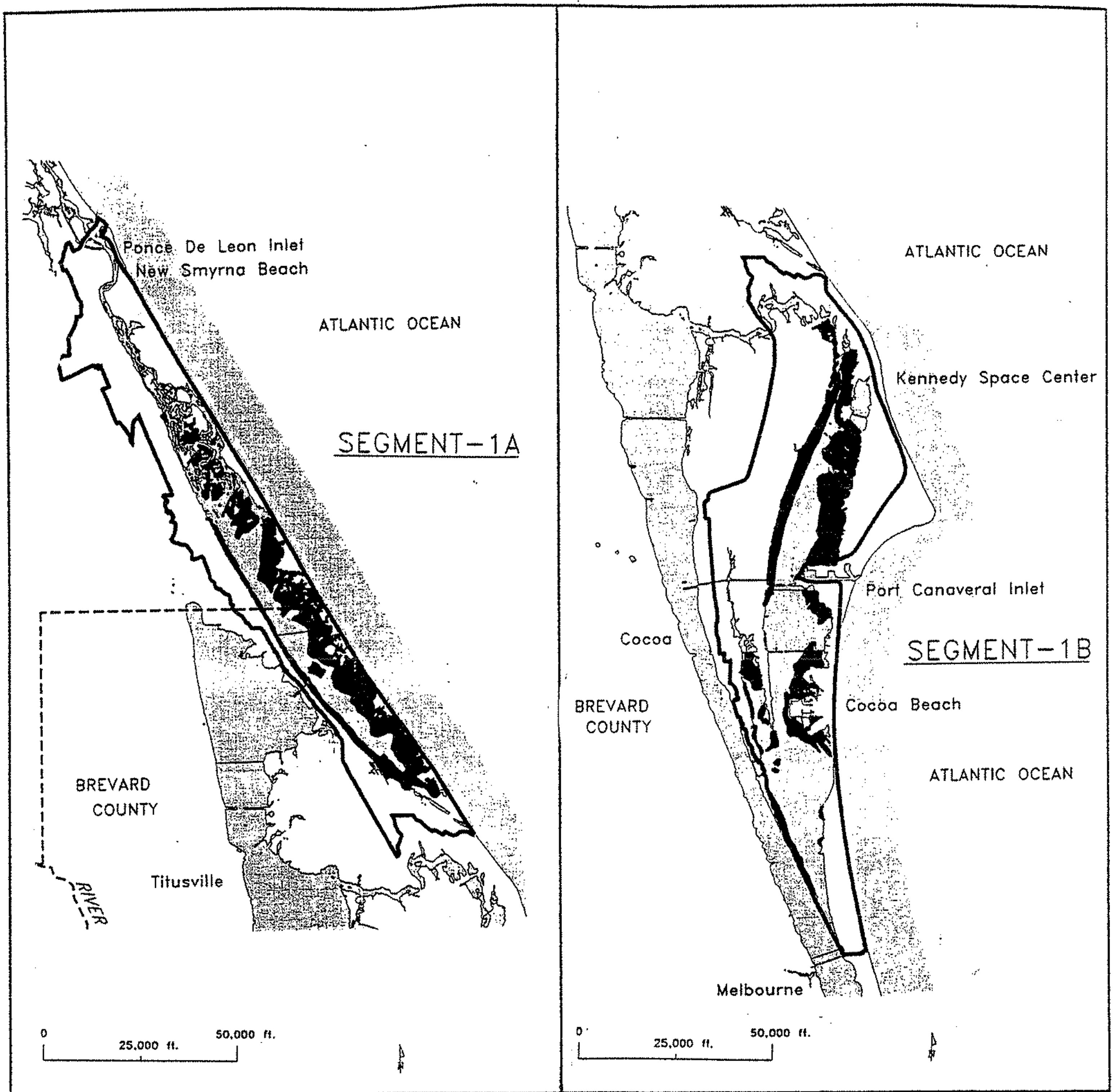
The various species have distinct distribution patterns in the Lagoon. Turtle grass is found only as far north as the Sebastian Inlet area and is found in dense beds only south of Wabasso Causeway and the Vero Beach area (Thompson, 1978). Johnson's seagrass and paddle grass appear to have similar distributions, but may not occur much north of Sebastian Inlet (Virnstein and Cairns, 1986; Kenworthy, 1993). Manatee grass and star grass extend north into Mosquito Lagoon, but their abundance levels in northern Mosquito Lagoon are not well known. Shoal grass and widgeon grass are found throughout the complex as well as much farther to the north.

Seagrass distribution also follows patterns related to depth. In most instances only the various species of *Halophila* are commonly found as deeep as 6.7 ft (2 m) within the Lagoon. In addition, spatial occurrence may be influenced by salinity or other factors.

Dense seagrass beds are found in many parts of the Lagoon. Figures 4-2 to 4-4 show the major areas of seagrass that were mapped in spring of 1992 (Natural Systems Analysts, 1993). Figures 4-2 to 4-4 have broken the Lagoon complex into six segments to display this distribution information because the distributions in the segments can be quite different and can best be discussed as separate sections. These segments are based on the segmentation scheme described in the Physical Features Technical Report and shown in Figure 1-2. These segments have been modified from SJRWMD drainage basin segments (Rao, 1987). The figures and the following sections describe the locations of major SAV beds and the general patterns of seagrass occurrence in each segment, beginning at the north end of the complex in Mosquito Lagoon (Segment 1A).

4.1.2.1 Segment 1A - Mosquito Lagoon

Some of the largest and most dense seagrass beds are located in the highly saline shallow waters of Mosquito Lagoon (Figure 4-2a) as far north as Orange Island (9 miles south of Ponce Inlet) in Volusia County. These beds are dominated by shoal grass and manatee grass in the southern end with manatee grass dropping out in the northern portion (Fletcher, 1993). Data from permanent transect studies from 1983 to 1990 (Provancha, et al., 1992) showed that cover within the beds averaged 55%, with shoal grass accounting for over 80% of total



Source; NSA, 1993.

• Woodward-Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysts	DRAWING NO.: DATE:	FIGURE 4-2	MAJOR SEAGRASS BED AREAS OF SEGMENTS 1A AND 1B OF THE INDIAN RIVER LAGOON SYSTEM

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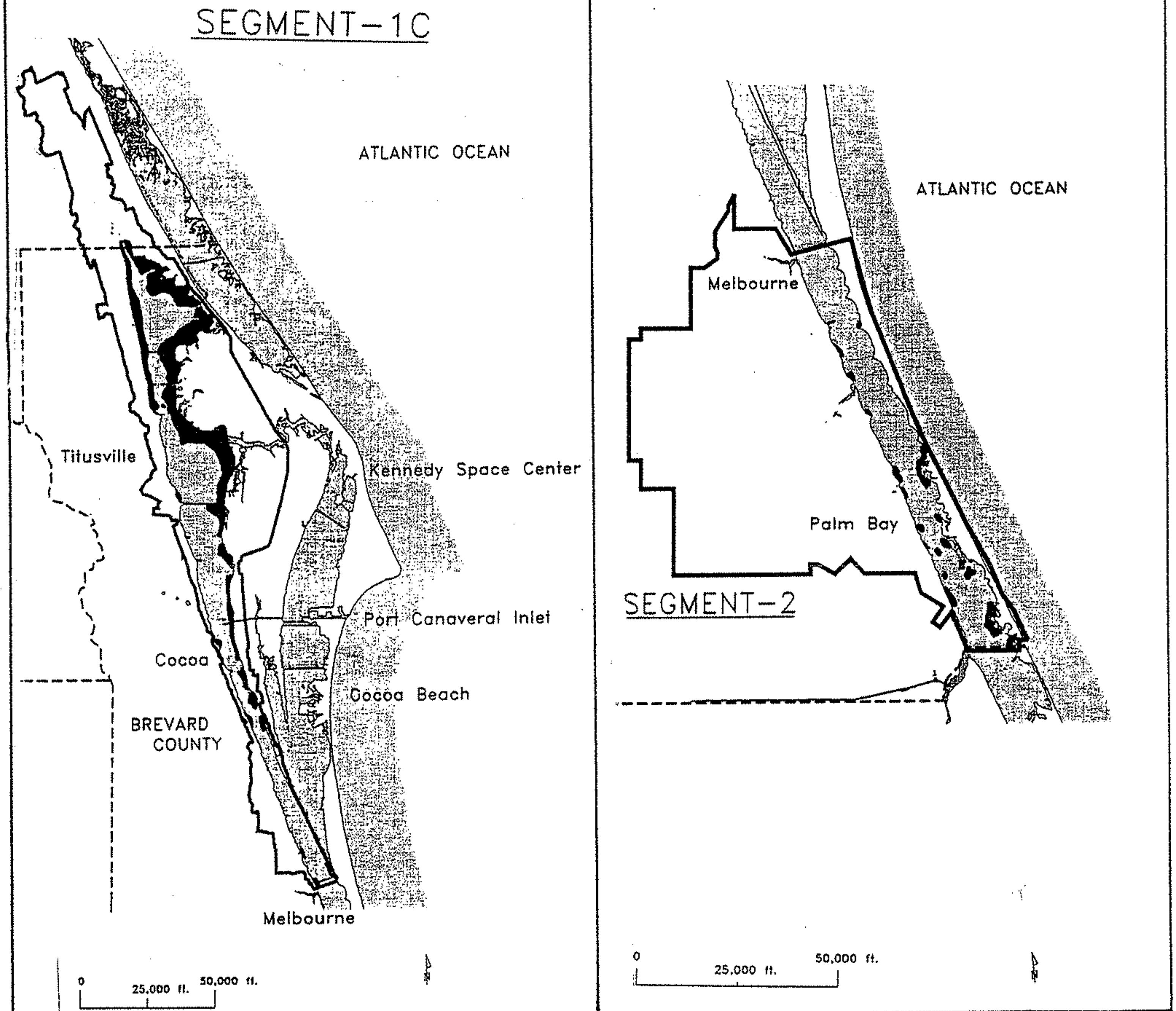

Source: NSA, 1993.

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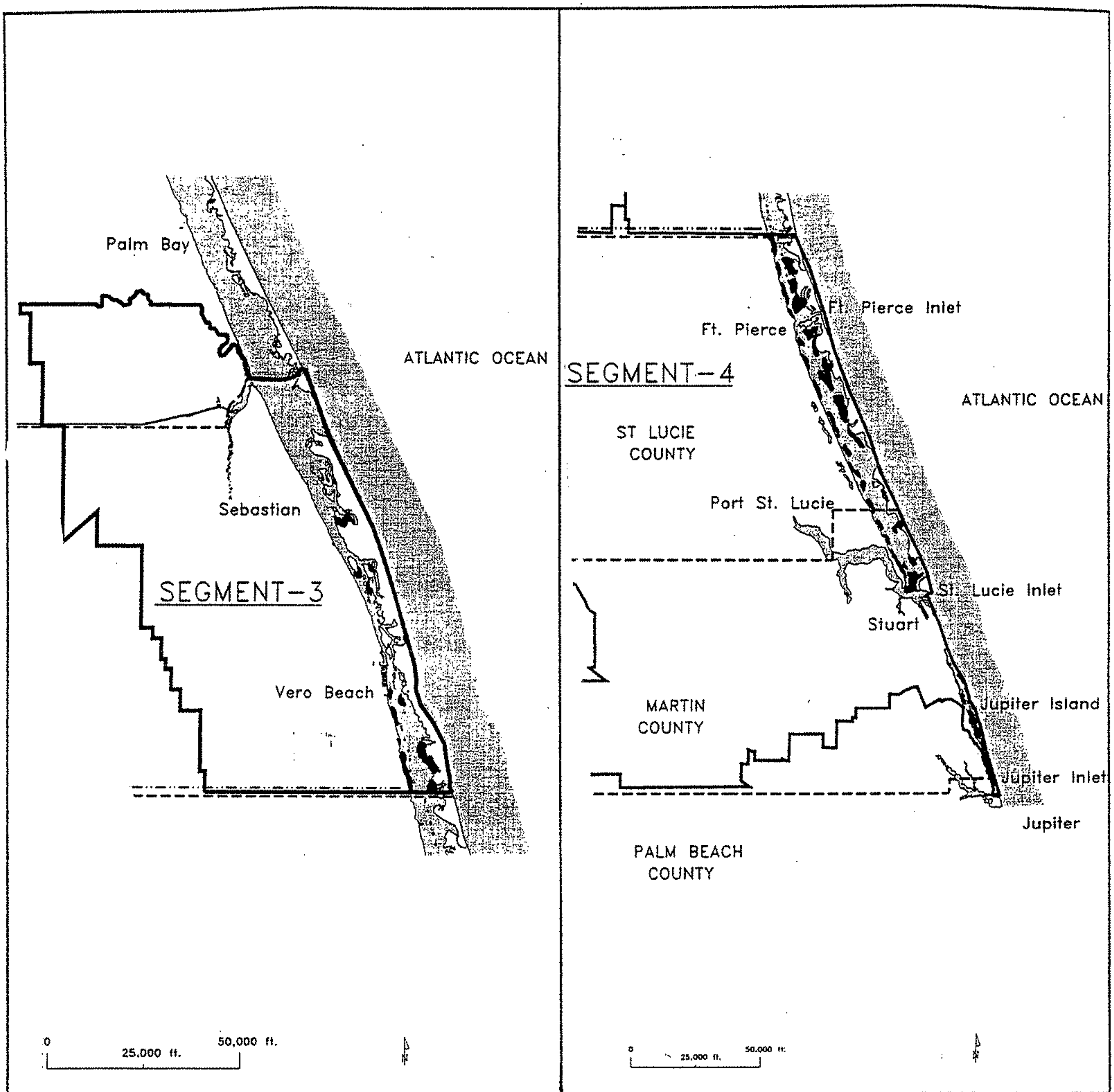
FIGURE 4-3 MAJOR SEAGRASS BED AREAS OF SEGMENTS 1C AND 2 OF THE INDIAN RIVER LAGOON SYSTEM



Source; NSA, 1993.

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FIGURE 4-4 MAJOR SEAGRASS BED AREAS OF SEGMENTS 3 AND 3 OF THE INDIAN RIVER LAGOON SYSTEM

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seagrass cover (Provancha, et al., 1992). Some star grass is also present. Very shallow areas and the more northern portions of Mosquito Lagoon contain extensive areas of widgeon grass.

4.1.2.2 Segment 1B - Banana River

The portion of the Banana River (Figure 4-2b) north of SR 528 (within the Merritt Island National Wildlife Refuge) contains extensive seagrass beds composed primarily of shoal grass with some manatee grass and widgeon grass (Down, 1978; White, 1986). Seagrass as well as macroalgae coverage has varied in this portion. The attached alga *Caulerpa prolifera* has covered as much as 90% of the total bottom of this portion at times such as in 1986 (White, 1986). The central portion of the Banana River generally does not have extensive seagrass beds, but beds of attached algae such as *Caulerpa prolifera* may be abundant. Seagrasses and attached algae are both generally abundant in the Thousand Islands area, with a wide assortment of both algal and seagrass species. The southern portion of Banana River from about Jones Creek south, including the Newfound Harbor and Sykes Creek areas, generally has either sparse or narrow seagrass beds along the shorelines, although the southern portion of Newfound Harbor may contain modest to extensive beds of shoal grass and manatee grass. *Caulerpa prolifera* and the drift algae *Gracilaria* spp. have also been abundant in these areas.

4.1.2.3 Segment 1C - Northern Indian River Lagoon

Indian River Lagoon north of NASA Causeway also has some of the most extensive grass beds in the system (Figure 4-3a). Almost 85% of the total bottom area north of the NASA railroad bridge has recently been vegetated with seagrasses (White, 1986). A large die-off occurred in 1991, but much of the area has recovered. Shoal grass, manatee grass, and widgeon grass are abundant seagrasses north of NASA Causeway (White, 1993). Algae is also abundant in the deeper portions of this segment. The majority of the beds in this area are on the east side of the Lagoon. Bed width and density decreased in 1992 in the north end near the mouth of Turnbull Creek and along the west side of the Lagoon near Titusville.

Bed size and density tends to decrease south to the Pineda Causeway, with shoal grass becoming more dominant. The portion of this segment south of the Pineda Causeway contains few significant seagrass beds, with shoal grass being the dominant seagrass (White, 1986; Natural Systems Analysts, 1993). Drift algae and *Caulerpa prolifera* have been reported as abundant in the Pineda area (White and Snodgrass, 1990; Natural Systems Analysts, 1993; Morris, 1994).

4.1.2.4 Segment 2 - North Central Indian River Lagoon

The portion of this segment (Figure 4-3b) north of a point about 8 miles north of Sebastian Inlet near Valkaria has only thin bands of seagrasses paralleling the shoreline which are dominated by shoal grass. Between Crane Creek and the Pineda Causeway (in Segment 1C) seagrass beds are less well developed than anywhere else in the Lagoon complex, although there have been recent indications that shoal grass beds have increased in size and density near the mouths of Crane Creek and Turkey Creek since 1992 (Morris, 1994). Seagrass abundance and density increase southward from Valkaria to Sebastian Inlet. Shoal grass and manatee grass were both reported as prevalent in this portion in 1986 (White, 1986), while manatee grass was present but not abundant in 1976 or 1992 (Thompson, 1978; Fletcher, 1993). Seagrass beds in this segment are concentrated on the east side of the Lagoon. Turtle grass reaches its northernmost limits in a few small patches in the Sebastian Inlet area (Virnstein, 1993). Large beds of macroalgae including *Gracilaria* spp. are present with the greatest concentration in 1992 being in the center and eastern portions near Grant Farm Island (Fletcher, 1993).

4.1.2.5 Segment 3 - South Central Indian River Lagoon

Moderate-sized areas of dense seagrass beds are found in this segment (Figure 4-4a) from Sebastian Inlet south past the Wabasso Causeway to Johns Island. Shoal grass and manatee grass are again the principal seagrasses, although turtle grass, and star grass occur in increasing abundance southward in the shallow and deep zones, respectively. Beds begin to thin around Johns Island and remain sparse to about three miles south of Vero Beach (17th Street Bridge). Shoal grass is the most abundant species, although all of the species are present in this vicinity. From approximately the Indian River County/St. Lucie County line south to Ankona (7 miles south of Ft. Pierce), shoal grass and manatee grass dominate large beds of mixed species (Thompson, 1978; Natural Systems Analysts, 1993), and dense patches and beds of turtle grass are present. Although the turtle grass beds appear to be expanding, beds generally get sparser south of the county line, but all three species of *Halophila* may be found (Virnstein and Cairns, 1986).

4.1.2.6 Segment 4 - South Indian River Lagoon

Beds have varied in density over time between Ft. Pierce and St. Lucie Inlets (Figure 4-4b), where dense beds are found around the shoals being formed at the mouth of the St. Lucie Inlet and the St. Lucie River. Seagrass beds in the Ft. Pierce area were moderately dense when mapped in 1986 (Virnstein and Cairns, 1986) but were less dense when mapped in 1992 (Fletcher, 1993). Turtle grass is common in this area, mixed with shoal grass. South of St. Lucie Inlet, to Hobe Sound, beds are largely restricted to bands fringing the narrow channel. Beds cover much of the total bottom area of Hobe Sound and Jupiter Sound, and depth penetration appears to be higher than in much of the Indian River Lagoon complex (Kenworthy, 1993). Turtle grass is found in this portion, although shoal grass and manatee grass dominate most of the beds. All three *Halophila* species are relatively well represented in the deeper waters of Hobe Sound.

4.1.3 Seagrass Ecological Requirements

The last decade has seen much research on ecological requirements of seagrasses. The main impetus behind this research has been the realization of two factors. The first is the importance of seagrasses and other SAV in the ecological stability and productivity of estuarine ecosystems (Zieman, 1982). Numerous studies have established that seagrasses perform numerous functions such as stabilization of sediments, prevention of re-suspension of particulate matter, cover and food for fish and wildlife resources, and other functions. Second, is the realization that SAV distribution and health bears a direct relationship to water quality and water clarity conditions of estuaries. It has, therefore, been determined that the status and health of seagrasses can be used as an indicator of estuarine water quality (Morris and Tomasko, 1993). Because of this direct relationship, it is possible to establish the water quality criteria necessary to support this vital ecological resource.

Numerous studies throughout the world have indicated that certain parameters are more important for SAV establishment and maintenance than others. The most critical habitat factor requirements have been shown to be water clarity and nutrient levels (Dennison, et al., 1993, Funderburk, et al., 1991). These water quality parameters are important because they differ from the critical water quality parameters that have been identified for many other important resources such as birds, fish, and shellfish (Funderburk, et al., 1991). Therefore, the habitat requirements and potential water quality restoration criteria for SAV may differ from those established for many other resources, although they may be just as critical for the survival of the SAV-dependent resources.

Physical and chemical factors affecting seagrass viability include water clarity, light intensity, water depth, substrate type, salinity, nutrient levels, and water temperature. Table 4-1 shows selected water quality and habitat conditions that are required or most favorable to six of the seven species of Indian River Lagoon seagrasses. Johnson's seagrass only occurs in the Indian River Lagoon and has not been sufficiently studied to compile complete information on its ecological requirements.

4.1.3.1 Water Depth and Zonation

The first detailed accounts of seagrass zonation in the Indian River Lagoon system were prepared by White (1986) for Brevard County, and Virnstein and Cairns (1986) for Indian River and St. Lucie Counties. Both research teams reported that no seagrasses were present within the intertidal zone. This is in contrast to observations by Phillips (1960) in Tampa Bay where shoal grass and widgeon grass were reported in this zone. Virnstein and Cairns, as well as White, postulated that heat stress is the primary reason for the lack of grasses in this zone, but the presence of large masses of wrack and drift algae may also affect survival. This depauperate zone often extends 0.7 to 1.0 ft (0.2 to 0.3 m) below mean water level and up to 170 ft (50 m) from shore.

Other factors also may be involved in the lack of seagrasses in many areas of this shallow zone. Fletcher (1993) noted that many of the intertidal and shallow zones had either large amounts of rocky debris on the bottom or had exposed beds of peat from drowned marshes. The action of wind-driven waves and boat wakes on these organic outcrops often results in eroding substrate causing poor water clarity due to suspension of organic particles. Water level fluctuation also may be a factor. Indian River Lagoon also differs from Tampa Bay in that it has significant water level fluctuations of up to 1.7 ft (0.5 m) that are caused by

TABLE 4-1

ECOLOGICAL REQUIREMENTS REPORTED IN THE LITERATURE FOR SEAGRASSES

SEAGRASS SPECIES	DEPTH[a] (CM)	SUBSTRATE	SALINITY[b] 0/00	TEMP[b] °C
Thalassia testudinum	30 - 200[1,2,5,6,9] 30 - 100[3,4] 30 -3300[2,5,6,8,13]	Pure mud - hardpacked sand - shell[1,2,6,8,9,13]	16 - 48[1,2,5,6,8,9,13] (24 - 35)	18 - 39[1,5,6,8] (22 - 30)
Halodule wrightii	5 - 250[1,5,6,9] 20 - 150[3,4,7] 5 - 3000[5,6,8]	Pure mud - muddy fine sand[5,6,8,9]	1 - 45[1,5,6,8,9] (22 - 34)	<39[1,5,8] ---
Syringodium filiforme	30 - 300[5,9] 30 - 150[3,4,7] 30 - 2500[5,8]	Soft black mud - mainly sand[5,8,9]	10 - 36[5,8,9] (20 - 28)	12 - 30[5,8] (24)
Ruppia maritima	60 - 100[5,10,12] 10 - 60[4,7] 20 - 60[5,10]	Muddy sand - sand[5,10,12]	5 - 32[5,10,12] (<25)	7 - 39[5,10,12] (18 - 30)
Halophila englemanni	15 - 250[5,11] 100 - 200[3,4] 5 - 9100[5]	Soft muddy sand[5,11]	29 - 31[5,11] ---	--- ---
Halophila decipiens	15 - 200[5,11] 100 - 200[3,4] 5 - 2900[5]	Mud - sand[5,11]	24 - 38[5] ---	--- ---

Sources:
1) Phillips (1960)
2) Taylor (1928)
3) White (1986)
4) Down (1978)
5) Humm (1956)
6) Phillips (1959)
7) Woodburn & Ingle (1959)
8) Reid (1954)
9) Voss & Voss (1954)
10) Funderburk, et al (1991)
11) Thorne (1954)
12) Anderson (1969)
13) Stephenson & Stephenson (1950)

a = Top - Range in coastal waters; Middle - Range in IRL; Bottom - Range in open ocean
b = Top - Range for Survival; Bottom - Best growth range

meteorological conditions rather than by tides. In many parts of the Lagoon, these fluctuations are more extreme than the tidal range. These non-tidal fluctuations result in more irregular periods of exposure which often last longer than tidal periods. Such periods of unpredictable prolonged exposure very likely play a major role in exclusion of seagrasses from this zone.

The first zone of consistent seagrass occurrence in most of the Lagoon consists of dense beds of shoal grass in water to approximately 1.3 ft (0.4 m) (Gilbert, 1976). In some areas, particularly in the northern portions of Indian River Lagoon and Banana River, widgeon grass replaces or intersperses with shoal grass in this zone. Widgeon grass often occurs in more shallow and more exposed areas than do the other grasses (Phillips, 1960).

Between about 1.3 to 3.7 ft (0.4 and 1.1 m), manatee grass becomes more dominant, but beds in this zone may range from pure shoal grass to pure manatee grass (Gilbert, 1976; Kenworthy, 1993). From Ft. Pierce Inlet south, turtle grass may form pure stands to depths of about 2 ft (0.6 m) (Virnstein and Cairns, 1986).

The zone from 2.0 to 5.0 ft (0.6 to 1.5 m) is usually dominated by manatee grass, with shoal grass being a major component in most parts of the Lagoon (Gilbert, 1976). Bed density decreases rapidly at depths greater than 3.3 to 4.0 ft (1 to 1.5 m) in most of the Lagoon. At depths greater than 2.7 ft (0.8) and increasingly at depths above 3.3 ft (1.0 m), several species of *Halophila* may become dominant (Virnstein and Cairns, 1986; Kenworthy, 1993).

Manatee grass and shoal grass may persist to depths of 5.0 to 6.7 ft (1.5 to 2 m) but occur very rarely beyond these depths in the Lagoon. Cover is less than 40% and usually less than 20% at depths greater than 5 ft (1.5 m) (Virnstein and Cairns, 1986; White, 1986). Down (1978) reported that the dense manatee grass/shoal grass zone extended to depths of 5.0 ft (1.5 m) in the channels and to as deep as 8.3 ft (2.5 m) in parts of Banana River and near Sebastian in the mid-1970s.

All seagrass species (except the endemic Johnson's seagrass) in the Lagoon have been reported to occur at much greater depths in other locations, particularly in the clear open ocean waters of the Florida Keys and Caribbean. Turtle grass has been reported at over 110 ft (33 m) in these waters (Phillips, 1959, 1960) with dense beds at 6.7 to 23 ft (2 to 7 m).

Shoal grass, star grass and paddle grass have been reported to 100 ft (30 m), 303 ft (91 m), and 97 ft (29 m) respectively (Taylor, 1928; Phillips, 1960). However, in these areas reported Secchi disk depths were at least 6 times greater than in the coastal waters of the Lagoon, indicating much clearer water and greater light penetration.

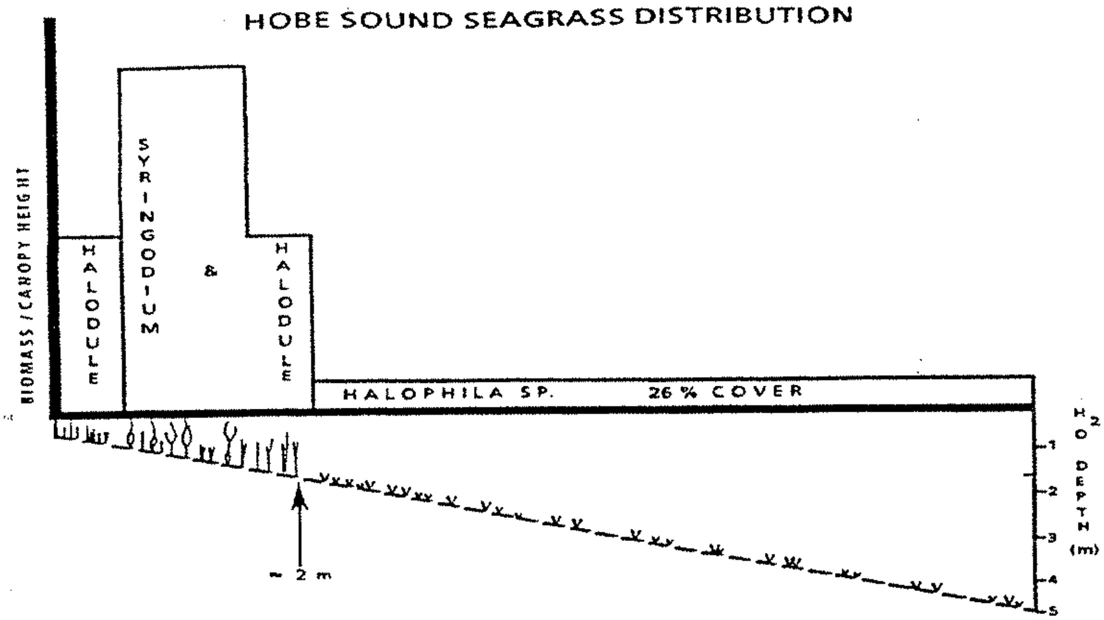
In the southern part of the Lagoon, turtle grass sometimes grows in mixed beds with shoal grass and manatee grass (Virnstein and Cairns, 1986). Phillips (1960) reported that shoal grass does not grow well in areas of thick turtle grass, but that it will colonize denuded areas more rapidly than turtle grass. As a species, turtle grass does not appear to be light-limited in the zones from 0 to 3.3 ft (0 to 1 m), but instead seems limited by competition from turtle grass, manatee grass, and widgeon grass (Phillips, 1960; Fourqurean and Zieman, 1990).

Johnson's seagrass, star grass, and paddle grass all may occur in depths greater than 1.0 ft (0.30 m), but they are most abundant at depths greater than 3.3 ft (1.0 m). In many cases one of these species will be the dominant species in depths greater than 3.3 ft (1.0 m) Virstein and Cairns (1986). However, the density of these deep beds is usually very low (White, 1986).

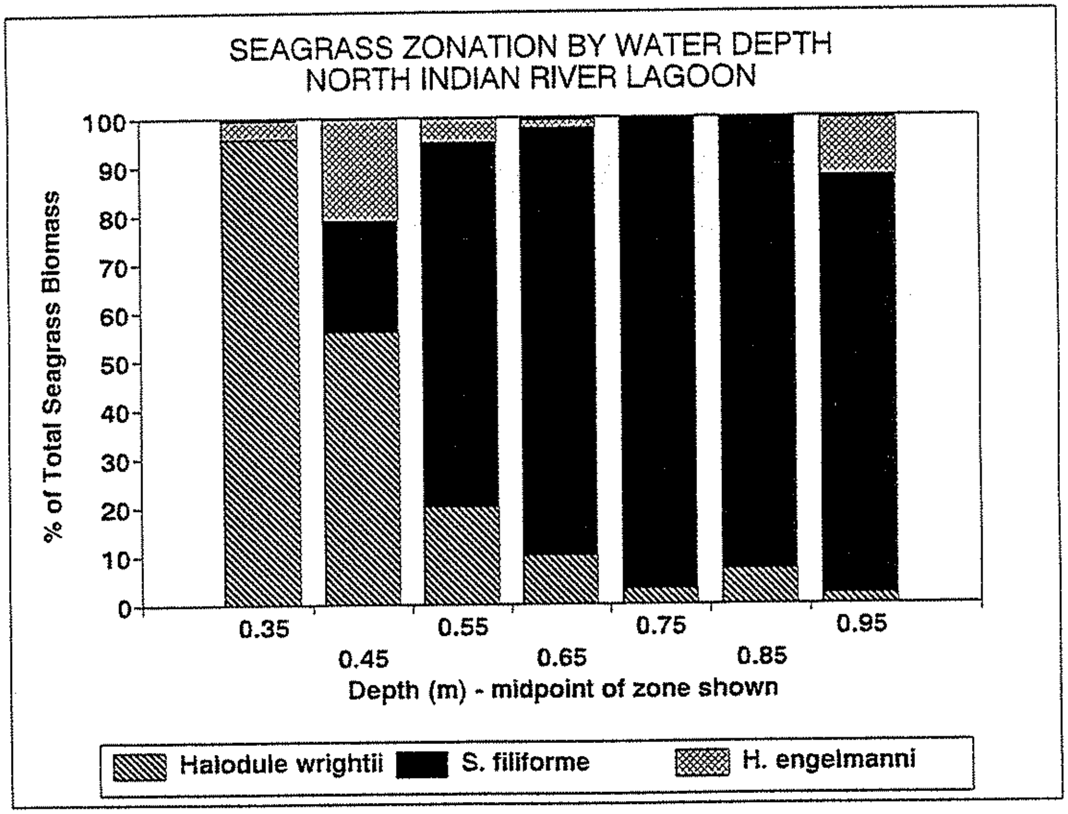
Figure 4-5 shows the approximate zonation and depths of occurrence of the more widespread species of the Lagoon at stations at Hobe Sound and near Titusville . Figure 4-6 shows depth distribution data for the two dominant seagrass species and for two common algal species from near Ft. Pierce in the Indian River Lagoon. These figures indicate that the maximum depths of occurrence may differ throughout the Lagoon system.

4.1.3.2 Water Clarity and Light Requirements

Like all photosynthetic plants, seagrasses need sunlight to survive. Photosynthetic levels and subsequent growth and survival depend on the amount of sunlight reaching the vegetation. Sunlight penetration into the water column is attenuated as a function of distance. The rate of attenuation in the water column is dependent upon such factors as absorption of light by chlorophyll (particularly chlorophyll *a*) and dissolved substances, scattering from suspended particles, and water color.



a) Qualitative illustration of the depth distribution of seagrasses in Hobe Sound (South Indian River Lagoon - Segment 4)



b) Quantitative illustration of the depth distribution of seagrasses in the North Indian River Lagoon (Segment 1C)

Source: a) Kenworthy, 1993
b) Gilbert, 1976.

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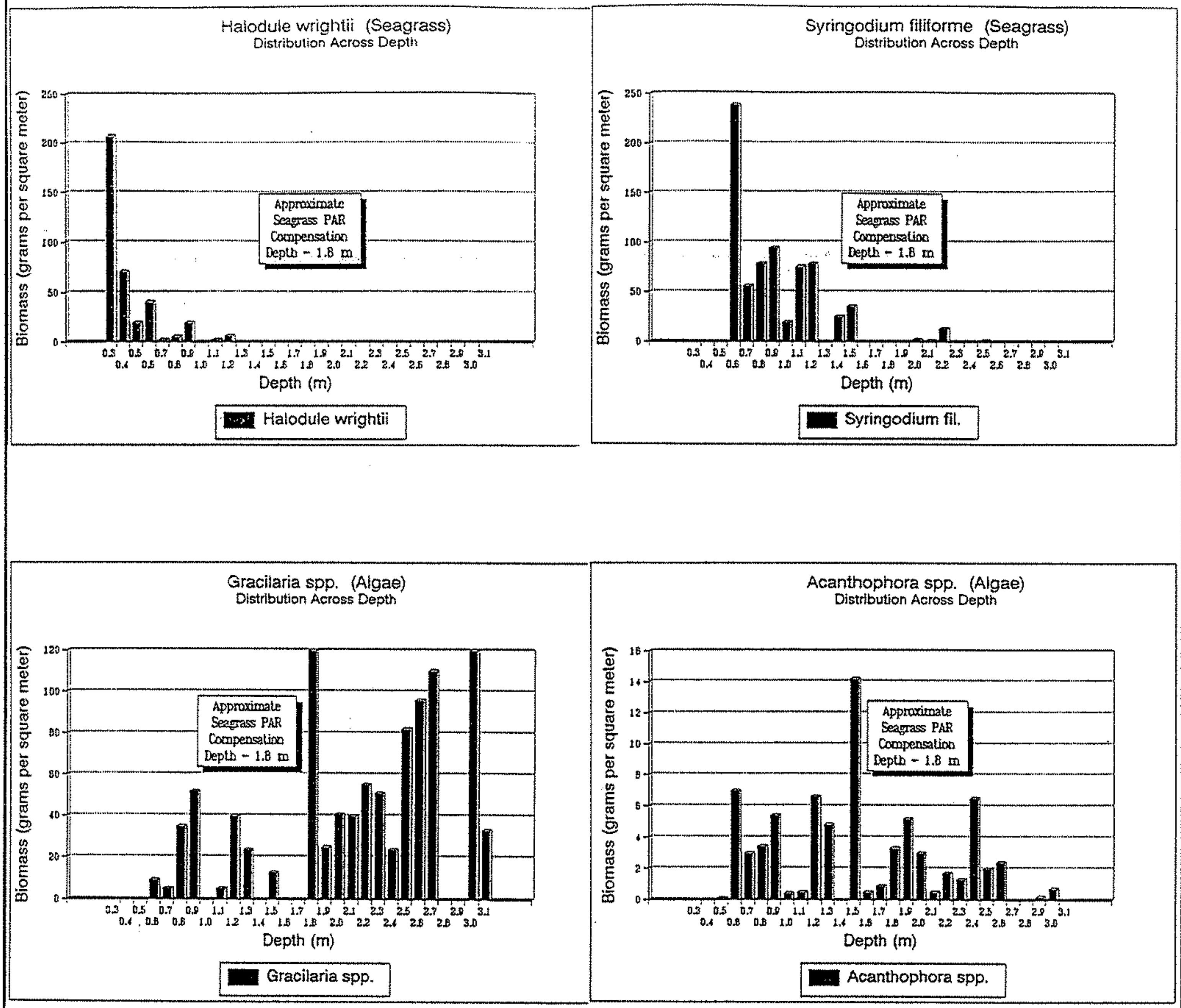

Source: Gilbert (1976)

Top: Seagrass Species

Bottom: Algae Species

Approximate Lower limit of seagrass growth (PAR depth) is 1.8M.

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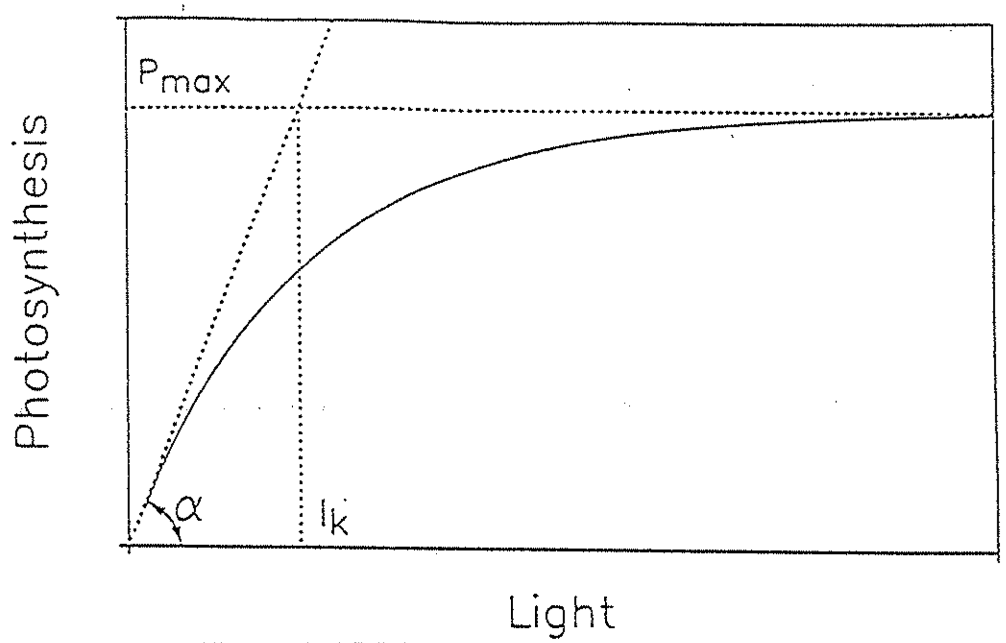
Photosynthetically active radiation (PAR) is the portion of the electromagnetic spectrum that can be utilized by plants in photosynthesis (Morris and Tomasko, 1993). The amount of light at or just under the surface of the water column is referred to as the incident radiation (I_o). The amount of light remaining in the water column at different depths is usually defined as a percentage of the incident radiation. The transparency of the water column can be described as a degree of loss of light by a coefficient of light extinction or attenuation called the K value (Kenworthy, 1993).

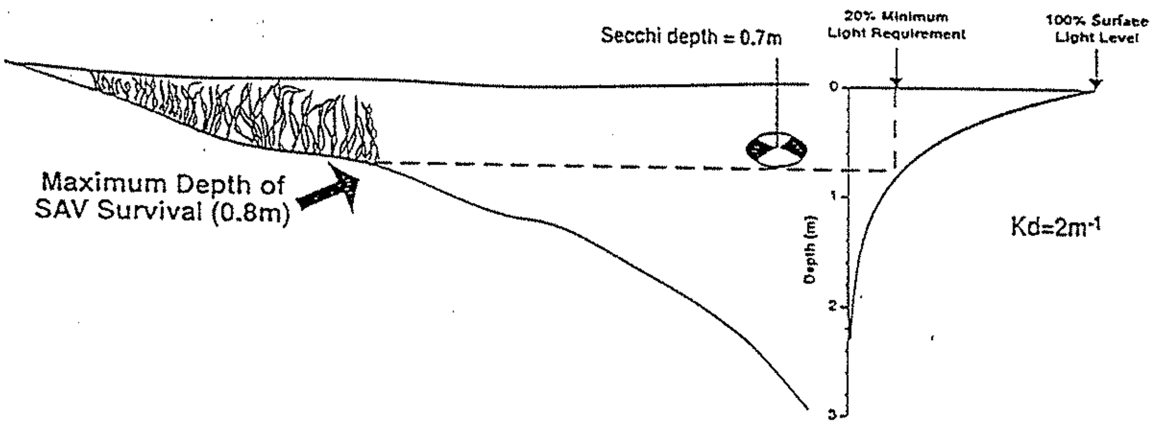
The variation among depths of occurrence of different species has been mentioned, as well as the variation among depths reported in different locations and waters. The overriding conclusion concerning the different sites has been that the depth of survival of seagrasses is dependent upon the degree of light penetration. Tomasko (1993) has reported a strong correlation between the depth at the outer edge of grass beds in Sarasota Bay to the light extinction coefficient (K) of the water. Factors normally affecting light penetration and the K factor are are often expressed in water quality monitoring programs as color, turbidity, and concentration of chlorophyll *a* in the water.

The rate of photosynthesis when plotted against light intensity has a characteristic shape shared by most plants. This curve is called the photosynthesis-irradiance curve (P-I) (Fourqurean and Zieman, 1991), as shown in Figure 4-7. The curve is characterized by a initial steep slope at lower light intensities which represents a rapid and often nearly straight line increase in photosynthesis rate with increasing light. The slope is defined by the angle "α". A steeper slope and higher "α" indicates a greater efficiency in low light conditions. With higher light intensities, the photosynthesis rate begins to stabilize to a point at which the curve approaches horizontal, indicating that the rate of photosynthesis will not increase with additional light intensity. This level (P_{max}) represents the maximum photosynthetic rate for the plant.

Even when plants are not actively growing, they continue to expend energy through respiration. If, over time, the rate of photosynthesis fails to exceed the rate of respiration, the plants will die. The point on the P-I curve where the rate of photosynthesis equals the rate of respiration is called the compensation point (C_p).



a) Hypothetical P-I Curve.
p_{max} = maximum photosynthetic rate, = initial slope or rate of photosynthesis in low light, I_K = minimum light level for survival



b) Effect of P-I Curve in Determining SAV Depth.
Secchi disk or PAR meter used to determine light at each depth, allowing P-I graph as in a) to be superimposed on depth profile. The maximum survival depth (minimum light or I_K depth) can then be read from figure as shown.

Source: From Fourqurean and Zieman, 1991; Orth, 1993

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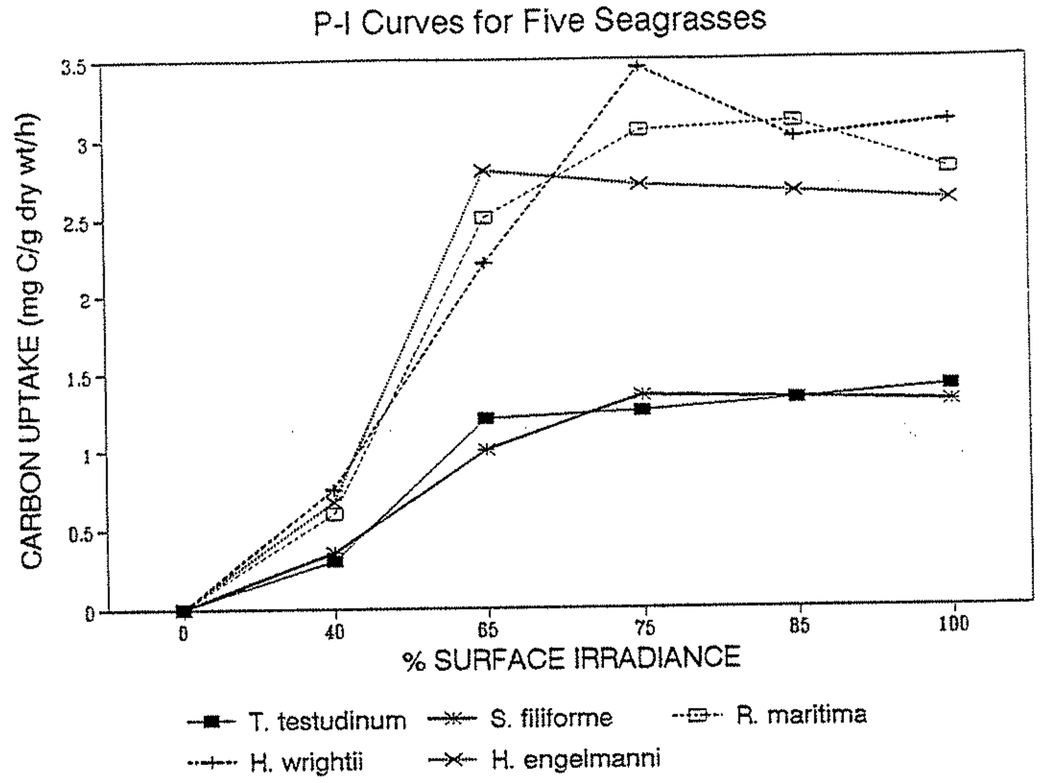
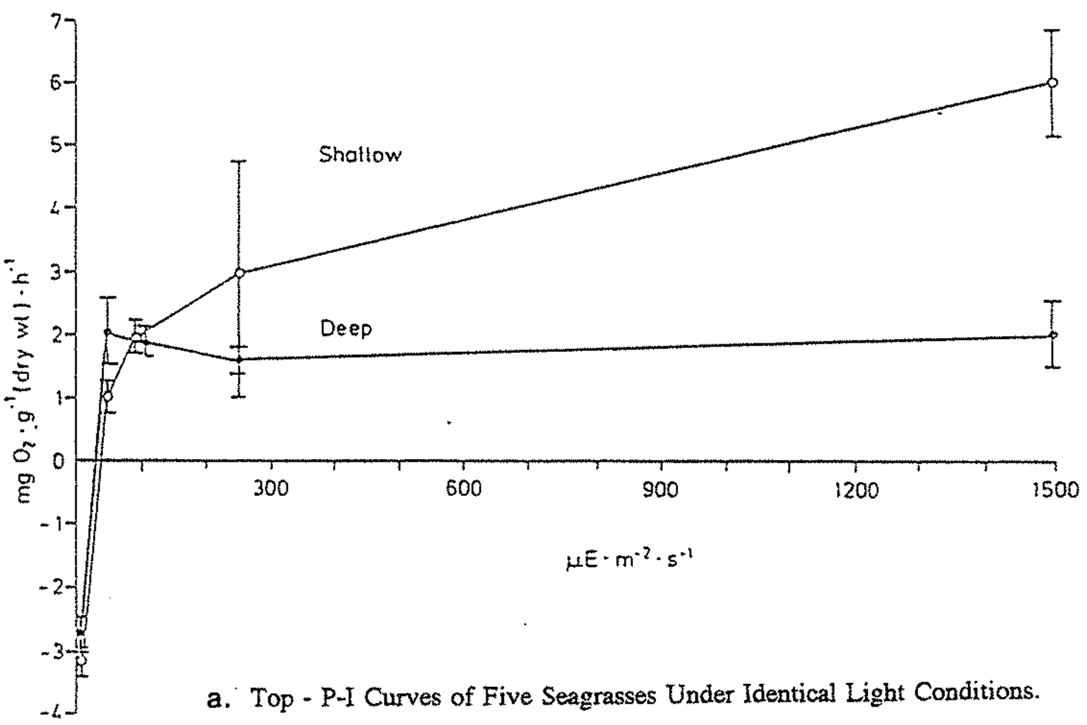
Figure 4-8a shows P-I curves developed by Williams and McRoy (1982) for five subtropical seagrass species that are also found in the Indian River Lagoon. They interpret these curves to indicate that there may be two groups of responses in seagrasses. The first is represented by turtle grass and manatee grass, which have very similar responses showing a slow steady response to increasing light. This group is described as the climax species response group. The other group is the colonizer species response group represented by shoal grass, star grass, and widgeon grass. Fourqurean and Zieman (1990) confirmed that shoal grass has a steeper curve than turtle grass and manatee grass. These species with steeper curves have a higher photosynthetic efficiency at lower light intensities and higher photosynthetic rates in general. It has been suggested that this group is better adapted to taking advantage of rapid responses and can grow rapidly under many conditions involving short-term fluctuations or acute stresses (Fourqurean and Zieman, 1990). The climax group may be better adapted for tolerating long-term chronic stresses in environments where there is little change over time. These characteristics may help to explain certain patterns of occurrence in the Lagoon as well as the manner in which seagrasses recover from stress conditions.

For example, the Indian River Lagoon complex differs from many estuaries because it has very restricted connection to the open ocean, whereas most estuaries have wide mouths and unrestricted water exchange. This maintains more consistent water quality parameters and constant concentrations throughout most estuaries, a condition which may favor species like turtle grass of the climax group. Of the three principal seagrass species in the Lagoon, only shoal grass consistently occurs throughout the length of the complex. This may be partially due to inherently faster response patterns to the greater environmental variability within the Indian River Lagoon estuary complex.

Variation can exist within species as well. Figure 4-8b (Tomasko, 1993) shows how turtle grass plants growing at deeper depths can acclimate to lower light regimes by increasing efficiency at low light intensities.

The maximum depth at which the C_p or the point of minimum light requirement occurs will determine the maximum depth of seagrass occurrence. Figure 4-7 also shows how light attenuation may determine the maximum depth of seagrass survival. From this figure, it can be seen that any factor affecting the rate of light attenuation will affect the maximum depth of survival. A decrease in light intensity has also been shown to reduce shoot density in





a. Top - P-I Curves of Five Seagrasses Under Identical Light Conditions.

b. Bottom - P-I Curves for Turtle Grass Plants From Shallow and Deep Edges of a Seagrass Meadow off Anclote Key, Florida.

b

Source: From Fourqurean and Zieman, 1991; Tomasko, 1993.

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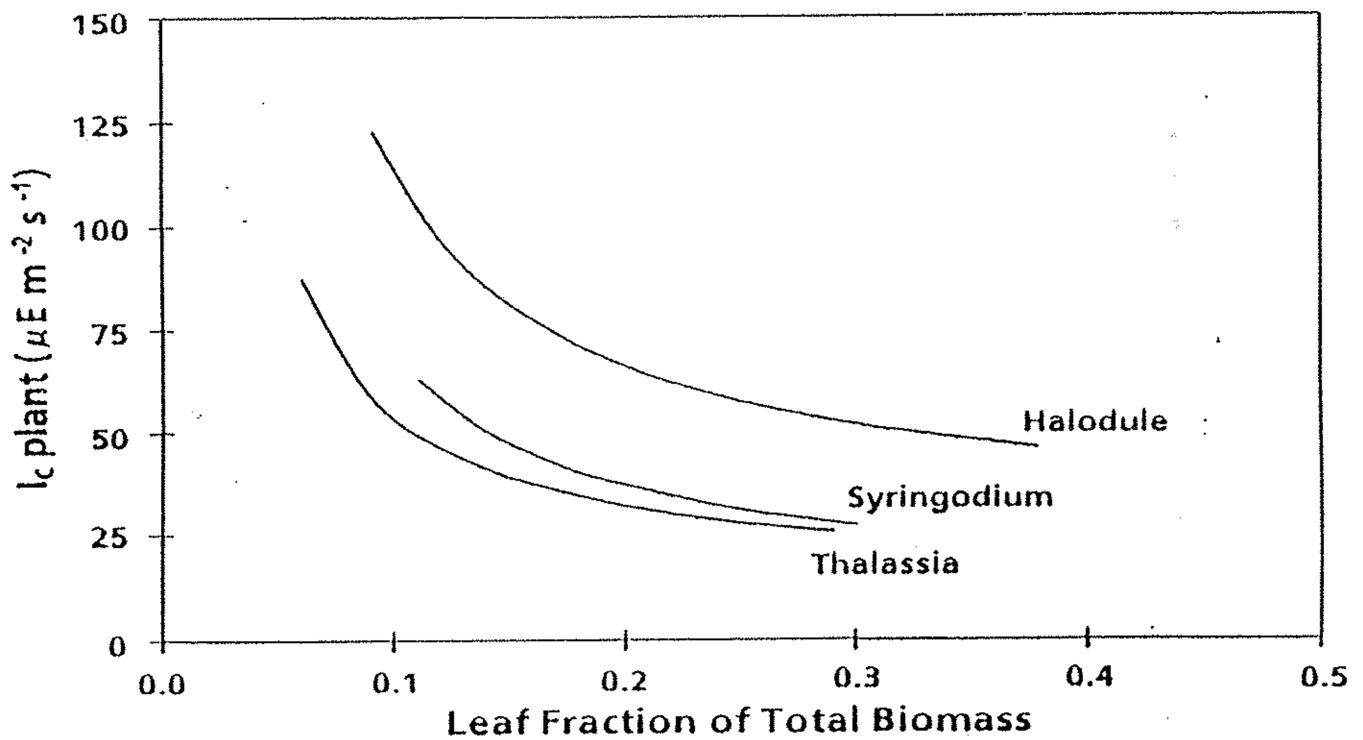
seagrasses, with the change in density almost identical to the change in the photosynthesis curve (Short, 1990).

Fourqurean and Zieman (1990) found that under laboratory conditions the light intensity levels at the compensation points for turtle grass, shoal grass, and manatee grass were 15, 33, and 14 uE m^{-2} s^{-1} (microEinsteins/meter^2/sec), respectively. Since much of the mass of a seagrass plant includes root or rhizome tissue that has respiratory needs but does not photosynthesize, the actual compensation point or level at which photosynthesis balances respiration for the entire plant will be substantially higher than the above noted compensation points. This higher value, the $I_{c\ plant}$, has been found by Fourqurean and Zieman to be about 40, 65, and 35 uE m^{-2} s^{-1} for these species. The actual value at any point in time would depend on the relative amount of photosynthetic leaf biomass on a plant. Figure 4-9 illustrates that the minimum light requirement rises as the fraction of leaves decreases. Under average daily incident light conditions, they estimate that a light level equating to 10 to 20% of the average light intensity at the water surface would be required for long term survival.

Field observations in several locations appear to support these experimental results very well. Onuf (1990) measured PAR at the bottom of Laguna Madre in Texas along grass beds consisting of manatee grass, shoal grass, and star grass where he found the percentage of surface radiance to be between 10% and 20% along the outer edge of the beds. Hall, et al. (1990) reported that shading (60% to 65% light reduction) of turtle grass grass beds decreased leaf biomass and growth by over 50% in some cases. They have reported that declines in shoot density occur more rapidly in widgeon grass and some other species than in turtle grass, and they attribute this to the more extensive below-ground reserves in the latter species.

Little information on PAR levels and seagrass responses has yet been obtained specifically from Indian River Lagoon, but what is available is consistent with the studies that have been presented above. Kenworthy, et al. (1990) studied seagrasses in Hobe Sound and found manatee grass and shoal grass grew to depths of about 5 to 6.7 ft (1.7 to 2 m), with average depths to 3.5 and 3 ft (1.1 and 0.9 m) respectively. All three species of *Halophila* were found at depths exceeding 2.0 m. At the maximum depth of growth for shoal grass and manatee grass, the percent of incident light varied between about 7 and 48% of that at the



Whole plant compensation irradiance as a function of the relative importance of leaf tissue to the total plant biomass.

Source: From Tomasko, 1993

• Woodward–Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysts	DRAWING NO.: DATE:	FIGURE 4-9	THE EFFECT OF THE AMOUNT OF LEAF BIOMASS ON THE MINIMUM LIGHT LEVEL (I) FOR SEAGRASS SURVIVAL

INDIAN · RIVER · LAGOON NATIONAL ESTUARY PROGRAM water surface, with annual average values of 23% and 27% for the two species respectively (Kenworthy, et al., 1990; Kenworthy, 1993). This level is based on an annual average. Several studies have indicated that the *Halophila* species have $I_{C\ plant}$ levels lower than the other species, closer to 2% to 5% of incident radiation than the 15% to 27% for the other species, and that this allows them to grow in deeper waters. However, Kenworthy, et al. (1990) have questioned this on the basis of their results.

Present information thus indicates that average minimum light levels between 10% and 20% of incident radiance are required for most species. Lower levels may be adequate for the three *Halophila* species. However, maximum irradiance levels occur for only a few hours in each day and solar radiation varies considerably annually. Light levels may also be influenced by clouds and other factors. Thus for annual or long-term survival, higher average levels of between 15% and 30% of incident irradiance may be required. The duration of time for which seagrass plants can exist on stored food reserves in the absence of required light levels is not yet clear. Geographic differences may also exist within species. This information is still lacking.

Once the necessary light levels for survival and acceptable growth levels are known for seagrasses, the next step in seagrass management is to ensure that this level is made available to the seagrasses. Light attenuation may be caused by many factors. In the Indian River Lagoon complex, water color may be an important factor due to the dark color imparted by large amounts of tannins and organic acids contributed by organic detritus in the streams and swamps of the region (Kenworthy, 1993). White (1993) has reported that large areas of seagrasses were killed in the north end of Indian River Lagoon as a result of discharge of a great volume of turbid and highly colored water from Turnbull Creek in late summer of 1991. Light penetration was greatly reduced for 20 to 60 days during this time, and most grasses disappeared. While it is possible that other factors such as salinity changes may have contributed to this die-back, the lack of light is the most probable cause. It was not determined whether mortality was less among those species with greater food reserves in underground parts or whether different species had different recolonization rates following the disturbance.

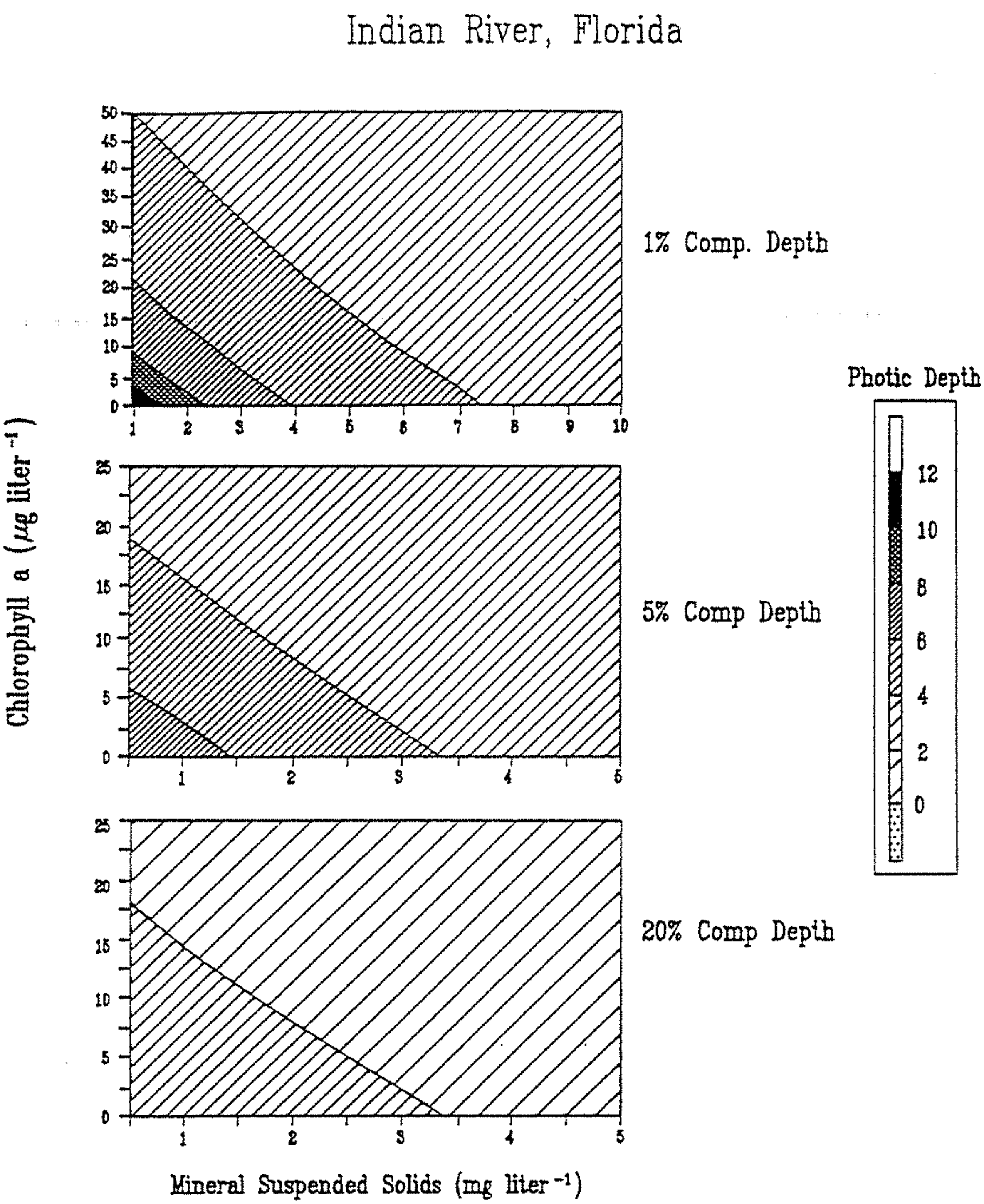
Another major factor affecting clarity is turbidity. Suspended particles in the water cause light to be scattered or absorbed. Thompson, et al. (1979) studied light scattering in Ft.

Pierce Inlet and concluded that particulate rather than dissolved substances were the major constituents affecting short wavelength energy in this system. Gallegos, et al. (1990) indicate that the suspended solids in the Indian River Lagoon have lower optical scattering cross sections than rivers in the Chesapeake basin, and that consequently light attenuation in the Indian River Lagoon complex may be less at a given MSS or TSS concentration level than has been reported in other estuaries.

The third major factor is absorption of light by chlorophyll, with chlorophyll *a* usually controlling the degree of absorption. Chlorophyll *a* is present within the water column in the form of phytoplankton and also as epiphytic algae on the leaf blades of the seagrasses. Phytoplankton have been shown to have I_C levels as low as 1% of surface irradiance (Dennison, 1987). Thus the suspended algae serve as an effective light resources competitor to the seagrasses. In Chesapeake Bay, a maximum annual average chlorophyll *a* limit of 15 micrograms (μg) per liter (L^{-1}) t as a habitat requirement for long-term seagrass survival (Funderburk, et al., 1991). In most parts of the Indian River Lagoon complex, the average annual chlorophyll *a* level is still below this limit for much of the time (see Water and Sediment Quality Technical Report) and does not pose a problem as it has within Tampa Bay, where annual average chlorophyll *a* levels up to 40 μg/L have been reported (Tomasko, 1992). However, the effect of water column chlorophyll *a* on water clarity and thereby on seagrass viability also is dependent upon the amount of color and turbidity present. Lesser amounts of chlorophyll *a* could result in depletion of light below desired levels given the presence of other attenuating materials.

Gallegos, et al. (1990) have developed a means for estimating the photic zone depths for Indian River Lagoon based on varied combinations of chlorophyll *a* and suspended sediments (Figure 4-10). Currently, this is only an untested model, but the concept may be useful in targeting what levels of chlorophyll *a* and suspended sediments should be set for the Lagoon and in examining which factor has the greatest influence on light attenuation and seagrass growth. Management could then be directed toward control of that parameter.

The K coefficient, or vertical attenuation coefficient, is the measure of the decrease in light from the water surface. The irradiance at the water surface is known as the I_o value (McPherson and Miller (1993). High K values mean that light decreases at a rapid rate. The K value, or rate of light loss, can be estimated to some degree from Secchi disk depth



Date Source: Gallegos, etal (1993)

Use of Model for Predicting Maximum Depth of Seagrass Growth

1) Determine photosynthetic compensation level of grasses (% of incident light) and use appropriate compensation depth chart (e.g., 1%, 5%, 20%)

2) Find existing chlorophyll *a* and MSS concentrations in the water column, and use appropriate depth chart to identify photic depth (by shading pattern).

3) Go to photic depth box on right to determine depth of seagrass growth

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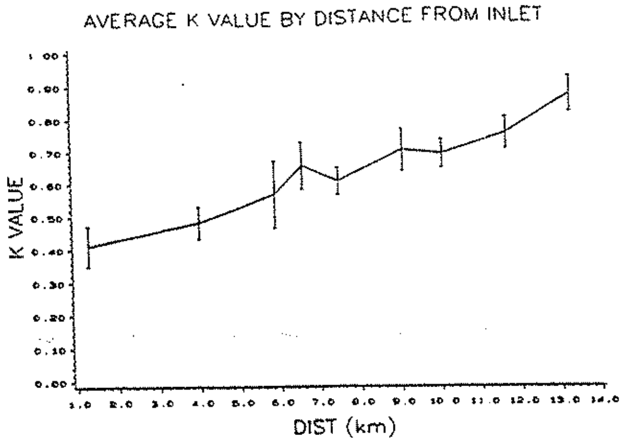
data, using equations for conversion that have largely been based on effects of scattering of light by suspended particles. However, this relationship is also dependent upon the relative effects of chlorophyll *a* and color. Secchi disk data collection from the Indian River Lagoon complex has been sporadic and inconsistent. In addition, many sampling stations appear to have depths less than the Secchi depth, making the readings from these stations inaccurate (see Water and Sediment Quality Technical Report). Because of these questionable values, the use of the existing Secchi disk database for determination of the K values for the Lagoon is of little value.

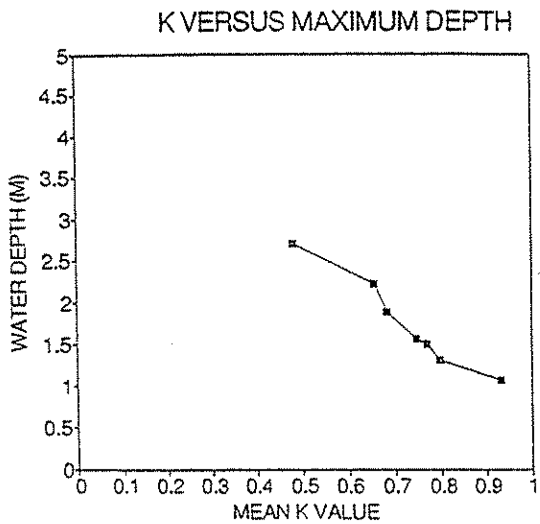
The best means of establishing irradiance level standards for seagrass survival in Indian River Lagoon would be direct measure of PAR. However, data has been collected in the Lagoon for this parameter for only a short time. A detailed study has been initiated by Harbor Branch Oceanographic Institution in late 1993 to monitor the PAR levels at target depths to determine what levels may be required for seagrass survival. This will require determination of a light attenuation coefficient, K, that will be applicable for the Lagoon. Information comparing levels at Jupiter Inlet and Hobe Sound (Kenworthy, 1993) indicates that different K values may occur throughout the Lagoon, and that different standards may be to be set for different areas. Figure 4-11a shows that the K values found by Kenworthy decrease from 0.89 to 0.42 with increasing distance from Jupiter Inlet, indicating a reduced light penetration in the area removed from the inlet's influence. Figure 4-11b shows Kenworthy's determination of seagrass K value limits for the Hobe Sound area (Kenworthy, 1993). This work, which provides the first data on K values for the Indian River Lagoon complex, indicates that seagrass maximum depth limits decrease from about 9.0 ft (2.7 m) where the K value is 0.42 (good light penetration) to about 2.7 ft (0.8 m) where a high (0.89) K value (poor light penetration) occurs. Kenworthy's reported depth of maximum occurrence were greater than the reported deep edge of the grass bed (Figure 4-11c) at similar K values reported for Sarasota Bay (Tomasko, 1993).

4.1.3.3 Epiphytic Algae and Drift Algae

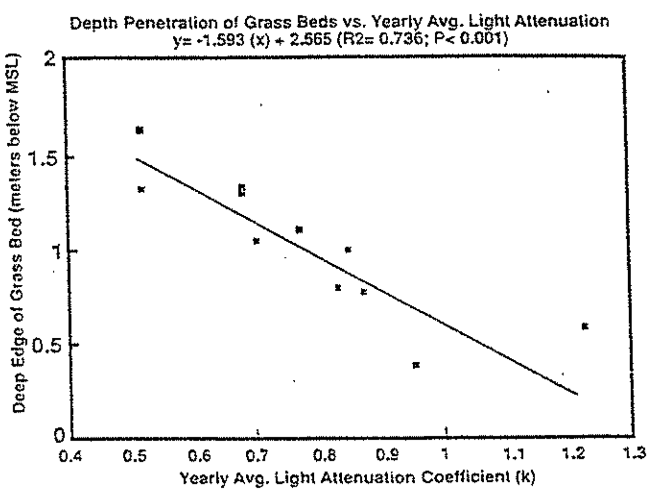
Even if the light attenuation factors and the light requirements of seagrasses are known, one other factor may influence survival and depth tolerance. This is the effect of shading of leaves by epiphytic (attached to seagrass leaves) algae, by macroalgae attached to the bottom,



a) Reduction in light penetration (= higher K Value) with increasing distance from Jupiter Inlet north through Hobe Sound (from Kenworthy, 1993).



b) Maximum depth of seagrass growth in Hobe Sound as a function of the light attenuation rate K (from Kenworthy, 1993).



c) Maximum depth of seagrass bed occurrence in Sararsota Bay as a function of the light attenuation rate K (from Tomasko, 1993).

• Woodward–Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysts	DRAWING NO.: DATE:	FIGURE 4-11	EXAMPLES OF LIGHT ATTENUATION AND EFFECT ON SEAGRASS DEPTH IN INDIAN RIVER LAGOON AND SARASOTA BAY

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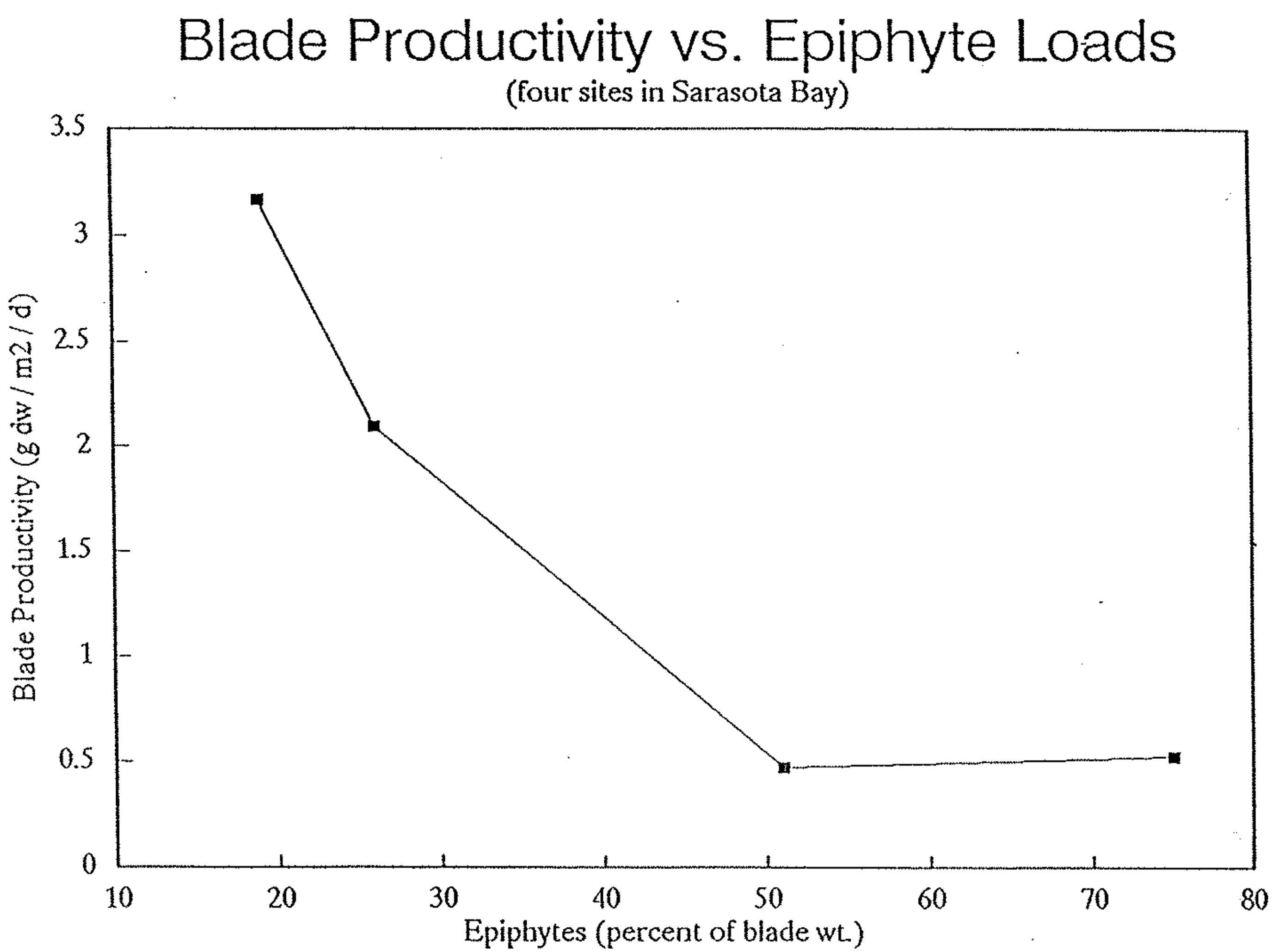
and by unattached and drifting algae. Both attached and drift macroalgae have been reported in the Lagoon as having up to 100% cover in areas with depths suitable for seagrasses. These algae may be excluding seagrasses by shading. Epiphytic algae may cover as much as 85% of seagrass leaf blade surfaces (White, 1986; Natural Systems Analysts, 1993). Tomasko and LaPointe (1991) have shown that the epiphytic algae may have a biomass that is almost as great as that of the leaf blades on which it lives, and that the amount of epiphytic growth is closely correlated with nutrient levels of the water column. Epiphyte cover has been associated (Tomasko, 1993) with up to 85% decrease in seagrass productivity in Sarasota Bay (Figure 4-12).

4.1.3.4 Substrate

As seen in Table 4-1, most of the seagrasses appear to tolerate a wide range of substrate conditions. Therefore substrate does not appear to be a major determinant of distribution or survival in the Lagoon. All seagrasses seem to grow on sandy or silty muds and on sands with some mud content (Reid, 1954; Thorne, 1954; Voss and Voss, 1955; Phillips, 1960). Hoskin (1983), in a study at Link Port near Vero Beach, found that the silt fraction in the sands underlying a turtle grass bed was higher than that in nearby unvegetated beds. Other studies (Wanless, 1981; Scoffin, 1970) have shown that the silt and clay fractions were also higher (14.6%) in dense beds than in open areas (2.3%).

All of the grasses appear to prefer some mud in the substrate. However, Phillips (1960) has commented that the substrate elevation in open patches in beds is often a few inches lower than among the grasses, indicating a build-up of sediment in the beds caused by the reduction of currents from the "baffling" effect of the seagrass leaves themselves. Thus the presence of mud or fine particles may be a result of the presence of the grasses rather than a prerequisite for establishment (Hoskin, 1983).

The sands of the Indian River Lagoon are generally composed of coarser sands than normally found further south and on the Gulf coast. Phillips (1960) has noted that turtle grass density decreases from Miami to the southern end of the Lagoon as the percentage of muds and silts decreases. He also mentioned that shoal grass is uncommon on hard packed fine sand, whereas turtle grass grows well on this substrate, and has proposed these possible substrate



Source: Tomasko (1993)

• Woodward-Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysis	DRAWING NO.: DATE:	FIGURE 4-12 AREAL BLADE PRODUCTIVITY OF TURTLE GRASS VERSUS LEAF BLADE EPIPHYTE LOADS

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preference differences as a reason for the limitation of turtle grass to the southern end of the Lagoon.

4.1.3.5 Nutrient Levels

Nitrogen (N) and phosphorus (P), whether in the substrate or the water column, are the nutrients which most affect seagrass growth. The effect of nutrients within the water column is generally indirect. These concentrations affect the concentration of phytoplankton and epiphyton, which in turn may control seagrass growth through shading as discussed previously.

Although light intensity apparently controls depth penetration of seagrasses, substrate nutrient availability has also been found to limit growth (Duarte, 1991; Dennison and Alberte, 1986). Nitrogen has generally been considered to be the more limiting nutrient in marine and estuary systems, while phosphorus has generally been found to be limiting for freshwater SAV (Murray, et al., 1992). Several recent studies have indicated that P may be more limiting in estuarine systems than previously thought. Short, et al. (1990) was able to stimulate manatee grass growth by 100% to 1,000% and turtle grass growth by 80% to 100% by the addition of phosphorus to the substrate. Murray, et al. (1992) also found that addition of P or of combined N and P stimulated growth of seagrasses, but that N addition alone had little effect.

Most information concerning marine P limitation has come from areas with carbonate substrates. Short, et al. (1985) state that the difference in nutrient cycling between these carbonate substrates and terrigenous sediments (muds and silts washed from the adjacent land) is due to the fact that P is more tightly bound to the substrate in the carbonate environment and is less available for plant uptake. Nitrogen appears to be more readily cycled and is usually present as NH_4 in the pore water of the substrates. This may explain why P appears more limiting in carbonate marine systems. Application of this information to the Indian River Lagoon complex might indicate greater P limitation in the southern part of the complex and along the coquina rock outcrops from Melbourne to Rockledge where carbonate substrates may be more common, and greater N limitation in the northern region and areas with more terrigenous muds in the substrate.

The ratio of N:P in seagrass tissues appears to be a relatively good means of determining whether N or P is most limiting. Comparison of this ratio to that of the water column or the substrate pore water may indicate which element is limiting at any time or place. However, normal levels for these ratios or for the level at which one nutrient becomes limiting have not been determined for seagrasses in the Indian River Lagoon. Thus the nutritional status of seagrasses in the Lagoon has not yet been well defined.

4.1.3.6 Salinity

Salinity may play a role in the distribution and survival of seagrasses in the Indian River Lagoon complex, since literature sources suggest differential response to salinities among species. Turtle grass appears to have the highest salinity tolerance and the highest optimum range. It has been reported as thriving in beds where salinities have ranged from 28 ppt to 48 ppt in the Keys and south Florida (Taylor, 1928). Phillips (1960) found a strong relationship between dominance by turtle grass and salinities of 28 ppt or higher in Tampa Bay. He reported that this species was much less prevalent in the upper parts of Old Tampa Bay where salinities ranged from 17 to 24 ppt. Turtle grass has been found in Crystal River on the Gulf coast where the usual salinity varied between 16 and 19 ppt, but growth was limited. Phillips reported that the range from 28 to 35 ppt is probably optimum for turtle grass and that 24 ppt is the probable lower limit for normal growth.

Shoal grass appears to be more tolerant of the wider range of salinities occurring in the Indian River Lagoon. In Florida Bay and the Keys, dense growth has been reported in the range between 24 and 38 ppt (Taylor, 1928; Phillips, 1960). Sparse to dense coverage has been reported in the St. Lucie River and Tampa Bay at salinities between 12 and 24 ppt, with 17 ppt the approximate lower limit for dense beds (Phillips, 1960). Although generally not restricted by the range of normally occurring salinities in the Indian River Lagoon, a large freshwater inflow from Lake Okeechobee was reported to have resulted in complete die-off (Phillips, 1960).

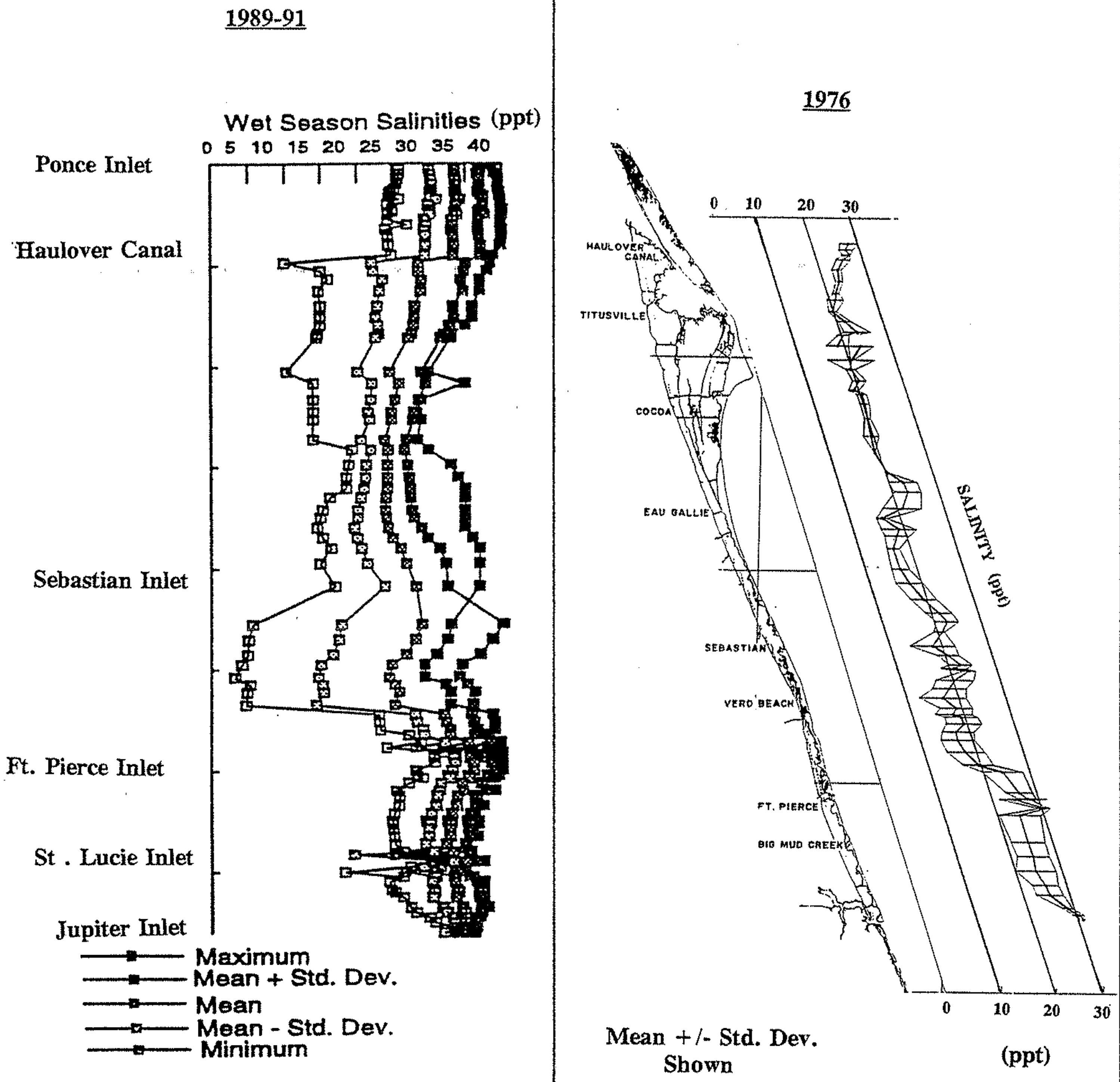
Dense beds of manatee grass have been reported in areas with 22 to 35 ppt salinity between St. Lucie and Sebastian Inlets (Phillips, 1960) and in central Brevard County (Woodburn and Ingle (1959). Dense growth has also been reported in Tampa Bay at salinities between 20 and 36 ppt, with survival down to 10 ppt. An optimum range for this species is probably between 23 and 30 ppt, although it tolerates a much wider range.

Widgeon grass has been reported in salinities from freshwater (1 ppt) to 32 ppt (Funderburk, et al., 1991; Phillips, 1960). In most instances it appears to be restricted to salinities below 25 ppt. This is probably due to an inability to effectively compete with the other species that are restricted to the higher salinities.

Little information is available for the species of *Halophila*. Paddle grass and star grass have been reported as occurring in salinities between 24 and 31 ppt and between 24 ppt and 38 ppt respectively. However, there is insufficient information to establish ranges for survival or optimum conditions.

To some extent, it seems that salinity may affect species distribution and dominance patterns of seagrasses in the Lagoon. Phillips (1960) has observed that shoal grass does not appear to be restricted by salinity within the ranges commonly found in Indian River Lagoon. It usually appears to be restricted by the degree of growth and competition from turtle grass, widgeon grass, and manatee grass, all of which have somewhat more specific salinity requirements.

In addition, salinity data from Indian River Lagoon during the 1989-1991 period (refer to Water and Sediment Quality Technical Report) indicates that salinity values remained high, consistently above 25 ppt, in the South and South Central segments (Segments 3 and 4) generally as far north as Sebastian Inlet (Figure 4-13). However, between Sebastian Inlet and the north end of the Lagoon, salinity values generally were substantially lower and showed more extreme fluctuations among stations and among dates. Consistently high salinity values were not encountered again until in the North Indian River Lagoon Segment (1C), generally north of Titusville. Data collected by Harbor Branch Oceanographic Institution (Young and Young, 1977) indicated a similar trend in 1976 with perhaps even lower overall salinities. Thus the northernmost limit of turtle grass appears to coincide fairly well with a zone of decreasing salinity in the Lagoon, and may indicate a possible factor limiting the northward distribution of this species.



Source: 1989-91 data from SJRWMD, 1993.
1976 data from Young and Young, 1977.

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FIGURE 4-13 RECENT AND HISTORIC SALINITY PROFILES OF THE INDIAN RIVER LAGOON

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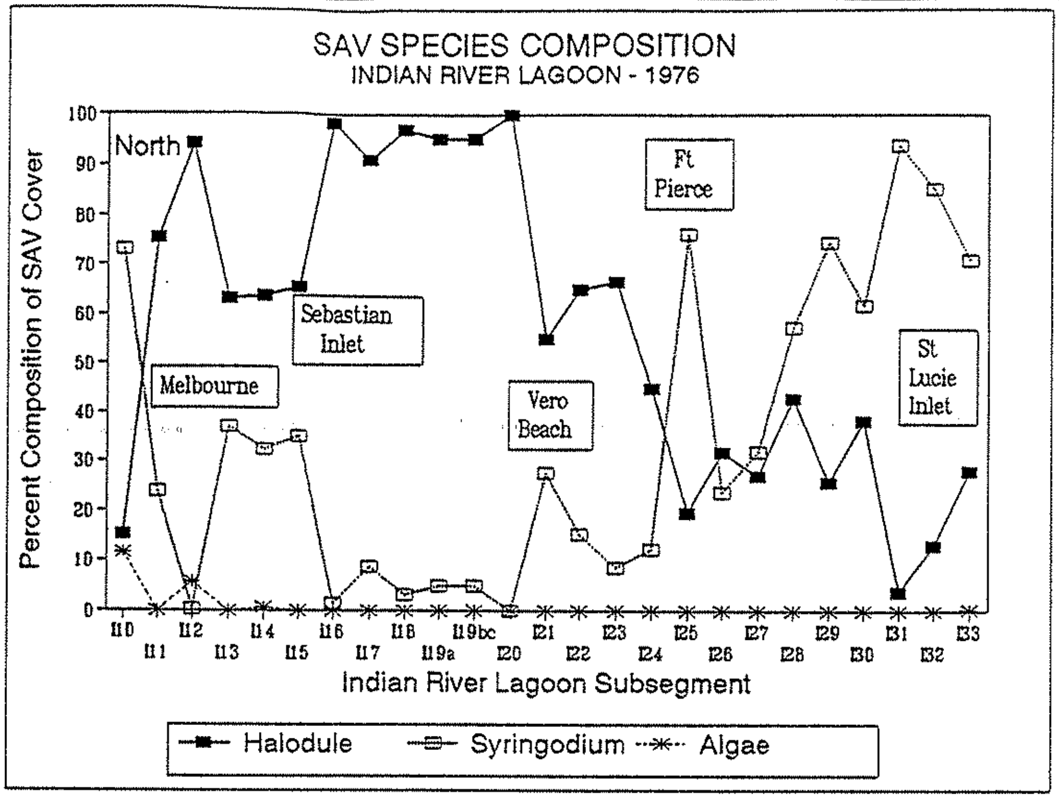
Thompson (1976, 1978) identified a decline in the overall seagrass density in the Vero Beach area, along with an even greater decline in the relative cover of manatee grass between Ft. Pierce Inlet and Merritt Island (Figure 4-14). He suggested that the decline was caused by lowered salinities in this portion due to the influence of the three major drainage canals in the Vero Beach area.

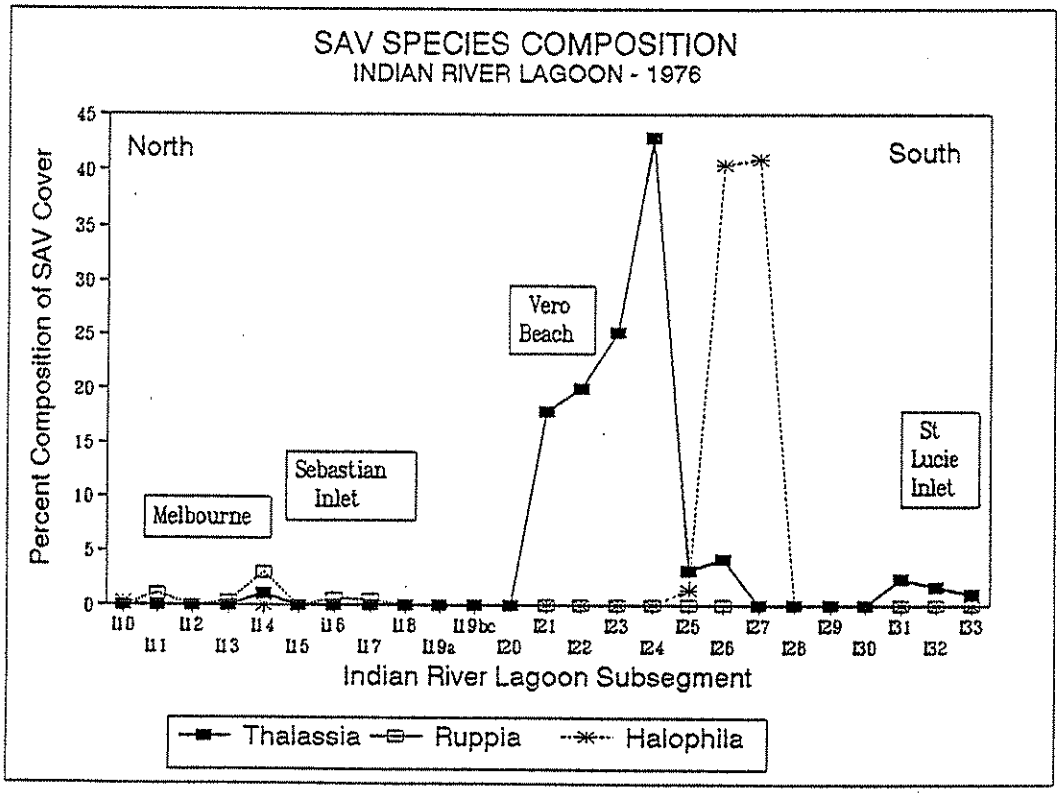
4.1.3.7 Temperature

Turtle grass extends no farther north than the Sebastian Inlet area on the east coast of Florida, although it extends along the entire northern Gulf coast and as far north as Bermuda in the Atlantic. Average temperatures along the northern Gulf coast are generally lower than within Indian River Lagoon, so temperature does not appear to be a limiting factor. However, incidences of extreme temperatures such as frosts could have affected seagrasses in this region. Phillips (1960) has reported a probable temperature range of 64 to 104°F (18 to 39°C) with peak growth around 66 to 86°F (22 to 30°C) for turtle grass (Table 4-1).

Shoal grass extends along the coast as far north as North Carolina. Phillips has reported it to be susceptible to frost, but tolerant of temperatures as high as 104°F (39°C) (Table 4-1). Manatee grass has a somewhat narrower temperature tolerance and appears to be less tolerant of high temperatures than the two preceding species. However, it generally is less exposed to high temperature extremes because of the greater depth at which it often grows. Phillips (1960) has reported that it begins to die back when water temperatures drop to 68°F (20°C) and that temperatures of 58 to 62°F (12 to 16°C) can be killing to all above-ground parts. When seasonal temperature rises above about 68 to 72°F (20 to 22°C), growth resumes in spring.

Gilbert and Clark (1981) felt that the northern distribution limit of manatee grass in Mosquito Lagoon and persistent patchiness in beds in northern Indian River Lagoon and Mosquito Lagoon was due to temperature limitations shown on Table 4-1. They postulated that the annual production is just equalled by dieback in this area, and that no additional food reserves are available to support sexual reproduction (which has not been observed in this species in this area). Without abundant seed production, this species may be incapable of readily filling in bare patches as it does farther south in the Lagoon.





Source: Thompson (1978)

• Woodward-Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysts	DRAWING NO.: DATE:	FIGURE 4-14 RELATIVE ABUNDANCE OF SAV SPECIES INDIAN RIVER LAGOON FROM MELBOURNE TO ST. LUCIE INLET

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Widgeon grass is the most northerly extending species of the Indian River Lagoon, reported as far north as Maine. Survival and growth has been reported at temperatures as low as 45°F (7°C). It has also survived at temperatures as high as 104°F (39°C). Temperatures between 68 and 82°F (20 and 25°C) are most conducive to growth, while temperatures from 76 to 85°F (23 to 29°C) have been reported as prime for flowering. Widgeon grass may invade beds of shoal grass in cold weather, and is often dominant in low salinities and low temperatures.

Not enough information is known about the temperature ranges for the species of *Halophila* to predict temperature extremes or optimum temperatures.

4.1.4 Associated Species and Communities

SAV beds contain a high diversity of communities, structural groups, and species. Some of the main communities are the macroalgae, epiphytic plants and animals, benthic invertebrate animals, bacteria, and fishes. The fish community is described in another section as a part of the overall fish community of the Lagoon. Some organisms may belong to more than one community. Examples of these are the gastropods and amphipods which may be found in both benthic and epiphytic locations within seagrass beds.

4.1.4.1 Macroalgae

Few of the seagrass bed areas in the Indian River Lagoon complex are composed solely of seagrasses. Most contain at least some mixture of seagrasses and macroalgae. The macroalgae community of the Indian River Lagoon complex contains both attached species and free-floating or "drift" algae and is apparently very diverse. The recent seagrass mapping studies (White, 1986; Virnstein and Cairns, 1986; Natural Systems Analysts, 1993) have all indicated that the algal biomass in the complex may be as great or greater than that of the seagrasses.

Drift Algae

Drift algae are a large component of the macroalgal community. The primary genera of drift algae in the Lagoon include *Gracilaria*, *Spyridia*, *Acanthophora*, *Hypnea*, and *Dictyota*

(Virnstein and Carbonara, 1985). Benz, et al. (1979) have identified a total of 63 species of drift algae in Indian River Lagoon, with the dominant species being *Acanthophora spicifera*, *Chondria tenuissima*, *Dictyota dichotoma*, *Hypnea cervicornis*, and *H. musciformis*. Many of the drift algae species are originally attached to substrates, but can survive and flourish when detached by storms or other factors.

White (1986) reported little drift algae in Banana River or the northern Indian River Lagoon, although *Gracilaria* spp. was present in abundance in deeper zones of the Indian River from Brewer Memorial Causeway (SR 408) at Titusville to near the Melbourne Causeway (SR 500) at Melbourne. Substantial amounts of drift algae were encountered during the 1992 seagrass mapping study in the Indian River Lagoon between Titusville and Melbourne and from north of Sebastian River to Ft. Pierce (Natural Systems Analysts, 1993).

Thompson (1976) reported the persistence of dense masses of drift algae in certain areas near John's Island 4 miles north of Vero Beach. Thompson also located similar features on 1945 and 1954 aerial photos in these areas. Observations of concentrations in this area in 1992 (Fletcher, 1993) tend to confirm Thompson's observations that the drift algae community has been a significant feature for at least the last 40 years and that algae tends to concentrate in certain areas, probably in response to circulation patterns and bottom topography. Numerous residents of the west shore area can attest that mats of drift algae consistently amass along their shore and decompose in summer months, producing very noticeable odors.

Attached Algae

Attached algae have not generally been recognized as significant resources in the Lagoon, yet beds of attached algae may in some places comprise the largest component of macroalgae. The attached algae may grow in water as shallow as 0.3 ft (0.1 m) if suitable substrates are available for holdfast attachments. In these areas they may compete with seagrasses for light, nutrients, and other resources. Algae have also been found to be capable of thriving in depths much greater than those required by seagrasses (Gilbert, 1976) (Figure 4-6). They have been reported in channels in the deepest parts of the Lagoon complex (Down, 1978).

The attached species which has been most documented in the Lagoon is *Caulerpa prolifera* which has short ribbon-like leaves similar to those of the *Halophila* seagrasses. This species appears to spread by underground rhizomes, and can spread rapidly in sandy substrates without the need for rocky substrates. Most other species of attached algae require a hard substrate for attachment. It is possible that the human-caused proliferation of hard substrate materials throughout the Lagoon may have allowed recent increases of other species. Materials such as rocks used for shoreline stabilization, fish traps, and pipes and pipe seals from dredging operations may be suitable hard substrates for colonization.

Caulerpa prolifera was not mentioned as a significant component of the SAV community by either Thompson (1976) or Down (1978), nor was it found to be abundant by Jensen and Clark (1983) in the period prior to 1983. However, it was found to be very abundant, covering much of the sand bottoms throughout Banana River and much of the northern third of the Indian River Lagoon in 1986 (White, 1986; Virnstein and Cairns, 1986; Virnstein, 1987). White reported it as the principal benthic plant species in Banana River in 1986, with cover values between 40% and 100% in much of Banana River and Newfound Harbor. White and Snodgrass (1990) reported that, by 1987, *Caulerpa prolifera* had disappeared from the Indian River north of Cocoa and drastic reductions had occurred in the Banana River. White and Snodgrass (1990) speculated that the loss may have been related to an increase in the population of algae-eating sea slugs (*Elysia* sp.) in the northern Indian River Lagoon at this time. *Caulerpa prolifera* was found only occasionally in the Lagoon complex during the 1992 SAV mapping (Natural Systems Analysts, 1993), with the greatest abundance occurring in Banana River and Newfound Harbor.

Down (1978) did find other species of attached algae, including *Gracilaria blodgetii*, *G. verrucosa*, and *Hypnea cornuta* to be very abundant in the Banana River and Sykes Creek in 1978. Down implied that these beds comprised a majority of the SAV beds in the Banana River. However, at approximately the same time, Thompson (1976) reported that attached algal beds accounted for only 0.8% of the SAV beds between Merritt Island and St. Lucie Inlet. Numerous genera, including *Dictyota*, *Gracilaria*, *Hypnea*, *Codium*, *Chaetomorpha*, and *Eucheuma* also were noted in the 1992 surveys, with the largest concentrations found in the Banana River, in Mosquito Lagoon, and in the Indian River Lagoon north of Titusville, between Grant and Sebastian Inlet, and along Sewalls Point in Martin County (Fletcher, 1993).

Macroalgae Ecological Functions

The ecological functions of macroalgae in the Lagoon are poorly understood. If standing biomass is any indication, they may have primary productivity rivaling that of the seagrasses (Heffernan and Gibson, 1983; Rice, et al., 1983; Fry, 1984; Virnstein and Carbonara, 1985). Jensen and Gibson (1986) have described net productivity of benthic macroalgae as high as 1.3×10^{-2} oz ft^{-2} (40 mg m^{-2}) of C hr^{-1}, about half that of seagrasses or seagrass epiphytes. However, the persistence and abundance over time may vary in as yet undetermined amounts as illustrated by the changes in *Caulerpa prolifera* abundance described above. Macroalgae have also been suggested as important mechanisms in the regulation of nutrient levels (Davis, et al., 1983). Movement of drift algae may provide a means of nutrient and organic matter transport and cycling in the Lagoon, but the significance of this has not been studied.

White and Snodgrass (1988) indicate that macroinvertebrate abundance is high in *Caulerpa prolifera* beds, but that the beds support a less abundant fish community than shoal grass beds. Several studies have indicated higher densities and/or diversities of macroinvertebrates and some species of fish when macroalgae are mixed with seagrasses than in seagrass or algae alone (Virnstein, et al., 1983; Eiseman and Benz, 1975). However, the reasons for this are as yet undetermined. It may be due to increased food sources, increased protection from predation, or other causes.

In an anecdotal sense, the areas of higher algal abundance appear to be areas of higher salinities associated with inlets or with areas where the evaporation to inflow ratio is above average. However, there have been no studies to produce data for this observation.

Macroalgae may compete with seagrasses for nutrient and other resources and have been suspected to cause seagrass declines in some areas due to shading effects and ability to outcompete seagrasses under low light conditions. This concept would tend to indicate that reductions in water clarity and light transmittal would result in a shift from seagrass beds to algal beds within the Lagoon. The large algal beds and drift packs that have been noted in recent years have produced some indication that this is indeed happening, but no definitive studies have addressed this question.

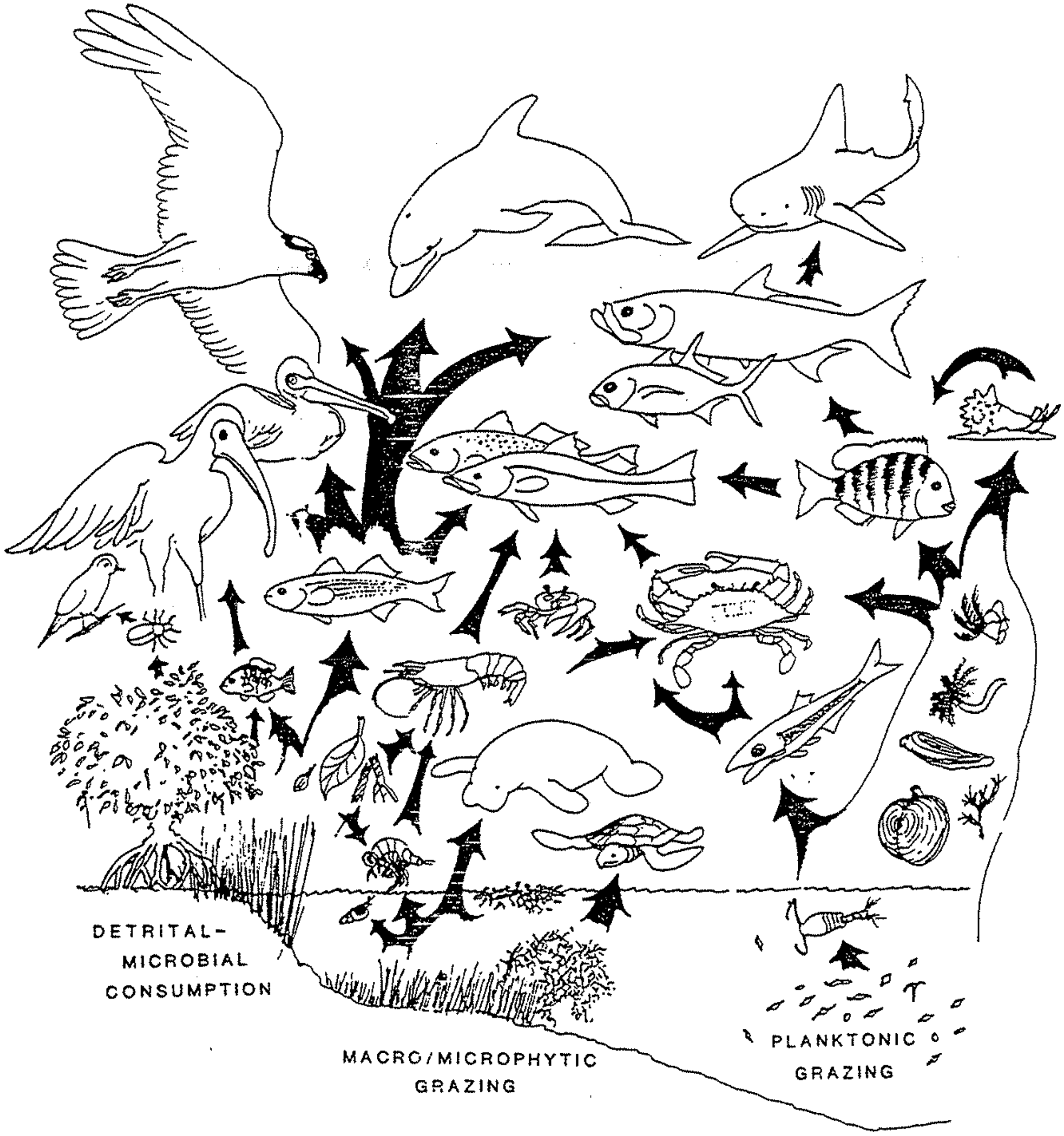
4.1.4.2 Epiphytes

Epiphytic (epi = upon; phyte = plant) periphyton are tiny rootless algal plant species that occur on substrates such as rocks or the leaves of other plants like seagrasses. Bacteria may also be significant members of the epiphyte community. Hall and Eiseman (1981) recorded 41 species of epiphytic algae on seagrasses in Indian River Lagoon. Major groups of epiphytes within the Lagoon include diatoms and filamentous green algae such as *Enteromorpha* and red algae. While individual plants may be small, the masses can cover the entire surface of seagrass leaves with a thickness up to 0.2 cm (Hall and Eiseman, 1981). Jensen and Gibsen (1986) have indicated that the range of epiphyte net productivity rates in seagrass beds of the Indian River Lagoon is similar to that of the seagrasses themselves. Fry (1984) found that the epiphyte productivity may be greater than that of manatee grass, with potentially greater carbon export to the Lagoon food web.

Epifauna are the small animal species which live on the seagrass leaves and eat the epiphytic periphyton, the leaves, or each other. Epifauna form an important link in transferring the energy produced by these plants to the higher consumers in the Lagoon food web (Figure 4-15). Major groups of epifauna include gastropods (snails) and crustaceans (amphipods, copepods, shrimp). These animals move along the leaf blades "grazing" on the epiphytic plants and bacteria. In other systems, it has been found that the epifauna may consume between 60% and 70% of the net productivity of the periphyton (Klumpp, et al., 1989; 1992).

4.1.4.3 Benthos and Invertebrate Fauna

The benthic community associated with seagrass beds has been well studied within the Lagoon. However, many of the studies are very specific to locations or to factors such as anatomy or taxonomy and are not well-suited to presenting an overview of the conditions of the Lagoon or describing trends or characteristics that can be extrapolated to other parts of the Lagoon. The known information on seagrass macroinvertebrate communities has been rather thoroughly summarized by Virnstein and Campbell (1987). A sampling of the reports on the seagrass invertebrate community includes Gore, 1972; Gore, et al., 1975, 1976, 1981; Grizzle, 1974, 1979b; Young, 1975; Young and Young, 1974, 1977, 1978; Young, et al.,



Source: From Marine Resource Council (Barile, 1984)

• Woodward–Clyde Consultants • Marshall McCully & Associates • Natural Systems Analysts	DRAWING NO.: DATE:	FIGURE 4-15 DIAGRAMMATIC REPRESENTATION OF THE THREE BASIC FOOD WEBS OF THE INDIAN RIVER LAGOON

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1974, 1976; Zimmerman, et al., 1979; Nelson, et al., 1982; Reish and Hallisey, 1983; Stoner, 1980, 1983b; Howard and Short, 1986; Virnstein, 1987; and Virnstein, et al., 1983). Virnstein and Campbell (1987) report that close to 700 species of benthic invertebrate species have been reported in the Lagoon. Benthic species can generally be split into two groups - the epifauna which includes species living on top of the substrate, and the infauna which comprises the species living underneath the surface.

Much of the research on invertebrate communities associated with the seagrass habitat has centered on the infaunal and epifaunal amphipod crustaceans, which appear to be one of the most significant components associated with the seagrass habitat (Young and Young, 1977; Nelson, 1980, 1981; Nelson, et al., 1982, Virnstein, et al., 1984). Studies by Young and Young (1977) and by Nelson, et al. (1982) have indicated little relationship of species number and diversity to latitudinal gradients in the Lagoon, and Virnstein, et al. (1984) reported an abnormally low number of amphipod species compared to that expected from this latitude. Young, et al. (1976) found that total abundance decreased from stations near Haulover Canal (1,331 organisms per square ft) and Banana River in the north to 373 ft^2 at St. Lucie Inlet, while Virnstein, et al. (1984) found little latitudinal variation in density or biomass. The most common species of amphipods that have been described for the Indian River Lagoon include *Grandidierella bonnieroides* and *Cymadusa compta* throughout the Lagoon complex; *Ampelisca abdita*, *Corophium lacustre*, and *C. ellisi* in the northern portion of the complex; and *Ampithoe longimana* in the southern portion (Nelson, et al., 1982).

Various explanations for the patterns of amphipod occurrence have been proposed, although there is still much that is unknown about the ecology of the seagrass associated epifauna. There appears to be some positive degree of relation between amphipod diversity and seagrass biomass (Virnstein, et al., 1984) and negative relation between abundance and proximity to inlets (Nelson, et al., 1982). Abundance of food source (primarily epiphytes) and susceptibility to predation by larger organisms appear to be the most widely discussed explanations for density and diversity patterns. Amphipods are known to be a prime food of the pinfish (*Lagodon rhomboides*) which often is the most abundant fish in the seagrass habitat (Stoner, 1980, 1983a).

Seasonal decreases of amphipods in seagrass beds have been found to occur in the summer from June through October in inverse relation to seagrass and epiphyte biomass. Pinfish abundance has been found to peak in spring and summer, possibly explaining some of the amphipod density patterns (Jones, et al., 1976; Nelson, et al., 1982). Pinfish are also more abundant in the vicinity of the inlets where amphipod abundance is lower (Jones, et al., 1976; Virnstein, et al., 1984).

Decapod (crabs and shrimp) and gastropod (snails) crustaceans are important components of the seagrass epifaunal invertebrate community. Blue crabs, penaeid shrimp, and hermit crabs are also common inhabitants of seagrass meadows, as well as several gastropods including the Atlantic modulus (*Modulus modulus*) and horn snails (*Cerithium* spp.). Although polychaete worms comprise the largest component of the Indian River Lagoon complex infaunal benthic community as a whole, they are probably not as closely tied to the seagrass habitat as epifaunal types because the difference in substrate types is not necessarily great between seagrass sites and non-seagrass open bottom habitats. Most polychaetes are infaunal species that occur in similar densities in the similar substrates regardless of the presence of seagrass cover.

4.1.4.4 Fish, Marine Mammals, and Sea Turtles

Seagrass beds support some of the most abundant fish populations in the Lagoon, with a large species diversity. Pinfish and several species of mojarra are very abundant in the seagrass habitat. These species are known to feed on seagrasses and on the epiphytes and epifauna of the seagrasses, providing a critical link in the food chain between the primary producers and the higher level consumbers such as the common snook and spotted seatrout. The fish community is described in more detail in Section 5.0.

The seagrass habitat is also a critical resource for the Florida manatee. This marine mammal depends on seagrasses for a major part of its food supply (Layne, 1978; Van Meter, 1989; Provancha and Hall, 1992). It has been reported that manatee grazing may result in up to a 68% decrease in seagrass biomass (Virnstein, 1987; Provancha and Hall, 1991a), illustrating the importance of seagrasses as manatee forage. Juvenile sea turtles have also been documented as foraging on turtle grass and other seagrasses in the Indian River Lagoon (Mendonca, 1981; Mendonca and Ehrhart, 1982).

4.1.5 Community Status

Changes in the extent and distribution of SAV beds and resources have been evaluated in more detail in a companion volume (Historical Imagery Technical Report). It appears that in many areas of the Indian River Lagoon complex, SAV beds have been and currently are relatively stable in terms of extent of coverage and species composition, although trends in biomass have not been evaluated adequately.

Decreases in areal extent of seagrass coverage have, however, been documented or observed in several areas. The main areas of such change have been along the east shore of the Indian River Lagoon between NASA Causeway and Bennett Causeway (SR 528) at Pine Island near Cocoa and the entire area between Cocoa and Grant (Segments 1C and 2) and in the Banana River between Bennett Causeway and Merritt Island Causeway (SR 520). Areas where suspected decreases have occurred but where an historical abundance of seagrasses has not been well documented include the Vero Beach area, the southern Banana River, the Indian River north of Titusville, and the Indian River from St. Lucie Inlet north to the Jensen Beach Causeway (SR 732).

Populations and areal coverage of drift and attached macroalgae appear to be increasing, although the extent has not been well documented (Virnstein, 1993; White, 1993: Fletcher, 1993). Attached algae beds appear to have constituted significant parts of the overall SAV coverage during certain time periods, particularly in the north Indian River Lagoon, in Banana River, and in the Indian River Lagoon between Wabasso and Grant (White, 1986; Fletcher, 1993). However, significant differences have occurred between years and the actual trends and causes are not known. *Caulerpa prolifera* has been shown to form extensive beds on sand substrates suitable for seagrasses, but its persistence and effects are not known (Virnstein and Cairns, 1986). Other attached algae appear to have increased in extent in recent years. These species may have possibly increased in response to increased availability of non-sandy substrate caused by placement of rip-rap and similar materials. Much of the attached algal beds may also be below the maximum potential depth of seagrass occurrence, causing the competitive effect to be slight. However, very little is known about these effects since they have not been studied extensively.

Several researchers have expressed concern about the possibility that the vertical distribution of seagrasses is becoming restricted due to reduced light penetration resulting from possible increases of total suspended solids, chlorophyll *a*, and other substances in the water column as a result of increased sediment and nutrient runoff from increasing agricultural and urban development. Overall in the Lagoon system, secchi disk readings have indicated that light penetration appears to be adequate to maintain the current maximum seagrass limits. However, the value of the secchi disk data is limited (see Water and Sediment Quality Assessment and Loadings Assessment Technical Reports) and may not be an adequate reflection of conditions. Analysis of seagrass depth limits over time (see Historical Imagery Technical Report) has indicated a trend of reduced depth penetration of seagrasses since 1943 in the South Central and North Central Segments (2 and 3) of the Indian River Lagoon. This data supports the suggestions that reduced light penetration may be reducing the extent of seagrasses in some portions of the system. Additional research is being initiated by Dr. Dennis Hanasak at Harbor Branch Oceanographic Institution on the status of PAR within the Lagoon, which should clarify this situation.

Other stresses on the health of the seagrass community include physical destruction of beds by boats and prop wash, effects of toxic contaminants, and loss of habitat from dredging and filling.

4.1.6 Future Trends

Future trends in seagrass abundance and health are not easy to predict. Overall, the Lagoon-wide acreage of seagrasses may not show significant consistent trends in the future, but changes in specific locations will probably occur. Localized changes may include increases in some areas such as around the inlets, and decreases in other areas. Decreases appear likely to continue in areas with large freshwater inflows, high turbidity, and high nutrient nutrient loading from adjacent drainages. Areas such as the Indian River Narrows near Vero Beach, the Banana River, and the Indian River Lagoon between Grant and Titusville appear to be have the greatest potential sensitivity to impacts and will probably experience the greatest declines if nutrient and sediment loads increase.

Much is unknown about the ecology and requirements of the seagrasses, attached algae, epiphytes, and phytoplankton in this system. The future status of these groups will be interconnected, based upon their differential responses to light dissipation, salinity, and nutrient conditions. Further research is needed before future trends can be adequately projected.

4.2 OPEN WATER COMMUNITIES

Included under this heading are the biotic communities that occur in the water column and those that occur on the substrate of the Lagoon outside of the seagrass and emergent wetland communities. In some cases such as the microorganisms, benthic macroinvertebrates, and fishes, members of the community can be found in both open water and vegetated habitats. Biotic communities that are present in the open water column of the Lagoon include the phytoplankton, zooplankton, and ichthyoplankton, and open water column fish communities.

These communities encompass representatives from all trophic levels ranging from photosynthetic and autotrophic primary producers such as the phytoplankton and bacteria, to top carnivores such as sharks and tarpon. These communities are very important to the balance and stability of the Lagoon ecosystem, and they are generally sensitive to changes in environmental factors such as temperature, salinity, and nutrient levels.

4.2.1 Microbes

The microbial community consists of microscopic organisms including bacteria and fungi. These may include the various commonly found naturally occurring forms which have important roles in the detrital food web. In addition, coliform bacteria are generally associated with digestive systems of higher organisms and may be introduced to the estuary through runoff or discharge from wastewater treatment plants. Fecal coliform bacteria normally are present only in minute amounts in the water column. In discharges from wastewater plants, their concentration may be many times higher. These bacteria are capable of causing illness in humans and can be transmitted through ingestion of raw seafood such as oysters or clams. Elevated levels of these bacteria can pose a public health hazard and their level is monitored by the FDNR (now FDEP). Elevated levels have been responsible for closure of shellfish harvesting areas and resultant economic losses.

4.2.1.1 Community Composition and Dynamics

Bacteria and fungi are important and necessary in their natural roles of decomposing organic material such as leaf litter that washes in from adjoining uplands and wetlands. Bacteria generally colonize these materials first, followed by fungi and algae (Livingston, 1981). The microbes are then eaten by zooplankton such as amphipods, gastropods, and fish larvae, thus converting detrital material into a base of the lagoonal food web.

4.2.1.2 Functional Role and Physiological Responses

The microbial community is particularly important in the carbon and nitrogen cycling processes in the Lagoon, converting complex carbohydrates such as cellulose into simple carbon compounds and particulate organic carbon (POC) that can be readily assimilated by other organisms. They also convert nitrogen compounds into forms which are more readily utilized by other organisms. Bacteria within sediments assimilate nitrogen into amino acid and protein forms which can then be utilized by other fauna.

Bacteria may also be important in the chemistry of both iron and sulfate in the sediment/water interface in several habitats of the Lagoon, including salt marshes, mangrove forests, and seagrass beds as well as unvegetated open waters and mud flats. The role of bacteria is important in understanding the water chemistry and effects of discharges from mosquito impoundments (David, 1992).

4.2.2 Phytoplankton

The open water column habitat supports a diverse and important community of animal and plant organisms that are often too small to be seen by the naked eye. This community of single celled or simple colonial-celled forms is referred to as the plankton community. The plant portion of this community is the phytoplankton component and the animal portion is the zooplankton component. Most of the plant portion consists of single celled algae, which are non-flowering plants that reproduce by asexual methods. Although the phytoplankton may not be readily seen as individual organisms, their presence is often indicated by the green color that their chlorophyll imparts to the water column.

The phytoplankton community is a very important factor in the ecological health of an estuary. Phytoplankton form a key base of the food web (Figure 4-15) and a low density can limit fisheries resources. However, an overabundance of phytoplankton can lead to water chemistry imbalances and fish kills, and can decrease light penetration. The reduced light can reduce seagrass production and disrupt other parts of the food web and health of an estuary.

4.2.2.1 Community Composition and Dynamics

Phytoplankton are often characterized by the size of the plants. Nanoplankton is a term describing smaller cells which are too small to be retained by a fine-mesh net (generally 20 to 35 μm). In estuaries such as the Indian River Lagoon, this portion of the community often is dominated by flagellate algae and small diatoms. Diatoms are silaceous (having glassy shells) microscopic plants in the Chrysophyta phylum. Larger forms which can be retained by these nets are called net plankton. The net plankton contains large diatoms and mobile forms such as the dinoflagellates (Pyrrhophyta) and euglenoids (Euglenophyta) which have pigments but also have characteristics of the single-celled animals (Prescott, 1964).

The phytoplankton community appears to maintain many of the same functional and structural characteristics in many different coastal estuary systems. The phytoplankton of the Indian River Lagoon system also appears to be consistent with these patterns in at least two ways. First, Margalef (1958) has proposed a general pattern for seasonal phytoplankton succession. This pattern consists of a first expansion or bloom in the phytoplankton community as water temperature rises in spring. This first bloom is dominated primarily by small-celled species, primarily small diatoms, which have rapid rates of cell division. This phase is then replaced by a second phase consisting of medium-size species of diatoms with moderate cell division rates. The final phase of succession usually occurs in late summer when larger, more slowly dividing species dominate the community. These larger species generally contain dinoflagellates (species capable of some movement based on whip- or hair-like flagella structures). In general, the number of cells or individuals decreases with increasing size of the cells.

Mahoney and Gibson (1983b) found that the general successional pattern within the Indian River Lagoon tended to parallel the above successional pattern as reported from other estuaries (Mulford, 1972; Hallegraeff, 1981). In the study year 1977, the first bloom of phytoplankton was observed to consist mainly of small chain-forming diatoms (Mahoney and Gibson, 1983b). In the second phase, the diatom portion decreased and dinoflagellates increased, although cell numbers decreased. Finally, in late summer, the third phase was accompanied by an increase in cell numbers and in the numbers of both flagellates and diatoms. Chlorophyll activity was also observed to increase at this time. Diatom densities varied by over three orders of magnitude during the year, while flagellate cell densities varied by only one order of magnitude.

Species composition and dominance patterns in Indian River Lagoon have also been shown by Mahoney and Gibson (1983a, 1983b) to be similar to those of other estuaries. Mahoney and Gibson (1983a) found 230 species of diatoms in 68 genera and 20 species of flagellates in 9 genera in the south central Indian River Lagoon. The dominant diatom was found to be *Skeletonema costatum* which comprised over 99 percent of the total phytoplankton biomass at some points of the year. Other prominent genera were *Chaetoceros*, *Nitzschia*, *Skeletonema*, and *Thalassiosira*. Table 4-2 shows the dominant species or species groups found by Mahoney and Gibson (1983b) for various portions of the year, illustrating the seasonal patterns of occurrence of several groups.

Most of the dominant species were consistently found over time to be diatoms. Flagellate algal species were present all year, but were most abundant in late summer through autumn. Various species of *Chaetoceras* and *Thalassiosira* were most abundant in warmer periods. The nanoplankton fraction of the phytoplankton community was also found to account for over 90% of cell density and biomass, and 78% of active chlorophyll *a* by Mahoney and Gibson (1983b). However, most of the studies of the phytoplankton community of the Indian River Lagoon have concentrated on the net plankton portion (Stephens, 1975, 1976; Youngbluth, et al., 1977). This fact indicates that a greater understanding of the role of the nanoplankton fraction and of the dynamics and nutrient responses of certain species such as *Skeletonema costatum* may be required to predict the responses of phytoplankton to changes in the Indian River Lagoon.

TABLE 4-2

SEASONALLY DOMINANT SPECIES GROUPS OF PHYTOPLANKTON
IN THE SOUTH CENTRAL INDIAN RIVER LAGOON

SEASONAL PERIOD	SPECIES GROUPS DOMINATING	
	NET PHYTOPLANKTON	TOTAL PHYTOPLANKTON
January - March	*Bacillaria paxillifer* *Melosira moniliformis* *Paralia sulcata* *Thalassiosira rotula*	*Skeletonema costatum* flagellates *Thalassiosira rotula*
April - June	*Chaetoceras* spp. *Thalassiosira rotula* *Skeletonema costatum*	*Nitzschia delicatissima* *Thalassiosira eccentrica* flagellates *Thalassiosira binata* *Skeletonema costatum*
July - October	*Chaetoceras* spp. *Bacillaria paxillifer* *Paralia sulcata*	flagellates *Thalassiosira binata* *Nitzschia delicatissima* *Skeletonema costatum*
November - January	*Thalassiosira eccentrica* *Bacillaria paxillifer* *Paralia sulcata*	flagellates *Thalassiosira eccentrica* *Skeletonema costatum*

Source: Data from Mahoney and Gibson (1983b).

4.2.2.2 Functional Role and Physiological Responses

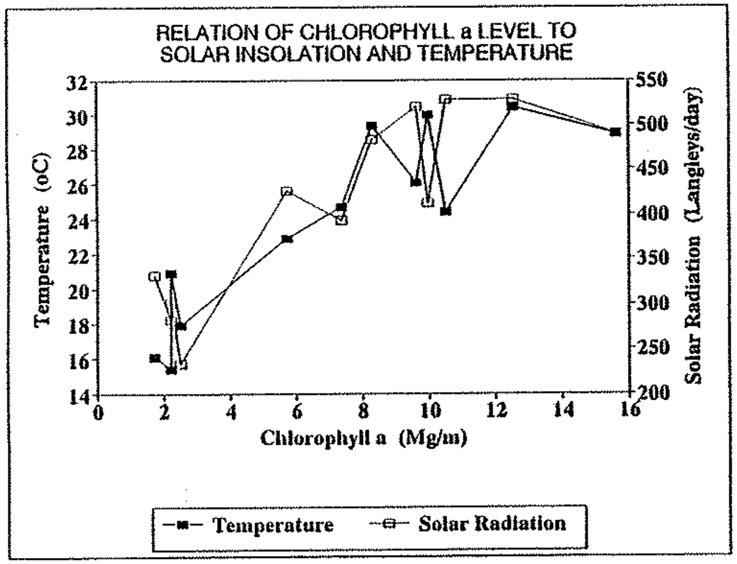
Phytoplankton may play a significant ecological role in the status of the Indian River Lagoon. Under normal conditions, phytoplankton is one of the bases of the Lagoon food chain. Zooplankton graze on the phytoplankton and are in turn eaten by larger organisms such as fish larvae and small fishes such as the bay anchovy (*Anchoa mitchilli*). The abundance of phytoplankton generally is reflected by the amount of chlorophyll in the water column. Light penetrating the water column is partially absorbed by the chlorophyll of the phytoplankton. Thus the level of light penetrating to the seagrass beds can be a function of the abundance of phytoplankton. High phytoplankton levels can thereby lead to a decrease in the abundance and productivity of seagrasses.

Indian River Lagoon has been described as a seagrass-based ecosystem (Clark, 1975) in which the bulk of the primary production and food chain base is from seagrass beds and associated attached plant species. In their 1983 study, Heffernan and Gibson estimated that phytoplankton represented only 2% to 7% of total primary productivity in seagrass meadows in the Indian River Lagoon, compared to 50% to 85% for seagrasses and 15% to 90% for epiphytes and benthic algae. An increase in density of phytoplankton could result in a shift from a seagrass-based system to a phytoplankton-based system (Wetzel and Hough, 1973; Windsor and Stewart, 1987). Factors contributing to changes in phytoplankton abundance could lead to major changes in the ecology of the Lagoon. Heffernan and Gibson (1983) concluded that the relative contribution of phytoplankton and attached species productivity in comparison to seagrass productivity might be used to indicate the degree of eutrophication within the Lagoon.

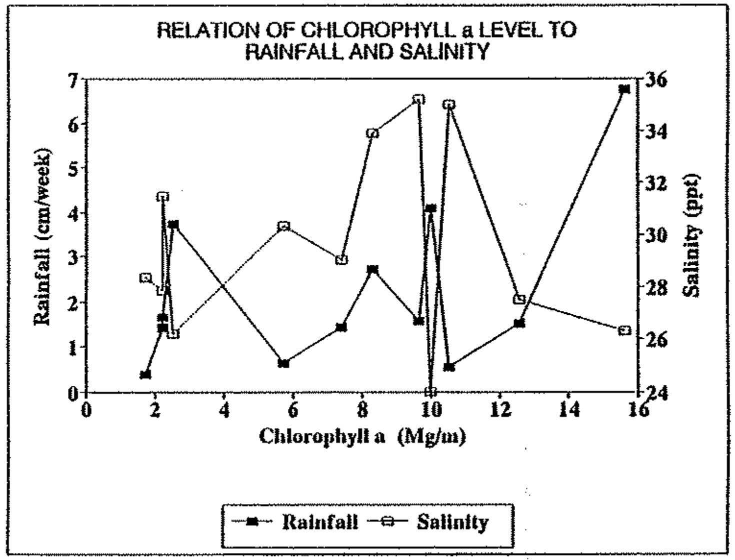
Primary production, photosynthesis, and phytoplankton abundance are mainly influenced by light levels, temperature, and nutrient levels (MacEwan, 1972: Callahan, 1977; Daneman, 1978; David, 1978). Changes in any of these factors may lead to changes in the abundance of this community. The seasonal succession pattern is largely a result of seasonal variations in light and temperature. Mahoney and Gibson (1983a) studied the ecology of the phytoplankton community over a one year period in the vicinity of Vero Beach. They found that cell densities and the concentration of active chlorophyll *a* in the water column were very highly correlated with temperature and solar radiation, with highest concentrations between April and October. However, within this overall trend, chlorophyll concentrations over shorter periods showed a direct correlation to nutrient concentrations. Mahoney and Gibson attributed the periods of increased phytoplankton standing stock and increased nutrient concentrations to periods of heavy rainfall in which nutrients were washed into the Lagoon through the extensive canal and flood control network in the region. Figure 4-16 is based on data from Mahoney and Gibson (1983b). Figure 4-16 illustrates the relationship of chlorophyll *a* concentration to temperature and irradiance and to several water quality parameters in the south central segment of Indian River Lagoon. This data does not present enough material to determine trends for the Lagoon complex, but may indicate that inorganic nitrogen components (nitrate, nitrite) have the most direct relationship to phytoplankton abundance in the Indian River Lagoon.

Tomasko (1992) has cited the work of Johannson in Tampa Bay, pointing out a link between chlorophyll *a* (and phytoplankton abundance) and total nitrogen loading. In Tampa Bay, a 50% drop in nitrogen loading to one segment has decreased the chlorophyll *a* concentration by about 33%. A recent synthesis of Tampa Bay water quality data (King Engineering, 1992) supports the evidence that dropping nitrogen loading is linked to dropping chlorophyll *a* levels in many parts of the bay. Tomasko attempted to define a similar correlation for Sarasota Bay, but was unable to do so with the limited data available. In addition, the chlorophyll *a* levels and loading rates are lower in Sarasota Bay, so that the same relationship may not be present. The chlorophyll *a* levels in Sarasota Bay were reported as being between 7 and 13 mg m^{-3} (7-13 μg/L), while those in the Tampa Bay segment ranged between 20 and 40 mg m^{-3}. In most of the Indian River Lagoon, levels in the 1989-1991 period were below 20 mg m^{-3}, so the responses in Indian River may be more similar to those in Sarasota Bay.

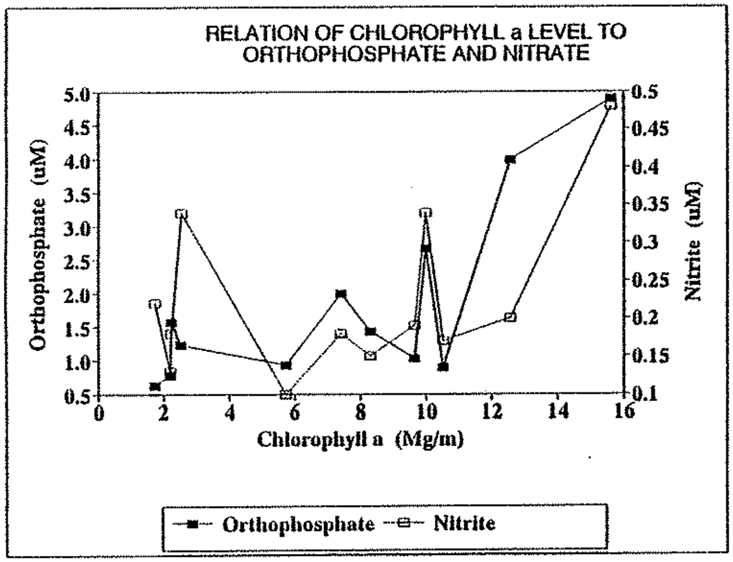
Several studies of nutrient effects on phytoplankton in Chesapeake Bay and other more northern locales have indicated that nitrogen has usually been the limiting nutrient factor, especially during the summer season when growth rates are highest. Fisher, et al. (1992) in addition found a pattern of seasonal shifting between phosphorus and nitrogen as the limiting factor. In periods of high spring rains and runoff, the ratio of dissolved inorganic nitrogen (DIN) to soluble reactive phosphorus (PO_4) in the water column was high relative to the N:P ratio in the algae. Thus, phosphorus was the limiting factor in this time period. In the summer, when runoff was greatly reduced, conditions were reversed and nitrogen



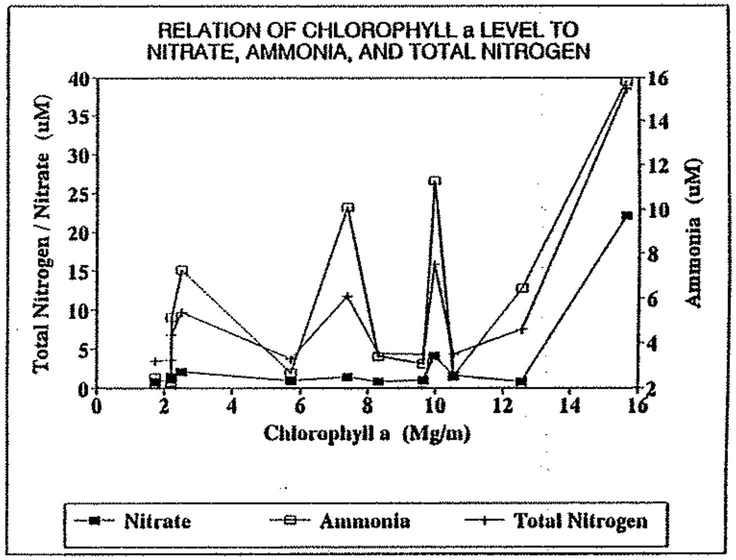
a) Response to Temperature and Solar Radiation



b) Response to Rainfall and Salinity



c) Response to Orthophosphate and Nitrite



d) Response to Nitrate, Ammonia, and Total Nitrogen

Source: Data from Mahoney and Gibson, 1983b.

•Woodward–Clyde Consultants •Marshall McCully & Associates •Natural Systems Analysis	DRAWING NO.: IIHESCAL.DWG DATE: 6-27-94	FIGURE 4-16	RELATIONSHIP OF PHYTOPLANKTON CHLOROPHYLL *a* TO ENVIRONMENTAL FACTORS IN THE INDIAN RIVER LAGOON

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became the limiting factor. A similar pattern of response was reported by Sanders, et al. (1987) in the Patuxent River.

Rudek, et al. (1991) also found, through the use of controlled nutrient addition experiments, that nitrogen was the limiting factor for phytoplankton productivity in the Neuse River Estuary. However, in spring when the ratio of DIN to total phosphorus (TP) was often above 5:1, nitrogen additions only stimulated growth when phosphorus was also added, showing that phosphorus was a co-limiting factor under these conditions. Jordan, et al. (1991) also found a seasonal flux in the N:P ratio in the Rhode River. In this case, it was concluded that nitrate inputs from river flow and runoff control chlorophyll *a* concentrations in spring, while recycling of inorganic nitrogen from organic matter produced in early spring controls phytoplankton productivity in summer.

The evidence therefore indicates that nitrogen is often the limiting nutrient factor for phytoplankton growth in estuaries and that this will be the case in Indian River Lagoon as well. However, no similar studies have yet been reported for the Indian River Lagoon, so the extent of the effect is not known. In this region, the high rainfall/runoff period is near to the peak summer productivity period rather than early in spring as was the case with the other estuaries studied. Another limit in the extent of information for Indian River Lagoon is the wide variation of water quality data throughout the Lagoon and over time. There has been little consistency in the species of nitrogen that have been monitored. DIN appears to be the most critical parameter for correlation to algal productivity, yet this value has only rarely been determined.

4.2.2.3 Phytoplankton Community Trends

The annual mean cell density in the 1977 Indian River Lagoon study (Mahoney and Gibson, 1983b) was reported as 1.38×10^{10} cells m^{-3} and mean chlorophyll *a* was 10.69 mg m^{-3} (10.69 μg/L). These mean cell densities were from 9 to 16 times higher than those reported for Tampa Bay and St. Andrews Bay, Florida. Chlorophyll *a* content was 5 times higher than reported for St. Andrews Bay, but substantially less than reported in Tampa Bay (Mahoney and Gibson, 1983b). Cell densities over the yearly period ranged from 1.72×10^{9} to 3.56×10^{10} cells m^{-3}, and chlorophyll *a* values ranged from 0.90 to 22.50 mg m^{-3}.

During the three-year period from 1989 to 1991, average monthly total chlorophyll *a* levels at the monitoring stations closest to Mahoney and Gibson's study site (IRL 34 -IRL 38 in the Water and Sediment Quality Technical Report) ranged from 3 to 16 mg m^{-3} during the dry season and from 7 to 32 mg $^{-3}$ during the wet season. This concentration range is somewhat higher than that reported in the 1977 study. Annual average chlorophyll *a* concentrations within the central portion of the Lagoon in the period from 1989 to 1991 have been close to the 10.69 mg m^{-3} average reported in 1977. Review of data from Windsor and Steward (1987) indicates that a general reduction has occurred in annual average from approximately 16 to 20 mg m^{-3} in the 1980 to 1985 period to 6 to 14 mg m^{-3} in the 1989 to 1991 period. While these numbers are only approximations based on a limited amount of data and stations, they appear to indicate that the community characteristics have remained similar to those in the 1977 study.

The period between 1980 to 1985 appears to have represented somewhat higher chlorophyll *a* levels in Indian River Lagoon (Windsor and Steward, 1987). The period between 1979 and 1984 also produced elevated chlorophyll *a* levels in Tampa Bay (King Engineering, Inc., 1992). Thus a similar pattern of peaking of chlorophyll and phytoplankton levels in the early to mid 1980s may be present in both estuaries. However, an extensive time series analysis of data for the Indian River Lagoon has not been undertaken, but would be useful for evaluating trends.

Mosquito Lagoon represents an area with relatively natural conditions and low nutrient loading (Provancha, et al., 1992), that may serve as a control for evaluating normal phytoplankton conditions in the Indian River Lagoon complex. Annual average chlorophyll *a* levels in Mosquito Lagoon between New Smyrna Beach and Edgewater ranged between 3 and 16 mg m^{-3} between 1970 and 1987 (Provancha, et al., 1992), with many individual samples of less than 1 mg m^{-3}. Annual average values for the 1988 to 1990 period in Mosquito Lagoon ranged from 3.0 to 9.1 mg m^{-3} (Provancha, et al., 1992), and between 6 and 9 mg m^{-3} between 1989 and 1991 (Water and Sediment Quality Technical Report). Although average chlorophyll *a* levels between 1985 and 1990 were 5.1 mg m^{-3} in south Mosquito Lagoon, the maximum value was 65 mg m^{-3}. These annual average levels are similar to the 1977 levels reported by Mahoney and Gibson (1983b) for the central Indian River Lagoon area, and they may represent a "natural" benchmark for phytoplankton population density. By this benchmark, the current levels in much of the Indian River

Lagoon complex are somewhat elevated from natural conditions, but still below levels reported in many other Florida estuaries.

4.2.2.4 Other Factors

One of the flagellate algae that has been found in the Indian River Lagoon is *Gonyaulax monilata*, a species commonly believed to be a cause of the "red tides" which have been implicated in fish kills. Evink (1980) described an algal bloom dominated by *Gonyaulax monilata* near the Eau Gallie causeway. Norris (1983) has pointed out that this species has been found in blooms in the Indian River Lagoon at five widely scattered times between 1951 and 1979.

Evink linked the algae bloom occurrence to the stirring of organic- and nutrient-rich sediments by wind. He implied that the nutrient flux from sediment release was the probable cause of the bloom. If this is the case, then increases in frequency as well as intensity of blooms should increase as nutrient enrichment of the Lagoon occurs through increased nutrient loading from greater development activities. However, Norris (1983) postulated that the organism lies dormant in benthic resting cysts for months or years and that it is the resuspension of these cysts in the water column that triggers the infrequent blooms. Other studies of *Gonyaulax monilata* and similar dinoflagellates (Owen, 1979; Donnelly, 1980; Owen and Norris, 1982) have also shown the importance of these cysts in maintaining the population through potentially unfavorable events. Norris' explanation also would explain Evink's observations and may indicate that the incidence of blooms is largely independent of nutrient levels in the sediments. Thus there appears to be insufficient information to predict whether "red tides" will become a problem in the Indian River Lagoon in the future.

4.2.3 Zooplankton and Ichthyoplankton

The animal portion of the microscopic floating community is the zooplankton. Like the phytoplankton, zooplankton are often divided into two size classes, the microzooplankton (<200 nm) and the macrozooplankton (>200 um). This community includes groups such as copepods and tintinnids. Copepods are usually the dominant macrozooplankton group throughout the Lagoon complex, while tintinnids and small copepods dominate the microzooplankton (Roulo, 1977). Rey, et al. (1991) found the two copepod species, *Oithona* *nana* and *Acartia tonsa* accounted for over 75% of the total number of individuals in the zooplankton fauna of impounded marshes. Other groups that may be present are foraminiferans, polychaete larvae; radiolarians, shrimp, chaetognaths, and the larval stages of bivalve mollusks such as clams and oysters. Youngbluth, et al. (1983) found that the densities of microzooplankton were generally two to three orders of magnitude larger than those of the macrozooplankton.

Zooplankton form an important part of the food chain in the Lagoon (Reeve, 1975). They are eaten by both larval fish and by both larval and adult stages of species such as bay anchovy, menhaden, and silversides and by juveniles of mullet, snook, ladyfish, and other species (Rey, et al., 1991). These species are in turn eaten by many higher predators including seatrout and redfish. Zooplankton graze on the phytoplankton and perhaps perform another important ecological role, as this grazing may be a form of control on phytoplankton density in the Lagoon and may control overpopulation and algal blooms. Zooplankton also are sensitive to factors such as temperature and salinity. Copepod dominance has been reported to increase with increasing salinity (Edminston, 1979) in Apalachicola Bay.

Ichthyoplankton are the larval size of fishes. Eggs of many fish species float in the open water column as the fish embryos develop and absorb the yolk sacs. When these eggs hatch, the larval fish are not fully developed and will also float in the water column at the mercy of waves and currents. Seatrout larval stages may be important components of the ichthyoplankton. The young fish eat phytoplankton and zooplankton in this stage of life. It has been estimated that the mortality rate for bay anchovy larvae is as high as 36% per day in Biscayne Bay (Leak and Houde, 1987).

The population dynamics of zooplankton and their consumer organisms is not well understood. However, Youngbluth, et al. (1983) and Jacoby and Youngbluth (in Virnstein, 1987) have estimated microzooplankton densities in the Lagoon from $2x10^5$ to $5x10^7$ organisms per cubic meter. Rey, et al. (1991) measured zooplankton density as between 1 x 10^4 to 1 x 10^5 organisms per cubic meter in impounded marshes of the Indian River Lagoon with an average density of about 4 x 10^4 m^{-3}. Minimum densities of $5x10^4$ to $1x10^5$ organisms per cubic meter have been estimated as required to support larval bay anchovy populations (Funderburk, et al., 1991). Thus it appears that the Lagoon is capable of supporting good populations of important food chain fishes such as the bay anchovy.

4.3 FINDINGS AND RECOMMENDATIONS FOR SUBTIDAL AND MARINE COMMUNITIES

Submerged aquatic plants include vascular plants known as seagrasses, as well as large attached and drifting algae species. These two groups are known as Submerged Aquatic Vegetation (SAV) and form large beds or meadows on the bottom of the Lagoon. Seagrass meadows are extremely valuable habitats within the Indian River Lagoon complex, providing cover and food resources for many of the animal species inhabiting the Lagoon at some point of their life cycles. Animal diversity and abundance are usually greater within the seagrass beds than in open bottom habitats. The SAV beds cover about 70,000 ac of the estimated 175,390 acres (40%) of the Lagoon which have water depths less than 2 m which would be potential habitat for the seagrasses. SAV abundance is moderate in Segment 4, with somewhat greater amounts occurring near the inlets and reduced amounts primarily between Hobe Sound and St. Lucie Inlet.

The largest concentration of SAV occurs in Segments 1A, 1B, and 1C in Mosquito Lagoon, Banana River, and the Indian River Lagoon north of Cocoa. SAV beds are at a minimum in Segments 2 and 3 in the Indian River from south of Vero Beach north to Cocoa. Low salinity and lack of suitable bottom type and depth are partially responsible for the low density in this area, but do not seem to account for all of the scarcity, since the percentage of potentially available habitat occupied is less in this area than in other areas.

Seven species of seagrasses are found in the Indian River Lagoon complex. Manatee grass and shoal grass are the two dominant species throughout all of the complex in water depths less than 1.5 m (5 ft). Widgeon grass is found only in scattered locations and turtle grass is restricted to the area south of Sebastian Inlet. Three species of *Halophila* occur primarily in deeper water between 1 and 2.5 m (3.3 and 8.3 ft). Johnson's seagrass is found primarily in limited areas south of Sebastian Inlet and has been proposed for listing as a threatened or endangered species because of its very limited known occurrence.

Temperature and salinity appear to play important roles in north to south distribution of the seagrasses. Five of the seven species of seagrass reach their northern limits of distribution in the Lagoon and temperature probably is the primary influence. Temperature definitely appears to limit the northward distribution of turtle grass and manatee grass. There is also a definite correspondence between the patterns of occurrences of manatee grass and turtle grass and salinity regimes in the complex, with a lack or reduction of these species in the reach of Indian River Lagoon between Sebastian Inlet and Cocoa where annual average salinity levels drop to less than 24 ppt.

Light intensity is the environmental factor controlling the depth of seagrass occurrence. Species such as turtle grass, manatee grass, and shoal grass appear to need light intensities of between 15% and 30% of the incident light at the water surface for long-term survival. The *Halophila* species appear to need less light (about 5% to 12%) and thus can exist in deeper water. The attached algae and the phytoplankton species appear to survive at light intensities as low as 1% of incident sunlight. Thus they can occur at deeper depths than any of the seagrasses.

These light requirements are only general, and additional data specific to the Indian River Lagoon complex needs to be acquired before a good understanding of the limits of growth and distribution can be obtained. Several studies have started to gather this data, and information to date indicates that the light penetration and resulting light levels within the water column vary throughout the Lagoon, depending largely on water color. The amounts of chlorophyll *a*, suspended solids, and dissolved solids also affect light penetration. Light penetration is generally highest near the inlets and becomes less with increasing distance from the inlets.

Depth distribution of seagrasses within the complex appears to agree with the theoretical and controlled studies for light requirements in seagrasses, so a strong causal case can be made for light (particularly PAR or photosynthetically active radiation) penetration as a major factor controlling the extent of seagrasses. It appears that several methods might be developed for use in determining the relative effects on PAR of color, turbidity, and solids for any location or set of circumstances. This approach would allow managers to evaluate the relative effectiveness of managing certain water quality parameters.

Phytoplankton ecology and importance has not been well studied in the Indian River Lagoon complex. It is important to have an understanding of this component since it is both an important base of many food chains and a potential source of water quality problems and possible threats to the seagrass beds. The sensitivity of the balance between too much plankton and not enough plankton for a healthy estuary is not understood, but should be an important factor for management implications.

An understanding of nutrient dynamics of the Indian River Lagoon complex is also lacking. There have been few studies of the effects and limiting levels of N and P in the complex, and on the implications for seagrass and phytoplankton ecology. In particular, DIN (dissolved inorganic nitrogen) may be an important component regulating phytoplankton growth dynamics. This parameter has been monitored only infrequently in the Indian River Lagoon, and needs to be better defined. Currently the phytoplankton, and corresponding chlorophyll, levels in the Lagoon appear to be similar to levels in the 1970s and perhaps slightly less than in the mid 1980s. The levels are generally less than levels that have been found in many other estuaries such as Tampa Bay. This implies that elevated chlorophyll levels and potential for algal blooms are not yet the problem that they have been in some other estuaries.

Ichthyoplankton communities have not been well studied in the Indian River Lagoon complex, and no significant findings have been made with respect to abundance and significance throughout the system. Available information suggests that the icthyoplankton populations are sufficient to support a healthy food chain in the Lagoon, but the available information is sparse.

Although there appear to be some trends in the benthic community through the length of the Lagoon, available information on this component is largely limited to studies of specific sites or species, making it difficult to extrapolate through the Lagoon. Reported variability within and between stations so far has tended to mask most trends. However, many additional samples are believed to have been collected but never analysed due to lack of resources (Nelson, 1993). It is possible that these larger data sets could help to provide additional insight into macroinvertebrate dynamics and trends in the Lagoon if they were to be analysed. It appears that this community may vary fairly significantly over time, and that it responds to localized effects rather than to regional effects, but insufficient information is available to make further assumptions.

5.0 IMPORTANT FISH AND SHELLFISH RESOURCES

5.1 ICHTHYOFAUNA

The Indian River Lagoon reportedly has the "richest estuarine ichthyofauna in the continental United States" (Gilmore, 1988a). Fishes have been the subject of several major review papers (Gilmore, 1977, 1988a; Gilmore, et al., 1981; Snelson, 1983; Virnstein and Campbell, 1987). Except on a fairly localized basis, however, no standardized sampling has been performed that would allow for detailed comparisons of fish populations throughout the estuary. Some quantitative studies have been performed of certain major habitat/community associations (e.g., Gilmore, et al., 1982; Mulligan and Snelson, 1983; Stoner, 1983; Brown-Peterson and Eames 1990).

5.1.1 Distribution

Representatives of at least 680 fish species have been recorded from the Lagoon system and immediately adjacent marine and inland waters (Gilmore, et al., 1981). Recent reports have indicated that a total of 788 species are present (Gilmore, 1994). At least half of these species have been documented in the Indian River Lagoon complex (Appendix A). The richness of this estuarine fish fauna reflects the diversity of available habitats and the fact that the Indian River Lagoon system lies in the transitional zone between warm-temperate (Carolinean) and tropical (Caribbean) assemblages of shorefishes (Briggs 1958, 1975).

More than twice as many fish species have been recorded in the southern portion of the Lagoon system as in the northern, primarily because of three interacting factors (Snelson, 1983):

- Latitudinal differences in climate

- Scarcity of hard-bottom and reef-like habitats in the northern portion
- The presence of several, relatively closely spaced, Atlantic inlets in the southern portion

Many tropical groups such as sea basses, cardinalfishes, snappers, grunts, damselfishes, wrasses, and parrotfishes are well represented in the southern portion of the Lagoon system, but poorly, represented, if at all, north of the Melbourne area. Representatives of these and other tropical families are particularly susceptible to cold weather (Gilmore, et al., 1978; Snelson and Bradley, 1978). There is a south-to-north progression of range terminations of tropical species of the Lagoon system. Although the overall diversity of the warm-temperate faunal component is lower, it does not exhibit a reciprocal (north-to-south) pattern of reduction in occurrence. Indeed, the range of only one Carolinean fish species, mummichog (*Fundulus heteroclitus*), ends in the Indian River Lagoon complex, and it occurs only in the extreme upper portion near Ponce de Leon Inlet (Snelson, 1983).

Reef-like habitats are prevalent in the southern portion of the Lagoon complex, especially south of Sebastian Inlet, whereas only one such area is reported in the northern part of the estuary. Almost a third of the species recorded exclusively in the southern portion of Indian River Lagoon are typically associated with reefs or reef-like habitats as adults (e.g., angelfishes, cardinalfishes, damselfishes, wrasses). These reef structures and other habitats will be discussed in more detail later in this report.

Proximity to Atlantic inlets appears to increase both the occurrence and abundance of many Indian River Lagoon fishes (Brown-Peterson and Eames, 1990; Gilmore, 1977, 1988a, 1988b; Gilmore, et al., 1981; Schmid, et al., 1988; Snelson, 1983; Williams and Snelson, 1981). The inlets provide a variety of habitats, as well as direct access to the Lagoon for many species of oceanic affinities. A number of species recorded from the Lagoon complex appear to occur only in the inlets or within areas of the Lagoon relatively close to the inlets.

5.1.2 Fish Habitat Associations

In a series of ichthyofaunal summaries, Gilmore and associates recognize 13 major habitat types (or "biotopes") in the Indian River Lagoon and the adjacent Atlantic continental shelf area (Gilmore, 1977, 1988a; Gilmore, et al., 1981). Eight of these habitats are found within the Lagoon proper, and each has a characteristic assemblage of fishes: 1) freshwater tributaries and canals; 2) canal and river mouths; 3) mosquito impoundments; 4) mangrove marshes; 5) open sand bottoms; 6) grassflats; 7) lagoon "reefs;" and 8) Atlantic inlets.

Many fishes use a variety of the habitats, particularly during different phases of their life histories and/or at different times during the year. But there are few Lagoon fishes that are truly ubiquitous in the sense of occurring relatively abundantly in most major habitats throughout all seasons. Examples of such wide-ranging species include bay anchovy (*Anchoa mitchilli*); hardhead catfish (*Arius felis*); redfin needlefish (*Strongylura notata*); common snook (*Centropomus undecimalis*); crevalle jack (*Caranx hippos*); spotfin mojarra (*Eucinostomus argenteus*); sheepshead (*Archosargus probatocephalus*); pinfish (*Lagodon rhomboides*); striped mullet (*Mugil cephalus*); and white mullet (*Mugil curema*). Even these seemingly ubiquitous forms tend to have only one or a few preferred habitats during certain phases of their lives.

5.1.2.1 Freshwater Tributaries and Canals

The major rivers, creeks, and canals entering the Indian River Lagoon complex from the mainland provide lotic (flowing water) conditions with varying degrees of tidal influence depending upon their size, discharge, and proximity to ocean inlets. Currents in these streams vary from sluggish to moderate. The margins are usually covered with dense vegetation (unless denuded by human activity). Various types of submerged, emergent, and floating aquatic vegetation are usually present, with the species composition varying according to flow, substrate type, and other physical factors. Tributary streams and canals are much more prevalent in the southern portions of the Lagoon system, especially the southern third.

Most of the predominantly freshwater fishes recorded from the Lagoon system, such as minnows (Cyprinidae), bullhead catfishes (Ictaluridae), and sunfishes (Centrarchidae) are found mainly or exclusively in the tributary streams. A few freshwater species are found in ponds and ditches on Merritt Island, at least some of which are believed to have been artificially introduced (Snelson, 1983). More than half of the species recorded from freshwater tributaries and canals are euryhaline (tolerant of a wide range of salinity) forms which also occur, often abundantly, in various other brackish to marine habitats. Rather then entire groups, there tend to be only certain species of euryhaline families or genera that are common and/or relatively abundant in the tributary streams. Examples of prominent euryhaline species in this habitat include all of the ubiquitous forms mentioned above as well as Florida gar (*Lepisosteus platyrhincus*); gizzard shad (*Dorosoma cepedianum*); flagfish (*Jordanella floridae*); bluefin killifish (*Lucania goodei*); mosquitofish (*Gambusia affinis*); least killifish (*Heterandria formosa*); sailfin molly (*Poecilia latipinna*); inland silverside (*Menidia beryllina*); gulf pipefish (*Syngnathus scovelli*); leatherjack (*Oligoplites saurus*); gray snapper (*Lutjanus griseus*); Irish pompano (*Diapterus auratus*); silver jenny (*Eucinostomus gula*); fat sleeper (*Dormitator maculatus*); bigmouth sleeper (*Gobiomorus dormitor*); and lined sole (*Achirus lineatus*).

5.1.2.2 <u>Canal and River Mouths</u>

The areas where larger tributaries and canals intersect the Lagoon are characterized by widely fluctuating salinities, predominantly sand-mud substrates, relatively high turbidities, and a general scarcity of submerged vegetation. According to Gilmore (1977), canal and river mouths are the innermost "truly estuarine" habitats in the Lagoon system. Composition of the fish communities of such areas tends to vary substantially with changes in season and salinities. Although the overall total of species found in this habitat is about the same as that of tributary streams, virtually all of the predominantly freshwater forms are excluded and replaced by transient euryhaline species. Fishes reported to be common and/or abundant around canal and river mouths include most of the species listed above as ubiquitous as well as yellowfin menhaden (*Brevoortia smithi*); gafftopsail catfish (*Bagre marinus*); timucu, a needlefish (*Strongylura timucu*); gulf killifish (*Fundulus grandis*); striped killifish (*F. majalis*); mosquitofish; sailfin molly; lined seahorse (*Hippocampus erectus*); chain pipefish (*Syngnathus louisianae*); gulf pipefish; tarpon snook (*Centropomus pectinatus*); Atlantic bumper (*Chloroscombrus chrysurus*); leatherjack; lookdown (*Selene vomer*); gray snapper; Irish pompano; silver jenny; great barracuda (*Sphyraena barracuda*); fat sleeper; emerald sleeper (*Erotelis smaragdus*); frillfin goby (*Bathygobius soporator*); darter goby (*Gobionellus* *boleosoma*); naked goby (*Gobiosoma bosc*); clown goby (*Microgobius gulosus*); bay whiff, a flatfish (*Citharichthys spilopterus*); gulf flounder (*Paralichthys albigutta*); lined sole; planehead filefish (*Monacanthus hispidus*); striped burrfish (*Chilomycterus schoepfi*); southern puffer (*Sphoeroides nephelus*); bandtail puffer (*S. spengleri*); and checkered puffer (*S. testudineus*).

5.1.2.3 Mosquito Impoundments

The diking of vast tracts of former intertidal mangrove and salt marsh areas in recent decades has created numerous shallow pond-like features along the margins of Indian River Lagoon. The impoundments were created to ensure seasonal flooding of intertidal sediments to prevent successful egg-laying by salt marsh mosquitoes. Many of the early impoundments were constructed without floodgates or culverts so that hydraulic exchanges with the estuary were limited to occasional introductions of Lagoon water by pumping and relatively rare overflows due to heavy rains. When thus excluded from tidal influence the ponds are prone to stagnation and/or hypersalinity during prolonged dry periods or conversely lack of salinity during prolonged rainy periods. The original vegetative community is replaced by a relatively monotonous growth of only a few plant species. Some of the impoundments were constructed with (or subsequently retrofitted with) culverts to allow some tidal exchange. The latter, less isolated ponds tend to retain, or experience a regrowth of, a more stable and diverse marsh plant community (Gilmore, et al., 1982). Due to tidal exchange they are also much less prone to adverse extremes of water quality.

Marsh impoundments excluded from tidal exchange are characterized by very few fish species, primarily representing the families Cyprinodontidae [e.g., sheepshead minnow (*Cyprinodon variegatus*) and gulf killifish] and Poeciliidae (e.g., mosquitofish and sailfin molly). Whereas most of these species are normally carnivorous or omnivorous, they tend to become almost exclusively herbivorous or detritivorous as hypoxia and hypersalinity drastically reduce the availability of invertebrate forage animals such as insect larvae (Gilmore, et al., 1982). A more diverse assemblage of fishes is usually found in the impoundments with tidal connections. This community includes many of the euryhaline forms mentioned above as characteristic of canal and river mouths, as well as juvenile tarpon (*Megalops atlanticus*); marsh killifish (*Fundulus confluentis*); tidewater silverside (*Menidia peninsulae*); rough silverside (*Membras martinica*); juveniles of several sciaenid species; and some additional gobiids. Although 41 species were ultimately recorded over all seasons in one such "open" impoundment (Gilmore, et al., 1982), this major habitat type generally has an extremely low diversity of fishes compared to all others in the Indian River Lagoon system (Gilmore, 1977; 1988a). The impounded marshes may nevertheless be very important nursery habitat for tarpon, common snook, and striped mullet.

5.1.2.4 Mangrove/Salt Marsh

Intertidal mangroves are major components of the vegetative cover on the Indian River Lagoon shoreline. The prop root system and adjacent water along these shorelines have a moderately diverse fish community comprised of resident forms, larvae and juveniles of several marine migrant species, and occasional predatory invaders. Examples of residents include ladyfish (*Elops saurus*); sheepshead minnow; marsh killifish; mosquitofish; sailfin molly; highfin blenny (*Lupinoblennius nicholsi*); and the frillfin goby (Gilmore, 1977, 1988a). The rare and unusual mangrove rivulus (*Rivulus marmoratus*) also resides in this habitat (Taylor and Snelson, 1992). Marine migrants which commonly use the mangrove areas as nursery habitat include a few herrings (Clupeidae); a few sea basses (Serranidae); several snappers (Lutjanidae); and several grunts (Haemulidae). Large predators frequently encountered along mangroves include tarpon, common snook, crevalle jacks, adults of some snappers, and great barracuda.

5.1.2.5 Open Sand Bottoms

Most of the open area of Indian River Lagoon is characterized by relatively flat, exposed substrate that is a mixture of fine sand and shell. A thin veneer of silt often overlays this bottom type in the more open portions of the estuary, while a surficial layer of organic detrital material is usually present in portions adjacent to shore areas (Gilmore, 1977). Nearly half of the fishes known to occur in the Lagoon proper can be found on or over the open sand bottoms at least as transients. The principal resident species in this habitat include inshore lizardfish (*Synodus foetens*); several searobins (Triglidae); and several lefteye flounders (Bothidae). Many other fishes are common and abundant over the exposed bottoms, but they tend to move in only at certain times from the peripheral habitats described above, as well as from grassflats or lagoon reefs.

5.1.2.6 Grassflats (Seagrass Beds)

The extensive seagrass beds, discussed in detail elsewhere in this report, remain an important habitat type for fishes. Of the habitats entirely confined within the Lagoon, seagrass beds support the richest fish community, in terms of both diversity (well over 200 species) and density (Virnstein and Campbell, 1987). Most of the species reported from grassflats occur there primarily as juveniles, which emphasizes the significance of this habitat as nursery (Gilmore, 1977). Examples of major groups for which seagrass beds serve as nursery habitats include sea basses (Serranidae); snappers (Lutjanidae); mojarras (Gerreidae); porgies and pinfish (Sparidae); grunts (Haemulidae); and drums (Sciaenidae). There are several species of pipefishes and seahorses (Syngnathidae) and cardinalfishes (Apogonidae) which are essentially restricted to this habitat within the Lagoon. The most frequently encountered fishes in long-term studies of seagrass beds in the southern portion of Indian River Lagoon, in descending order, were pinfish; silver jenny; code goby (*Gobiosoma robustum*); bay anchovy; and silver perch (*Bairdiella chrysoura*) (Gilmore, 1988a). Numerically, the dominant species were bay anchovy, yellowfin menhaden, and pinfish. Mojarras have also been reported as a major species of the seagrass fish community.

Among Indian River Lagoon grassflats, there is substantial spatial and temporal variation in the occurrence and abundance of fishes (Stoner, 1983). Although proximity to certain other habitats (especially ocean inlets) must also play a role, Stoner (1983) concluded that heterogeneity within seagrass meadows (e.g., discontinuities such as scour channels) was the main factor negatively affecting fish species diversity. He found that relative abundance of fishes was positively correlated with grass blade density. This was surmised to be related to the increased densities of small invertebrate forage animals and the fact that a preponderance of the fishes are juveniles taking advantage of the cover provided by the dense foliage. The seasonal differences in composition of seagrass fish communities are largely attributable to the timing of spawning and recruitment of the various species.

5.1.2.7 Lagoon "Reefs"

This habitat is comprised of a variety of situations where there is natural or artificial relief above the Lagoon bottom associated with relatively hard surfaces. The most extensive reeflike features are rock ledges carved by dredging along the margins of the Intracoastal

Waterway, mainly in the southernmost third of the Lagoon. These ledges are often colonized by gorgonian corals and associated invertebrate growth. Similar, more localized, reeflike conditions are created by wrecks, pilings, and other submerged structures.

More than 90 kinds of fishes are reported to occur in association with Lagoon reefs and reeflike areas. Most of these fishes are considered primary reef fishes and are seldom, if ever, found in any of the other habitats within the Lagoon (Gilmore, 1977; Gilmore, et al., 1981). Examples include scorpionfishes (Scorpaenidae); cardinalfishes (Apogonidae); butterflyfishes (Chaetodontidae); angelfishes (Pomacanthidae); damselfishes (Pomacentridae); wrasses (Labridae); and parrotfishes (Scaridae).

5.1.2.8 Atlantic Inlets

The number and locations of natural connections between Indian River Lagoon and the Atlantic fluctuated until five stable inlets were established by installation of rock jetties and maintenance dredging. The modern inlets are typically less than 5 meters deep, with sand substrate and relatively strong tidal currents. The range of salinities in the inlets is somewhat narrower than those found in most parts of the interior of Indian River (Gilmore 1977).

The Atlantic inlets (particularly the southernmost three) have the richest assemblage of fishes among the habitat types recognized by Gilmore (1977). As noted above, many of the species reported from Indian River Lagoon proper are basically marine forms that penetrate only slightly, if at all, into the interior. Such fishes constitute nearly half of the inlet community, and are also associated with inshore Atlantic habitats (especially reefs). Examples of this component of the inlet assemblage include many sharks (Carcharhinidae, Sphyrnidae); several morays and snake eels (Muraenidae, Ophichthidae); some surgeonfishes (Acanthuridae); some butterfishes (Stromateidae); several filefishes or "leatherjackets" (Balistidae); and some boxfishes (Ostraciidae).

Most of the remaining fishes found in the inlet habitat are transient euryhaline forms, including many of those which spawn in the Atlantic and use portions of the interior of the Lagoon as nursery and in some cases primary feeding grounds (e.g., snook, some sea basses, some jacks, several drums, mullets).

5.1.3 Trends in Ichthyofaunal Populations

Although there is a substantial amount of anecdotal information indicating a decline in population of many fish species of the Indian River Lagoon, there are few studies documenting this trend. Total fisheries landings have increased in the period 1958 to 1988 for the region (see Uses of the Lagoon Technical Report), but the landings figures include catches from outside of the Lagoon as well. Total catch statistics also may not reflect the level of effort for species targeted. For example, reported catches of silver mullet increased dramatically in the md-1970s (Rathjen and Bolhassen, 1988), but this was probably due to the fact that this was not a targeted species prior to that time.

One species in which a dramatic drop in reported catches has occurred is the spotted seatrout. Commercial landings in the Indian River Lagoon region have declined steadily since 1952 (Virnstein, 1987) with the 1988 catch being only about 40 percent (%) of that in 1958 (see Uses of the Lagoon Technical Report). The spotted seatrout is a species largely restricted to the estuary and strongly associated with grassbeds of the Lagoon. However, this species has declined greatly throughout Florida and its decline may be linked to factors not directly associated with the Lagoon.

Populations of other fish species resident in the Lagoon complex appear to have increased in recent years, again based on anecdotal evidence of recreational fishing reports. In particular the red drum and common snook have increased. The common snook was declared a sport fish in 1986, thus removing it from the pressures of commercial fishing. Strict commercial and recreational bag and size limits imposed on red drum and common snook have also been credited with increasing population size. Such strict limits have not been imposed on the spotted seatrout.

Changes in fish populations within mosquito impoundments have been well documented (Gilmore, et al., 1981; 1982; 1987). Impoundment has generally led to a decline in fish diversity within impoundments. It has also led to a change in composition with declines in transient fish species and increases in resident fish specie populations. The resident fish in closed impoundments may serve as a food source for wading birds and upland species, but contribute little to the food chain of Lagoon fishes. There has been recent evidence that reconnecting the impoundments to the Lagoon with culverts has led to increased fish populations and increased use of impoundments by transient species from the Lagoon (David, 1992; Gilmore, et al., 1990).

Numerous fish kills have been reported along the Lagoon, usually in association with stormwater or mosquito impoundment discharges low in dissolved oxygen (David, 1992). However, most instances have been minor with no significant effect on overall population. Some fish mortality from other causes has been reported. Red drum mortality in 1980 in Mosquito Lagoon has been described as possibly resulting from ingestion of blue crabs contaminated with heavy metals, but no conclusive evidence was given (Provancha, et al., 1992).

5.1.4 Findings and Recommendations for Fish Resources

The ichthyofauna community of the Indian River Lagoon complex is one of the richest and most diverse of United States waters, with more than 600 species having been identified. The reasons for this diversity are many. The Lagoon spans several biogeographic provinces and has both a tropical and temperate influence. The Lagoon complex also has a high diversity of habitats including tidal inlets, sand bottoms, seagrass meadows, and adjacent mangrove forests and freshwater creeks. A higher diversity in the southern portion of the Lagoon has been ascribed to greater abundance of inlets, presence of reef-like habitats not present in the north, and greater tropical representation.

Several groups of fishes are important in the overall ecology of the complex. Species such as the commercially important bay anchovy, striped mullet, and silver mullet may eat plankton at least in some parts of their life cycles and they represent a key food chain link converting plant material to animal protein. Such species constitute the greatest biomass and numbers of fish in the estuary. Higher level predators such as the common snook, spotted seatrout, and red drum are important recreational and/or sport fishes which spend most of their lives within the estuary.

The status of fish resources is normally difficult to establish on a quantitative or definitive basis and much information must come from anecdotal sources and non-scientific reports. Such information indicates that populations of many fish have declined in the period from about 1952 to 1989. Populations of some species such as the common snook and red drum appear to have increased in recent years, probably in response to catch limitation regulations, while others such as the spotted seatrout have continued to decline.

Reconnection of the thousands of acres of mosquito impoundments may have a beneficial effect on ichthyofaunal food chains and lead to increased populations of fishes, while changes in seagrass abundance may also affect fish abundance. There currently is no adequate means of quantifying such changes and in identifying trends on a "real time" basis. The Florida Department of Environmental Protection (FDEP) is conducting a juvenile fisheries study from the Melbourne office, which offers the best potential for identifying trends in fisheries resources. However, the program has not been operating long enough to have developed meaningful information.

5.2 IMPORTANT FISH SPECIES

This section presents descriptions of some representative species of the Lagoon. These species have been selected to include representatives of different trophic levels which are important to the ecology or the fisheries of the Lagoon. The bay anchovy and striped mullet are representative of species which are planktivorous at some major life cycle stages, while spotted seatrout, red drum, and common snook are higher level carnivores. The bay anchovy has been reported as the most numerically abundant fish in the Lagoon, while the pinfish is the most abundant species in the important seagrass habitat. Red drum, spotted seatrout, and common snook are also three of the most sought recreational fish in the Lagoon, while the bay anchovy and striped mullet are important commercial species. In this section, length measurements are reported in mm or m since this is the commonly applied unit of measurement for reporting standard length (SL) for fishes.

5.2.1 Bay Anchovy - *Anchoa mitchilli* (Valenciennes)

The bay anchovy is one of the most abundant fishes in estuaries along the Atlantic and Gulf coasts of the United States. Gunter and Hall (1963) suggested that the biomass of bay anchovies may exceed that of any other fish along the south Atlantic coast. A major consumer of zooplankton, the bay anchovy in turn is forage for a wide variety of predators, thus playing a key role in estuarine and coastal food webs. Most ichthyological surveys of the Indian River Lagoon system have reported the species to be among the most common and abundant fishes in the system. Gilmore (1988a) stated that the bay anchovy "is now the most abundant fish species within the Indian River lagoon," implying that this may not have been the case prior to 1950.

The bay anchovy is one of six kinds of anchovies reported to occur in the Indian River Lagoon system; however, it is clearly the most ubiquitous and abundant. The striped anchovy, *A. hepsetus* (Linnaeus), is the only other relatively common and abundant representative of the family in the estuary. The bay anchovy ranges from Maine to the Yucatan Peninsula.

5.2.1.1 Life History

Results of studies in other estuaries (Killam, et al., 1992; Houde and Zastrow, 1991; Houde and Lovdal, 1984; Livingston, 1983) suggest that bay anchovies spawn throughout much of the Indian River Lagoon system from early spring through late autumn. Some spawning may occur virtually year-round, particularly in the southernmost portions of the estuary. Reproductive activity generally peaks in late spring and summer.

Bay anchovies are serial spawners, with individual females producing up to 50 batches of eggs (about 600-700 eggs per gram of female) over a reproductive season (Houde and Zastrow, 1991). The eggs are typically broadcast near the surface in open water during evening hours. Although some bay anchovies survive into their fourth calendar year (Age III), Zastrow and Houde (1989) found that Age I females were responsible for nearly all of the eggs produced during two successive spawning peaks in mid-Chesapeake Bay.

Fertilized eggs of the bay anchovy are slightly ellipsoid, about 1-millimeter (mm) in diameter and pelagic. Development is rapid, and hatching occurs in a day or less at temperatures greater than 75°F (25°C) (Houde and Zastrow, 1991). Egg mortality rates are typically high, averaging an estimated 86% in one study in Biscayne Bay (Leak and Houde, 1987).

Newly hatched bay anchovy larvae are about 2 mm long (Kuntz, 1914). The yolk sac is depleted in a day or two, depending upon temperature, and in one study feeding began when the larvae were 3.4 mm long at 2-3 days posthatch (Houde, 1974). Growth of larvae was estimated at 0.43 to 0.56 mm per day in Biscayne Bay (Leak and Houde, 1987). The larval phase is believed to be the most sensitive period in the life of the bay anchovy (Houde and Zastrow, 1991), with estimated mortality ranging from 26% to 36% per day in the Biscayne Bay study. Predation accounted for 2 to 3 times as much larval mortality as did starvation (Leak and Houde, 1987).

In Tampa Bay, the juvenile phase (i.e., all fin rays completely developed and finfolds absorbed) is attained by bay anchovies as small as 15 mm standard length (SL) (Killam, et al., 1992). The same authors report that sexually mature females as small as 20 mm SL have been observed in Tampa Bay, whereas the juvenile phase normally persists up to 35-40 mm SL in more northern parts of the range. Growth of juvenile bay anchovies in mid-Chesapeake Bay is about 0.2-0.3 mm per day (Houde and Zastrow, 1991), and is presumably somewhat more rapid in Florida. For most individuals that survive to adulthood in Indian River Lagoon, the entire early life history probably transpires in less than two months. Even with the high mortality rates, serial spawning produces a nearly constant supply of recruits to the population. Survival to the third calendar year is probably rare in Indian River Lagoon; on the west coast of Florida two year-classes appear to comprise the bulk of bay anchovy populations (Springer and Woodburn, 1960).

5.2.1.2 Ecological Role

The bay anchovy is a key link between primary consumers (zooplankton) and higher trophic levels in estuaries such as the Indian River Lagoon. The substantial literature on feeding and food habits of bay anchovies indicates that they primarily consume zooplankters, which are taken as individual particles (Houde and Zastrow (1991). Prey are selected according to size and type, in a progression from micro- to macrozooplankton as the anchovies grow (Detwyler and Houde, 1970; Odum, 1971; Johnson, et al., 1990).

In most estuaries the main initial foods of larval bay anchovies are copepod nauplii, rotifers, and tintinnids. Older larvae tend to select larger copepodites and adult copepods. The bulk of the diet (75%) of larval bay anchovies in Biscayne Bay was copepods, although tintinnids, rotifers, and bivalve mollusk larvae were also heavily consumed (Houde and Lovdal, 1984). Juvenile and adult bay anchovies feed primarily on macrozooplankton, especially fish eggs and larvae (including their own), mysids, and young decapod crustaceans (crabs and shrimp). In some systems juvenile bay anchovies also prey heavily on small benthic crustaceans (amphipods, ostracods, harpacticoid copepods, mysids) and mollusks, which may account for the frequent reports of ingestion of algae and detrital material (Darnell, 1958, 1961; Odum, 1971). Because of their wide distribution and abundance, bay anchovies may play a significant role in the dynamics of both benthic invertebrate and zooplankton populations (Johnson, et al., 1990).

5.2.2 Striped Mullet - *Mugil cephalus* (Linnaeus)

The striped mullet is one the most important inshore commercial and recreational finfishes in Florida. Although commercial landings are somewhat higher on the west side of Florida, the striped mullet is still of major economic significance in the Indian River Lagoon system (Rathjen and Bolhassen, 1988). It is one of the most ubiquitous and abundant species in the system and is of major ecological significance as a primary consumer and forage organism. Broadly euryhaline, the striped mullet is common throughout all major habitats except lagoon reef areas (Gilmore, 1977). The species is highly dependent upon estuaries, generally spawning in "outside" areas but spending the bulk of the remainder of its life in protected inshore waters. Large juvenile and adult striped mullet are herbivores and detritivores.

Mugil cephalus, also known as the black or grey mullet, occurs extensively in marine waters and coastal freshwaters around the world between the respective north and south latitudes of 42° (Thompson, 1966). Juveniles are occasionally encountered beyond these latitudes (Martin and Drewry, 1978), but the species is essentially confined to temperate and tropical zones. The striped mullet is one of four members of the genus reported to occur in Indian River Lagoon. However, only the white (or silver) mullet, *M. curema* (Valenciennes) is also relatively widespread and abundant. The other two species are tropical forms infrequently encountered in the southernmost portion of the estuary.

5.2.2.1 <u>Life History</u>

Adult striped mullet typically exhibit annual cycles involving periods of high mobility associated with spawning migrations, interspersed with relatively sedentary "trophic" periods spent in estuaries and rivers (Martin and Drewry, 1978). During the trophic phase, local movements consist largely of travel to and from shoal areas (e.g., tidal flats) with the tides or in relation to day and night (Tabb and Manning, 1961). Often feeding occurs at night in shallows, followed by retreat to channel areas during the day.

Along Florida's east coast, striped mullet spawning migrations begin in late summer and early autumn. Males and larger females are usually the earliest to begin moving seaward. Schools appear to increase in density, and then movement out into the ocean occurs. Striped mullet apparently spawn in a wide range of depths over the continental shelf. Although there is some evidence of spawning nearshore and along beaches in the Gulf of Mexico (Breder, 1940; Gunter, 1945), most of the activity seems to be at least several kilometers offshore. Eggs are broadcast near the surface (usually at night) and development is fairly rapid, with hatching typically in less than two days when sea temperatures exceed 20°C (Martin and Drewry, 1978). With the assistance of onshore winds and currents, the planktonic larvae move toward estuaries which they enter at about 4-6 weeks posthatching. By the time they enter estuaries, the young striped mullet are in the post-larval or "prejuvenile" phase (10-20 mm total length, TL).

As interpreted from the appearance of young in estuaries of peninsular Florida, some spawning occurs as early as September and persists through the following spring, with pronounced peaks in November-December and again in February-March (Martin and Drewry, 1978). Upon entering estuaries, young striped mullet congregate in low-salinity peripheral areas, such as the lower reaches of tributary rivers/canals and marshes. As they increase in size, the young mullet are captured less frequently and in lower numbers in marginal habitats. However, it is unclear if this reflects a definite ontogenetic shift in habitat preference or merely the fact that striped mullet become increasingly adept as they grow (especially beyond 80 mm TL) at avoiding the fine-mesh gear used in shallow habitats (Springer and Woodburn, 1960). The consensus of literature indicates that once striped mullet transform from an omnivorous to herbivorous diet (at about 50 mm TL, see below) they become ubiquitous within the estuary like adults.

Growth of juveniles is relatively slow in the winter and early spring, averaging only a few millimeters per month (Springer and Woodburn, 1960). Later, presumably in response in increased temperatures and availability of forage, the striped mullet grow more rapidly so that the average incremental increase over the first year of life is about 100 mm (Killam, et al., 1992). In adults, growth tends to slow to 40-60 mm per year.

Age at maturity varies widely throughout the extensive range of striped mullet (Martin and Drewry, 1978), but tends to occur at 1-3 years in Florida populations (Broadhead, 1953). Males mature at about 250-300 mm TL and females at about 280 to 350 mm. The maximum size achieved by striped mullet is about 900 mm (Martin and Drewry, 1978), although few Florida individuals exceed 500 mm. Annually, each female striped mullet produces about 600 to 700 eggs per gram of body weight.

5.2.2.2 Ecological Role

The striped mullet is one of the few large fishes in the Indian River Lagoon system that feeds almost exclusively (as juveniles >50 mm and adults) on the lowest trophic level -- i.e., living and dead vegetable material. As such, the striped mullet plays an important ecological role in the flow of energy in the estuary (Odum, 1970; Collins, 1985). Initial feeding of the pelagic marine larvae is on zooplankton. Harrington and Harrington (1961) found that when the striped mullet first enter Indian River marshes (at <20 mm TL) they prey entirely on copepods and mosquito larvae. As they grow larger, the juvenile mullet tend to consume increasingly greater proportions of vegetable detritus and become strictly herbivorous at about 50 mm (Killam, et al., 1992).

The feeding behavior of larger juvenile and adult mullet varies widely to take advantage of the various forms in which plant material is available. The diet includes primarily epiphytic and benthic microalgae, macrophyte detritus, and sediment particles. In the gizzard-like pyloric stomach of the mullet, ingested sediment functions as a grinding medium. When sediment particles are heavily populated by adherent micro-organisms (e.g., bacteria) they appear to be selectively ingested for their nutritional value (Odum, 1970). Juvenile and adult mullet often graze on algae attached to submerged surfaces (both free and bottom substrates), as well as on drifting algal mats. They are also commonly observed "nibbling" at the water surface where algal/detrital froth ("scum") is concentrated by the wind and/or currents.

Competitors of striped mullet include its congener (*M. curema*), pinfish, sheepshead minnows, and some decapod crustaceans which occasionally consume significant quantities of vegetable detritus (e.g., pennaeid shrimp). Because of their relative abundance and tendency to occur in large aggregations, striped mullet are common prey of many fish larger than themselves, as well as piscivorous (fish-eating) birds and mammalian dolphins.

5.2.2.3 Habitat Requirements

The striped mullet exhibits wide tolerance to most environmental variables, particularly as adults. Although adults are broadly euryhaline and commonly occur in freshwater, there is some evidence that young <40 mm TL are incapable of surviving direct transfer from brackish to fresh conditions (Nordlie, et al., 1982).

Like many other Indian River Lagoon fishes, the striped mullet is vulnerable to the effects of severe cold weather. Gilmore, et al., (1978) observed mortality among adults (but not juveniles) where water temperatures dropped below 10°C.

5.2.3 Spotted Seatrout - *Cynoscion nebulosus* (Cuvier)

The spotted seatrout (commonly known as speckled trout or "speck") is an economically and ecologically important species in the Indian River Lagoon complex. Among the species which support both commercial and recreational fisheries, the spotted seatrout is probably the most valuable finfish on a systemwide basis (Anderson and Gehringer, 1965; Snelson, 1983). It is a schooling, voracious predator, occurring in sufficient frequency and abundance to play a major role in the dynamics of forage animals. Essentially nonmigratory, the spotted seatrout spends its entire life in the estuary and moves into the Atlantic only occasionally in response to environmental extremes (Tabb, 1966). Information on commercial landings of this and other important species are included in the Uses of the Lagoon companion volume in this Technical Report series.

Aa member of the family Sciaenidae (drums), the spotted seatrout ranges along the Atlantic and Gulf of Mexico coasts from Cape Cod to the Gulf of Campeche. Two other members of the genus *Cynoscion* are known to occur in Indian River Lagoon, but neither the silver seatrout (*C. nothus*) nor the weakfish (*C. regalis*) is common in the interior waters of the estuary (Gilmore, 1977).

5.2.3.1 Life History

Spotted seatrout may spawn throughout much of the year in Indian River Lagoon (Killam, et al., 1992), although Tabb (1958) noted that most activity occurs from spring through autumn when water temperatures are 21°C to 28°C. While a wide variety of spawning habitats has been reported, Tabb (1961) and others have suggested that preferred sites are in deeper areas inside the Lagoon (e.g., scour channels in grassflats). The trout gather in milling schools to broadcast their eggs at night. Fecundity estimates have ranged from 14,000 to 1.5 million eggs per spawn, depending upon size and age of the female (Pearson, 1929; Tabb, 1961; Sundararaj and Suttkus, 1962). Over the life span of a spotted seatrout cohort, most of the eggs are produced by 2- to 4-year-old females.

The fertilized eggs are clear and spherical, ranging in diameter from 0.73 to 0.98 mm (Miles, 1950; Arnold, et al., 1976; Fable, et al., 1978). At salinities around 25 ppt, spotted seatrout eggs are demersal (sink), whereas at 30 ppt they are pelagic (float) (Kostecki 1984).

Hatching occurs at 1.30-1.56 mm SL, after 15 to 40 hours, depending upon temperature (Smith, 1907; Fable, et al., 1978). At 25°C, the mouth is formed within 40 hours and yolk is absorbed by 60 hours post-hatching (Fable, et al., 1978). Initially, spotted seatrout larvae tend to be pelagic and then move to the bottom after 4-7 days (Kostecki, 1984). During most of the larval and early juvenile phase of development (up to about 50 mm total length, TL), which typically requires 6 to 8 weeks, spotted trout tend to remain scattered near the bottom and in association with cover such as vegetation or shell rubble (Tabb, 1966). Following this demersal phase, the trout begin to school. Strong schooling behavior tends to persist until the trout are 5 or 6 years old, by which time most of the males have died and surviving females assume a more solitary existence.

Growth rates and maximum size achieved by spotted seatrout vary substantially among and within different estuaries, largely in response to physical conditions and availability of food (Kostecki, 1984). Because of their tendency to remain confined in natal bays and lagoons, spotted seatrout exhibit significant genetic differences between estuarine stocks (Weinstein and Yerger, 1976). In Indian River Lagoon, most males and roughly half of the females mature at about 300 mm TL in their second calendar year (Age I); virtually all of the fish are capable of spawning by 400 mm at Age II (M. Murphy, FDNR, personal communication to Killam, et al., 1992). Whereas they mature earlier, male spotted seatrout grow more slowly and have shorter life spans than females.

5.2.3.2 Ecological Role

On a systemwide basis, the spotted seatrout is probably the dominant large aquatic carnivore in the Indian River Lagoon. They may compete locally and/or seasonally with such predators as sharks, snook, bluefish, jacks, and flounder, but spotted seatrout are more ubiquitous and abundant. Furthermore, they tend to feed throughout the water column while some of the other large predators concentrate on either demersal or pelagic prey.

A number of studies have documented pronounced changes in the diet of spotted seatrout as they grow (Moody, 1950; Carr and Adams, 1973; Tabb, 1961; Lorio and Perret, 1980; Perret, et al., 1980; Hettler, 1989). Larvae and early juveniles (<30 mm) feed primarily on copepods, although larval mysids, larval decapods (crabs/shrimp), larval fish, and amphipods are also commonly taken. As the trout progress through later juvenile phases, mysids, grass shrimp, penaeid shrimps, and fishes increase in dietary importance. Older juvenile and adult spotted seatrout feed primarily on fish and larger penaeid shrimp. Tabb's (1966) list of the most frequently and abundantly consumed prey of spotted seatrout encompasses many of the ecologically dominant primary and secondary consumers from various estuarine habitats: anchovies, sheepshead minnows, pinfish, mojarras, sailor's choice (a grunt), mullet, gobies, and brown and pink shrimp.

Spotted seatrout capture their prey by rapid lunging or darting. The conspicuous canine teeth assist in grasping relatively large prey during capture and swallowing. Seatrout are capable of subduing and ingesting fish up to a third as long as themselves, and are commonly observed with portions of large victims still protruding from the mouth (Tabb, 1966).

Important predators of spotted trout (besides humans) include large sharks (e.g., hammerheads), bluefish, large jacks, porpoises, and some birds.

5.2.3.3 Habitat Requirements

Spotted seatrout are primarily estuarine residents and are known to use, at least on occasion, virtually all major types of habitat within the Indian River Lagoon. They tend to remain in nontidal portions of estuary where seasonal changes in temperature and salinity rather than daily fluctuations are the primary controlling factors (Tabb, 1966). In comparing populations throughout the range, Tabb (1966) noted that spotted seatrout tend to be particularly successful in largely landlocked systems such as Indian River Lagoon.

The following factors appear to be of greatest importance in determining habitat suitability for the spotted seatrout (Tabb, 1958; Kostecki, 1984):

- Availability of large areas of shallow, quiet, brackish water
- Absence of predators
- Absence of competitors
- Presence of large areas of submerged vegetation (e.g., seagrass beds)
- Abundance of grazing crustaceans (e.g., penaid or palaemonid shrimp) and fishes of suitable size to be eaten year-round
- Relatively stable temperature, ranging from about 60°F to 80°F (16°C to 27°C)
- Adequate deeper areas (10-20 ft [3-6 m]) adjacent to seagrass flats that can serve as refuge from winter cold

Spotted seatrout are well-adapted to estuarine conditions and therefore tolerate a wide range of physiochemical conditions. Tabb (1966) noted that, unlike many estuarine forms in which the young tend to prefer and/or tolerate lower salinities, spotted seatrout young and adults seem about equally tolerant to environmental variations. Relatively abrupt changes in physicochemical conditions (e.g., storm-induced freshets or severe cold waves) are known to elicit mass movements as the trout seek to avoid the extreme conditions. To the extent that they are unable move far enough, quickly enough, spotted seatrout (especially the young) may suffer large-scale mortality due to rapid drops in both salinity and temperature (Tabb, 1966; Kostecki, 1984). For example, Tabb (1958) noted a die-off in the upper Indian River Lagoon system when temperatures in deeper channel areas dropped from about 85°F (18°C) to below 50°F (10°C). He (1966) described how the usual pothole and channel sanctuaries of the Lagoon can become "death traps" during severe cold waves. Before they can react, the fish become immobilized and many individuals are stranded. At such times the remoteness of tidal inlets, normally considered an asset for the species, becomes a significant liability (Tabb, 1966).

Given sufficient time for acclimation, spotted seatrout are able to survive at temperatures between 36°F and 105°F (4°C and 40°C), but the optimal range is considered to be 68°F to 89°F (20°C to 32°C) (Kostecki, 1984). According to Arnold, et al. (1976), optimal spawning temperatures range from 68°F to 86°F (20°C to 30°C).

Spotted seatrout are capable of surviving at salinities from 0.2 to 77 ppt, although the ideal range for adults appears to be 15 to 35 ppt (Tabb, 1966). Optimal spawning salinities in the laboratory are 20-35 ppt (Arnold, et al., 1976), and the spawning peaks of wild Florida spotted seatrout were reported at 30-35 ppt (Tabb, 1958, 1966).

As predominantly sight-feeders, spotted seatrout tend to prefer relatively clear water. Hurricane induced turbidity has been cited as contributing to mortality in some estuaries (Tabb and Manning, 1961; Perret, et al., 1980).

5.2.4 Red Drum - *Sciaenops ocellatus* (Linnaeus)

The red drum (commonly known as redfish) is one of the most important sportfishes around the entirety of Florida's coast. A sizeable commercial fishery for this species formerly occurred in many areas around Florida, but sales were outlawed by the state in 1987, primarily in response to substantial declines in stocks along the Gulf coast (Killam, et al., 1992). Red drum are frequently encountered in all major habitats of the Indian River Lagoon system except tributaries/creeks and mosquito impoundments (Gilmore, 1977). Snelson's (1983) account and a consensus of reports from the popular literature suggest that red drum are more common in the northern part of the system (e.g., Mosquito Lagoon). Although they spawn primarily (if not exclusively) outside the Lagoon system, and most mature individuals tend to spend much of their time in Atlantic continental shelf waters, red drum are heavily dependent upon the estuary as a nursery and foraging area during the first few years of life.

Red drum are members of the family Sciaenidae (drums) and occur along the western Atlantic and Gulf of Mexico coast from the Gulf of Maine to Vera Cruz, Mexico (Mercer, 1984). The genus *Sciaenops* contains only this species.

5.2.4.1 Life History

The overall spawning season of red drum along the east coast of Florida may extend from late spring through early winter, although most of the activity appears to be from late summer through early autumn (Johnson, 1978; Mercer, 1984). An autumn peak of recruitment of young into the Indian River Lagoon is indicated by Brown-Peterson and Eames (1990). Spawning occurs primarily along outer coasts near inlets (Johnson, 1978), although there is some evidence of egg laying in the lower portions of estuaries (Killam, et al., 1992). Depending on size and age, females produce 0.5 to 3.5 million eggs (Pearson, 1929), which upon release are buoyant, transparent, spherical, and average 0.93 mm in diameter (Holt, et al., 1981b).

Hatching of red drum eggs occurs in about one day at 72°F to 78°F (22°C to 24°C) (Arnold, et al., 1977; Holt, et al., 1981b). The newly hatched larvae are slightly less than 2 mm long, and are transported by tidal currents into bays and lagoons. The time from hatching until arrival in the shallow marginal areas of estuaries is a critical period for red drum (Buckley, 1984). Laboratory studies suggest that both temperature and salinity play a key role in the survival of yolk-sac larvae (Holt, et al., 1981a).

The yolk-sac phase persists for 2-4 days, depending upon temperature, and first feeding typically occurs on the third day after hatching (Holt, et al., 1981a). The mouth is well-formed and fin rays begin to appear when the larvae are about 4 mm long (Johnson, 1978). The juvenile phase, as defined by attainment of the full complement of fin rays, is achieved when red drum are about 15-20 mm long.

Growth varies substantially depending upon location, but is generally quite rapid, averaging about 30 mm per month during the first six months and about 25 mm per month over the first two years (Buckley, 1984). Males and females usually achieve maturity by third or fourth, and fourth or fifth year of life, respectively (Pearson, 1929). Five-year-old fish are believed responsible for the bulk of spawning (Johnson, 1978). Size at maturity is typically

700-800 mm, although some "ripe" males as short as 400 mm have been reported (Simmons and Breuer, 1962).

Red drum can ultimately reach total lengths exceeding 5 ft (1.5 m) and weights up to 88 lbs (40 kg) (Mercer, 1984). Offshore populations in the northern Gulf of Mexico appear to be comprised mainly of individuals more than 10 years old, with maximum longevity estimated at 37 years (Beckman, et al., 1988). One specimen from the east coast of Florida was estimated to have lived 33 years (Mercer, 1984). It is reported that red drum generally spend most of their time outside estuaries after their first spawning migration (Buckley, 1984), but older adults are commonly taken in some bays and lagoons. For example, Snelson (1983) mentioned the capture of individuals up to 35 lb (16 kg) in deeper areas of the northern part of the Indian River Lagoon system.

5.2.4.2 Ecological Role

The red drum is an important carnivore in Indian River Lagoon and adjacent waters of the Atlantic. Larvae feed primarily on planktonic microcrustaceans, especially copepods (Bass and Avault, 1975; Peters and McMichael, 1987). Juveniles up to about 50 mm total length prey largely on mysidaceans, amphipods, and polychaetes, depending upon availability. As they grow larger, red drum in estuaries continue to use mysids, but decapod crustaceans (penaeid shrimps and crabs) and fish become increasingly important in the diet (Boothby and Avault, 1971; Killam, et al., 1992). Common fish prey include mullet, spot, and pinfish. The blue crab (*Callinectes sapidus*) is heavily used by red drum whenever available; several studies suggest that blue crabs may be the most important prey of large adult red drum (Boothby and Avault, 1971; Overstreet and Heard, 1978; Mercer 1984; Killam, et al., 1992).

Red drum compete for food with all other carnivores of comparable size and abundance. The importance of red drum as prey is not well documented (Springer and Woodburn, 1960), but they are presumably vulnerable to capture by any common, active carnivores larger than themselves.

5.2.4.3 Habitat Requirements

Red drum adults are broadly euryhaline and eurythermal, but abrupt changes in either salinity or temperature tend to induce movement into deeper areas of more stable conditions (Mercer, 1984; Buckley, 1984). Red drum juveniles and adults have been captured in salinities from 0-55 ppt and at temperatures from 36°F to 90°F (2°C to 33°C). In Texas, the red drum have been successfully transplanted into freshwater reservoirs; nevertheless, Simmons and Brueur (1962) considered 20-40 ppt to be the optimum salinity range. Both salinity and temperature appear to be important limiting factors in spawning and embryonic/larval development (Buckley, 1984).

Laboratory studies indicate that the optimum salinity and temperature for red drum spawning are about 30 ppt and 82°F (25°C), respectively (Holt, et al., 1981a). The eggs tend to sink at salinities <25 ppt, which is considered detrimental. After about 24 hours post-hatching, salinity seems no longer to be a limiting factor in survival and growth of the young, but temperature remains important. Holt, et al., (1981a) found that temperatures below 82°F (25°C) reduced larval survival and growth. These authors felt that the critical transition to active feeding may be inhibited when the water temperature drops below 68°F (20°C). Red drum year-class strength may be adversely affected by unusually low salinities or temperatures in the nearshore Atlantic spawning areas or tidal inlets at critical periods in early development (Holt, et al., 1981a).

Studies in Tampa Bay suggest that smaller juvenile red drum preferentially inhabit the low- to moderate-salinity (0.5-18 ppt) portions of the estuary. *Sciaenops ocellatus* is one of several species cited by Gunter (1938; 1945) as exhibiting a tendency for smaller (younger) individuals to prefer lower salinities than larger (older) specimens.

Although the red drum is fairly eurythermal compared to many estuarine species of Florida, they are susceptible to mass mortalities when temperatures approach freezing (Gunter, 1941; Gunter and Hildebrand, 1951; Schwartz, et al., 1981). Apparently, however, red drum are quicker (than some others) to respond to declining temperatures and move into deep refuges (Killam, et al., 1992).

Small juvenile red drum (< 100 mm) tend to avoid current and almost exclusively inhabit the shallow, protected areas of estuaries (Buckley, 1984). They are attracted to seagrass beds, when available, but are also common over open, usually muddy, bottoms. Older juveniles commonly occur in or along the edges of marshes. In estuaries where shallow "mud flats" exist adjacent to marshes it is not unusual for large aggregations of older juvenile and young adult red drum to move into and feed in such areas, particularly in the twilight hours at dawn and dusk. Most coastal anglers are also keenly aware of the tendency for red drum (and other large carnivores) to congregate near the mouths of marsh and mangrove creeks during ebb tides, where they take advantage of an exodus of forage animals.

5.2.5 Common Snook - *Centropomus undecimalis* (Bloch)

The common snook remains one of the most popular estuarine gamefish in Florida, despite a substantial decline in overall abundance in recent decades. The species once supported a commercial fishery, but concerns about over exploitation led the State of Florida to ban the harvest of snook for sale in 1957. Marshall (1958) believed that habitat degradation and loss also contributed significantly to reduction of snook populations. Common snook are euryhaline and occur throughout the Indian River Lagoon system (Gilmore, 1977; Snelson, 1983). They are voracious predators that consume a wide variety of forage fish and decapod crustaceans.

Common snook, also known as robalo, live in coastal waters of the tropical and subtropical western Atlantic from South Carolina to Brazil. The common snook is one of three members of the genus reported to occur in Indian River Lagoon. The fat snook, (*C. parallelus*) Poey, and the tarpon snook, *C. pectinatus* Poey, are taken only occasionally, in the southern portion of the Lagoon.

5.2.5.1 Life History

Although a non-migratory estuarine species throughout most of its life, common snook of the Indian River Lagoon system appear to spawn almost exclusively in shallow, nearshore waters of the Atlantic (Gilmore, et al., 1983). The overall spawning season is protracted, from spring through late autumn. Peaks of juvenile recruitment into the Lagoon usually occur from June to August and again from October to January, according to Gilmore, et al., (1983). These authors noted little relationship between temperature or salinity and spawning, but found a high positive correlation with mean monthly rainfall.

In the Indian River Lagoon, young common snook exhibit a very structured pattern of successive use of different habitats as they grow (Gilmore, et al., 1983). Upon entering the estuary at an estimated 15-30 days posthatching, they tend to congregate in freshwater areas near tributary and canal mouths. Favored habitat for late larvae and early juveniles is within or near shoreline vegetation such as panic grass and smartweed. At about 40-70 days of age (40-60 mm standard length, SL) the juvenile snook move into salt marshes, where they remain until about 100 mm SL. The snook then move into ill-defined transitional habitat(s), perhaps channel areas (Gilmore, et al., 1983), and re-appear at an estimated 5-11 months of age (150-300 mm, mean 240 mm SL) in seagrass beds of the open Lagoon. Grass beds with relatively high percent cover (regardless of plant species) and located fairly far from Atlantic inlets appear to be favored (Gilmore, et al., 1983).

Growth rates of juvenile Indian River common snook estimated by Gilmore, et al., (1983) varied with peak recruitment seasons and habitats, but the overall average was about 1 mm per day, which is similar to that reported in other parts of Florida and in captivity (Fore and Schmidt, 1973; Shafland, 1977; Killamm, et al., 1992).

Some common snook achieve maturity at 300 ml SL, in the second calendar year of life, and most are mature by 415 mm SL (Marshall, 1958; Volpe, 1959; Fore and Schmidt, 1973). There is substantial evidence that, at least in Tampa Bay, snook commonly exhibit protandric hermaphroditism, or male-to-female sex reversal, with growth (Killam, et al., 1992). Thus, most younger, smaller adults are males and most older, larger adults are females. This is not uncommon in many groups of marine spiny-rayed fishes and may also occur in snook of the Indian River Lagoon. Some common snook may survive as long as 20 years and achieve lengths exceeding 1.0 m.

5.2.5.2 <u>Ecological Role</u>

The common snook is strictly carnivorous throughout its life. Larvae and early juveniles (<45 mm SL) tend to prey mainly on microcrustaceans, especially mysidaceans (opposum shrimps) and calanoid copepods (Killam, et al., 1992). While concentrated in the peripheral freshwaters and marshes of Indian River Lagoon, the young snook rely heavily on small fish and palaemonids (grass shrimp), and occasionally consume insects (Gilmore, et al., 1983). Recently emerged young of the prolific livebearing mosquitofish (*Gambusia affinis*) are extremely important prey of opportunistic juvenile snook along vegetated shorelines. Other cyprinodontoid fishes which abound in such habitats (killifishes, topminnows), as well as anchovies and silversides, are also important forage for common snook.

The larger snook associated with seagrass beds have slightly wider diet, but still eat primarily the locally dominant forage fishes (e.g., anchovies, pinfish) and grass shrimp (Gilmore, et al., 1983). Like most predatory fish, common snook are known to be cannibalistic. Adult common snook tend to have a much wider diet than the young (Marshall, 1958; Fore and Schmidt, 1973). Shrimp and crabs are more heavily used, but the adult snook are still predominantly piscivorous. Important prey fishes include pinfish, anchovies, sardines and other herringlike forms, mojarras, and lizardfish.

Chief competitors of the common snook are other ubiquitous predators such as spotted seatrout, carangids (jacks), piscivorous birds, and dolphins (the mammals). Snook are themselves eaten by most carnivorous vertebrates.

5.2.5.3 Habitat Requirements

Like many primarily estuarine species, the common snook is tolerant of a fairly wide range of environmental conditions. Within the normal ranges of salinity and temperature, physical habitat features appear to be much more important to the survival and success of common snook than water quality (Killam, et al., 1992).

However, as representatives of a basically tropical group, common snook are fairly sensitive to low water temperatures. Cold weather usually causes juvenile snook to seek deeper areas with more stable temperatures (Killamm, et al., 1992). Mortality among juveniles seems to occur as temperatures drop below 57°F (14°C), and feeding tends to cease about 3°F (2°C) higher than the lethal minimum for a given experiment (Shafland and Foote, 1983). Adult common snook have been reported to exhibit cold stress at temperatures as high as 54°F (13°C), and are believed to be unable to survive below 43°F (6°C) (Gilmore, et al., 1987).

Common snook are one of the main species considered susceptible to severe cold waves in Indian River Lagoon and other Florida estuaries. Abrupt drops in temperatures, such as occasionally caused by hurricanes along near-shore marine habitats, may temporarily suppress spawning of common snook (Gilmore, et al., 1983).

In the absolute sense of tolerance, common snook are quite euryhaline in the range from freshwater to oceanic salinities. However, the progressive use of preferred habitats by juveniles in Indian River Lagoon described by Gilmore, et al., (1983) (see Life History) creates the impression of a positive correlation between salinity and size.

Gilmore, et al., (1983) postulated that dissolved oxygen concentrations may be an important factor in the ontogenetic habitat shifts of Indian River Lagoon snook. There is some evidence that juveniles are more tolerant of hypoxic conditions than adults (Shafland and Koehl, 1979), but even the small snook appear to be forced out of flooded marsh and mangrove habitats when dissolved oxygen levels become persistently low. Peterson and Gilmore (1991) and Peterson, et al. (1991) described the effects of hypoxic conditions on the occurrence and vertical distribution of juvenile common snook, and have found that hypoxic conditions force the snook to the surface of the water column.

Except when involved in their spawning migrations or forced by cold into deeper areas, common snook show a strong tendency to associate with vegetation and/or other forms of submerged or emergent structure.

5.2.6 Pinfish - *Lagodon rhomboides* (Linnaeus)

The pinfish (sometimes called pin perch) is one of the most commonly encountered fishes throughout most major habitats of the Indian River Lagoon system (Gilmore, 1977) and is a numerical dominant in seagrass beds (Stoner, 1983; Gilmore, 1988b). Widely reported as an important prey item for many carnivores, the pinfish is a popular bait. It is a grazing omnivore which tends to become increasingly herbivorous with age. Because of its ubiquity and abundance, the pinfish plays a major role as a lower-level consumer in many estuaries.

Pinfish occur in nearshore marine and estuarine waters of the Atlantic and Gulf of Mexico from Cape Cod, Massachusetts to the Yucatan Peninsula (Caldwell, 1957). The pinfish is one of eight members of the "porgy" family, Sparidae, reported to occur in Indian River Lagoon. The only other common and relatively abundant sparid in the Lagoon is the sheepshead (*Archosargus probatocephalus)*, which is a much larger, but also omnivorous/herbivorous, fish of some commercial and recreational value.

5.2.6.1 <u>Life History</u>

Pinfish are believed to spawn offshore, primarily near the surface (Johnson, 1978). In late summer and early autumn, aggregations of pinfish which have been relatively sedentary inside estuaries begin moving out into nearshore marine areas. Maturation of the gonads appears to be delayed until during the migration or after the fish have arrived near spawning locations (Hansen, 1970). As judged by the appearence of larvae, spawning off eastern Florida occurs from about mid-October through March, with a December/January peak (Caldwell, 1957).

At about 67°F (20°C) and roughly oceanic salinities, most pinfish eggs hatch in 48 hours (Johnson, 1978). The larvae are pelagic and find their way, presumably with the assistance of onshore winds and currents, into estuaries by the time they are about 11 mm standard length (SL). Recruitment of the young pinfish into shallow estuarine areas occurs primarily from December to May (Caldwell, 1957). The juvenile phase of development begins at about 15-20 mm SL. Smaller juveniles tend to remain in relatively shallow portions of the estuary and are particularly abundant in and around seagrass beds (Stoner, 1983, Gilmore, 1988b). Larger juveniles and small adults are somewhat wider ranging in the Lagoon system, but they still have strong affinities for grass beds and other areas with some type of cover. After their first year of life pinfish tend to spend most or all of their time outside the estuary in nearshore marine habitats (Johnson, 1978).

Pinfish achieve a maximum total length of about 250 mm (Hoese and Moore, 1977), and probably seldom survive beyond their fourth year. The earliest recruits tend to reach 70-75 mm by the end of their first summer, and some exceed 100 mm by the end of their first year (Caldwell, 1957). Daily growth is fairly rapid (0.2-0.3 mm) in the spring and summer and much slower (0.01 mm) in the autumn. Annual growth averages 55 mm and 45 mm, respectively, in the second and third years of life. Some pinfish may become sexually mature during their first year (at total lengths of 80-110 mm) and, in Florida, virtually all individuals spawn during their second year (Hansen, 1970). Few data are available on fecundity, but Caldwell (1957) estimated that a 157-mm female taken near Vero Beach in late November contained 90,000 eggs.

5.2.6.2 Ecological Role

Like those of most marine fishes, the pelagic larvae of pinfish presumably feed on planktonic microcrustaceans. Soon after they transform into juveniles, a temporary set of conical teeth is relaced by incisorlike teeth adapted for shearing (Johnson, 1978). Early juvenile pinfish appear to feed primarily on small invertebrates, especially amphipods, which are gleaned from among seagrass blades or coarse bottom materials (Stoner, 1980, 1982, 1983). As they grow larger, the pinfish increasingly graze on plant material. Adults are essentially herbivorous, although benthic invertebrates are occasionally ingested (Hildebrand and Schroeder, 1928; Gunter, 1945).

Competitors of the pinfish within the Lagoon include other small-mouthed grazers of invertebrates (e.g., some pipefishes and gobies) and vegetable material (e.g., mullets). Because they are ubiquitous and relatively abundant, pinfish are heavily used as forage by most predators (e.g., snooks, seatrouts, snappers, barracuda, jacks).

5.2.6.3 Habitat Requirements

The pinfish is broadly euryhaline and eurythermic. Pinfish have been recorded from freshwater to salinities as high as 44.5 ppt, and in temperatures from 45°F to 100°F (7°C to 38°C) (Johnson, 1978). The most important factor in habitat choice appears to be availability of vegetation (Gunter, 1945; Kilby, 1955; Caldwell, 1957), or at least some form of cover such as pilings. In the absence of cover, pinfish appear to show no particular preference for any bottom types. Caldwell (1957) observed that pinfish sometimes completely bury themselves in soft substrates when under stress.

5.3 SHELLFISH

5.3.1 Shellfish Industry

The major sources of consumable shellfish within the Indian River Lagoon are the blue crab (*Callinectes sapidus*), the southern hard clam (*Mercenaria campechiensis*) and the northern hard clam (*Mercenaria mercenaria*), and the American oyster (*Crassostrea virginica*). Table 5-1 shows recent commercial harvest amounts of these three species, as well as the stone crab (*Menippe mercenaria*) which is a relatively minor species commercially. The life history, ecological role, and habitat requirements of the three major species are detailed in Section 5.3.3. These shellfish were used by early native Americans such as the Timucan and Ais Indians as a major component of their diet (Doran and Dickel, 1988), and they remain important seafood products today.

The blue crab is a decopod crustacean that is common throughout the Gulf and Atlantic coasts of the United States. It is capable of surviving in a wide range of salinities and other water quality conditions (Van Heukelem, 1991) and is common throughout the Indian River Lagoon complex in many different habitats. Of the major shellfish species, it is the only one that moves from habitat to habitat and site to site during its adult life stage.

The blue crab also has been the most heavily harvested shellfish species in terms of total poundage, accounting for almost 80% of the total commercial shellfish landings between 1958 and 1988 in the Indian River Lagoon complex (see Uses of the Lagoon Technical Report). Total landings peaked in 1966 with over 5 million pounds (Rathjen and Bolhassen, 1988). Landings have ranged between 1.5 and 3 million pounds from 1976 through 1988 in a fairly stable manner. Non-commercial blue crab harvesting is also a major activity throughout the Indian River Lagoon complex. Crabs are caught for recreation and home consumption in crab traps, on baited lines, and in dip nets fished from piers throughout the region, although they appear to be most prevalent in Brevard, Indian River, and Volusia Counties which account for over 90% of the commercial catch.

TABLE 5-1

SHELLFISH HARVESTS WITHIN INDIAN RIVER LAGOON REGION - 1988

COUNTY	LANDINGS IN POUNDS			
	HARD CLAM	OYSTER	BLUE CRAB	STONE CRAB
Volusia	77,778	50,018	304,286	552
Brevard	627,792	6,533	1,768,650	9,742
Indian River	55,052	425	14,479	0
St. Lucie	162	0	19,328	1,344
Martin	0	0	440	0
TOTAL	**760,784**	**56,976**	**2,107,183**	**11,642**

Source: Florida Department of Natural Resources and Marine Fisheries Information System

The American (or eastern) oyster was second to the blue crab in total commercial harvest poundage in the region from the earliest documented records in 1958 to about 1977, when it was surpassed by the hard clam (Rathjen and Bolhassen, 1988). Except for the years 1969-1971 and 1982, total commercial landings have been less than 150,000 pounds. Almost all of the commercial harvest has come from Volusia, Brevard, and Indian River Counties, with Brevard County generally accounting for over 70% of the regional total.

The American oyster is a filter feeding bivalve mollusk that has a short free-swimming larval stage and then as an adult becomes permanently attached to a hard substrate. Colonies of oysters generally tend to form beds or "bars" composed of shells from many generations of oysters. Because of their abilities to tightly close their shells, they are well adapted to estuarine conditions and can tolerate fairly wide ranges of salinity and other water quality factors (Kennedy, 1991). Although the oyster itself may withstand a wide range of water quality variation, it can concentrate contaminants such as heavy metals and also fecal coliform bacteria because of its filter feeding (Kennedy, 1991). Thus, while it may survive water quality degradation, it may no longer be suitable for harvest and ingestion by humans. Numerous other species that feed on oysters may also be subject to effects of accumulated contaminants as well.

The hard clam is a common bivalve mollusk that is often referred to as quahog, little neck, and cherrystone (depending on the size of the clam). Although found throughout the Indian River Lagoon complex, by far the largest concentrations are located in Brevard and Indian River Counties. The nomadic Timucan and Ais tribes first ate the clam during their travels to and from the Lagoon. As these tribes became more permanent residents, clams became a staple food source, which is documented by the presence of clam shells found in Indian middens (refuse mounds) scattered along the Lagoon (Hale, 1984). The shallow waters, combined with moderately hard sandy bottoms and salinity from 20 to 35 ppt, created an abundance of harvestable clams. As native Americans were pushed away from the Indian River Lagoon by the early Spanish and English settlers, the hard clam became limited as a food source, used only by local residents inhabiting the shores of the Lagoon.

Commercial harvesting of hard clams in Florida began in 1880. Although it is unclear when commercial clamming began in the Indian River Lagoon, it is assumed to have been around the same time (Barile and Rathjen, 1985; Rathjen and Bolhassen, 1988). Throughout the settlement and urbanization period of the Indian River region to 1970, the clamming and shellfish industry was limited in scope. In the early 1980s, harvests of hard clams increased tenfold over previous years. This increased production of hard clams in the Indian River Lagoon was partly attributed to the decline of clam populations elsewhere in the United States with an abundant supply of clams available for harvest in the Lagoon. Production of hard clams was also enhanced by the use of several methods for growing and cleansing clams. These include aquaculture of clams and depurpuration (cleansing of bacteria) by relaying and UV light.

By 1985, over 1.5 million pounds of hard clams worth an estimated 6 million dollars were harvested, packaged and shipped annually to domestic and international markets from the Indian River Lagoon (Rathjen and Bolhassen, 1988). This new-found demand for hard clams created an economic boom for Brevard and Indian River Counties. The number of commercial clam harvesting licensees was 551 in 1989. Local clammers quickly found that the notoriety of the abundance of Indian River clams had spread to other states, and large numbers of clam harvesters immigrated from traditional clamming states such as Rhode Island, North Carolina and Virginia, to the Indian River Lagoon. The clamming/shellfish industry grew exponentially between 1970 and 1985, when a peak in harvest was apparently reached. By 1989, the total hard clam harvest had dropped to 760,784 pounds. The tremendous increase and subsequent decline in shellfish harvesting has resulted in the implementation of numerous rules and regulations to protect and prevent the over the exploitation of this valuable resource.

5.3.2 Shellfish Regulations

Hard clams, oysters, and blue crabs are consumable seafoods and therefore must be free of contaminants and designated as safe for human consumption. Many programs administered by federal and state agencies mandate laws and regulations that involve the management, public health, and future of this valuable renewable resource. The state of Florida is a member of the National Shellfish Sanitation Program (NSSP) and the Interstate Shellfish Sanitation Conference (ISSC). These organizations establish uniform public health standards.

The shellfish industry within the Indian River Lagoon is regulated by the FDEP and the Marine Fisheries Commission (MFC) which is delegated rule making authority over harvesting and culture of marine life. The FDEP is responsible for the conservation of the natural resources of the state. The Comprehensive Shellfish Control Code, Chapter 16R-27 Florida Administrative Code (FAC), regulates the sanitary practices for catching, harvesting, packaging, and preserving shellfish. Additionally, Chapter 46-17 FAC provides protection for shellfish resources and controls depletion. The Chapter also includes protection of seagrass beds, provides minimum size limits, regulates the season and time in which harvesting can occur, limits harvesting methods (such as feet and hands or use of hand rakes for hard clams), and prohibits harvesting of hard clams and oysters by mechanical methods. "Shellfish" regulations such as these apply almost exclusively to clams and oysters, with very few provisions for other shellfish such as crabs or shrimp.

The FDEP Division of Marine Resources, Bureau of Marine Resource Regulation and Development (BMRRD), enhances shellfish resources, restores oyster reefs on submerged lands, administers private shellfish leases, classifies coastal waters for shellfish harvesting for the protection of public health, and inspects and certifies shellfish processing plants. There are three divisions of this bureau: Shellfish Assessment and Enhancement Section, Shellfish Environmental Assessment Section, and Processing Plant Inspection Section. The FDEP Division of Law Enforcement (Florida Marine Patrol) provides law enforcement.

FDEP classifies and manages shellfish resources of the Indian River Lagoon so that shellfish harvested from the Indian River Lagoon are safe for consumption. The Indian River Lagoon complex is subject to man's influence and waste disposal. Wastewater treatment plants are sources of bacteria that affect specific areas of the Lagoon. The urbanized areas adjacent to the Lagoon also contribute stormwater runoff which is a source of pollution and contaminants to the waters of the Lagoon. Shellfish harvesting areas are classified using NSSP bacteriological water quality standards, which are designed to prevent seafood-borne illness. The use of these standards allows harvesting only from areas where water qualities are considered safe. Areas which do not meet these water quality standards are closed until the pollution source is eliminated. Areas in the vicinity of domestic wastewater treatment (sewage) plants are closed waters.

Shellfish harvesting areas are classified as approved, which allows full use of the resource, or conditionally approved which allows use of the resource under certain conditions. Conditionally approved areas are areas where the water quality is known or suspected to have unacceptable water quality at some times, but is acceptable under most conditions. Conditional areas are closed after rainfall events which may serve as a source of bacterial contamination. The conditional areas are not re-opened for harvest until water quality sampling indicates that bacteria levels are within specified water quality standards. To ensure public health, bacteriological water quality sampling is a necessity.

Certain parts of the Lagoon are also approved for relaying of clams. This allows clams taken from certain closed areas to be transferred or relayed to approved open areas to allow the clams time to purge themselves of the contaminants prior to final harvest.

5.3.3 Shellfish Species Descriptions

5.3.3.1 Hard Clams - *Mercenaria mercenaria* (Linnaeus) and *Mercenaria campechiensis* (Gmelin)

Hard clams, or quahogs, are bivalve mollusks which were always prominent members of many infaunal benthic communities of the Indian River Lagoon system and nearshore portions of the adjacent continental shelf. Since the early 1980s, they have become extremely important in commercial and recreational harvests, and are the object of intensive mariculture efforts. Hard clams skyrocketed from essentially trivial commercial status in the late 1970s to become the most valuable species in Indian River Lagoon landings by the mid- to late 1980s (an estimated $30 million in direct and indirect value in 1985; Virnstein and Campbell, 1987), with a dockside landings value of over $7.5 million in 1993 (FDEP, 1993). Because recruitment was poorly understood, there was concern that hard clams would turn out to be a "boom-and-bust" fishery. Substantial research has been conducted on hard clams in the Indian River Lagoon in recent years (Hesselman, et al., 1989; Jones, et al., 1990; Arnold, et al., 1991).

Once they settle and transform into juveniles, hard clams remain essentially sedentary, and the entire life cycle can occur within the estuary. As filter feeders, hard clams are important primary consumers. The young provide valuable forage to a variety of higher consumers. The larger, more sedentary clams are able to tolerate a wide variety of water quality conditions; in general, however, the hard clams (especially the southern quahog) tend to be most successful in the higher salinity portions of the estuary (>20 ppt).

The commercially and recreationally important "hard clams" are currently regarded as two species of the genus *Mercenaria*. The northern quahog, *M. mercenaria*, occurs in intertidal and subtidal coastal waters from the Gulf of St. Lawrence to Texas (Johnson, 1934). The southern quahog, *M. campechiensis*, ranges from New Jersey to the St. Lucie Inlet, Florida, along the Atlantic coast, and from Florida to Texas along the Gulf of Mexico coast (Mulholland, 1984). *Mercenaria mercenaria* has been widely introduced outside its natural range (Roegner and Mann, 1991). Northern quahogs grown in Massachusetts were extensively introduced in Florida coastal waters, as part of a seeding program called "Operation Baby Clam," in the early 1960s (Sims and Stokes, 1967). In the jargon of the fishery, the hard clams or quahogs are also known as little-neck, cherrystone, and chowder clams, depending upon their size. Hard clams can ultimately grow to a shell length of about 4.7 inches (120 mm); it is the largest individuals that are known as chowder clams.

Life History

Hard clams have a typical marine bivalve life history, with a planktonic larval phase and relatively sedentary juvenile and adult phases. The following description is derived mainly from Mulholland (1984) and Roegner and Mann (1991), and relates specifically to *Mercenaria mercenaria* (unless otherwise noted). However, all available evidence suggests that the life cycles of both northern and southern quahogs, at least in Florida, are very similar if not identical (Dalton and Menzel, 1983). The quahogs are protandrous hermaphrodites, in that all individuals first mature as males and later change into females. The clams develop functional male gonads when about 6-7 mm in shell length, usually in the first year of life. By the time they reach 30 mm, some individuals become females. Normally, however, males achieve full sexual maturity at about 20-30 mm at about one year of age and females reach full maturity at about 40 mm after two years. Peak reproductive capability is normally achieved at around 60 mm. Larger, older clams gradually lose reproductive capacity and may eventually become senescent (Belding, 1931).

Some spawning occurs year round in the Indian River Lagoon system, although there is a distinct bimodal pattern in intensity, with a major peak in the spring and a lesser peak in autumn (Hesselman, et al., 1989). Water temperature appears to play a major role in determining the onset of spawning. When stimulated by the proper temperature, males release semen containing sperm and pheromones, which in turn stimulate the females to begin releasing planktonic eggs through their exhalent siphons (Nelson and Haskin, 1949). The eggs are encased by a gelatinous membrane that swells on contact with the water to increase buoyancy. The sperm released by males contacts the eggs and fertilization occurs.

Fecundity in hard clams is extremely high, with average-sized females releasing about a million eggs per season. Some of the larger individuals produce several times as many eggs. Although there is a direct relationship between size and fecundity (up to about 60 mm shell length), egg survival is related to egg size rather than the size of the parent (Kraeuter, et al., 1981). Larger eggs (44 μm) tend to survive much better than smaller ones (25 μm).

The fertilized egg develops rapidly into a ciliated larvae known as the trochophore (90 X 65 μm) that soon develops a functional mouth and shell gland. About 24-36 hours post-fertilization, the shell gland has finished secreting the bivalve shell and the larva has achieved the initial, or straight-hinged veliger stage. After 1-3 days of further development, the larva has developed a thickening near the valve hinge and is known as the umboned veliger.

The umboned veliger stage lasts from 6-20 days, after which it develops a foot and enters the pediveliger phase. The pediveliger settles and crawls along the substrate, but is still capable of limited swimming by means of the ciliated velum it has retained since the trochophore stage. Once a desirable substrate is selected, the velum is lost and the pediveliger becomes exclusively benthic. A thicker shell begins to accumulate, and the young clam fastens itself to the substrate by means of a secreted, thread-like structure known as the byssus. At this time the clam is known as a byssal plantigrade, and it tends to alternate between temporary byssal attachment and crawling. This final larval phase lasts for several weeks, until the young clam is about 9 mm long (Carriker, 1961).

The clam has now entered the "juvenile plantigrade" phase, meaning that it has lost the byssus and begins to maintain its position beneath the sediment surface by means of the foot alone. The shell has assumed essentially its final shape (albeit not as thick) and both the inhalent and exhalent siphons are fully developed, enabling the juvenile clam to remain buried below the surface of the sediment.

As juvenile quahogs grow, their movement (especially horizontal) lessens. By the time they become adults, the clams generally stay buried (about 1 in [2 cm] in sand and 0.5 in [1 cm] in mud) with only the siphons exposed. Lateral movement, if any, is extremely limited and agonizingly slow (e.g., a reported extreme is 1 ft (30 cm) in two months; Killam, et al., 1992).

Ecological Role

Like most bivalve mollusks, hard clams feed primarily on phytoplankton or suspensions of microalgae throughout all stages of life. Adults are also known to consume suspended detrital material and its attached bacteria (DiDomenico and Iverson, 1977). Specialized cilia on the gills draw a current down the inhalent siphon, through the gills, and out the exhalent siphon. Food particles are filtered out by other cilia, trapped in strings of mucus, and transported to structures known as labial palps. Organic and inorganic particles of about 5-15 μm are selectively sorted and imbedded in the mucus strings for ingestion. Material rejected during the sorting process, known as pseudofeces, concentrates near the base of the inhalent siphon and is periodically ejected by rapid closing of the valves.

Hard clams are heavily preyed upon by a wide variety of animals. Unlike oysters, the quahogs are relatively insusceptible to diseases, so the primary natural control on clam populations is predation. Planktivorous invertebrates (e.g., ctenophores) and vertebrates (larval fish) consume tremendous quantities of hard clam larvae. The benthic juvenile and adult clams are preyed upon by fish, birds, starfish, other mollusks (whelks and drills), and especially mud crabs and blue crabs.

Habitat Requirements

Although well-adapted to estuaries, *Mercenaria* spp. are generally limited to areas where salinities exceed 20 ppt (Roegner and Mann, 1991). The early developmental (planktonic and pediveliger) stages are much more susceptible to fluctuations in environmental conditions than older clams. Although survival is possible under a wide range of conditions (at 20+ ppt salinity), temperature and salinity requirements for spawning, development, and growth are fairly critical. While adult clams can tolerate salinities as low as 10 ppt for several weeks, a salinity of 15 ppt has been found to cause mortality in larvae and juvenile seed clams (Barile and Rathjen, 1985).

Hesselman, et al. (1989) found that spawning of hard clams in Indian River Lagoon is largely confined to periods when temperatures range from 65° to 83°F (18°C to 28°C). Optimum temperatures for growth are in the range of 62°F to 92°F (18°C to 30°C) (Killam, et al., 1992). Normal development of hard clam larvae occurs within a salinity range of 20-35 ppt, although the optimum is reported as 26.5 to 27.5 ppt (Davis, 1958). The optimum salinity for growth of adults is in the range of 24 to 28 ppt for the northern quahog and 35 to 36 ppt for the southern quahog (Killam, et al., 1992).

Although adult quahogs appear capable of surviving hypoxic conditions for extended periods, dissolved oxygen concentrations >4 mg/L are needed for normal development and growth (Killam, et al., 1992). If pH levels drop much below 7.0, hard clam recruitment can be adversely affected (Calabrese, 1972).

Substrate is a major factor in the distribution of hard clams (Thorson, 1955; Carriker, 1961; Keck, et al., 1974). The most favored bottoms are those containing some shell and covered with a thin layer of detritus, followed by sandy sediments. Muddy bottoms are the least colonized. Areas with some current are more favorable than slack-water habitats. Several studies have suggested that seagrass beds, although not essential to survival, are conducive to better production of southern quahogs (Peterson, 1982; Mulholland, 1984).

5.3.3.2 American Oyster - *Crassostrea virginica* (Gmelin)

Oysters are the only other significant bivalve harvested in the Lagoon complex. In 1988, the total oyster landings were less than 10% of the hard clam landings (Table 5-1). Oysters generally prefer a softer mud substrate than the clams, although oysters generally occur in dense congregations in the same location for several generations, thus building oyster bars of shells of dead oysters. Although oysters occur in the southern Indian River near Sebastian and Ft. Pierce, the commercial center of abundance is in the north Indian River and Mosquito Lagoon.

Life History

The life cycle of the American oyster occurs entirely within the estuary. Spawning begins as water temperatures near 20°C, and release of gametes probably occurs through all except the coldest months (Quick and Mackin, 1971; Killam, et al., 1992). Males typically spawn first, and their release of sperm and pheromones stimulates other males and females to begin spawning (Cake, 1983). It is likely that a given mature oyster spawns many times a year in Indian River, as do those in the Gulf of Mexico. Depending upon the size of female, stage of maturation, and water quality conditions, 23 to 86 million eggs are released per spawning (Davis and Chanley, 1955).

Fertilization occurs externally as the sperm and eggs come in contact; larval development, as described by Kennedy (1991) is summarized as follows: Depending upon temperature, the embryos develop into veliger larvae in 24 hours or less. The initial stage is known as the straight-hinge, or "D-stage" veliger, which has two simple shells (valves) and a velum, or ring of locomotory cilia. Over the next two to three weeks, the free-swimming larvae grow through several more veliger stages. When the larvae reaches 260-300 μm in length, it develops a more rounded hinge, a foot, and two simple eyes. This pediveliger stage is still capable of swimming, but tends to settle and the foot is used to crawl and investigate the substrate. When a suitable surface is found, a cementlike substance is extruded from a pore in the foot and the left valve becomes attached to the substrate. The locomotory velum is shed, the foot shrinks, and gills and a digestive tract rapidly develop. The resulting, attached, juvenile oyster is referred to as a spat. The planktonic veligers are the only mobile stages; they can move up and down in the water column, but are generally carried some distance horizontally by currents.

At the latitudes encompassed by Indian River Lagoon, spat can develop into mature American oysters in 4-12 weeks (Killam, et al., 1992). Spawning by young of the year and production of two generations in a year is likely, although the contribution of first-year spawners to year-class strength is probably insignificant. American oysters are dioecious, but protandrous hermaphroditism is relatively common (Bahr and Lanier, 1981). That is, young oysters are predominantly males, and over ensuing breeding cycles tend to transform into females (Galtsoff, 1964).

Growth of American oysters is most rapid during the first year of life (Bahr and Lanier, 1981). Overall lengths of 40-50 mm are likely to be achieved by the end of the first year in Indian River Lagoon (Berrigan, 1990). Growth is much slower once maturity is achieved and metabolic reserves are increasingly devoted to maintenance of reproductive activities and soft tissues (Killam, et al., 1992). Under ideal conditions, American oysters may survive for 10 or more years (Cake, 1983).

Ecological Role

The American oyster is ecologically important as a filter-feeding primary consumer, as prey for numerous higher consumers, and as a habitat-former.

American oysters feed primarily on living phytoplankton throughout all stages of life. Veliger larvae can ingest particles ranging in size from 0.2 to 30 μm, but appear to be selective of those greater than 20 μm (Kennedy, 1991). The adults are less efficient at retaining particles <3 μm but, unlike larvae, appear to eat some bacteria, probably those attached to detritus (Killam, et al., 1992).

The filter feeding of American oysters is regarded to be of extreme ecological significance (Newell, 1988). It is estimated that an oyster filters water at a rate of about 1,500 times its body volume per hour (Loosanoff and Nomejko, 1946). Declines of the major filter-feeding assemblage provided by extensive oyster beds is cited by Newell (1988) and others as a major factor in an apparent shift to microbial food webs and increases in zooplankton densities in Chesapeake Bay.

The free-swimming larvae of oysters are heavily preyed upon by many planktivores (e.g., ctenophores, anemones, some larval fishes). More than 99% of gametes, embryos, and larvae are believed to be lost, primarily to predation, before settlement (Kennedy, 1991). Newly formed spat are eaten by carnivorous worms and various small crabs (e.g., mud crabs and juvenile blue crabs). The larger spat and small adult American oysters are heavily consumed by a variety of predators, including blue crabs, stone crabs, whelks, oyster drills, skates, rays, and several sciaenid fishes (e.g., black and red drum).

Most estuaries are essentially depositional features, with the result that their basins are predominated by soft sediments. Due to its production of shell, the American oyster tends to provide the greatest volume of hard substrate found in temperate and tropical estuaries of the western Atlantic. Under natural conditions, oyster reefs can be very large, and provide extensive attachment area for oyster spat and numerous associated species such as mussels, tunicates, bryozoans, and barnacles.

Habitat Requirements

Like most sessile estuarine animals, the American oyster is anatomically and physiologically well-adapted to a wide range of temperature, salinity, and dissolved oxygen. Oysters are particularly capable of surviving environmental extremes, so long as the conditions do not persist for extended periods.

Optimum temperatures for reproduction, embryonic development, and growth of American oysters appear to lie in the range of 68°F to 86°F (20°C to 30°C) (Killam, et al., 1992); developmental anomalies begin to appear when temperatures drop below or increase above this range (MacInnes and Calabrese, 1979). Although capable of surviving at salinities from about 5-40 ppt, the optimum range for oyster reef growth and reproduction is in the range of 10-30 ppt (Galtsoff, 1964). The salinity tolerance of oyster larvae is dependent upon the salinity at which the parents spawned (Davis, 1958). An inverse relationship has been observed between the ability of oysters to survive low salinity extremes and temperature (Andrews, 1982; Loosanoff, 1953). Low dissolved oxygen concentrations appear to be much less of a problem for American oysters than most other estuarine organisms (Berriganm, et al., 1991; Kennedy, 1991).

Water movement is important for the successful development of American oysters, as currents replenish food resources, remove waste products, and tend to prevent smothering due to accumulation of sediment (Galstoff, 1964; Berrigan, et al., 1991). Appropriate substrate for the setting of spat is a key factor in oyster production. Although very soft mud and shifting sand appear to be the only substrates that are completely unsuitable (Galtsoff, 1964), the ideal surface is horizontal and comprised of shell (especially of oysters) (Kennedy, 1991).

5.3.3.3 Blue Crab - *Callinectes Sapidus* (Rathbun)

In terms of total landings, blue crabs constituted the major shellfish resource in the region in 1988. However, these crabs occur in habitats other than the Lagoon, and the proportion that come from the Lagoon is not known. Although commercial crab production is centered in the north end of the complex, blue crabs occur in many habitats throughout the Lagoon complex.

Life History

In Florida, mating of blue crabs occurs from early spring through early winter when water temperature is >72°F (22°C) (Steele, 1982). Females approaching the final molt marking the end of the juvenile phase move into low salinity waters where males tend to remain concentrated. As a female starts to shed her juvenile exoskeleton, she is grasped and carried by a male. When molting occurs, the male inseminates the female and continues to carry her until her shell hardens. The female then migrates to a higher salinity area in the vicinity of an ocean outlet.

Sperm are stored internally by females and may remain viable for many months. Females that have mated late in the year will overwinter before spawning in the spring. When fertilized, the eggs are extruded and attached to fine, hairlike appendages on the abdomen of the female. Such females, known as "sponge" or "berried" crabs, will carry from 750,000 to 8,000,000 eggs (Prager, et al., 1990). The eggs are carried for two to three weeks, gradually enlarging and changing from yellowish orange through dark brown or black as the yolk is used up and the embryos develop.

Hatching usually occurs just inside the estuary, in the passes, or just outside. The first larval phase is planktonic and is known as the zoea. The zoeae develop through seven molt stages over a period of 30 to 50 days, mainly in nearshore waters over the continental shelf. The larvae then transform into a stage known as the megalops, which lasts 6-20 days depending upon temperature (Costlow and Bookout, 1959). Blue crab megalopae are carried into estuaries on flood tides (Van Heukelem, 1991), soon after which they settle (ideally in seagrass beds) and molt to transform into the first "crab" or juvenile stage.

Carapace width (CW) of the first crab stage is about 2 mm. Growth occurs by numerous successive molts and is highly variable, depending upon temperature, salinity, and food availability (Killam, et al., 1992). Male blue crabs usually achieve sexual maturity at about 89 mm CW in about one year, after which they will molt several times and may achieve maximum widths of almost 200 mm. Females usually mature after 18 to 20 molts, regardless of size (Van Engle, 1958). Most females are sexually mature at 120-140 mm CW. Few female blue crabs are known to exceed 150 mm CW, and it was long believed they did not molt after mating. However, some females may molt at least once after achieving maturity.

In Florida, few blue crabs appear to live beyond their second year, but some individuals may live as long as four years (Tagatz, 1968a, 1968b). Despite their impressive fecundity, it has been estimated that only about one ten-thousandth of 1% of viable eggs survive to adulthood (Van Engle, 1958).

Ecological Role

Blue crabs play a major role in the ecology of the Indian River Lagoon, because of their widespread occurrence and abundance, broad diet, and importance as prey to numerous other species.

The diet of early larval blue crabs in natural waters is presumed to consist primarily of plankters smaller than themselves, such as rotifers, worm larvae, and copepod nauplii (Van Heukelem, 1991). After a few molts, the zoeae probably feed mainly on adult copepods. From the time they have entered estuaries and become juveniles, blue crabs adopt opportunistic feeding behavior that persists for the remainder of their lives. An extensive literature has accumulated regarding the food habits of juvenile and blue crabs, as summarized in Van Heukelem (1991) and Killam, et al., (1992).

Most studies have shown that blue crab diets vary substantially, depending upon size, habitat, and season. Laughlin (1982), however, observed that they are likely to consume whatever food is locally available at any time. The seasonal and spatial differences in food habits tend to be more pronounced in smaller blue crabs than adults. In most estuaries, bivalve mollusks tend to be the most important food of all sizes of blue crabs -- to such an extent that several authors have suggested that blue crab predation may well determine the abundance of some clam, mussel, and oyster populations (Van Heukelem, 1991). Juvenile blue crabs <31 mm CW commonly eat substantial quantities of vegetable matter and detritus, particularly when in areas where plants are readily available such as seagrass beds and marshes. Other prominent components of blue crab diets include polychaetes, gastropods, xanthid (mud) crabs, and fish. Blue crabs become increasingly predacious as they grow larger and are also highly cannibalistic.

Because, as noted by Laughlin (1982), blue crabs will eat virtually anything of organic derivation, they have many competitors. Perhaps their most significant competitors are some of the animals that also feed extensively on clams, such as mud crabs, American eels, several species of sciaenid fishes (drums), and canvasback ducks.

Blue crabs are heavily preyed upon by virtually all carnivorous animals large enough to catch and ingest them. Among fishes, some of the most significant predators on blue crabs are American eels, catfish, sciaenids (especially the large drums), several types of sharks, and cownose rays. Loggerhead and Atlantic ridley turtles are known to consume large quantities of blue crabs, as are herons, egrets, and various diving ducks. Mammalian predators include dolphins and (especially) raccoons.

<u>Habitat Requirements</u>

Blue crabs are extensively distributed throughout all portions of the Indian River Lagoon system, although (as noted above) the females tend to remain in the higher salinity areas except when mating. Salinities greater than 20 ppt are required for larval survival (Costlow and Bookout, 1959), but once the juvenile phase is reached salinity alone appears to have little influence on the distribution (at least of males).

Provided they are given a chance to acclimate, blue crabs appear capable of surviving most temperature extremes likely to be encountered in Indian River Lagoon (Van Heukelem, 1991). They are somewhat less tolerant of low temperatures at very low salinities, and the males which occupy the fresher waters tend to move into deeper channels during cold weather.

Blue crabs are relatively intolerant of poorly oxygenated water, which they will avoid if possible. In some areas blue crabs are known to actually leave the water to escape hypoxic conditions, a phenomenon known as crab "jubilees" along the northern Gulf of Mexico coast. Crabs caught in fishermen's traps set in hypoxic waters sometimes exhibit substantial mortality, but this "trap death" has been observed to be highly variable in waters of essentially the same level of oxygen saturation (Killam, et al., 1992). It is nevertheless clear that low dissolved oxygen concentrations can adversely affect blue crab production.

In some estuaries such as the Chesapeake Bay, seagrass beds and/or other vegetated areas appear to provide a crucial structural habitat for the settling of the blue crab megalopae (Van Heukelem, 1991). The vegetation provides a refuge from predators and is also a food source for the small juvenile blue crabs. On the other hand, several estuaries in the Gulf of Mexico with little or no submerged vegetation support large blue crab populations. Here, the juvenile blue crabs tend to be associated with soft mud substrates, into which they are known to burrow for protection.

5.3.4 Shellfish Harvesting Areas

The State of Florida endeavors to protect public health and maintain shellfish populations through several means. Under the authority of Chapter 16B-28, FAC, in order to protect public health, the FDEP has the authority to regulate shellfish growing areas. Under this authority, the Shellfish Environmental Assessment Section has established approved shellfish harvesting areas based on the potential for shellfish contamination by fecal coliform bacteria. Waters of the Lagoon are regulated as Approved, Conditionally Approved, or Closed for shellfish harvest. Approved areas have been shown by FDEP surveys to be safe for harvest and consumption. The Conditionally Approved designation indicates areas are routinely closed for oyster or clam harvesting after rainfall events and reopened for harvesting only when water quality monitoring indicates that bacterial standards are not exceeded. Closed areas have been found to be routinely unsafe and commercial harvesting is prohibited in these areas.

The State of Florida has also classified surface waters according to suitability for designated uses under Chapter 17-3, FAC. In this classification, Class II waters are designated as suitable for shellfish harvesting or propagation. Chapter 17-3 establishes water quality criteria which are to be met and which are considered to be adequate for survival and propagation of shellfish and for protecting public health from shellfish consumption. The primary intent of the surface water classifications is to maintain water quality suitable for shellfish propagation.

The currently Approved shellfish harvesting areas and the designated Class II waters in the Indian River Lagoon system are not identical and in many cases do not coincide. The Class II waters and shellfish harvesting areas are mapped and discussed further in the Water and Sediment Quality Technical Report. All of Mosquito Lagoon south of Edgewater is designated Class II, but only the area approximately south of the Volusia/Brevard County line is approved shellfish harvesting waters; the remaining area is conditionally approved. None of Banana River is designated Class II and the entire area is closed for harvesting.

In the North Indian River Lagoon (Segment 1A), there are several areas north of Melbourne that are Approved (only Body A - an area north of the NASA Rail Bridge at Titusville) or Conditionally Approved. These areas are known as Bodies, A, B and C, or the North Brevard County Harvesting Area. The Approved or Conditionally Approved shellfish harvesting areas in this Segment actually include some areas that are not Class II water. The Indian River Lagoon in the North Central Indian River Lagoon (Segment 2) from near Turkey Creek to Sebastian Inlet is also a Class II water. However, there is no Approved shellfish harvesting area in this reach, and the Conditionally Approved area (Body F) does not include the north end near Turkey Creek, or the south end near the Sebastian River or certain other areas.

Although much of the Indian River in the South Central (Segment 3) and South (Segment 4) Indian River Lagoon is a designated Class II water (primarily in the eastern half of the Lagoon), there is only a small area of approved shellfish harvesting north of Ft. Pierce Inlet and a small area of Conditionally Approved water south of Sebastian Inlet.

Most of the major shellfish harvesting areas (harvesting areas generally mean oyster and clam harvesting only), with the exception of a portion of the north Indian River and most of Mosquito Lagoon are designated as Conditionally Approved Areas. The most significant harvesting areas in the complex are Bodies B and C (North Brevard County Harvesting Area) between Titusville and Cocoa in the Indian River and Body F (South Brevard County

Harvesting Area) from Valkaria to Sebastian River. Mosquito Lagoon (Body A) also is an important area. The South Brevard area generally consists of managed beds in shallow water on leased lands, whereas the North Brevard area is concentrated in deep water near mid-channel.

The southern Indian River is not a significant hard clam or blue crab harvesting area, with virtually no harvest occurring south of the Sebastian Inlet area. Very little oyster harvest occurs in the Indian River. The greatest amount of oyster production occurs in Mosquito Lagoon, particularly in Volusia County.

Recent studies by Arnold (1993) show that the Body C (north Brevard) hard clam population is currently concentrated between the Bennett Causeway (SR 528) and the FPL generating station to the north at Frontenac. Within this area, sampling studies in 1992 (Arnold, 1993) found hard clam densities from 0.2 to 1 clam ft^{-2} (2 to 10 m^{-2}). Densities of up to 0.6 clams ft^{-2} (6 clams m^{-2}) were found in Body D in the vicinity of Cocoa and the Pineda (SR 404) and Eau Gallie (SR 518) Causeways.

Another area of high hard clam density found by Arnold was near Turkey Creek south of Melbourne, where up to 1 clam ft^{-2} (10 clams m^{-2}) occurred. Lesser amounts were found to the south from Turkey Creek to the mouth of the Sebastian River. Another area of high density area again occurred near the mouth of the Sebastian River. No significant concentrations occurred south of Sebastian. It appears that the areas of highest hard clam density may extend beyond the Approved shellfish harvesting waters.

5.3.5 Hard Clam Harvesting Technologies

In recent years, advances in techniques for propagating and harvesting hard clams have been initiated in the region. These practices of aquaculture and mariculture equate to terrestrial agriculture except aquaculture occurs in water. Aquaculture in salt water may be called mariculture. By actively cultivating the shellfish resources, increased harvests and a safer and higher quality product may be obtained. Aquacultural practices which have been tested in the Indian River Lagoon region include the relaying and transfer of clams, depuration, andf raising of clams on artificial or controlled substrates.

Relaying and transfer is a technique intended to allow these filter feeders to flush pollutants from theis systems. Hard clams are harvested from potentially contaminated areas and transferred to safe areas for several weeks. During this period, the clams are routinely monitored for the presence of fecal coliform bacteria, which is a realtively easily monitored indicator organism of a contaminated condition. By this process, there may be a relatively high assurance that the clams are free of bacterial pollution when harvested, and there is an assumption that other pollutants have been flushed from the shellfish. However, if the clams contain relatively immobile pollutants such as metals or certain chemical compounds that do not flush at the same rate as bacteria, the clams may still be contaminated by these compounds at harvest.

Another advanced technique for optimum utilization of the resource is the use of depuration. This is a process in which oysters, mussels, and clams that have been moderately contaminated by bacteria can be purged of bacteria. In this method, water is sterilized by running it under a UV light source to kill bacteria in the water. This sterilized water is then pumped through trays of clams for several days, thus purging bacteria from the clams. This method also cleanses bacteria from clam tissue, but does not effectively remove metal, pesticide, or viral contaminants. Depuration has several disadvantages which have caused it to be largely abandoned. A main problem is the relatively high cost in relation to relaying. Depuration also may lead to stress on the clams through a change in the quality or temperature of water, and by a build-up of of compounds such as nitrates or ammonia in water that is recycled.

Mariculture and, in particular, the cultivation of hard clams on leased tracks of substrate has become a thriving industry in the parts of Brevard and Indian River Counties in the north-central portion of the Lagoon. Sections 253.67 through 253.75, and 370 F.S. allow sovereign and submerged lands of the state to be leased by individuals cultivating hard clams. These leases were initially used primarily for cultivation of oysters and large "chowder" clams, but are now used mainly to raise small "littleneck" clams. In 1992, there were 134 leases involving 1,060 acres in the Lagoon, with 72% of this acreage in Brevard County (FDEP, 1993).

The hard clam has been better suited than the oyster for aquaculture in the Lagoon for several reasons, including greater hardiness and ability to survive in fluctuating salinity conditions, rapid growth rate, market demand especially for juvenile sized clams, and available technology. Farming of these organisms is a complex process which requires stringent operating conditions. A typical clam mariculture operation includes several phases. The first phase involves the collection of small juvenile "seed" clams. In a few cases, eggs eggs have been obtained, graded, and fertilized. Collection from eggs is not widely practiced by the harvesters in the Lagoon because of the increased effort and cost. Most cultivation operations purchase juvenile clams from other sources. Small seed clams may be nurtured in tanks until they reach 10 mm in size, when they are transferred into field plots. In these plots, these seed clams may be spread over natural bottom and covered with netting to reduce predation until growout (the time when they are large enough to harvest). The most common method of growout used in the Lagoon is to place the clams into 1/4" mesh porous fabric bags until harvest. Other less common methods include stone- or shell-lined trays or racks which have been fenced for protection and containment.

This controlled growth has several advantages over harvest of clams growing on natural unmanaged areas. It allows harvesting of a more evenly graded crop of clams at the most economic opportune time, as smaller juvenile sized clams (cherrystones and littlenecks) have a higher market value than the large adult size (chowders). It also allows more cost-effective concentration of effort in a small area.

5.3.6 Current Status

Table 5-2 shows the clam harvest in the Lagoon basin from 1985 to 1993. The data shows a steady decline in the poundage of clams harvested from the peak harvests years of 1984-86 to 1990. These data indicate that the decline has occurred mainly in southern Brevard County (Body F) and in St. Lucie County. In St. Lucie County, the harvest is now virtually non-existent. Annual harvests in Brevard County have ranged between approximately 300,000 pounds and 950,000 pounds in the period from 1987 to 1993, following peaks of about 1,300,000 pounds in 1985 and 1986 (FDEP, 1993). Body C now produces the majority of hard clams in the Lagoon.

The increased harvest in the 1970s and 1980s was apparently due in part to an increase in the hard clam population in Brevard County, although an increase in harvesting intensity and

TABLE 5-2

HARD CLAM HARVESTS WITHIN INDIAN RIVER LAGOON FROM 1985 TO 1993

COUNTY	LANDINGS IN POUNDS								
	1985	1986	1987	1988	1989	1990	1991	1992	1993
Volusia	43,630	27,214	17,363	27,822	14,238	13,430	11,509	13,904	7,188
Brevard	1,320,825	1,361,466	994,153	627,792	305,203	312,655	407,951	951,311	885,631
Indian River	56,226	52,710	83,095	54,876	22,472	25,519	27,300	42,344	53,108
St. Lucie	18,757	619	124	162	29	0	0	0	0
Martin	111	97	0	0	0	0	0	0	0
TOTAL	**1,439,549**	**1,442,106**	**1,094,735**	**710,652**	**341,942**	**351,604**	**446,760**	**1,007,559**	**945,927**

Source: Florida Department of Natural Resources (FDNR) and Marine Fisheries Information System (MFIS), various dates number of harvesters may also may have been a factor. The reason for the possible population increase is not known, but some investigators have postulated that increases in nutrients or salinity of the Lagoon may have been responsible (Barile and Rathjen, 1985). An increase in salinity in that portion of the Lagoon does appear to have occurred subsequent to 1976 and prior to the 1989-1991 period (Figure 4-13), so there may be some basis for this claim. Other possible reasons may also explain the increase, and there are currently high densities in portions of Brevard county where salinities are lowest (Arnold, 1993). Consequently, much is still unknown about the population dynamics of hard clams in the Indian River Lagoon.

Closure of harvest areas for water quality violations, impacts on clam survival caused by large drops in salinity due to heavy stormwater discharge events, and possibly over-harvesting have been implicated in the decline of the clam harvest since the 1984-86 period.

Rather than reliance on natural production, increased emphasis is being put on aquaculture operations to produce shellfish. The aquaculture process may involve raising shellfish larvae in controlled conditions, cultivation of shellfish in bags or other controlled areas, and relaying or depuration of harvested shellfish, as described above. The cultivation of shellfish may concentrate shellfish resources in small specific areas. In this case, the shellfish resource may become more susceptible to perturbations or changes in water quality in localized areas. Many areas that appear to have the greatest potential for shellfish aquaculture also have other significant resources such as seagrass beds which could be impacted by the operations.

5.3.7 Future Trends

The future of shellfishing within the waters of the Lagoon is unpredictable, largely due to the fact that the industry is dependent upon the water quality of the Lagoon. As examples, bacteria and other contaminants decrease the marketability of shellfish, and oysters are susceptible to salinity variations. Because much of the Lagoon is an estuarine system with limited tidal influences and limited of ocean water influence, flushing of the system is low. This poor flushing is particularly applicable in the Bodies A, B, and C North Brevard County Shellfish Areas. Without the ability to flush itself the Lagoon can become a trap for all pollutants introduced. These pollutants may be retained in in the sediments or become part of the biological food web.

Basic information regarding the biological status of hard clams and other shellfish is needed. Continuing research is being conducted throughout the Lagoon by the Division of Marine Resources section of the FDEP. Additionally, the water management districts are finding new methods to prevent large influxes of freshwater to the Lagoon during high rainfall events. The control of these discharges may be important for future shellfish production.

5.3.8 Findings and Recommendations for Shellfish Resources

Blue crabs, hard clams, and American oysters have been significant sources of seafood in the Indian River Lagoon complex for hundreds of years, with the blue crab the largest in terms of total pounds landed. The American oyster was the second most utilized resource until the mid 1970s when it was exceeded by hard clam harvests. Hard clam landings in the Indian River Lagoon region increased from less than 50,000 pounds in 1958 to over 1.4 million pounds in 1985. Hard clam harvests have decreased since 1986, but the reasons for the changes in harvest and carrying capacity of the systems have not been determined. Almost all of the current shellfish harvest is confined to the northern half of the system in Indian River, Brevard, and Volusia Counties, with Brevard County producing the great majority of shellfish.

While relatively tolerant of water quality changes, hard clams and oysters still have some sensitivity to salinity and other changes. While adult clams can tolerate salinities as low as 10 ppt for several weeks, the eggs, larvae, and young clams are much more sensitive and can be adversely affected when salinities drop below 20 ppt. Much of the clam industry is concentrated in areas of Brevard County where low salinities are most prevalent and where salinity change following rainfall is greatest. This makes the hard clam population vulnerable to salinity effects.

The industry is also vulnerable to bacterial contamination of the Lagoon from wastewater treatment discharges and from stormwater runoff. Trends in this contamination are difficult to predict based on existing data.