
FLORIDA MARINE RESEARCH PUBLICATIONS

Number 45

E-4



**Assessment of Fisheries Habitat:
Northeast Florida**

MICHAEL J. DURAKO, MICHAEL D. MURPHY, AND KENNETH D. HADDAD

1988

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ABSTRACT

Durako, M. J., M. D. Murphy, and Kenneth D. Haddad. 1988. Assessment of Fisheries Habitat: Northeast Florida. Fla. Mar. Res. Publ. No. 45. 51 pp. Northeast Florida lies in the southern part of the coastal plain in a physiographic division known as the coastal lowlands. Barrier islands, coastal lagoons and estuaries, and a series of coastal ridges with intervening valleys are the characteristic landforms. Surface fresh water is supplied by three drainage basins that act as a link between the coastal zone and the interior. Most of the estuaries of northeast Florida are well-mixed and support a diverse array of habitats ranging from salt marshes in the north to mangroves and seagrasses in the more southern coastal lagoons. Thematic Mapper data for October 1984 indicate that the region has 37,451 ha of wetlands, 92% of which are salt marshes. Three important non-macrophyte-dominated coastal habitats — mud flats, oyster reefs, and exposed beach surf zones — are also fairly extensive in this region. The coastal fish fauna of this region can be characterized as temperate, although species having tropical Caribbean affinities occur during warm periods of the year. Sciaenids are commercially and recreationally the most important finfish family, although mullet dominate the catch by weight. Important shellfish resources consist of three species of penaeid shrimp, blue crabs, oysters, and clams. A review of landings data for the region shows highest productivity in Brevard and Volusia counties, which include the Mosquito Lagoon/Upper Indian River complex. An historical assessment of fisheries habitat alteration from the 1940's and 1950's to the present indicates that the highest rates of habitat loss have occurred around inlets, which, coincidentally, are the first "habitats" encountered as fish enter estuaries. Major growth issues affecting coastal northeast Florida are the prevention of continued environmental degradation through seemingly unrelated small impacts and an increase in scientific and public awareness of the complex requirements and dynamics of species important to fisheries.

This project was partly supported by a grant from the Florida Office of Coastal Management, Department of Environmental Regulation, with funds provided by the U. S. Office of Ocean and Coastal Resource Management, NOAA, under the Coastal Zone Management Act of 1972, as amended.

This public document was promulgated at an annual cost of \$4,488.02 or \$4.49 per copy to provide scientific data necessary to preserve, manage, and protect Florida's marine resources and increase public awareness of the detailed information needed to wisely govern our marine environment.

Assessment of Fisheries Habitat: Northeast Florida

MICHAEL J. DURAKO, MICHAEL D. MURPHY, AND KENNETH D. HADDAD

INTRODUCTION

Since the 1950's, Florida's population has soared, with up to 7,000 people establishing residence in the state each week. Recent projections by the U. S. Census Bureau indicate that, if present trends continue, Florida will be the third most heavily populated state by the year 1995, with 13.5 million inhabitants. Today, seventy-five percent of Florida's population resides in coastal areas. Northeast Florida's population has increased 21% in the last decade, with a 103% increase in unincorporated areas, compared to only a 19% increase in municipalities (Northeast Florida Regional Planning Council, 1982). Although the rate of population growth in this region is about half the statewide average, the low-density development patterns here result in significant changes in land use to accommodate additional growth. Major urban centers in northeast Florida are developed on bodies of water that are important breeding and nursery areas for fish and shrimp, which support the region's fishing industry (Northeast Florida Regional Planning Council, 1982).

Loss or alteration of wetland habitats, resulting from population growth and development, is probably the most important issue affecting coastal fisheries resources in northeast Florida. Wetland systems are dynamic, while man's impact emphasizes permanence and stability (Gosselink and Baumann, 1980). Many activities that stabilize the landscape (e.g., dredging and filling, bulkheading, channelization) cause direct loss or stress to wetland systems, resulting in reduced fisheries production as demonstrated for penaeid shrimp and blue crabs (Orth and Moore, 1983; Turner, 1977). For these species, yields are directly related to area of estuarine vegetation, and not to area of bottom, depth, or volume of estuarine water; an important factor in this relationship is the actual wetland edge. A similar relationship between seagrasses and red drum also has been suggested (Holt et al., 1983).

In addition to these direct impacts, secondary effects of coastal development, such as alteration of freshwater inflow and increased pollutant loading to estuaries, can reduce wetland and fisheries production (Cross and Williams, 1981; Odum et al., 1974). This paper presents some of the physical and biological characteristics of coastal northeast Florida, analyzes the areal extent of existing estuarine fisheries habitat, reviews the historical loss of coastal vegetation of selected areas, and discusses some impacts of development that have directly or indirectly affected coastal habitats and fisheries resources. In addition, landings trends for some coastal fisheries species are discussed.

DESCRIPTION OF THE ENVIRONMENT

PHYSICAL ENVIRONMENT

The following description of the northeast Florida coastal region is by no means exhaustive. Certain growth issues and impacts are of a physical

as well as biological nature; however, the importance of physical influences, relative to habitat considerations, is sometimes overlooked. For more detailed information on specific areas of interest, the reader should refer to such publications as: the U. S. Department of Agriculture, Soil Conservation Service County Soil Surveys; Florida Department of Natural Resources, Bureau of Geology publications on geologic and water resources; U. S. Geological Survey, Water Resources Data Publications (Volume 1 of the annual series covers northeast Florida); and National Oceanic and Atmospheric Administration Annual Summaries of local climatological data.

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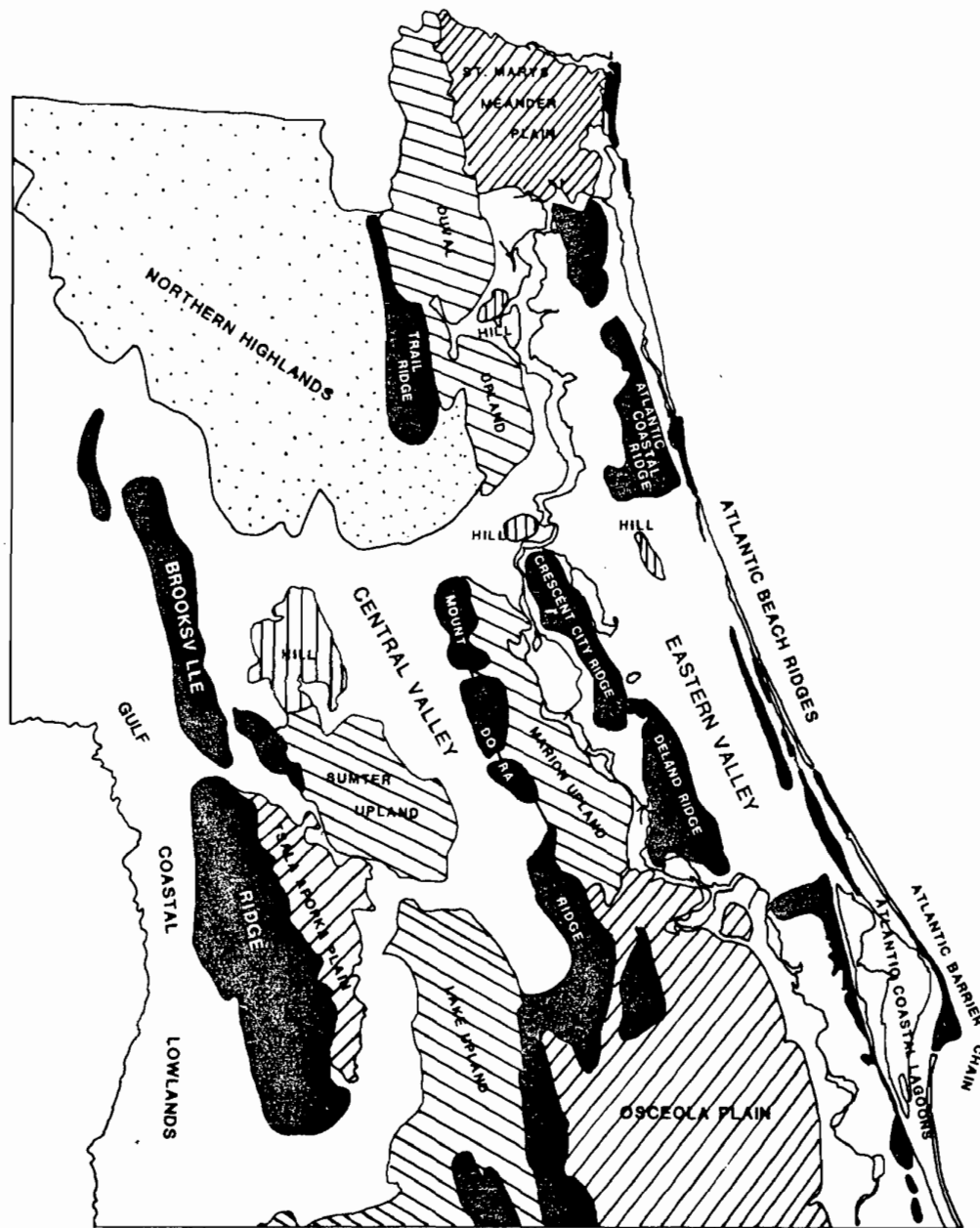


Figure 1. Physiographic map of northeast Florida (from Puri and Vernon, 1964).

GEOLOGY AND PHYSIOLOGY

Northeast Florida lies in the lower part of the Atlantic Coastal Plain. The coastal region occupies a physiographic division known as Coastal Lowlands, which are low in elevation and poorly drained. Coastal land forms are composed of barrier islands, lagoons, estuaries, coastal ridges, sand dune ridges, relict spits, and bars with intervening valleys (Puri and Vernon, 1964). These features parallel the coast,

reflecting the influence of marine forces. In this regard, most of the topography of northeast Florida was formed during the Pleistocene epoch, when sea level rose and fell several times (Cooke, 1945). Marine terraces corresponding to Pleistocene shorelines are named Wicomico, Penholoway, Talbot, Pamlico, and Silver Bluff. Their relict shorelines are at 30.5, 21.4, 12.8, 7.6, and 2.4 meters above sea level, respectively (Healy, 1975). Between these ridges are poorly drained swales through which

present-day rivers and streams course (Morrill and Olson, 1955). Areas adjacent to the Atlantic Ocean and St. Johns River are of more recent geologic origin (Soil Conservation Service, 1980). Consequently, most of the surface sediments in this area are of Pleistocene to Recent age; the carbonate rocks of the lower sequence (known as the Floridan Aquifer) are of middle and upper Eocene age (Cooke, 1945).

Physiographically, much of the northeast coast of Florida can be divided into four regions (White, 1970): the Atlantic Beach Ridge, the Atlantic Coastal Lagoons, the Atlantic Coastal Ridge, and the Eastern Valley (Figure 1). The Atlantic Beach Ridge is a barrier island chain consisting of a beach, a series of dunes, and the present shoreline ridge. It is separated from the mainland by the Atlantic Coastal Lagoons. The Atlantic Coastal Ridge is composed of relict shoreline ridges, most between 7.6 and 10.7 meters above sea level. The Eastern Valley, composed of the Pamlico and Talbot terraces, occupies much of the area west of the Atlantic Ridge to the St. Johns River. North of the St. Johns River, the St. Marys Meander Plain occupies the region west of the Atlantic Coastal Ridge to the Wicomico terrace.

Soils of northeast Florida are partly sedimentary and partly derived from underlying formations. The major source of the Pleistocene sediments is probably the Piedmont Region of the Southern Appalachian Mountains, where materials were moved southward by streams and long-shore currents (Morrill and Olson, 1955). Little or no silt or clay have accumulated farther south than the St. Johns River inlet, because Florida upland rocks do not weather to produce such materials and no northeast Florida rivers drain true interior areas like the Piedmont (Tanner, 1960). The presence of relatively large quantities of clay, coupled with low-to-moderate wave energy levels, may account for the salt marsh "Sea Islands" of South Carolina, Georgia, and extreme northeastern Florida.

South of the St. Johns River inlet, beaches are composed of quartz sand, and no barrier islands or lagoons are present for approximately 40 km (Figure 2). The percentage of quartz sand decreases toward the south; sand is replaced by increasing quantities of shells, shell fragments, and pebbles derived from exposures of the Anastasia Formation (Tanner, 1960). This formation consists of a sandy coquina held together by calcareous cement, and obtained its name from Anastasia Island opposite St. Augustine (Cooke, 1945). From St. Augustine southward for about 240 km, intermittent exposures of the Anastasia Formation form the backbone of the Atlantic Beach Ridge. This may be responsible for the persistence of barrier-island-lagoon complexes along the east coast and may be why the lagoons are unusually narrow (Tanner, 1960). The barriers are

perched over a core of Anastasia beachrock, and the moderate-to-high wave energy along this coast removes less beach material than it would if no core were present. This reduced rate of shoreline erosion results in a lagoon-width-to-barrier-width ratio of 0.5 to 2.0, compared to an average of 6.0 in much of the rest of the world (Tanner, 1960). If the barrier islands were not so constructed, they probably would have disappeared long ago, as the case may have been along the shore just south of the St. Johns River mouth. However, much of the east coast of Florida is still eroding because wave energies increase from the Georgia border southward (Figure 2) with no increase in the littoral drift load supplied at the upcurrent end of any given stretch of beach (Tanner, 1960).

Greatest erosion occurs during infrequent northeastern storms that coincide with spring tides and higher sea levels in the fall (Morrill and Olson, 1955). Erosional effects are particularly visible south of the St. Johns River inlet. Since 1923, an average 24.1 m beach-width recession has occurred from the south jetty for 10.5 km southward (Jacksonville Area Planning Board, 1979). In most areas, severe erosion is usually followed by an almost equal accretion caused by the persistent mild southeast winds (Morrill and Olson, 1955; U. S. Army Corps of Engineers, 1981b). However, severe net erosion in northeast Florida is generally associated with man-made structures, such as jetties at inlets and seawalls/revetments along beaches (Florida Bureau of Coastal Zone Planning, 1976; Jacksonville Area Planning Board, 1979).

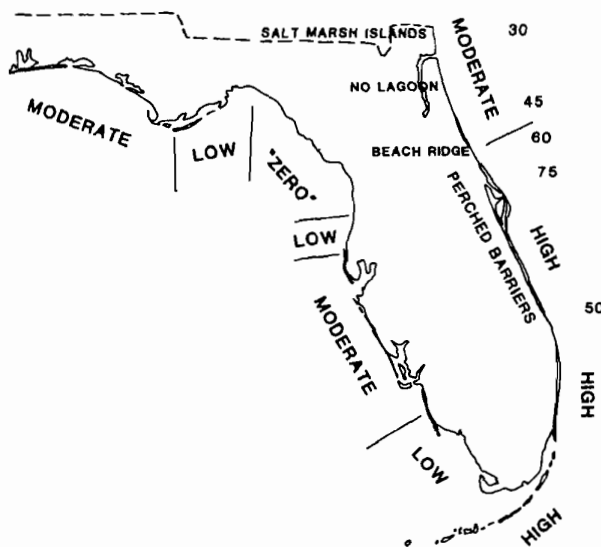


Figure 2. Map of Florida, showing coastal energy levels and the main coastal features of northeast Florida. Wave heights are average values in cm (Adapted from Tanner, 1960).

HYDROLOGY

The Floridan Aquifer is the principal groundwater source in the coastal lowlands of northeast Florida. This aquifer, one of the major sources of groundwater supplies in the United States, underlies all of Florida, southeastern Georgia, and small parts of Alabama and South Carolina (U. S. Geological Survey, 1983). In northeast Florida, it consists of a series of hydrologically-connected, water-bearing zones composed of soft porous limestone, dolomite, and sand beds (Snell and Anderson, 1970). Aquifer thickness ranges from 150 m to more than 3,000 m, with depths varying from 15 m below mean sea level (msl), in southern Flagler and west central Volusia Counties, to more than 168 m below msl, in Duval County (Snell and Anderson, 1970).

Overlying the water-bearing zones of the Floridan aquifer, in many areas, are relatively impermeable confining beds of sandy clay and shell, called aquicludes. Vertical movement of water is restricted in these areas. Where aquicludes occur, the water is under sufficient pressure to rise above the top of the aquifer through tightly cased wells, and it often flows freely at the land surface. These are known as artesian conditions. The height to which water rises in wells that penetrate the Floridan aquifer is known as the piezometric surface. The piezometric surface fluctuates in response to aquifer recharge and discharge. Cones of depression have developed in farming and urban industrial areas of northeast Florida because discharge has exceeded recharge. Recharge to the Floridan aquifer occurs mainly in the western portion of the coastal counties and through lateral flow from Clay, Putnam, and Marion Counties (Jacksonville Area Planning Board, 1979). However, increased urban and industrial development, with accompanying impermeable buildings, streets, and parking areas, reduces the natural recharge area (Snell and Anderson, 1970).

In 1980, about 2,420 million l of water per day, mostly for industrial use, were withdrawn from the coastal strip of southeast Georgia/northeast Florida. As a result, long-term water-level declines of more than 6 m occurred from Jacksonville and Fernandina Beach north to Hilton Head (U. S. Geological Survey, 1983). As artesian pressure drops in these areas, saltwater intrusion becomes pronounced. This has happened in areas of natural discharge in south-central Flagler County and along the coast in eastern St. Johns and Flagler Counties. Saltwater intrusion is an ever-increasing problem in areas of artificial discharge (Jacksonville Area Planning Board, 1979).

Of a total discharge of approximately 2,000 cubic meters per second from the Floridan Aquifer, about 75% goes to springs and rivers, 7% is seepage, and 18% is pumpage (U. S. Geological Survey, 1983). Groundwater development (use of ground

water by municipalities) has reduced spring flow and discharge to rivers by almost 5%, and discharge by seepage in coastal areas by about 30%. Approximately 20% of the ground water pumped originates from spring flow and river discharge, 20% is from seepage in coastal areas, and the remaining 60% is from additional recharge that is induced by the lowered water levels in the aquifer.

In addition to tapping into the Floridan Aquifer, some small municipalities and rural domestic users obtain ground water from shallow sand or sand and shell aquifers that occur above the aquifer. The thickness of this "water-table" aquifer overlying the Floridan Aquifer ranges from less than 1 m in the interior to over 122 m in Indian River and St. Lucie Counties (Florida Department of Natural Resources, 1970). Shallow aquifers are recharged directly by local rainfall and percolation from surface water. Surface water is used for irrigation in source areas, and a few municipalities obtain water from lakes (Parsont et al, 1971).

Surface freshwater resources include streams, lakes, and their associated drainage basins. Often, the drainage basins are well removed from the coast, but act as a link between the coastal zone and the interior (Florida Bureau of Coastal Zone Planning, 1976). Impacts on them may be transmitted throughout the entire basin; consequently, careless management and use of upland resources can create environmental problems and economic losses in coastal areas.

The northeast coastal zone contains three major drainage basin systems (Florida Bureau of Coastal Zone Planning, 1976): the St. Marys/Nassau River Basin, St. Johns River Basin, and East Coast Basin (Figure 3). The East Coast Basin drains land directly along the coast, while the St. Johns and St. Marys/Nassau systems drain upland areas. The St. Marys/Nassau Drainage Basin drains more than 1,770 square km of the northeastern corner of Florida (Florida Department of Environmental Regulation, 1979). The headwaters of the St. Marys River begin in the Okefenokee swamp, which drains more than 2,220 square km. Nummedal et al (1977) indicated that 79% of the lagoonal area that drains through St. Marys Entrance is covered by marshland. The Nassau River originates in Duval County, drains approximately 780 square km, and discharges into the Atlantic Ocean along the southern boundary of the basin. The Amelia River, an estuary connecting the St. Marys and Nassau Rivers, also occurs in this basin. Net river discharge at St. Marys Entrance amounts to less than 5% of the total discharge attributable to tides (Parchure, 1982).

The St. Johns Drainage Basin covers approximately 2,280 square km (Florida Department of Environmental Regulation, 1979). Most land surface in the coastal zone segment of this basin has less

than a one percent slope, which inhibits drainage and aggravates localized flooding. Drainage patterns are generally dendritic, except where modified by man-made construction. This basin is divided into three sub-basins: the Upper St. Johns River, the Oklawaha River, and the Lower St. Johns River. The St. Johns River is perennially tidal as far upstream as Lake George (171 km) and, under combined conditions of drought and high tide, tidal effects (i.e., flow reversals) occur far upstream [259 km (Anderson and Goolsby, 1973)]. At Jacksonville, 34 km upstream from the ocean, average tidal flow volumes are more than seven times greater than the average freshwater flow (Anderson and Goolsby, 1973).

The Florida East Coast Drainage Basin encompasses approximately 5,700 square km of the east coast from north of St. Augustine to south of Vero Beach (Florida Department of Environmental Regulation, 1979), and drains directly into the ocean or into coastal lagoons (Snell and Anderson, 1970). This basin is divided into upper and lower sub-basins. The Upper East Coast sub-basin includes seven drainage areas, extending from St. Johns to Indian River Counties: the Tolomato River, draining coastal St. Johns County north of St. Augustine to St. Augustine Inlet; Moultrie Creek, draining 60 square km of ridges and creeks and flowing into the Matanzas River; the Matanzas River, draining south coastal St. Johns County, north to St. Augustine

Inlet and south to Matanzas Inlet; the Tomoka River, the largest coastal drainage basin (394 square km) in northeast Volusia County, flowing to the Halifax River; the Halifax River, flowing north along the coast of Volusia County and south of Daytona Beach to Ponce de Leon Inlet; and the Indian River North and Mosquito Lagoon, exchanging with Ponce de Leon Inlet to the north and, via the Haulover Canal, with the Indian River lagoon and Banana River to the south. With the exceptions of the Tomoka River and Moultrie Creek, the above "rivers" are really coastal lagoons connected by artificial channels created to establish continuity of the Intercoastal Waterway. Water draining from the coastal areas into the lagoons reaches the ocean through the inlets that connect the lagoons to the ocean (Snell and Anderson, 1970). A comparison between coastal northeast Florida and Georgia reveals that inlets occur, on the average, every 48-64 km in Florida, but about every 16 km along the Georgia coast. This reflects some of the basic hydrologic and geologic differences between the two areas.

CLIMATE

The climate of the northeast Florida coastal region is under a pronounced maritime influence (National Oceanic and Atmospheric Administration, 1982). The relatively close proximity of the Gulf Stream moderates the heat of summer and cold of winter. As a result, the area has a humid, warm, temperate to semi-tropical climate characterized by long summers with heavy rainfall and relatively mild and dry winters. Since maritime tropical air masses are occasionally displaced during the winter, the local weather is categorized into two general regimes: the frontal regime from mid-September to mid-May, and the air-mass regime from June to September (Parsont et al., 1971). In addition, a hurricane season, from June 15 through November 15, overlaps both regimes.

Annual mean temperatures range from 21.1°C in Fernandina (Parchure, 1982) to 22.8°C in the vicinity of Cape Canaveral (Parsont et al., 1971). June, July, and August are the hottest months, with average temperatures near 26.6°C; December, January, and February are the coolest months, with mean temperatures near 12°C. The temperate and sub-tropical zones are separated by the -4°C-average-annual-minimum-temperature line, which intersects the coast about 16 km south of New Smyrna Beach (Florida Department of Natural Resources, 1970). This line also approximates the northern limit for citrus production. Above the line, near Jacksonville, temperatures fall to freezing or below about 12 times a year, but the 1976-77 season produced 37 days with minimum tempera-

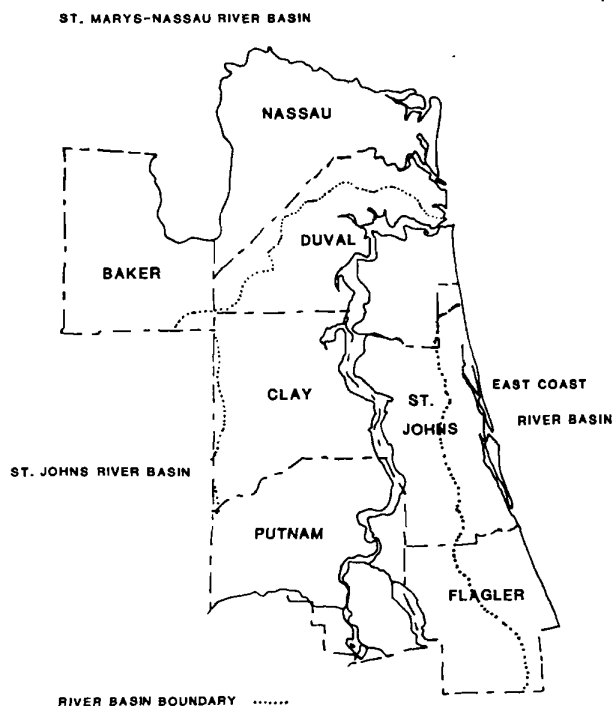


Figure 3. Drainage basins of northeast Florida.

tures of 0°C or below (National Oceanic and Atmospheric Administration, 1982).

An average annual rainfall of 125 cm to over 140 cm occurs, with over 50% falling between June and September. Most summer rainfall comes from thunderstorms of short duration, which can be expected almost every other day. These heavy showers can cause localized flooding and add to runoff problems. Ocean breezes tend to retard the movement of rainstorms moving west to east, so the amount of rain falling directly along the coast is less than that in the interior regions (Jones and Mehta, 1978). The area also is subject to tornadoes each year.

For the entire northeast coastal region, prevailing winds during fall and winter months are from the northeast. Spring and summer winds are predominately from the south and east along the southern end of the northeast region and southwesterly at the northern end (Jones and Mehta, 1978; National Oceanic and Atmospheric Administration, 1982). Winds average 13 kph to 18 kph and are three kph to five kph higher during the early afternoon than in early morning. Most hurricanes reaching these latitudes tend to move parallel to the coastline, keeping well out to sea, or to lose much of their force moving over land before reaching the area (National Oceanic and Atmospheric Administration, 1982). Hurricanes and northeast storms are the two storm types that cause major beach erosion because of their long durations (Parchure, 1982).

ESTUARIES

Much of coastal northeast Florida is composed of estuaries, the vital ecological links between inland freshwater habitats and the oceans (Comp and Seaman, 1985).

An estuary is generally defined as a semi-enclosed body of water that has a free connection with the sea, and within which sea water is measurably diluted by fresh water from land drainage (Figure 4; Pritchard, 1967). The freshwater influence differentiates an estuary from a coastal lagoon, which is simply a coastal zone depression connected with the sea but protected by some type of barrier (Lankford, 1977). Estuaries and lagoons occupy 80% to 90% of the Atlantic and Gulf coasts of the United States (Day and Yanez-Arancibia, 1982). The specific upstream limit of an estuary is usually defined as the average upper intrusion of the one-part-per-thousand (ppt) isohaline (Kjerfve, 1976). Therefore, estuaries exhibit a measurable salinity gradient, which is important in determining distributional limits of benthic populations as well as controlling distribution and movements of fish or other nekton (Cronin and Mansueti, 1971). Comprising the transition zone between land

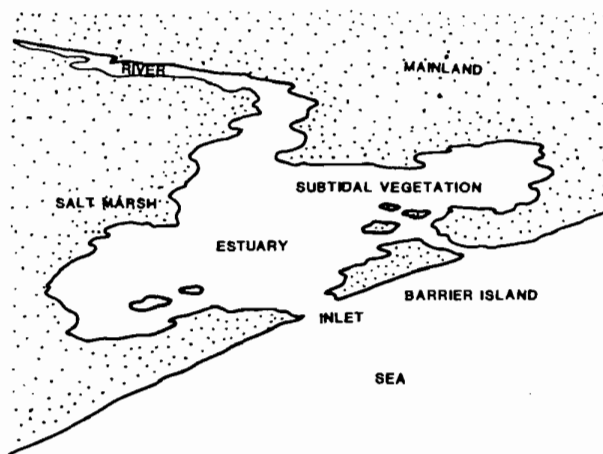


Figure 4. Outline of a "typical" estuary (from Comp and Seaman, 1985).

and sea, estuaries may be subjected to a variety of inputs associated with adjacent upland and riverine systems.

Water circulation and mixing are an important part of the physical, chemical, and biological interactions within estuaries. Day and Yanez-Arancibia (1982) described several factors that exert major influences on the hydrography of estuaries:

- 1) The semi-enclosed nature of estuaries buffers oceanic effects, allowing the development of a unique environment.
- 2) Freshwater inflow carries dissolved and suspended materials into the estuary, providing a major energy subsidy to these environments.
- 3) Through turbulent mixing, tidal action exerts a profound influence on estuarine circulation and provides another major energy subsidy.
- 4) Wind-induced surface turbulence affects the bottom as well as the surface because estuaries are shallow. Thus, stratification patterns usually do not exist.
- 5) In addition to winds and riverine and tidal currents, geomorphology affects the complex water circulation patterns in estuaries. Strong physical energies, which move sediments, make estuaries areas of relatively rapid geomorphologic changes.

Typical mixing patterns trap nutrients within the estuary (Figure 5). As fresh water enters the estuary, its velocity decreases and particles begin to settle out. In addition, dissolved colloidal compounds precipitate, flocculate, or aggregate when they contact sea water, which has a higher ionic strength than fresh water (Barnes, 1974). The settling and flocculation-aggregation result in an area termed the "turbidity maximum" (Conomos and Peterson, 1977). This pattern of circulation reduces the export of nutrients from the system, but

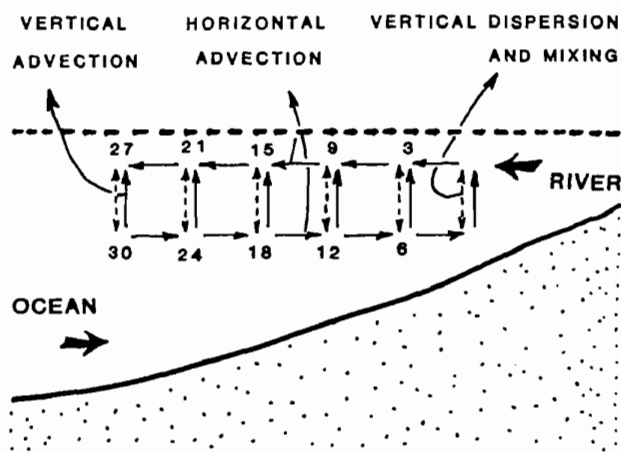


Figure 5. Diagrammatic representation of a two-layer and partially mixed estuary showing general patterns of mixing, diffusion, stratification and salinity gradient (Day and Yanez-Arancibia, 1982).

also tends to trap and recirculate pollutants that are flushed into the estuary. Thus, estuarine sediments function as a sink for both nutrients and contaminants.

Areas where nutrient-rich estuarine water exchanges with sea water during ebbing tides often support diverse biological communities, because the nutrients are dispersed by along-shore currents (Comp and Seaman, 1985). Turner et al. (1979) found that nearshore productivity and densities of zooplankton, fish eggs, and larvae were strongly influenced by the areal extent and productivities of local estuaries. Tidal flow is important in transporting eggs and larvae of fish and shellfish that spawn offshore into the estuary. For example, post-larval shrimp utilize tidal currents and salinity gradients to enter estuaries by alternately floating in the water column during flood tides and burrowing into the sediments during ebb tides (Eldred et al., 1961; Williams, 1955). Tagatz (1968) found first and second stage blue crab zoeae as far as 40 km upstream from the mouth of the St. Johns River, demonstrating the effectiveness of this floating/burrowing behavior in transporting "planktonic" life stages upstream.

While tidal flow is relatively independent of human influence, freshwater flow patterns can be altered by a number of human activities in coastal areas and farther upstream in the drainage basins. The role and importance of fresh water in estuaries has been discussed in numerous publications (Cross and Williams, 1981; Henley and Rauschuber, 1981; Seaman and McLean, 1977; Snedaker et al., 1977). Snedaker et al. (1977) summarized the dominant effects that have been observed following reduced freshwater inflow to estuaries:

1. Nearshore waters become more saline.

2. Mixing due to salinity differences is diminished.
3. A salt-wedge may develop farther upstream in the discharge channel.
4. Saltwater intrusion appears in coastal ground waters and surface water.
5. The estuary is starved of essential nutrients of terrestrial origin.
6. Benthic substrate tends to become anaerobic and heavy metals sequestered in the substrate are liberated; sulfur cycles become dominant.
7. Particulate and soluble organic matter inputs are not dispersed, but are reduced and/or flocculated and deposited near shore.
8. Certain fisheries are entirely lost for a variety of reasons, such as increased salinity, reduced food supply; loss of a large area of low salinity, etc.
9. Euryhaline species lose dominance to stenohaline species and, in general, selection is for species adapted to the new conditions.
10. Salt-tolerant mosquito and dipteran populations increase.
11. Schistosomiasis becomes rampant (not presently a problem in Florida).
12. All negative effects are aggravated during low-flow conditions.
13. Salt marshes and/or mangroves and seagrasses deteriorate under constantly elevated salinity.
14. Renourishment of sand/silt ceases; downstream shoals erode.
15. Littoral drift patterns and nearshore circulation are altered.

The following example illustrates how these effects can interact to compound the problems. Reduced freshwater inflow allows intrusion of salt water into estuarine marshes and eliminates large areas of oyster habitat because of the influx of the oyster drill, *Thais haemastoma*, a predator intolerant of low-salinity water (Chew and Cali, 1981). In addition, the areas suitable for oyster cultivation may shift inland (or upstream), closer to sources of pollution, resulting in more frequent oyster harvesting closures.

The timing of freshwater flow is also important because the usefulness of the estuary as nursery habitat for many marine organisms is determined by salinity distributions during the season when post-larvae are abundant (Durako et al., 1985). Fortunately, juveniles are more tolerant of wide ranges of salinity than adults in many species (Henley and Rauschuber, 1981).

The interaction between tidal and river flows, which are the dominant physical processes in an estuary, results not only in salinity fluctuations, but

water-level fluctuations, too. The latter expose intertidal areas to alternating periods of inundation and drying and to relatively wide temperature fluctuations. These physical energies can be viewed as both subsidy and stress. Estuarine organisms have adopted physiological and behavioral mechanisms to minimize stress induced by alternate flooding and exposure and to use the physical energies as subsidies (Cronin and Mansueti, 1971; Gosselink et al., 1979; Vernberg and Vernberg, 1976). In fact, estuaries are among the most productive ecosystems on earth (Table 1). The high primary production of estuaries reflects their nutrient-rich conditions and the presence of several classes of primary producers, including submerged vascular plants, macro- and micro-algae, and emergent grasses, shrubs, and trees.

Five major factors (Nixon, 1981) hypothesized to account for estuarine production are (1) the fertilizing effect of nutrients in fresh water, (2) the advection of nutrient-rich offshore water, (3) the trapping of nutrients due to estuarine circulation patterns, (4) the outwelling of nutrients from associated wetlands, and (5) the rapid recycling of nutrients within the estuary. Remineralization appears to be slower than the formation of new organic matter in estuaries, so heterotrophic pro-

cesses may play an important role in regulating primary production in these systems (Nixon, 1981). In addition, primary production rates are very similar among estuaries, possibly due to a common limit on the rate of nutrient recycling. A detailed discussion of the chemical and biological processes responsible for the high productivity in Florida's estuaries is presented in a review by Comp and Seaman (1985).

Along the northeast Florida coast, most estuaries are probably well mixed because average tidal flow exerts a greater force than does freshwater inflow, resulting in a fairly homogeneous salinity throughout the water column. For example, at the St. Marys River entrance, net river discharge amounts to less than 5% of the total discharge attributable to tides (Parchure, 1982). Profiles of temperature, salinity, and dissolved oxygen indicate that this system is well mixed, even at the increased depths generated by dredge operations related to the nearby Trident submarine shoreside facility (Jones, Edmunds and Assoc., 1984). However, the St. Johns River, between Jacksonville and the ocean, may be classified as a slightly stratified estuary with some vertical stratification and a fair amount of vertical mixing (Anderson and Goolsby, 1973; Morrill and Olson, 1955). Numerous salt springs that drain into the St. Johns River result in locally elevated salinities in some upstream areas. These springs and the far-reaching tidal influence described earlier appear to be responsible for the presence of a number of oceanic fish species (Table 2) in the river's upper reaches. The St. Johns River also is unusual in that it discharges directly into the Atlantic Ocean, rather than into an embayment, as is typical of most estuaries.

South of the St. Johns River mouth, the coast is characterized by a high energy shoreline with long barrier islands protecting narrow, shallow coastal lagoons. These lagoons, which include the Tolomato River, Matanzas River, Halifax River, Indian River North, and Mosquito Lagoon, exhibit estuarine characteristics although they receive freshwater inflow mainly through surface runoff and a few small rivers and streams (Beccasio et al., 1980; Comp and Seaman, 1985). Tidal marshes rim the lagoonal rivers in the northern part of the northeast region, while mangroves become more prominent southward.

The Tolomato system is characterized by a series of small lagoons and swamps adjacent to the man-made Intracoastal Waterway and the Tolomato River (Briley, Wild and Assoc., 1980). Physical modifications resulting from dredging and maintaining the Intracoastal Waterway have greatly affected flushing characteristics of the Tolomato River. In addition, a dam built in the 1950's sealed off a portion of the Guano River, converting the upstream portion into a freshwater lake. The tidal energy that once flowed through the Guano and Tolomato Rivers now flows only through the latter.

TABLE 1. NET PRIMARY PRODUCTION OF MAJOR ECOSYSTEMS (Whittaker, 1975).

Ecosystem	Net Primary Production (g dwt/m ² /yr)	
	Range	Mean
Lake and stream	100-1500	500
Swamp and marsh	800-4000	2000
Tropical forest	1000-5000	2000
Boreal forest	400-2000	800
Woodland and shrubland	200-1200	600
Savanna	200-2000	700
Temperate grassland	150-1500	500
Tundra and alpine	10- 400	140
Desert scrub	10- 250	70
Extreme desert, rock, and ice	0- 10	3
Agricultural land	100-4000	650
Open ocean	2- 400	125
Continental shelf	200- 600	350
Attached algae and estuaries	500-4000	2000

TABLE 2. FISHES KNOWN TO OCCUR
IN OCALA NATIONAL FOREST (Snedaker and Lugo, 1972).

Scientific name	Common name
<i>Dasyatis sabina</i>	Atlantic stingray
<i>D. americana</i>	Southern stingray
<i>Acipenser oyrhynchus</i>	Atlantic sturgeon
<i>A. brevirostrum</i>	Shortnose sturgeon
<i>Megalops atlanticus</i>	Tarpon
<i>Anchoa mitchelli</i>	Bay anchovy
<i>A. hepsetus</i>	Striped anchovy
<i>Opisthonema aglinum</i>	Atlantic thread herring
<i>Bagre marinus</i>	Gafftopsail catfish
<i>Arius felis</i>	Sea catfish
<i>Centropomus undecimalis</i>	Snook
<i>Caranx hippos</i>	Jack crevalle
<i>Lutjanus griseus</i>	Grey snapper
<i>Diapterus olisthostomus</i>	Irish pompano
<i>Eucinostomus argenteus</i>	Spotfin mojarra
<i>Archosargus probatocephalus</i>	Sheepshead
<i>Lagodon rhomboides</i>	Pinfish
<i>Cynoscion nebulosus</i>	Seatrout
<i>Sciaenops ocellatus</i>	Red drum
<i>Micropogon undulatus</i>	Atlantic croaker
<i>Bairdiella chrysaura</i>	Silver perch
<i>Leiostomus xanthurus</i>	Spot
<i>Mugil curema</i>	White mullet
<i>M. cephalus</i>	Striped mullet
<i>Paralichthys lethostigma</i>	Southern flounder

The Matanzas River system is similar to the Tolomato system, but lacks the extensive man-made modifications and has less natural flushing (Briley, Wild and Assoc., 1980). Matanzas River extends northward to St. Augustine Inlet and southward from Matanzas Inlet for approximately 13 km, connecting with Ponce de Leon Inlet, 83 km south, through the Intracoastal Waterway, Smith Creek, and the Halifax River (Mehta and Jones, 1977). Salinity conditions favorable to numerous marine and estuarine species are generated by freshwater inflow from Pellicer, Moultrie, and Moses Creeks,

the San Sebastian River, and a number of artesian springs (Briley, Wild and Assoc., 1980).

Ponce de Leon Inlet connects the Atlantic Ocean with the Halifax River and Indian River North estuaries. The Halifax extends northward for 38 km, past Port Orange, Daytona Beach, and Ormond Beach, joining with the Tomoka River north of Ormond Beach (Jones and Mehta, 1978). The northern part of the Halifax River estuary is highly urbanized, resulting in poor-to-moderate water quality (Volusia Council of Governments, 1977). As urban development decreases southward along the Halifax, mangrove islands increase. The area around the inlet is sparsely developed, well flushed by tides, and has generally good water quality. Estuaries north of Port Orange primarily support *Spartina* grasses (*Spartina alterniflora*, *S. bakeri*, and *S. patens*) and needle rush (*Juncus roemerianus*), while those to the south are characterized by black, red, and white mangroves (*Avicennia germinans*, *Rhizophora mangle*, and *Laguncularia racemosa*, respectively). The North Indian River and Turnbull Bay are ecologically sensitive estuarine systems, supporting harvestable shellfish beds and serving as the habitat for almost ten endangered species (Volusia Council of Governments, 1977). The Intracoastal Waterway extends southward through Mosquito Lagoon, passes through Haulover Canal to the Indian River lagoon, and continues southward. In contrast to the estuaries to the north, Mosquito Lagoon receives little freshwater inflow (Comp and Seaman, 1985), and, consequently, has relatively high salinities. Because the lagoon is connected to the ocean at only a few isolated inlets and has restricted circulation, portions of it are hypersaline for much of the year (Mulligan and Snelson, 1983; Nevin et al., 1972). This results in a "miniature ocean" environment where some species that normally migrate offshore to spawn may remain in the lagoon to complete their life cycles (W. E. Carr, personal communication).

HABITATS

The term "habitat" refers to the place occupied by an entire community of organisms (Odum, 1971). Coastal northeast Florida possesses a diverse array of wetland habitats, ranging from the salt-marsh-dominated "Sea Islands" north of the St. Johns River to the mangrove, seagrass, and salt wort/mangrove/marsh habitats of the more southern coastal lagoons. Estuaries can be considered ecosystems because they are composed of numerous subsystems or habitats (Cain, 1968).

Northeast Florida's estuaries occur in the Carolinean province delineated by the U. S. Fish and Wildlife Classification System (Cowardin et al., 1979). This province, which extends from Cape

Kennedy to Cape Hatteras, is characterized by marshes and well-developed barrier islands, turbid and productive waters, small-to-moderate tidal range, and a biota with temperate and seasonally tropical elements. The wetlands and estuaries of northeast Florida are economically and ecologically important to the region, supporting at least 72% of the 89 commercially-landed species of finfish and shellfish and 74% of the 84 recreational species (Harris et al., 1983).

The following sections of this paper will briefly describe some general characteristics of the habitats of northeast Florida that are important to the production of fishery resources. For more detailed descriptions, the reader is referred to recent reviews of Florida's estuaries, salt marshes, and mangroves by Comp and Seaman (1985), Durako et al. (1985), and Lewis et al. (1985), respectively.

SALT MARSHES

Salt marshes are intertidal herbaceous plant communities that develop along the shorelines of estuaries where wave energy is low (Humm, 1973). The vegetation of salt marshes consists of a number of species in the grass (Poaceae), sedge (Cyperaceae), and rush (Juncaceae) families. Salt marshes are typically intertidal, occurring from near low water to mean high water and, consequently, can withstand rapid changes in salinity, drainage, and temperature. This rigorous environment restricts the number of species that can inhabit marshes. However, salt marshes, like the estuaries they surround, are among the most productive natural ecosystems in the world (Table 1; Bagur, 1977; Westlake, 1965). This, again, seems to occur because of the nutrient and "energy" subsidies supplied by tidal action (Odum, 1971). The organic matter produced by marsh vegetation is important in estuarine and marine food webs, but the extent of this importance is currently subject to much controversy (Haines, 1976, 1977, 1978; Peterson et al., 1980). Marshes

and associated tidal creeks also protect shorelines from erosion, filter nutrients from runoff, and provide protection and habitat for juvenile and adult fish, birds, and invertebrates.

Salt marshes of the South Atlantic, including northeast Florida, are dominated by smooth cordgrass, *Spartina alterniflora*. Northeast Florida salt marshes developed near the coast on Pamlico terrace sediments, which are higher in silt, clay, and carbonate content than Gulf coast marsh sediments (Kurz and Wagner, 1957). In addition, marshes in northeast Florida are under the influence of high-to-moderate tidal amplitudes and are characterized by numerous dendritic creeks and deep tidal channels (Cooper, 1974). Tidal amplitude and salinity control plant zonation, one of the most striking features of the marshes (Figure 6). In this regard, marshes characteristic of Florida's Gulf coast generally are flooded irregularly and experience smaller tidal amplitudes. As a result, the proportions of plant species and the rates of primary and secondary productivity in Atlantic and Gulf coast marshes are different (Table 3).

Spartina alterniflora is well adapted to sea-strength salinity (35 ppt) and attains its tallest growth (> 1.0 m) on levees adjacent to creek bank zones (Teal, 1962). Inland from this streamside zone, plant height decreases to a medium size (50-60 cm) and then to the inland short form (< 50 cm; Figure 6). The reduction in plant height from streamside to inland seems to occur because of changes in a number of substrate factors, such as increasing salinity (Cooper, 1974), decreasing nitrogen availability (Broome et al., 1975; Mendelssohn, 1979; Patrick and Delaune, 1976), and decreasing redox potentials with corresponding increases in sulfide levels (Mendelssohn et al., 1981; Mendelssohn and Postek, 1982). Short *S. alterniflora* becomes mixed with *Salicornia virginica* (glasswort) and *Distichlis spicata* (salt grass) on sandy substrates near the high water mark. Large areas of high marsh, dominated by the black needle rush, *Juncus roemerianus*, occur where tidal flow is restricted and

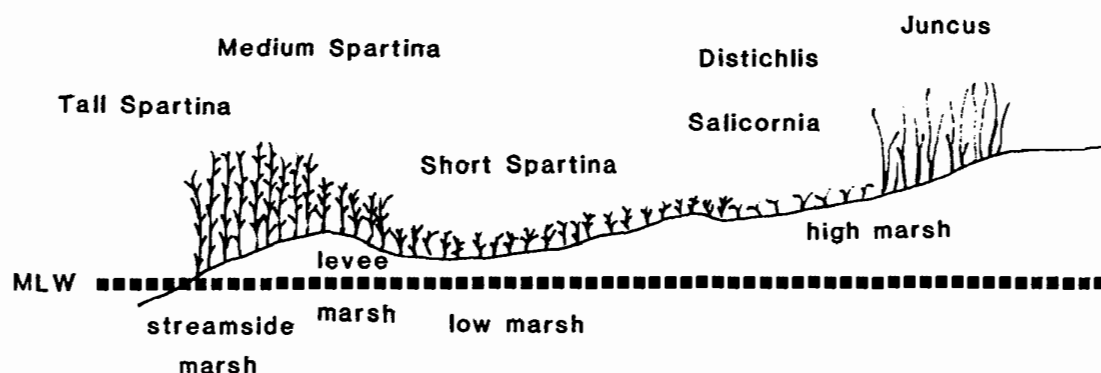


Figure 6. Zonation of plants in a typical South Atlantic salt marsh (Teal, 1962).

TABLE 3. COMPARISON OF SOUTH ATLANTIC AND GULF COAST MARSHES (adapted from de la Cruz, 1981).

Item	South Atlantic	Gulf Coast
Dominant plant species	<i>Spartina alterniflora</i>	<i>Juncus roemerianus</i>
High marsh plant association	<i>Salicornia</i> - <i>Distichlis</i> - <i>Juncus</i>	<i>S. patens</i> - <i>Distichlis</i> - <i>Salicornia</i>
Inland marsh plant association	<i>Spartina cynosuroides</i> - <i>Typha</i>	<i>S. cynosuroides</i> - <i>Phragmites communis</i> - <i>Cladium</i>
Tidal amplitude	2.0 m	0.3 m
Tidal cycle	Semi-diurnal	Diurnal
Salinity	10-30 ppt	2-15 ppt
Annual precipitation	120 cm	140 cm
Primary productivity	1000-2000 g dwt/m ² /yr	1500-3000 g dwt/m ² /yr
Secondary productivity		
Penaeid shrimp	132 kg/ha	33.9 kg/ha
Total fish	320.2 kg/ha	485.4 kg/ha

wind effects predominate (Woodhouse and Knutson, 1982).

The importance of salt marshes to fisheries production results, for the most part, from the marshes' high rates of primary production and their interaction with the estuary. Primary production sets an upper limit to the flow of energy through the marsh-estuarine food web (Gosselink et al., 1979). Estimates of net areal primary production (NAPP) in salt marshes range from approximately 300 to 3000 g dwt/m²/yr (Durako et al., 1985). In a north Florida salt marsh, lower productivity was associated with high or mixed marsh communities, while highest values were associated with streamside or pure stand communities (Kruczynski et al., 1978). Turner (1976) suggested that standing crop and net production tend to increase from north to south, paralleling solar inputs, despite wide disparities in estimated production. However, both Kruczynski et al. (1978) and Young (1974) reported relatively low productivity values for two salt marshes on Florida's Gulf coast. Young (1974) attributed the low values to small tidal amplitude and low nutrient content of these waters.

Until recently, most productivity studies considered only above-ground plant parts (leaves, shoots, and inflorescences) and little was known about root and rhizome growth. This was mainly due to the difficulty in sampling and quantifying below-ground biomass. However, the few projects that studied below-ground production have shown that it equals or exceeds above-ground production, making total production more than twice previous estimates (de la Cruz and Hackney, 1977; Gallagher and

Plumley, 1979; Schubauer and Hopkinson, 1984; Smith et al., 1979; Valiela et al., 1976). The quantity of sediment organic matter in marshes generally does not increase, indicating that the below-ground production is somehow transported or lost from the sediments, but its fate is uncertain (Schubauer and Hopkinson, 1984).

Ninety percent or more of the net primary production of a salt marsh may form detritus (de la Cruz, 1973), i.e., particulate organic matter in various stages of decay. The export (outwelling) of detritus has long been considered one of the most important contributions of marshes to estuarine and coastal productivity (Odum, 1980). However, some marshes are not "leaky" and may actually retain and utilize much of their production (Correll, 1978); others receive net imports (Woodwell et al., 1977).

Microorganisms modify detritus by converting lignins and cellulose into proteins, fats, and sugars, and act as the first consumers in a detrital food web. The second trophic level is dominated by detritivores rather than herbivores (Figure 7). Blue crabs, several species of shrimp, and fish such as striped mullet and killifish belong in this group. These detritivores, some of which are also referred to as opportunistic omnivores (Haines, 1978), are consumed by carnivorous fish. Animal production is high in marsh-estuarine systems because both primary production and its consumption by animals (secondary production) are high (Turner, 1982).

Salt marshes also provide sites for reproduction and a favorable environment for early life stages (Figure 8; Odum and Smith, 1981). Because of the problems involved with sampling in marshes, the

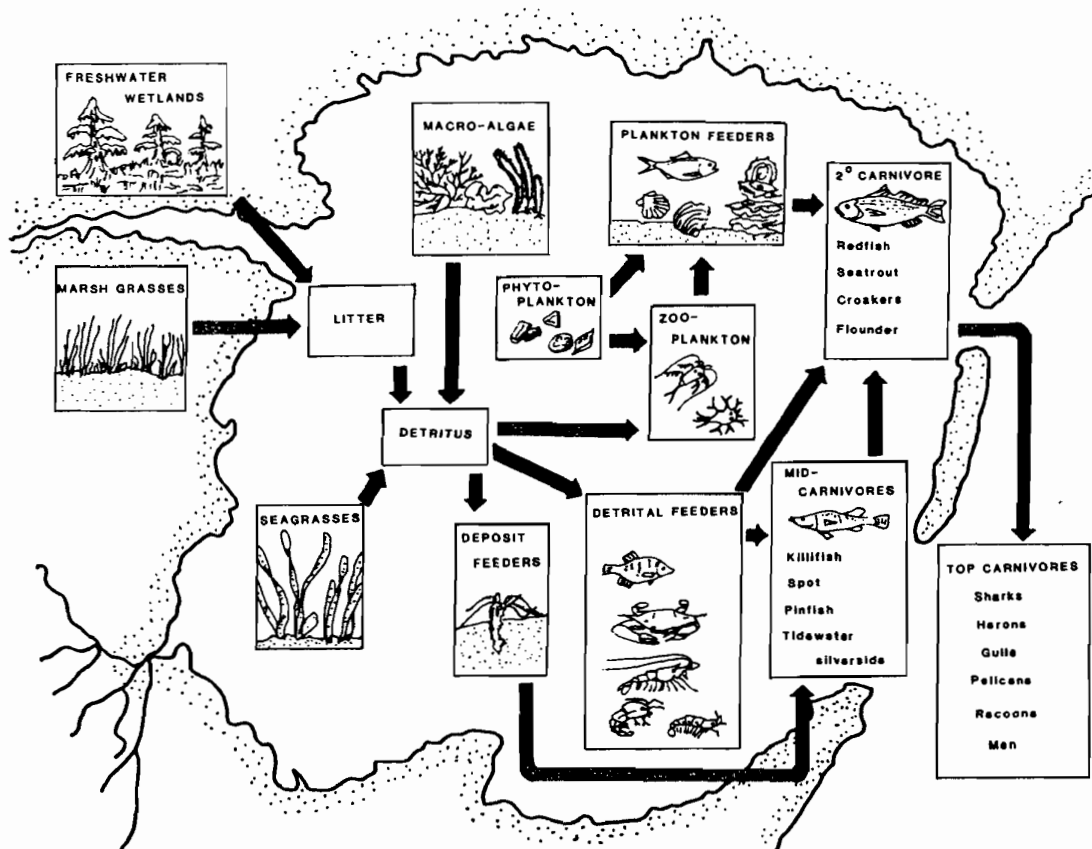


Figure 7. Generalized marsh-estuarine food web (Durako et al., 1985).

importance of salt marshes as habitat for young fishery organisms has not been well studied. Day et al. (1973) reported that marsh faunal diversity is comparable to that of adjacent open-water areas, but biomass is higher. Marsh fauna exhibit zonation patterns analogous to those of the flora, with the seaward edge having greater biomass and diversity than the inland marsh (Subrahmanyam et al., 1976). Zimmerman et al. (1982) found that the concentration of brown shrimp was much higher at the base of *S. alterniflora* culms than in nearby open-water areas. Emergent vegetation provides greater protection from predation simply because the predator's field of view may be restricted by vegetation (Vince et al., 1976). In addition, the supply of potential food for juvenile fish and shrimp is most abundant at the site of production; consequently, detritus does not have to be exported to the estuary to be available to estuarine-dependent species. Several carnivorous fish species move into marshes to feed at high tide, then move back to the bay-estuary at low tide (Subrahmanyam and Drake, 1975). Thus, predators export some marsh production when they move into coastal waters where they may be eaten by larger fish (Durako et al., 1985).

MANGROVES

The three species of mangroves commonly recognized throughout Florida and found in the southern part of the northeast region are *Rhizophora mangle* (red mangrove), with conspicuous prop roots that make it easy to recognize, *Avicennia germinans* (black mangrove), with characteristic vertical roots called pneumatophores, and *Laguncularia racemosa* (white mangrove), with salt glands at the bases of its leaves and bulbous, knee-like projections rising from its roots. A fourth species, *Conocarpus erectus* (buttonwood), is closely associated with mangroves at upland transition zones, but it is not usually thought of as a true mangrove because it lacks such typical mangrove characteristics as vivipary (germination of the seed while attached to the parent plant) and aerating roots. Nonetheless, it contributes both biomass and habitat to the mangrove ecosystem (Lewis et al., 1985).

The northern distribution of mangroves is limited by their intolerance of freezing temperatures. Just south of Daytona Beach, salt marshes characteristic of the south Atlantic coast are replaced by mangroves, which form the tropical and subtropical

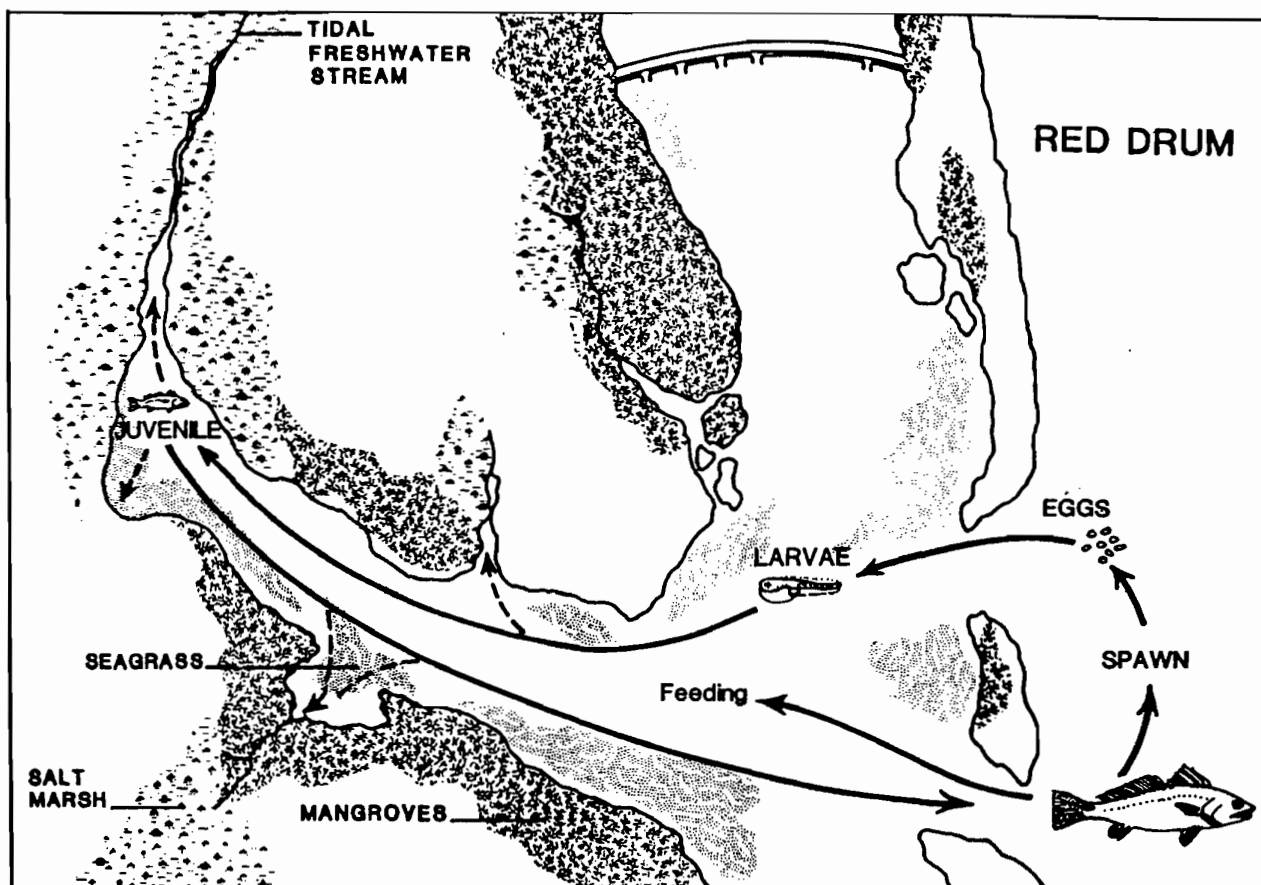


Figure 8. Life cycle of the red drum, *Sciaenops ocellatus*, which uses the marsh-estuarine systems for nursery grounds (Durako et al, 1985).

equivalent of salt marshes (Woodhouse and Knutson, 1982). Black mangroves are the most cold-hardy, occurring in Florida as far north as 30°N latitude (Savage, 1972). They become more common around Matanzas Inlet (Mehta and Jones, 1977; Joe Halusky, personal communication), but mangrove communities do not dominate the estuarine intertidal vegetation north of Port Orange on the southern Halifax River (Volusia Council of Governments, 1977). Both red and black mangroves occur in the vicinity of Ponce de Leon Inlet (Jones and Mehta, 1978). White mangroves, which exhibit the least tolerance to low temperatures, extend northward only to Brevard County (Savage, 1972).

In addition to north-south geographical distribution patterns, mangroves may also exhibit characteristic intertidal distributions (Figure 9). According to Davis (1940), red mangroves generally occur at the lowest elevations, followed by black then white mangroves at higher elevations. This scheme is based on observations in south Florida. However, local variations and exceptions to this zonation pattern commonly occur in response to differences in

substrate type, climate, tidal sorting of propagules, sea level rise, and interspecific competition (see Odum et al, 1982, and references therein). In St. Johns and Volusia Counties, incursions of freezing temperatures are probably the most important factor influencing occurrence of mangroves. Black mangroves typically dominate the intertidal zone in this region, with glasswort (*Salicornia* spp.), and saltwort (*Batis maritima*) occurring above mean high water (Birkitt, 1983). Because of freezes, mangroves may go through a cyclical successional pattern in this region (Lugo and Snedaker, 1974). For example, the severe freeze on 25 December 1983 resulted in almost total leaf drop in mangroves in the Port Orange area; only 10% of the trees exhibited regrowth the following spring (Steve Beeman, Eco-shores, Inc., personal communication). Lugo and Zucca (1977) noted that temperature stress modifies forest complexity by reducing tree height and leaf size and number, as well as increasing tree density.

Mangrove forest communities exhibit tremendous variation in form, due to different geological and hydrological processes. Lugo and Snedaker

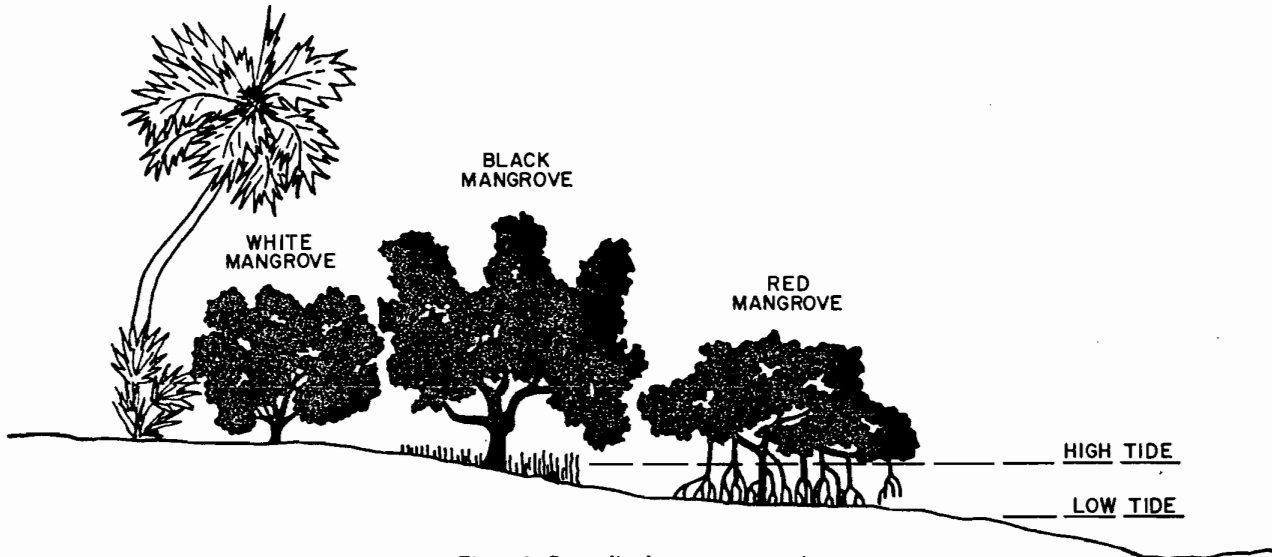


Figure 9. Generalized mangrove zonation.

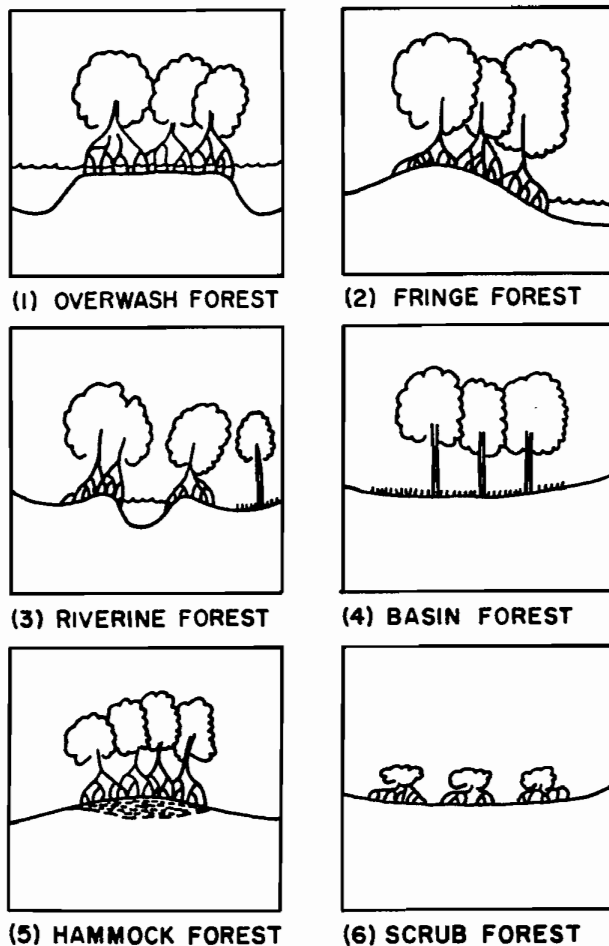


Figure 10. The six mangrove community types (Lugo and Snedaker, 1974).

(1974) based descriptions of six major community types on forest physiogomy (Figure 10). In addition, another variant of the basin community, labeled "lagoonal type," has recently been suggested (Lewis et al., 1981). Each community type, while reflecting different physical regimes, is characterized by distinctive rates of primary production, litter decomposition, and nutrient recycling. Pool et al. (1977) compared mangrove communities in southern Florida, Puerto Rico, and Central America using complexity indices and species-importance values, which allowed them to assess the effects of various environmental factors on forest structure. However, Lewis et al. (1985) noted that relatively few studies have been conducted in the less-developed mangrove stands in northern Florida. The amount of mangrove production cycled through northern marine ecosystems may be significantly different from that of southern mangrove populations. This information is needed for proper ecosystem management and would help in assessment of potential contributions of mangroves to nearshore marine ecosystems of east-central and northeast Florida.

Healthy mangrove forests generally are more productive, in terms of net primary production of biomass, than salt marsh, seagrass, and most other coastal ecosystems (Odum et al., 1982). Odum et al. (1982) listed factors that are important in controlling the productivity of mangroves:

- 1) species composition of the stand,
- 2) age of the stand,
- 3) presence or absence of competing species,
- 4) degree of herbivory,
- 5) presence or absence of disease and parasites,
- 6) depth of substrate,
- 7) type of substrate,

- 8) nutrient content of substrate,
- 9) nutrient content of overlying water,
- 10) salinity of soil and overlying water,
- 11) transport efficiency of oxygen to root system,
- 12) amount of tidal flushing,
- 13) relative energy of waves,
- 14) presence or absence of nesting birds,
- 15) periodicity of severe stress (hurricanes, fires, freezes, etc.),
- 16) time since last severe stress,
- 17) characteristics of ground water,
- 18) inputs of toxic compounds or nutrients from human activities,
- 19) human influences such as diking, ditching, and altering patterns of runoff.

The interaction and effects of these factors led Carter et al. (1973) and Lugo et al. (1976) to hypothesize the general existence of an inverted-U-shaped relationship between distance from the shoreline and net mangrove-community productivity (Figure 11). This relationship results in highest net primary productivity in the middle zone of the mangrove forest and low productivity at the fringe. This is distinct from the pattern that exists in salt marshes, where the streamside zone is most productive and productivity decreases in a landward direction.

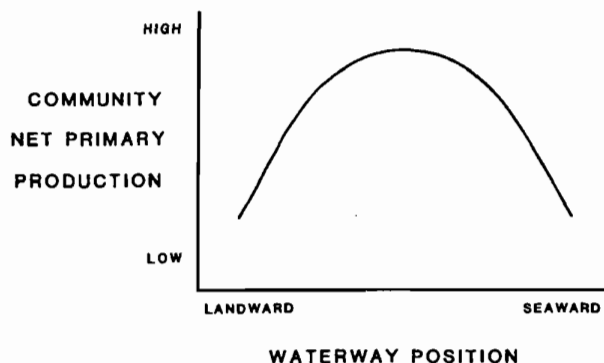


Figure 11. Hypothetical relationship between waterway position and community net primary production of Florida mangrove forests (based on Carter et al., 1973).

Mangrove production generally is thought to be important to fisheries resources as leaf litter, which is the dominant energetic component of the detritus-based food webs within mangrove swamps (Figure 12). However, the relative importance of mangrove production to the system depends on the areal extent of the plants, relative to other primary producers, and their connection to the estuary. Mangrove stems and roots provide valuable substrate for algal and shellfish attachment, and serve as habitats for juvenile fish and crustaceans. The root systems are important in sediment stabilization

and also take up nutrients and heavy metals from the water column, improving the general water quality in areas with runoff.

North of Port Orange, cordgrass and needle-rush dominate intertidal vegetation. South of Martin County, red mangroves are dominant. Between these areas (Brevard County through St. Lucie County), both salt marsh plants and mangroves exist. Lewis et al. (1985) point out that both cordgrass marshes and red mangrove swamps are predominantly low-marsh habitats, with most plant growth below mean high water. In contrast, east-central Florida marshes are predominantly high marsh, dominated by black mangroves and succulents. These areas receive less energy subsidies of tidal and freshwater flow than low-marsh habitats and may develop as seasonally flooded, halophytic macrophyte communities (Harrington and Harrington, 1982). Harrington and Harrington (1961) reported that most fishes in the high marshes were carnivorous, herbivorous, and/or omnivorous, with detritus constituting only 7% of their diets. Cyprinodontids, poeciliid live bearers, larval and juvenile ladyfish, and larval and juvenile mullet dominate the high-marsh ichthyofauna (Lewis et al., 1985).

Lewis et al. (1985) noted that extensive seasonal migration of fishes occurs across the upper marshes of saltwort-mangrove areas that are inundated only during exceptionally high tides. Twenty fish species, eight of sport and commercial fishery value, have been recorded from upper marshes. The number increases in shallow depressions connected to the open estuary. Lewis et al. (1985) concluded that, although the dominant flora, fauna, and trophic relationships in temperate salt marshes and in tropical mangrove ecosystems differ, the processes that lead to the presence of fishery species are similar. During fall, climatic patterns cause sea level to rise and rainfall to occur more often. This promotes favorable nutrient conditions and increases in plankton growth. It also makes peripheral habitat available as a site for reproduction by residents and arrival of larval and juvenile transients, including important fishery species. Lewis et al. (1985) suggested that the direct fishery value of these areas depends on reclamation from the isolation caused by extensive mosquito-control impoundments during the past 25 years.

SEAGRASSES

Seagrasses are submerged flowering plants that live and reproduce in shallow brackish and marine waters. They are not true grasses, but their growth habit and ribbon-like leaves result in "meadows" resembling terrestrial grasslands. Seagrass beds occur in a relatively narrow range of depths and extend into the low intertidal zone. Sea-

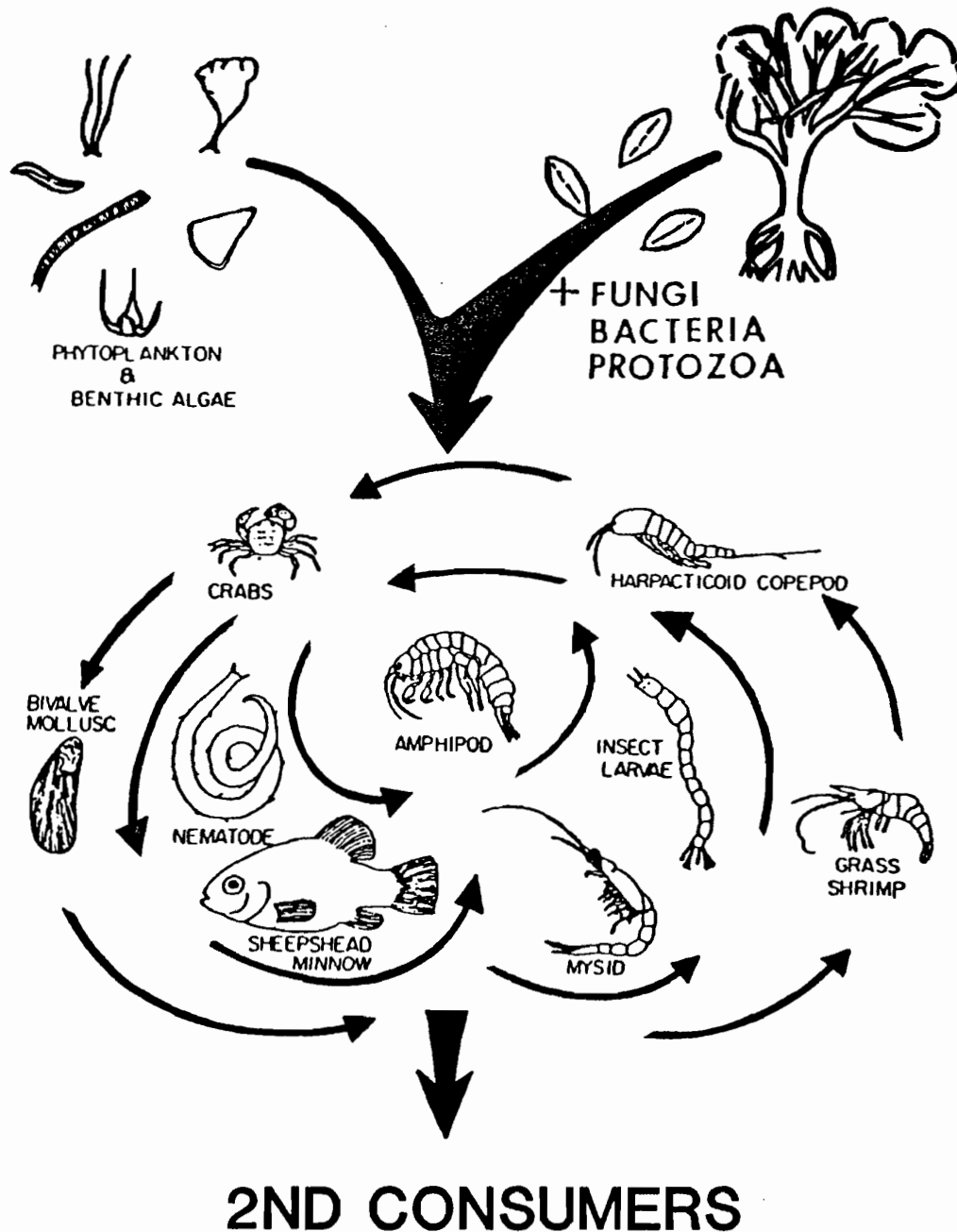


Figure 12. Detrital food chain based on red mangrove detritus (Odum and Heald, 1972).

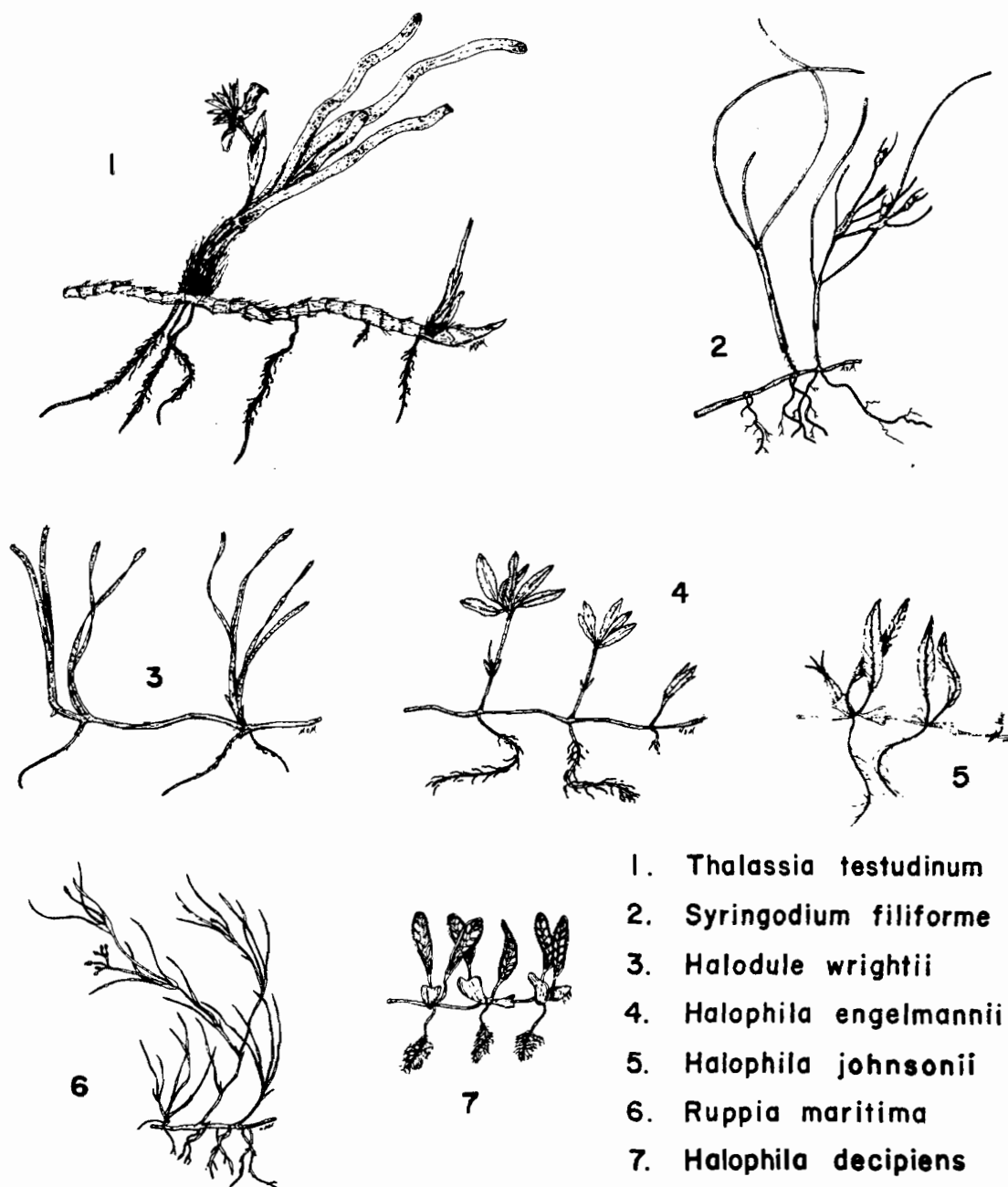
grass meadows are highly productive, and their complex structure provides substrate, habitat, and protection from predators for large populations of invertebrates and fishes (Zieman, 1982).

Seven species of seagrasses inhabit Florida waters (Figure 13):

- 1) *Thalassia testudinum* Banks ex König (turtle grass) is the dominant species, forming

extensive meadows. It has strap-shaped leaves up to 35-40 cm long and 2-12 mm wide.

- 2) *Syringodium filiforme* Kützinger (manatee grass) is usually found intermixed with other species in deeper waters. Leaves are cylindrical, 1-4 mm in diameter, and up to 35 cm in length.



1. *Thalassia testudinum*
2. *Syringodium filiforme*
3. *Halodule wrightii*
4. *Halophila engelmannii*
5. *Halophila johnsonii*
6. *Ruppia maritima*
7. *Halophila decipiens*

Figure 13. Seagrasses of Florida.

- 3) *Halodule wrightii* Ascherson (shoal grass) is generally thought to be the most environmentally tolerant species. It has narrow leaves, 0.5-3 mm wide, up to 40 cm long, with 2-3 points at the leaf tips.
- 4) *Ruppia maritima* Linnaeus (widgeon grass) occurs in both fresh and saltwater environments, often intermixed with *H. wrightii*.

- Leaves are thin, about 1 mm wide, up to 10 cm long, and tapering toward the tip.
- 5) *Halophila engelmannii* Ascherson can occur as pure stands or intermixed with *S. filiforme* and *H. wrightii*. It produces 4-8 oblong leaves up to 3 cm long and 2-5 mm wide, on a stem 2-4 cm long.
 - 6) *Halophila decipiens* Ostenfeld occurs on the

Continental Shelf adjacent to the coast in deeper (20 m) waters. It produces pairs of elliptical leaves 10-20 mm long and 3-5 mm wide at each node.

- 7) *Halophila johnsonii* Eiseman is primarily intertidal and grows intermixed with *H. wrightii* or between this species and the high tide line. Its leaves differ from *H. decipiens* in that their veins emerge from the midrib at 45° angles instead of 60° angles.

All seven species occur as far north as Indian River lagoon (Eiseman, 1980), but only four species, *H. wrightii*, *S. filiforme*, *R. maritima*, and *H. engelmannii*, occur in Mosquito Lagoon (Down, 1978; R. M. Willard, personal communication). Seagrasses occur as far north as Ponce de Leon Inlet (Florida Bureau of Coastal Zone Planning, 1975), although Beeman (1977) noted that they were absent in an area directly west of the Inlet.

Seagrass habitat value is summarized by Wood et al. (1969):

1. Seagrasses have high rates of production and growth.
2. The leaves support large numbers of epiphytic organisms that have biomass approaching that of seagrasses themselves.
3. Although few species feed directly on them, seagrasses produce large quantities of detritus, a major food source for many species.
4. Seagrasses bind sediments and prevent erosion, providing a quiescent environment in which a great variety of organisms can grow.
5. Seagrasses provide organic matter that encourages sulfate reduction and an active sulfur cycle.
6. Seagrasses act as nutrient sinks and sources.

In addition, seagrasses also take up and accumulate trace or heavy metals (French and Montgomery, 1983; Montgomery and Price, 1979; Pulich, 1980).

In the Indian River lagoon system, where seagrass coverage has been estimated at only 2% of the lagoon bottom (Thompson, 1976, 1978), seagrass production is thought to be very significant in supporting food webs (Stoner, 1980a, 1980b; Young et al., 1976; Zimmerman et al., 1979). In this regard, Heffernan and Gibson (1983) reported that seagrasses and benthic microalgae were the dominant primary producers in this system. Seagrass productivity rates, like those of salt marshes and mangroves, rival those of subsidized agricultural systems (Westlake, 1965). This productivity is transferred to the animal community via two main pathways: direct herbivory and detrital food webs (Figure 14).

Only a small number of species graze directly on seagrasses, but, in some areas, these species can be abundant (Zieman, 1982). Seagrass herbivores include sea turtles, manatees, parrot fish, surgeonfish, pinfish, blue crabs, and sea urchins. The detrital

food web is thought to be the main path of energy flow in seagrass systems (Ogden, 1980; Zieman et al., 1979). Penaeid shrimp and mullet can feed directly on detritus, but most fishes in grass beds feed on small mobile epifauna (Zieman, 1982). Stoner (1980a) found that abundances of epifauna, suspension feeders, and carnivorous polychaetes correlated with seagrass biomass. Increase in epifauna was related to increased surface area of leaf blades. Taylor et al. (1973) reported that for each square meter of bed area, *Thalassia* leaf blades have a total surface area of 18 m². This large surface area provides substrate for both epiphytes and epifauna. Some fish species that occur in seagrass beds seem to follow developmental sequences that encompass various trophic levels from herbivory to carnivory (Livingston, 1982). Many economically important fish are present in seagrass beds as juveniles, obtaining both food and shelter from the system.

OTHER

In northeast Florida, unvegetated subtidal bottom underlies most open estuarine water that is too deep for seagrasses to exist or that is within the seagrass zone, but lacking seagrass cover (Peterson, 1981). Intertidal unvegetated bottom areas that lie between the extreme spring high and low tide lines in sounds, lagoons, estuaries, and river mouths are defined as intertidal flats or mud flats (Peterson, 1981; Peterson and Peterson, 1979). These unvegetated flats often lie between seagrass beds and salt marshes or mangroves.

Intertidal flats have been considered relatively unimportant because of one structural characteristic: no macrophytes exist there. Consequently, these habitats generally have not been considered in the management of estuaries. However, intertidal flats are inhabited by microscopic, benthic algae. Pomeroy (1959) suggested that "mud algae" may contribute as much as one-third of the total estuarine productivity in Georgia. Van Raalte et al. (1976) measured productivity of benthic algae within a *Spartina* marsh and found rates up to almost half those of *Spartina*. Stable carbon isotope analyses led Haines and Montague (1979) to suggest that diatom detritus may be a substantial part of the diets of detritivores in estuaries.

The relative importance of benthic productivity is considerable because the algal production can be immediately utilized by herbivores. For example, commercial shellfish, like oysters, clams, and scallops, are almost completely dependent on suspended benthic microalgae and phytoplankton (Haines, 1978). Algae-based food webs eliminate the loss of energy associated with trophic intermediates (i.e., bacteria and fungi) in detritus-based food webs. As Peterson (1981) notes, 2.5 kg of marsh grass pro-

duction may be required to provide the same amount of food to consumers as only 1 kg of benthic algae, if assimilation efficiency is rather high at 40%. In addition, fragments of salt marsh plants, mangroves, and seagrasses are abundant on and in the mud flat sediment (Peterson and Peterson, 1979). This environment, then, is a major site of conversion of plant biomass into invertebrate animals, which ultimately serve as prey for larger estuarine predators (Peterson, 1981). Diurnal fluctuations in utilization of intertidal flats also occur, with numerous species of birds feeding there during the day (Peterson, 1981), and shrimp, crabs, and fish

becoming major consumers at night (Summerson and Peterson, 1984).

In the Cumberland Sound area, the lack of seagrasses seems to be responsible for the lack of animal assemblages common to grass beds. Hoese (1973) reported that the bay scallop (*Argopecten irradians*), a species commonly associated with seagrasses, is not found in Georgia, presumably because of the absence of seagrasses. The presence of some common grass-bed species, such as *Cynoscion nebulosus* (spotted sea trout) (Naval Facilities Engineering Command, 1977), indicates certain species are capable of adapting to (or existing in) environments

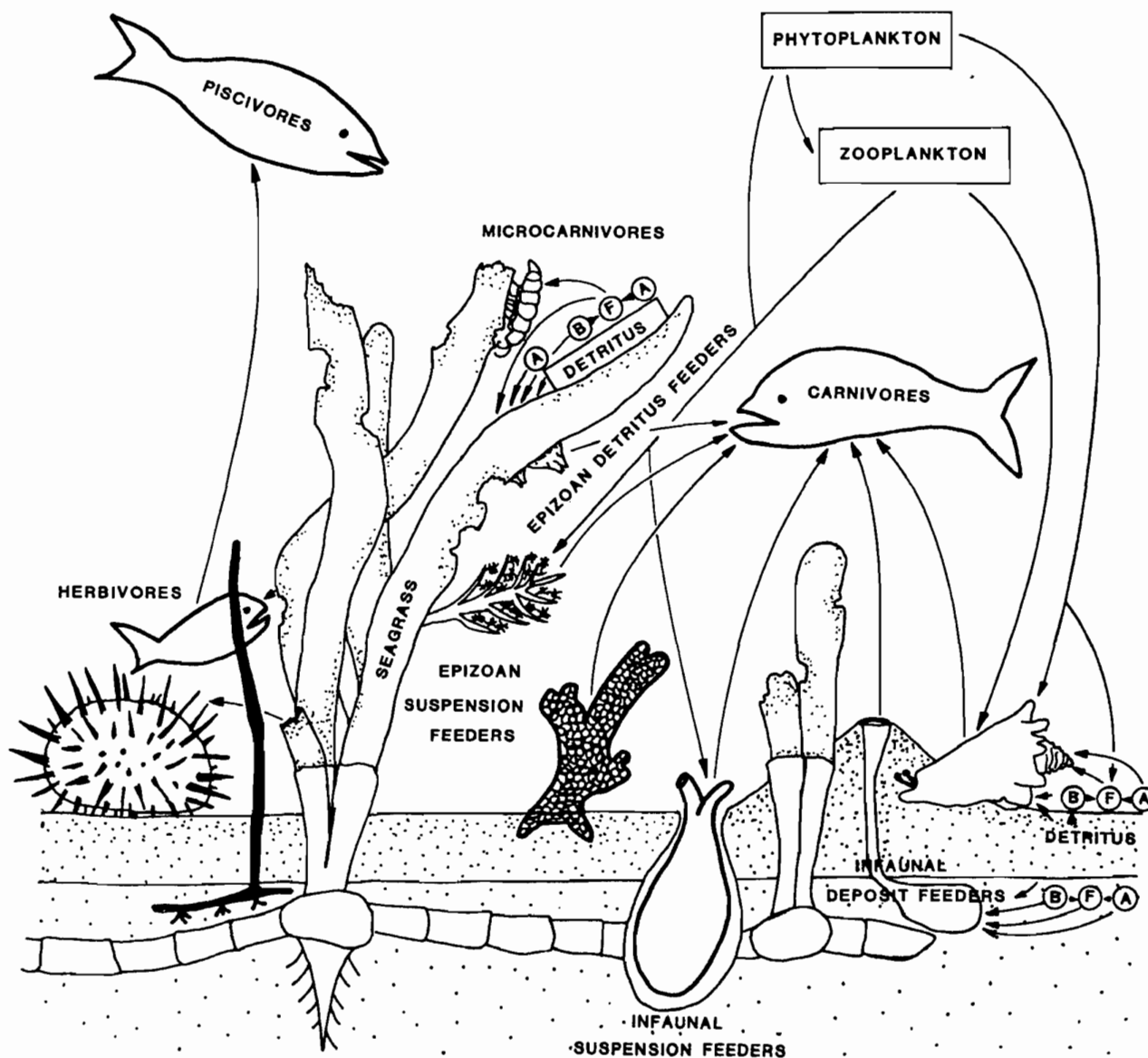


Figure 14. Energy flow in a seagrass bed (from Ogden, 1980). A = algae; B = bacteria; F = fungi.

without the structure or refuge provided by sea-grasses. In such areas, the highly turbid waters may provide some degree of protection from predators, providing a substitute refuge.

Epifauna are sparsely distributed on most intertidal flats (Moore et al., 1968). However, the most obvious epifaunal invertebrate of the northeast Florida estuaries, the oyster *Crassostrea virginica*, is often abundant intertidally and subtidally. For example, in St. Johns County, shellfish beds (predominantly oysters) occur in almost all estuarine areas except deeper waters of the Intracoastal Waterway (Briley, Wild and Assoc., 1980).

Oyster reefs or mounds represent another community that provides habitat for a wide variety of organisms. Dame (1976) determined that if oysters occupied five percent of the estuary, they would be the most important primary consumers. Oysters are filter feeders, taking in suspended algae, detritus, bacteria, and other particulate matter. Their feeding behavior and sedentary nature make them vulnerable to a variety of man-induced stresses (Table 4). Oyster reefs also seem to be important in the remineralization of nitrogen, possibly affecting the type of microalgae that dominates an estuary (Dame et al., 1984).

Oyster communities are composed of a variety of marine plants and animals. Oyster and clam shells provide hard substrate for attachment in otherwise soft-sediment environments (Peterson and Peterson, 1979). Every square meter of oyster bed provides up to 50 square meters of hard substrate (Bahr and Lanier, 1981). This substrate is colonized by many suspension- and deposit-feeding macrofaunal consumers preyed upon by carnivores, such as the blue crab (*Callinectes sapidus*) and the black drum (*Pogonias cromis*). Beeman (1977) lists 19 species of invertebrates associated with the oyster communities of Ponce de Leon Inlet, including mussels and juvenile stone crabs.

Oyster reefs also affect the physiography and

hydrology of estuaries by modifying current velocities, passively changing sedimentation patterns, and actually augmenting sedimentation through biodeposition (Bahr and Lanier, 1981). Thus, oyster reefs may have a stabilizing influence on erosional processes, while providing a stable island of hard substrate.

Another extensive but little studied coastal habitat of northeast Florida is the exposed beach surf zone. Although the turbulent wave conditions appear to result in an unstable and harsh environment, the surf zone is an important habitat for a number of fish species. Florida pompano (*Trachinotus carolinus*), gulf kingfish (*Menticirrhus littoralis*), whiting (*Menticirrhus sp.*), scaled sardines (*Harengula jaguana*), and striped anchovy (*Anchoa hepsetus*) appear to depend highly on surf zones as nursery areas (Finucane, 1969; McMichael, 1981; Modde, 1980; Ruple, 1984). For species adapted to this environment, the wave energy may provide a subsidy by supplying plankton and detritus to sedentary filter feeders, exposing prey to fishes, and concentrating plankton along the swash zone (Ross, 1983). Swash zones also are important as biological purification systems for coastal water, filtering approximately 10 m³ water per m beach per day (Riedl, 1971).

Surf zones form functional ecosystems because the amount of nutrients remineralized by interstitial bacteria, microfauna, and macrofauna is sufficient to support local phytoplankton blooms (McLachlan, 1980; McLachlan et al., 1981). The cellular circulation of the surf zone retains these nutrients, with the bulk of the energy turnover occurring within the zone. External subsidies are relatively small and variable, coming in the form of importation of particulate organic matter, carrion, and fish feces. Phytoplankton are the dominant primary producers in surf zones. Seasonal variations are accompanied by changes in fish abundance (McFarland, 1963). Detached plants also may wash into surf zones, pro-

TABLE 4. SOME MAN-INDUCED STRESSES THAT INFLUENCE OYSTERS (c.f., Bahr and Lanier, 1981).

Stress	Effects
1) Sedimentation	Burial and anoxia of adult oysters, reduced availability of cultch for spatfall
2) Salinity increase	Increased predation and/or fouling
3) Eutrophication	O ₂ depletion in bottom water, toxic effects of blue-green algae, excess POC
4) Toxicants	Sublethal effects, increased mortality, reduced resistance to natural stress, subtle changes in entire community, reduced gametogenesis
5) Physical effects of pollutants	Impairment of feeding mechanisms
6) Thermal loading	Decreased community diversity, enhanced oyster production, increased respiratory costs
7) Overharvesting	Depletion of breeding stocks and cultch and decrease in bottom stability
8) Loss of wetlands	Loss of wetland-water interface prime reef habitat, decline of primary production

viding food and substrate for invertebrates such as amphipods. However, the dominant macrofaunal invertebrates are detrital feeders, primarily deposit feeders, or planktivores (Shelton and Robertson, 1981).

Surf zone fish faunas are characterized by relatively few species comprising the majority of individuals. Ross (1983) reported that four to ten species comprised 90% of the individuals collected along the Gulf coast. The same pattern is true for the Atlantic coast, including northeast Florida. Peters (1984) found that five species comprised approximately 90% of the individuals collected at his primary study sites at Melbourne Beach and Sebastian Beach. Additional collections at Anastasia and Flagler Beach State Recreation Areas were dominated by one species, the Florida pompano (55% and 82% of total catch, respectively). Seventy-five species of fishes were collected from various surf zones along the east coast of Florida during this study.

Surf zone ichthyofaunas in different areas are quite similar. Ross (1983) listed the fishes broadly characteristic of high-energy beach areas: scaled sardines (*Harengula jaguana*), gulf menhaden (*Brevoortia patronus*), bay anchovies (*Anchoa mitchilli*), dusky anchovies (*A. lyolepis*), striped anchovies (*A. hepsetus*), sea catfish (*Arius felis*), Atlantic threadfin (*Polydactylus octonemus*), silversides (*Menidia peninsulae* and *M. beryllina*), white mullet (*Mugil curema*), Florida pompano (*Trachinotus carolinus*), Atlantic bumper (*Chloroscombrus chrysurus*), Atlantic croaker (*Micropogonias undulatus*), gulf kingfish (*Menticirrhus littoralis*), and pinfish (*Lagodon rhomboides*). For some fish species, the surf zone is used only by larval stages, with juveniles occurring in other, primarily lower salinity, environments. Other species spawn offshore and utilize the surf zone as a juvenile nursery area. A third group spawns offshore and nearshore and may be found in the surf zone as larvae, juveniles, or even adults. The surf zone region may be used by various life stages of fishes for most or all of the following functions (Ross, 1983): shelter from predation by larger fishes, a feeding area, or a spawning area. Ross (1983) proposed that if many species move along the outer, exposed beaches feeding on abundant zooplankton before entering estuaries, then the quality of the surf zone habitat may have more effect on population success of commercial, sport, and nongame fishes than we presently understand.

COASTAL FISHERIES RESOURCES

GENERAL FAUNAL NOTES

Early studies of the ichthyofauna in northeast Florida were conducted on the St. Johns River,

including its estuarine portions. Goode (1879) published a preliminary list of 223 species known or expected to occur in the St. Johns River and along the east coast of Florida. The first comprehensive checklist of Florida freshwater fishes included 112 species from the St. Johns, 28 of which were found only at the inlet (Evermann and Kendall, 1900). More recently, McLane (1955) collected 118 species from the St. Johns River, during a ten-year study begun in the mid 1940's, and found that marine forms comprised at least 53% of the fish species. These included anadromous fish, such as the American shad (*Alosa sapidissima*), catadromous fish, such as the American eel (*Anguilla rostrata*), and many marine forms that inhabit low-salinity areas as juveniles, such as the drums and croakers (Sciaenidae). Tagatz (1968) also studied the St. Johns River ichthyofauna and found that 115 of the 170 species known to occur there were euryhaline.

Since the late 1960's, environmental studies on the effects of power plant impingement, entrainment, and thermal stress have contributed greatly to an understanding of the fish communities in the northeast region (Dames and Moore, Inc., 1979; Envirosphere, 1981). Rehm et al. (1975) described the fauna of the estuarine section of the St. Johns River, 13 to 42 km inland from its mouth, noting seasonal trends in finfish abundance. This baseline information was used to evaluate the effects of local electric generating stations on the fauna. Descriptive data on the biota of the tidal wetlands near Ponce de Leon Inlet were collected in anticipation of a large dredging project west of the Inlet (Beeman, 1977). Ichthyofaunal surveys of the southern part of the northeast Florida region, conducted by Gilmore (1977) and Snelson (1981), included collection stations in the Mosquito Lagoon and as far north as Ponce de Leon Inlet.

Ichthyofaunal studies conducted north of northeast Florida have provided descriptions and life history information for many of the fish found in northeast Florida waters. These include Hildebrand and Schroeder's (1928) classic study of the fishes of the Chesapeake Bay and Dahlberg's (1972) study of the coastal fishes of Georgia. Fowler (1945) studied the fish fauna of the southeast United States coastal plain, and Struhsaker (1969) described the composition and distribution of commercially important fish of the southeast United States Continental Shelf. The nearshore fauna of the Continental Shelf in this area has been studied by Anderson and Gehringer (1965), Bullis and Thompson (1965), and Futch and Dwinell (1977).

During warm periods of the year, fish with tropical-Caribbean affinities can be found in northeast Florida. Many have been described in studies conducted south of the region (Gilmore 1977; Snelson 1981, 1983). Christensen (1965), Gunter and Hall (1963), and Springer (1960), surveyed the

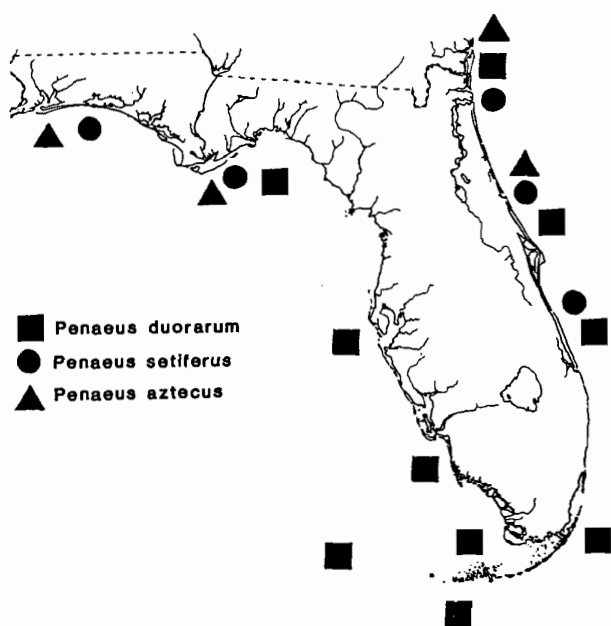


Figure 15. Distribution of penaeid shrimp in Florida (Durako et al., 1985).

fauna of the southern part of the Indian River lagoon, which connects to waters of this study site.

IMPORTANT SHELLFISH AND FINFISH RESOURCES

The fauna of this region include many important shellfish and finfish that are utilized directly by man and depend on the estuaries for food and shelter during some period of their development. The most important exploited invertebrates in this region include blue crabs, oysters, clams, and the three species of penaeid shrimp (Figure 15).

Juvenile penaeid shrimp share a common dependence on the estuary as a nursery ground (Joyce and Eldred, 1966). In general, all three species spawn offshore (Figure 16), where their eggs and larvae develop before drifting into estuaries (Joyce, 1965). As juveniles, they reside several months in estuaries, where seagrasses provide their habitat. Brown shrimp spawn during the late winter, with peak inshore recruitment of juveniles in late February and March (Cook and Lindner, 1970; Joyce, 1965); white shrimp spawn later, and recruitment into the

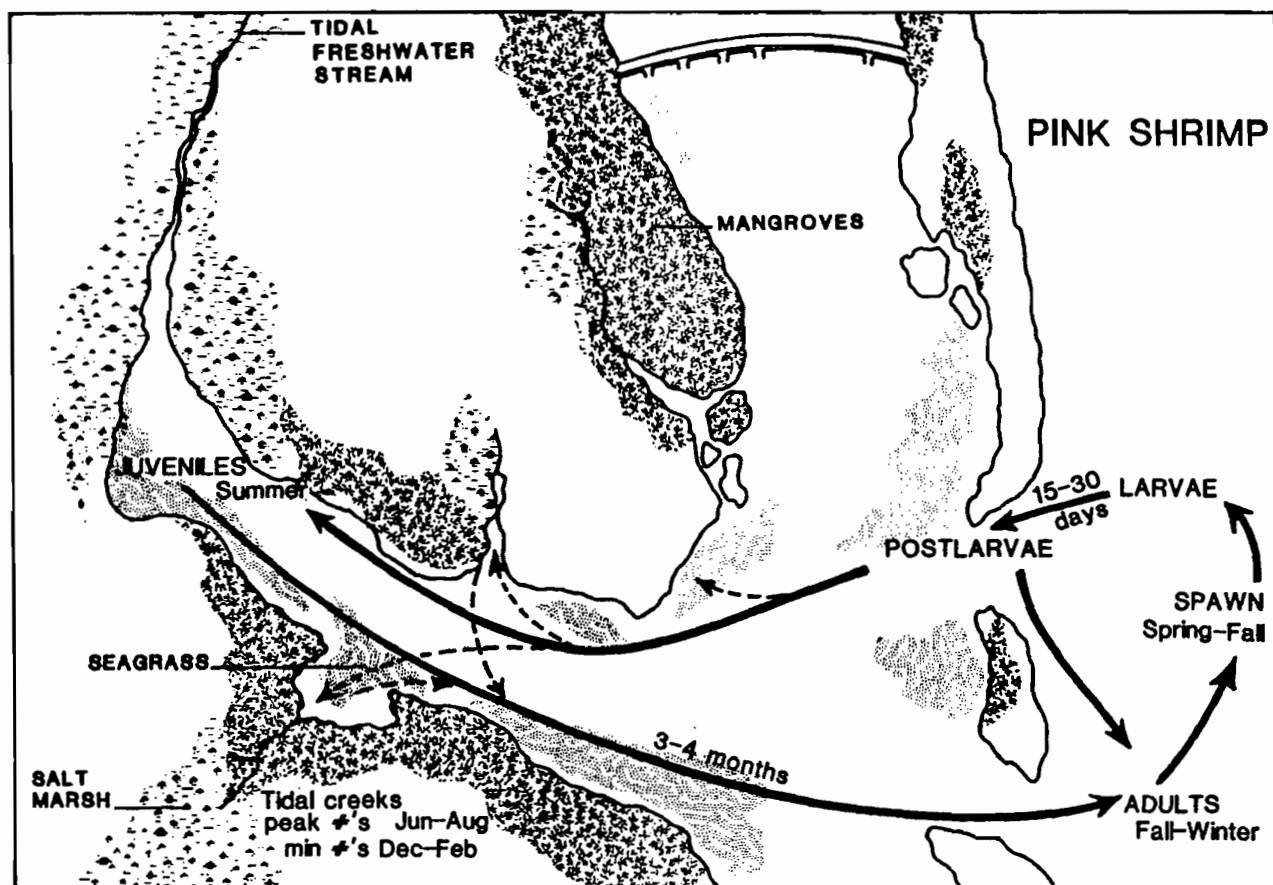


Figure 16. Life cycle of the pink shrimp, *Penaeus duorarum* (Durako et al., 1985).

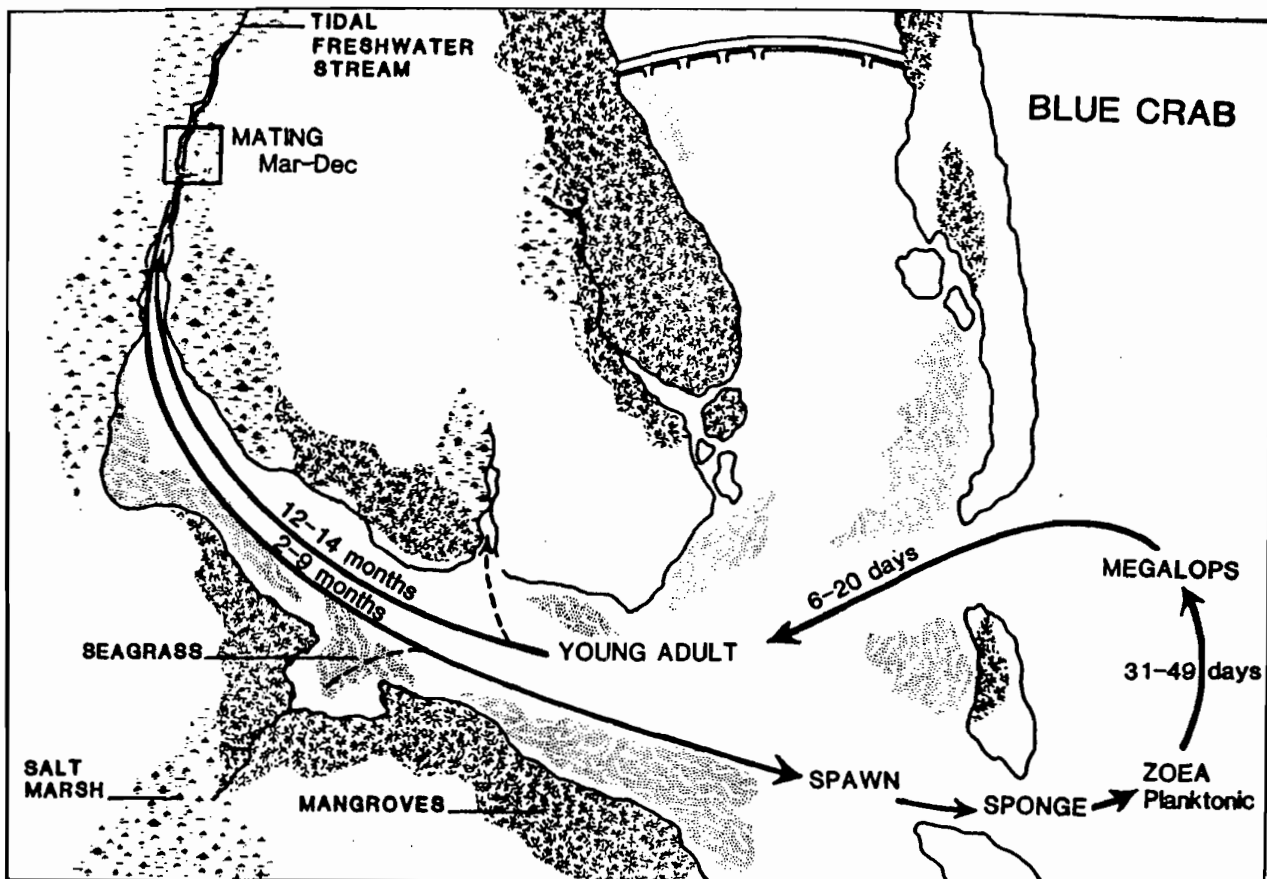


Figure 17. Life cycle of the blue crab, *Callinectes sapidus* (Durako et al., 1985).

estuaries occurs in May and June (Joyce, 1965; Lindner and Cook, 1970). Both species grow rapidly through their juvenile stages. Most brown shrimp migrate offshore by August or September; most white shrimp migrate by late fall. Brown shrimp prefer higher salinities and deeper water (Cook and Lindner, 1970; Williams, 1955); white shrimp prefer areas adjacent to low-salinity estuaries (Joyce, 1965).

Pink shrimp form only a small part of the commercial catch in northeast Florida, but are a major constituent of the live-bait fishery extending south from Ponce de Leon Inlet (Kennedy and Barber, 1981). They spawn year-round off northeast Florida, with a peak in early spring. Pink shrimp prefer higher salinities than brown shrimp, but often overwinter within the estuary (Costello and Allen, 1970). The feeding habits of all three shrimp species are similar. As larvae, they are planktivorous, feeding on algae and zooplankton. As post-larvae, juveniles, and adults, they are omnivorous, feeding on detritus and microorganisms (Williams, 1955).

Blue crabs support a large commercial and recreational fishery in northeast Florida (Steele,

1979). Except during female spawning migrations, blue crabs spend their entire lives within estuaries. Spawning occurs when water temperatures exceed 22°C, i.e., during all but the coldest months in northeast Florida (Tagatz, 1968a). After mating in brackish waters, the females migrate to high-salinity waters near the mouth of the estuary to spawn (Figure 17). Along the Atlantic coast of Florida, female blue crabs exhibit an offshore/onshore migration pattern (Figure 18) that tends to keep crabs of one system from mixing with those of adjacent systems (Tagatz, 1968). This is in contrast to patterns observed on the Gulf coast, where offshore/onshore and offshore/alongshore migrations are common (Oesterling and Adams, 1979; Oesterling and Evink, 1977; Steele, unpublished data). The latter pattern is directed toward the Appalachicola Bay region, which may be the primary spawning ground for Florida Gulf coast populations. Males remain in low-salinity areas year-round. Blue crabs pass through seven zoeal stages, then molt to a megalops and ride tidal currents back into the estuary (Tagatz, 1968a). Small crabs occupy shallow-water habitats and gradually move to deeper water

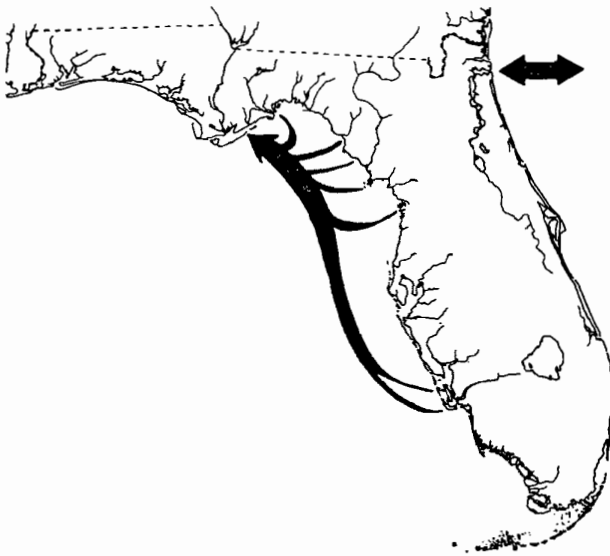


Figure 18. Migration patterns of female blue crabs in Florida (from Oesterling and Evink, 1977; and Tagatz, 1968).

as they increase in size. Blue crabs eat a wide variety of foods, including both live and dead fish, aquatic vegetation, mollusks, crustaceans, insects, and annelid worms (Tagatz, 1968a; Williams, 1955).

American oysters are also commercially and recreationally important in this area and are common along salt marsh creeks and other estuarine habitats, where they form large mounds or bars. Oysters are dioecious, and mass spawnings occur during the warm months (Loosanoff and Engle, 1950). Fertilized eggs sink rapidly and a ciliated veliger stage develops after about one or two days. This stage then searches out and attaches to suitable hard substrate within two to three weeks. General habitat requirements include a free exchange of water, salinities between 5 ppt and 30 ppt, and temperatures 1°C to 30°C. Oysters are sessile filter feeders that non-selectively ingest phytoplankton, bacteria, and detritus.

Hard clams are restricted to areas of suitable sand, sand-mud, or shell-rubble substrates (Pratt and Campbell, 1956). Good water circulation and salinity ranging from 20 ppt to 38 ppt also are required (Pratt, 1953). About half the clams in a population are protandrous, beginning as males and changing to females during their second year. Clams may spawn several times in a season, but have maxima from April to August. Spawning is induced by an increase in water temperature to 22°C to 28°C. Larvae are planktonic for 6 to 12 days (Loosanoff and Davis, 1950). As soon as they develop a foot, they alternate between swimming and crawling. Late larvae attach themselves to suitable substrate, then, as juveniles, they detach and begin burrowing. Clams, like oysters, are filter

feeders that require habitats where good water circulation suspends detritus and microorganisms.

Several families of finfish contribute to important recreational and commercial fisheries in northeast Florida. The most important of these families is Sciaenidae, which includes whittings (*Menticirrhus* sp.), spotted seatrout (*Cynoscion nebulosus*), weakfish (*C. regalis*), croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), black drum (*Pogonias cromis*), and red drum (*Sciaenops ocellatus*). The young and juveniles of these species require estuaries for nursery grounds, and the adults are either permanent residents of estuaries or inhabitants of shallow coastal waters. Other important fish include those on lower trophic levels, such as anchovies (*Anchoa* spp.), herrings (*Clupeidae*), which include menhaden (*Brevoortia* spp.) and American shad (*Alosa sapidissima*), and mullet (*Mugil* spp.). Flounders (*Paralichthys* spp.) also contribute significantly to catches, as do sheepshead (*Archosargus probatocephalus*), pinfish (*Lagodon rhomboides*), sea catfish (*Arius felis*), and bluefish (*Pomatomus saltatrix*).

Fish occupying low trophic levels serve as forage for other fish and as an abundant source of protein for man. The bay anchovy, *Anchoa mitchilli*, is an abundant forage fish in the estuaries of this region (Mulligan and Snelson, 1983). It spawns nearly year-round and filter feeds on diatoms and copepods (Hoese, 1965).

Menhaden are important fish that are common prey for many recreationally and commercially important fish. They support the largest fishery, by weight, in the United States (Christmas et al., 1983). Menhaden are filter feeders, using their long gill-rakers to filter phytoplankton, zooplankton, and detritus from the water column. The young require low-salinity areas of estuaries as nursery grounds; as they grow they join the large migratory schools of adults that disperse by size and age along the U. S. Atlantic Coast (Reintjes, 1969).

Mullet are targeted by a large commercial fishery. In northeast Florida, the black (striped) mullet (*Mugil cephalus*) is dominant although other species are present (principally, *M. curema*). Black mullet spawn in fall in oceanic waters over the outer Continental Shelf (Arnold and Thompson, 1958). Young remain over the Continental Shelf until they are about 2.5 cm long, when they enter estuarine habitats. Larvae and small juveniles feed on zooplankton, but juveniles and adults are herbivorous, feeding on algae. Except during their spawning migration in the fall, mullet remain in estuaries or in coastal waters.

Spotted seatrout are a popular inshore recreational and commercial species, typically spawning from April through August in the lower reaches of the estuary or along beaches near inlets (Tabb, 1961, 1966). Juvenile spotted seatrout are common

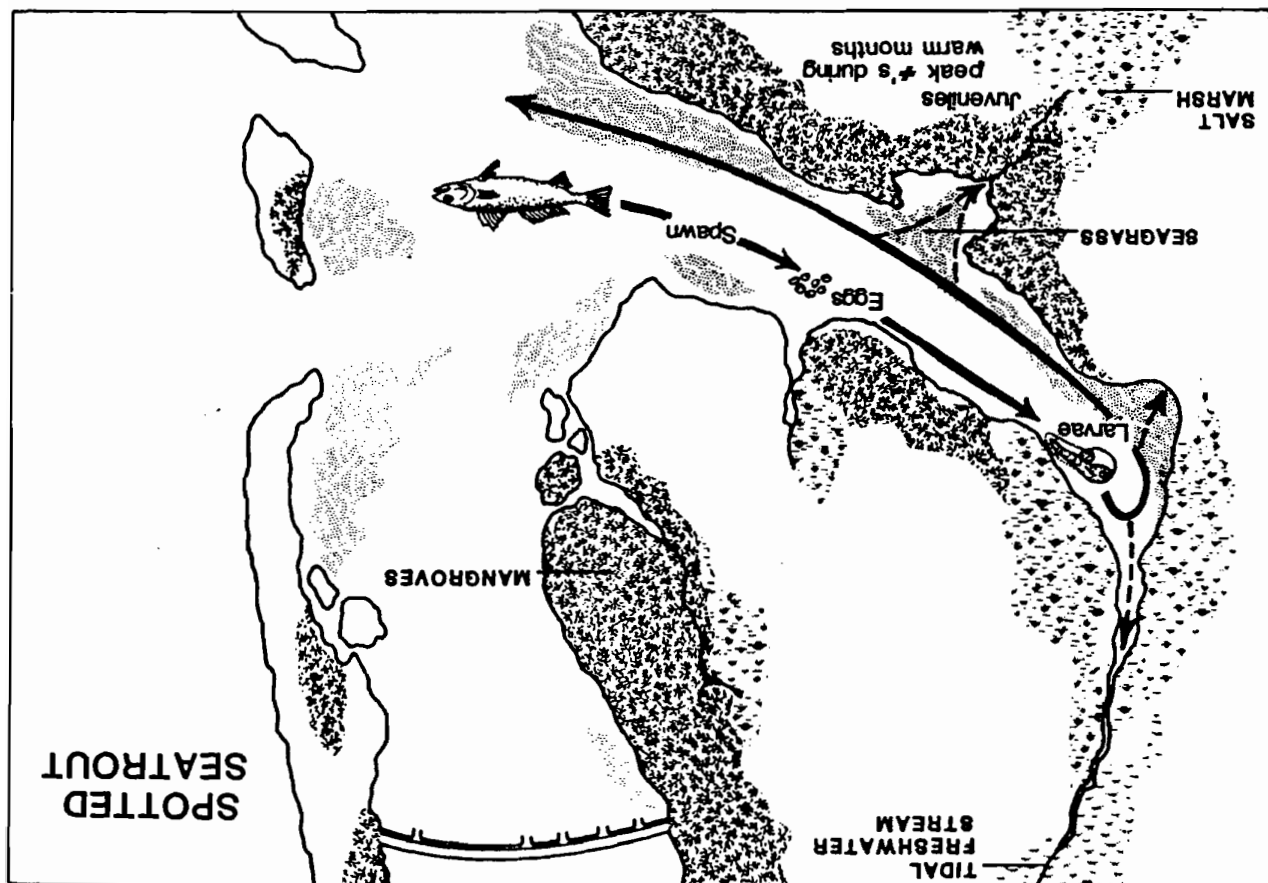


Figure 19. Life cycle of the spotted seatrout, *Cynoscion nebulosus*, which spawns within the estuary (Durako et al., 1985).

Remaining members of the drum family in this region spawn outside the estuary or near passes. However, all inhabit the estuary during juvenile stages and most remain in the estuary or nearshore as adults.

Feeding habits are similar to those of spotted seatrout. Back into estuaries (Powles and Stender, 1978). of spotted seatrout, most spawning takes place in oceanic waters, and young drift on tidal currents in September, with a peak in April. In contrast to that season is protracted, lasting from March through migrate inshore and to the north. The spawning the winter (Wilk, 1979). During summer, they migratory, moving out of estuaries and southward in Pafford, 1984). Weakfish, unlike seatrout, are found in deeper estuarine waters (Music and trout. Adults prefer similar habitats, but more often are closely related to spotted sea-

Small seatrout feed on small crustaceans, such as mysids and copepods, but larger seatrout feed primarily on fish of lower trophic levels.

Sciaenids can be divided into fall-winter spawners and spring-summer spawners. The fall-winter spawners include spot, red drum, and croaker (Jannke, 1971; Springer and Woodburn, 1960; White and Chittenden, 1977). Spot and croaker spawn over the Continental Shelf in deep waters, but red drum spawn near estuarine inlets (Figure 8). juvenile red drum and croaker enter the bays in late fall and juvenile spot enter somewhat later, in the winter. Croaker and spot juveniles are attracted to low-salinity areas with mud-detritus bottoms, where they feed mainly on polychaetes and detritus (Parker, 1971). Red drum seek low-salinity areas with sand-mud bottoms and feed on grass shrimp and small crabs as juveniles (Peters and McMichael, in preparation). All three species inhabit Continental Shelf waters as adults.

The spring-summer spawners include black drum, star drum, and whiting (Hildebrand and Cable, 1934; Jannke, 1971; Welsh and Breder, 1923). Black drum spawn in the inlets of bays; whiting and star drum spawn in coastal waters. Juvenile black drum enter the bay in early spring;

juvenile star drum and whiting are most abundant in the estuary in early summer. Black drum juveniles feed on small mollusks and crabs (Richards, 1973); star drum and whiting feed on grass shrimp and mysids (McMichael, 1981).

The bothids or left-eyed flounders contribute significantly to recreational and commercial fisheries of this region. The most important include the southern flounder (*Paralichthys lethostigma*) and the summer flounder (*P. dentatus*), whose life histories are similar (Topp and Hoff, 1972). Adults migrate offshore in fall and winter to spawn. Juveniles inhabit shallow grass flats and sand and mud bottom areas in the estuary. Marine worms, crustaceans, and squids make up the majority of their diet (Stickney et al., 1974).

The American shad (*Alosa sapidissima*) is the most important anadromous fish in northeast Florida, commercially and recreationally. Shad spawn demersal eggs during the spring, in the St. Johns River (Williams and Bruger, 1972). Juveniles move downstream and by June-July most have moved to tidal, nonbrackish areas. With the onset of cold weather in November and December, shad move out of the river. Adults inhabit the river only during the spawning season, and most die after spawning (Wahlburg and Nichols, 1967). Juveniles descend the river in spring and some migrate along the U. S. Atlantic Coast to their summer feeding grounds in the Bay of Fundy (Scarrett and Dadswell, 1983).

Sheepshead and pinfish are recreationally important porgies (Sparidae) found in this region. Sheepshead (*Archosargus probatocephalus*) may inhabit either rocky, shell hash areas and mud flats in the estuary, or nearshore and offshore reefs (Hildebrand and Schroeder, 1928; Music and Pafford, 1984). Pinfish juveniles are found mostly in shallow, grass-flat habitats, but adults prefer open water with some vegetation (Caldwell, 1957). Juvenile sheepshead less than 50 mm long inhabit grass flats, where they feed on small, soft-bodied forms associated with the grass. Larger sheepshead develop crushing dentition and feed on mollusks and barnacles. Small pinfish feed on zooplankton, but adults switch from an omnivorous diet to a herbivorous diet.

Sea catfish (*Arius felis*) are abundant in estuaries and comprise a major portion of the recreational fishery in this area. Adults are found in shallow estuarine and coastal waters over sand or mud (Lee, 1937). Spawning takes place from May through August. The large demersal eggs are carried in the mouth of the male, and sometimes the female, until they are hatched and the larvae have absorbed their yolk sacks. Juveniles are more numerous than adults in low-salinity areas. Sea catfish are scavengers, feeding largely on dead animal tissue, but also on live shrimp and fish.

The bluefish (*Pomatomus saltatrix*) is an ex-

ample of a coastal pelagic species whose young utilize the estuary as a feeding ground. Peak spawning off north Florida is during the winter (Deuel et al., 1966; Homer, 1959; Richards, 1965). Large schools of young bluefish frequently feed on small fish in the lower reaches of estuaries (Norcross et al., 1974).

COASTAL FISHERIES TRENDS

Commercial landings often are used as a gross index of relative abundance of fish stocks. However, without effort data, trends in commercial landings can be a misleading measure of relative abundance. In Florida, effort data are not currently available for most fisheries. A marine fisheries information system was implemented in 1985, by the Florida Department of Natural Resources, to record effort data.

Important invertebrate species for which Florida commercial landings data are available include shrimp, blue crabs, and clams. In the northeast Florida region, overall shrimp landings declined from 5 million lbs during the 1960's to a low of 2.2 million lbs in 1977. Since that time, wide fluctuations in the catch have occurred. Most shrimp landings in this region were in Nassau and Duval Counties. In certain years, especially the 1960's, Brevard, St. Johns, or Volusia Counties contributed a significant proportion to the catch.

From 1962 through 1971, blue crab landings fluctuated widely between about 4 million and 7.4 million lbs. Variations in year-class strength and distribution of stocks have been cited as the preliminary causes of these variations (Steele, 1979). During the 1970's, landings dropped to between 400,000 and 1.25 million lbs. In the 1980's, landings increased to between 4 and 5 million lbs. Large fluctuations in catch by county have occurred; no county has consistently recorded the majority of blue crab landings in this region.

Clams are an ephemeral resource, with productive beds appearing and disappearing quickly in response to open and closed areas, market conditions, and stock abundance. From the mid to late 1960's through 1971, clam landings in northeast Florida increased greatly, to a maximum of 900,000 lbs. No landings were reported from 1972 to 1976. The catch dropped from 150,000 lbs in 1977 to 50,000 lbs in 1979, but rebounded to about 140,000 lbs in the early 1980's. Brevard and Volusia Counties provide the great majority of the region's landings, but most landings from the east coast come from south of Cape Canaveral. A recently productive bed in the Indian River is being heavily exploited, with 230,000 lbs landed in the first seven months of 1984 (S. Michael, personal communication).

The mullet fishery in northeast Florida is large and, due to the high prices paid for roe, most

landings occur during the late fall/early winter roe season. Market conditions often limit mullet landings when fish wholesalers limit the sizes and amounts of mullet they will buy. Landings in northeast Florida declined from 2.2 million lbs to 900,000 lbs between 1962 and 1972. They fluctuated, but generally increased, until 1980, after which, landings declined to a low of 1 million lbs in 1983. Most mullet are landed in Volusia and Brevard Counties.

Large fisheries for members of the drum family also exist in the northeast Florida region. Annual landings for Atlantic croaker are generally less than 30,000 lbs, but in 1966 to 1967, 60,000 to 180,000 lbs were reported. Most croaker are landed in Duval County, although in 1966 to 1967, extremely large landings occurred in Brevard County. Spot landings also have been steady, between 250,000 and 500,000 lbs, since 1962, except for an increase to about 1 million lbs in 1971 to 1972, and a major peak of 3 million lbs during 1981 to 1983. Within the northeast region of Florida, most spot are landed in Brevard County, although during some years, especially 1971, a large proportion of the total was landed in Duval and Volusia Counties.

Red drum and spotted seatrout are pursued by both commercial and recreational fishermen in Florida. Although the recreational catch has been estimated to be equal to or greater than the commercial catch, the magnitude of recreational catch in each region is unknown (Muller, 1985) because only commercial landings can be examined. Red drum (red bass) landings averaged about 100,000 lbs annually during the 1960's. Wide fluctuations occurred during the 1970's, with peaks in 1973 at 140,000 lbs and in 1981 at 240,000 lbs, and a low in 1975 of 40,000 lbs. Brevard, Volusia, and Duval Counties account for most of the landings of red bass in this region.

Spotted seatrout landings have fluctuated since 1962 and, except for large catches in 1981 and 1982, have tended to decrease. Brevard, Volusia, and Duval Counties account for most fish caught.

This short synopsis of landings data for important commercial fish in the region shows the high productivity of Brevard and Volusia Counties. Although we have no information on the number of fishermen or the effort expended, we are broadly interpreting the landings data as a measure of abundance of fish in each county. The greater landings in counties with large expanses of estuary, such as Brevard, Volusia, and Duval, may reflect the high productivity of estuarine environments there. Brevard and Volusia Counties include the Mosquito Lagoon/Upper Indian River complex. Duval County includes the St. Johns River estuary. St. Johns and Flagler Counties have less estuarine acreage, which may explain their low landings numbers and can possibly reflect a lesser potential for marine fishery production.

GROWTH ISSUES AND IMPACTS

SOME DIRECT PERTURBATIONS RESULTING IN LOSSES

Fernandina Beach, Atlantic Beach, Neptune Beach, Jacksonville Beach, St. Augustine, Ormond Beach, Daytona Beach, and a number of small communities in northeast Florida border the Atlantic Ocean, as well as the estuaries and lagoons. Even though only 10-15% of the total land area in the northeast region is developed (Northeast Florida Regional Planning Council, 1982), approximately 50% of the ocean-fronting shoreline is developed (Table 5). Perhaps more significant, less than 20% of the shoreline is in public ownership, so relatively rapid development of beachfront property may be expected to continue. In contrast, highly urbanized Dade and Pinellas Counties have approximately 30% of their ocean-fronting shorelines in public ownership, and over half of that is preserved as park lands (Table 5). The State of Florida's increasing concern for its beaches has resulted in a statewide beach acquisition and preservation plan (Henningsen, 1981). Some beachfront property in northeast Florida is currently recommended for State acquisition and preservation (Figure 20), and the Northeast Florida Regional Planning Council (1982) also recommended the acquisition of 21 km of saltwater beaches by the year 2000.

The effects of ocean-front development on surf-zone-dependent fishes are unknown. Surf-zone areas may be among the most sensitive regions of the coastal environment, but their dynamic nature renders detection of man-made perturbations difficult (Dye, 1981). Bulkheads eliminate shoreline feeding ground for fishes that depend on waves to expose prey at the land/water interface, and destroy feeding habitat for shorebirds. Beaches are the first line of defense against coastal storms, but the presence of bulkheads along beaches alters sand movement patterns and the distribution of wave energies. As evidenced by the severe erosion that occurred during the fall of 1984, this alteration can have drastic consequences. Bulkheads may accelerate the rate of erosion (U. S. Army Corps of Engineers, 1981b), which often results in costly offshore dredging for beach renourishment. Thompson (1973) reviewed the ecological effects of both offshore dredging and the deposition of fill on sand beaches and concluded, from very little information, that few long-term detrimental effects occurred.

Beaches are also the first coastal environment to be affected by offshore pollution. As stated in draft environmental impact statements (Minerals Management Service, 1982, 1984), increased Outer Continental Shelf (OCS) oil exploration and production activities will result in increased risk of coastal pollution. In addition, Outer Continental

TABLE 5. INVENTORY OF SANDY BEACHES FRONTING THE ATLANTIC OCEAN AND GULF OF MEXICO (Henningsen, 1981).

Ownership	Nassau		Duval		St. Johns		Flagler		Volusia		Dade		Pinellas	
	ALL*	(%)	ALL	(%)	ALL	(%)	ALL	(%)	ALL	(%)	ALL	(%)	ALL	(%)
Federal	-	-	1,753	(2.5)	1,585	(2.5)	-	-	16,337	(22.7)	-	-	-	-
State	823	(4)	8,897	(35.1)	2,423	(3.8)	1,067	(3.9)	-	-	1,981	(5.6)	6,931	(14.5)
County	-	-	-	-	-	-	-	-	-	-	3,627	(10.2)	5,410	(11.3)
City	290	(1.4)	-	-	-	-	-	-	-	-	5,867	(16.5)	-	-
Inlets	-	-	671	(2.6)	1,189	(1.9)	-	-	457	(0.6)	2,347	(6.6)	803	(1.7)
Developed	10,805	(52.1)	12,320	(48.6)	31,974	(51.0)	4,862	(18.0)	39,213	(54.5)	21,138	(59.3)	33,361	(69.6)
Undeveloped	8,809	(42.5)	1,719	(6.8)	25,557	(40.7)	21,098	(78.1)	15,987	(22.2)	671	(1.9)	1,417	(3.0)
Total	2,073		25,359		62,723		27,021		71,994		35,631		47,924	

*ALL = Approximate linear length in meters.

Shelf activities and coastal energy-related activities in the Jaxport area could have a significant impact on coastal water quality (City of Jacksonville Planning Department, 1980).

Ocean-front development has resulted in increased stormwater runoff and a proliferation of package-type sewage treatment plants to serve specific areas. For example, at Ormond Beach alone, almost 20 individual wastewater treatment plants exist (Volusia Council of Governments, 1977). Another 17 individual plants are operating between St. Augustine and Matanzas Inlets, east of A-1-A (Briley, Wild and Associates, 1980). This increase in point and non-point pollution sources along beach areas poses a significant threat to surf zone and other coastal habitats. Larger wastewater plants, serving broad geographic areas, not only are more efficient, but the requirement of fewer installations would allow regulatory agencies to enforce treatment standards more effectively. Also, methods of reusing treated waste water for municipal and urban purposes, such as lawn watering, are technically feasible and utilized by some municipalities in Florida.

Impacts of development in or adjacent to estuarine habitats are also numerous and, unfortunately, most are negative. The most acute is the direct removal or burial of parts or all of an estuarine habitat. This perturbation is associated with such activities as channel dredging and maintenance, dredge and fill, causeway construction, and shell mining. On a smaller scale, clam digging and propeller cuts from motor boats also result in damage by destroying seagrass habitats (Harris et al., 1983).

Construction and maintenance of navigation

channels represent the most drastic forms of estuarine alteration in Florida (Lindall and Saloman, 1977). Odum (1970) suggested that the actual primary impact of channel dredging could be minimal (i.e., affecting only the area of the channel) if the dredging process were properly engineered. Stickney (1972) investigated the effects of Intracoastal Waterway dredging in Georgia on ichthyofauna and benthic macroinvertebrates and reported that most of the changes were transient. However, dredge spoil is typically deposited as nearby spoil banks that erode, transporting material back into the channels, and resulting in a "hydraulic dredge cycle". This creates more persistent turbidity and alteration of circulation patterns. In the St. Johns River between Mayport and twenty miles upstream, 611,680 cubic meters of sediment are removed annually from the channel; much of this is deposited on small parcels of land adjacent to the channel (U. S. Army Corps of Engineers, 1981a).

Some advantages of channelization include 1) connection of isolated waters and marshes, which makes them available as fish nursery areas, 2) provision of routes of escape or refuge for fish during cold periods, 3) improvement of water exchange and circulation, and 4) release of nutrients trapped in bottom sediments (Chapman, 1969; U. S. Army Corps of Engineers, 1979). For a more complete list of the biological effects of channelization, the reader is referred to the annotated bibliography prepared by Ford et al. (1983).

Channel construction and maintenance, the largest sources of fill on the Gulf coast, only account for five percent of Florida's total fill (Lindall and Saloman, 1977). Much of the 10,000 ha or more of

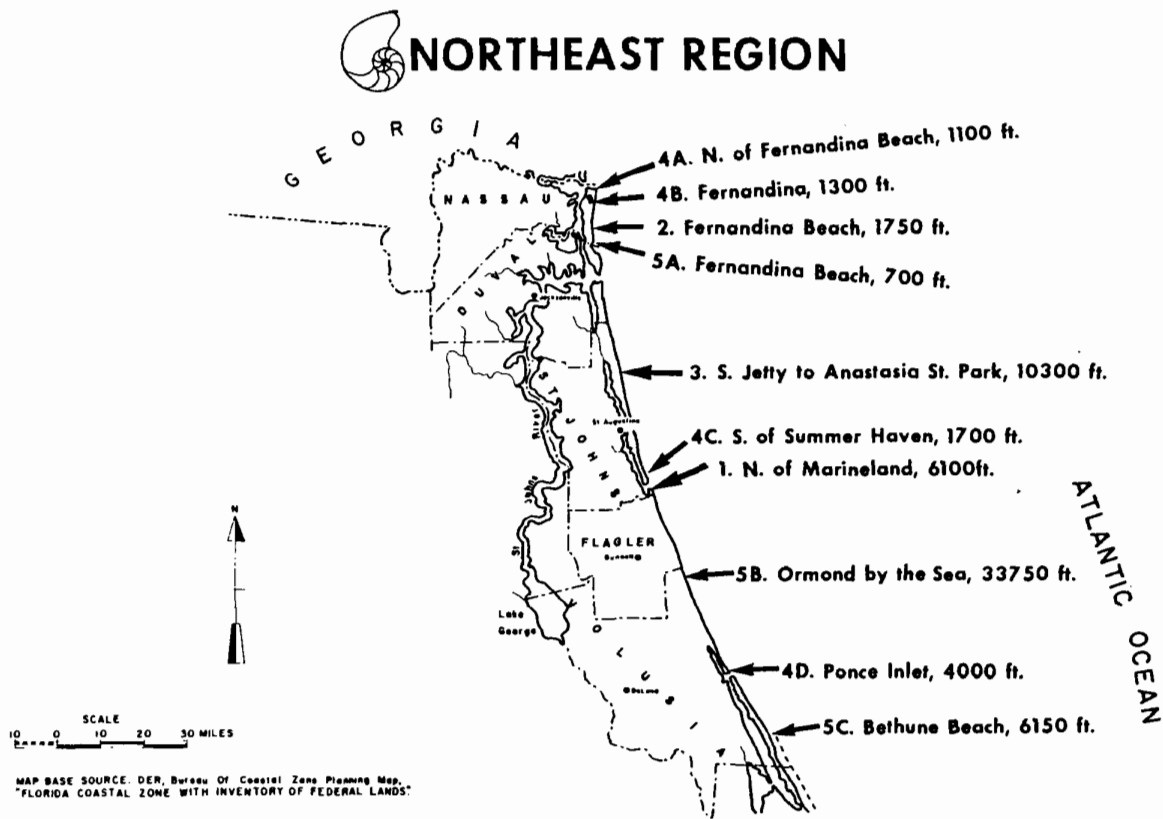


Figure 20. Beachfront parcels selected for potential acquisition by the State of Florida (Henningsen, 1981).

fill in the state was produced by dredging adjacent water bottoms. An extreme example of the impact of a dredge and fill operation is the destruction of 1,100 metric tons of seagrasses of Boca Ciega Bay, Florida (Taylor and Saloman, 1968). This resulted in the immediate loss of an estimated 1,800 metric tons of infauna, 20% reduction in bay size, and annual loss of approximately 73 metric tons of fisheries products.

Impoundment of coastal wetlands for mosquito control results in a number of detrimental impacts, some of which are similar to those of channelization. Both activities cause significant losses and/or changes in vegetation (Harrington and Harrington, 1961, 1982) and can result in reduced detrital export to the estuary (Durako et al., 1985) and reduced availability of wetland habitats to young marine organisms (Birkitt, 1983; Browder and Moore, 1981). Almost 16,000 ha of coastal wetlands have been impounded along the east coast of Florida (Birkitt, 1983). The placement of "high marsh" margins in the Indian River lagoon, Banana River, and Mosquito Lagoon has effectively impounded 5,300 ha of mangrove swamps and salt marshes (Gilmore et al., 1982). Isolation of extensive areas of wetlands blocks exchange of detritus, nutrients, and

organisms between impounded high marsh and the estuary, significantly altering marshes as nursery, feeding, and refuge areas. Of 16 species of fish found in an Indian River lagoon marsh before impoundment, only five remained after diking (Harrington and Harrington, 1982). Gilmore et al. (1982) also found fewer species in closed impoundments and noted a shift from carnivory and omnivory in open systems to herbivory in impoundments. When tidal connections to an impoundment in the same area were re-established, Gilmore et al. (1982) found 41 species, 12 of which were recreationally or commercially important. Re-establishment, in a qualitative sense, was rapid after the impounded marsh was reconnected to the estuary. Lower diversity of fish in impoundments seems to be partially related to the lack of vascular plants that provide cover and are the source of detritus, which forms the base of the natural food web (Harrington and Harrington, 1982). This relative lack of detritus may cause a shift to algae as the basic food source in impoundments.

Reports such as these have led to continuing research on impoundments, with the goal of managing them effectively for mosquito control while increasing their value to the estuary. Re-establish-

ment of tidal influence has been the primary objective of mitigation efforts. This has been attempted through the use of flap-gate, riser-control structures on culverts that extend through the dikes (Birkitt, 1983) and, in Volusia County impoundments, by rotary ditching, which eliminates discernible spoil mounds (Goetzfried and Lau, 1984).

Construction of causeways across estuaries is frequently cited as a major disruption (Mulvihill et al., 1980; Wamer and Gilbrook, 1983). Causeways have two major impacts: first, the direct burial of existing habitat; second, and more serious, the resulting modification of natural movement of water by tide and wind. In an investigation of the impacts of bridges along the Port Orange causeway, Wamer and Gilbrook (1983) concluded that the addition of "relief" bridges would not benefit fisheries resources and might even negatively impact a brown pelican breeding colony. However, these conclusions may apply only to this particular system. Although the impacts of causeways are detrimental, they may be insignificant compared to those associated with population growth and development, which precede and/or follow causeway construction.

Whereas causeway construction frequently follows population growth, bulkheading represents the first step in a chain of events that leads to habitat losses or alterations due to growth and land development (Mulvihill et al., 1980). Bulkheading and backfilling are frequently used to create shore-front real estate. The transition zone between intertidal and adjacent subtidal zones is the most productive area in estuaries (Odum, 1971). Lindall and Saloman (1977) estimated that about 10,000 ha of Florida estuarine habitat were filled for housing and industrial developments. As mentioned earlier, bulkheads promote erosion of the foreshore. In the deep water zone in front of bulkheads, adverse effects on fish are primarily related to development of anoxic conditions (Barada and Partington, 1972). These areas also tend to have lower amounts of detritus, phytoplankton production, and benthos than adjacent natural shoreline areas (Odum, 1970).

Iverson and Bannerot (1984) have developed a habitat improvement technique that helps mitigate some of the ecologically adverse effects associated with dredged canals: placement of large rocks under docks. Areas previously characterized by periodically anoxic conditions and inhabited by few or no fish, soon become populated with numerous fish. Similarly, Calinski (1983) found that artificial nursery habitats placed in a stressed estuarine system could increase survival and recruitment of several important crab species. The habitats were designed to encourage growth of attached plants and animals that provide food and protection for small crabs. These habitats work well in eutrophic waters, where phytoplankton are abundant. Both of these studies suggest that some of the detrimental

impacts of coastal development can be minimized, "providing various political and economic barriers can be overcome" (Calinski, 1983), and that artificial habitats can be developed to maintain or encourage recruitment of certain species.

SOME INDIRECT PERTURBATIONS RESULTING IN LOSSES

In addition to habitat destruction, man's activities in the coastal zone often result in a number of stresses that may affect the quality of remaining habitat. Declining water quality, resulting from ever-increasing point and non-point pollution sources, is one of the major growth issues facing the people of northeast Florida. This topic is discussed in detail in a review by Delfino et al. (1984) and will only be superficially treated here.

Pollution enters estuaries from several sources: from upland areas as runoff, from rivers as inflow, directly from outfalls, from vessels via dumping or spillage, and from atmospheric fallout. The pollutants can be toxic chemicals, nutrients, micro-organisms, or heat. Sessile organisms, such as oysters and clams, are most heavily affected by water pollution. Oyster production is inversely proportional to human population growth and water pollution (Bahr and Lanier, 1981). Clams and oysters are filter feeders, and, consequently, they concentrate pollutants (Bahr and Lanier, 1981). Wastes also adversely affect oysters by reducing the length of time the shell remains open, thereby reducing feeding time. Oysters and clams often are transported from polluted to unpolluted areas for depuration of toxins and bacteria. In 1983, 38 permits for relaying oysters were issued in Florida, and one clam depuration plant was opened in Brevard County (Florida Department of Natural Resources, 1984).

Municipal discharges and package sewage treatment plants are the most significant contributors to existing-point source pollution (Florida Bureau of Coastal Zone Planning, 1975, 1976). Increased biochemical oxygen demand (BOD), suspended solids, coliform bacteria, chlorine, nitrogen, and phosphorus are the primary water quality problems related to point sources (Volusia Council of Governments, 1977). In a study of 149 secondary sewage treatment plant outfalls, Tsai (1973) found that sewage chlorine and turbidity were the major causes of reduction in fish-species diversity for areas adjacent to the outfalls. Grizzle (1979) found that heavy nutrient enrichment in Sykes Creek, Brevard County, reduced numbers and diversity of macrobenthos and allowed the invasion of opportunistic species. The creek also had high phytoplankton densities and low dissolved oxygen levels. Increased fecal coliform levels have caused the closing or threatened closing of many shellfish harvesting

areas in northeast Florida (Briley, Wild and Associates, 1980). In fact, overall, statewide harvesting area has decreased 17% in the last 10 years (Table 6).

TABLE 6. ACREAGES OF SHELLFISH HARVESTING AREAS IN FLORIDA.

	1984	%	1974	1971
Approved	512,553	22	663,126	663,834
Cond. Approved	110,281	5	84,099	83,334
Prohibited	292,226	13	1,024,966	1,025,023
Unclassified	1,352,635	60	494,908	494,908
TOTAL	2,267,977	100	2,267,099	2,267,099

Data provided by the Food and Drug Administration, Northeast Technical Services Unit.

High BOD effluents from industrial activities, such as pulp mill, dairy, and seafood processing plants, are major point-source pollutants in northeast Florida. Areas receiving pulp mill effluent exhibit a decrease in abundance and number of species of estuarine and marsh fish (Livingston, 1975), as well as a change in species composition of benthic macrophyte assemblages (Zimmerman and Livingston, 1976). Heavy metal pollution is not always fatal to fishes, but it can weaken them, increase their susceptibility to predation, and reduce their reproductive capacity. Cardeilhac et al. (1981) concluded that heavy metal contamination in the Indian River lagoon and Mosquito Lagoon was responsible for a 1980 fish kill of red drum. The metals may have been accumulated by blue crabs, on which larger red drum fed.

Power plants are commonly located adjacent to estuaries for easy access to water required for cooling. Construction of the plants usually results in direct destruction of shoreline habitat (Harris et al., 1983), as well as a point source for heated effluent, which is generally considered a pollutant (Horton and Bridges, 1974). Thermal effluents from a coal-fired power plant destroyed 80 ha of seagrasses and lowered diversity of benthic invertebrates by 60% (Blake et al., 1976). Elevated water temperatures from a steam-electric station near Jacksonville reduced the suitability of the marsh as a nursery area for fish that were important to man (Carr and Giesel, 1975). Only white mullet used the area receiving heated effluents as a nursery, but similar marsh areas that were not affected by the effluent served as nursery habitat for a more diverse group of fishes.

Organisms can get trapped on screens that

filter the cooling water (impingement), or they may pass through the intake screens and be subjected to rapid temperature increases and turbulence from the pressurized cooling process (entrainment). In the upper reaches of estuaries, many fish are juveniles and/or small (i.e., past the larval stage) with limited mobility; therefore, impingement is the major problem. Rehm et al. (1975) assessed the effect of three electricity-generating stations on the St. Johns River and found that most fish were impinged during July and August and that nearly 50% of these were Atlantic croaker. Most fish were small (< 150 mm) and were migrating to areas of higher salinity in the lower reaches of estuaries. Impingement/entrainment impacts can be minimized by installation of modified water intakes with traveling screens and networks of fish-return troughs known as Fish Return Systems (FRS). The FRS of the Jacksonville Electric Authority northside station resulted in 80% survival of penaeid shrimp, 96 hours after they were transported through the system, but Atlantic menhaden only averaged 5% survival (Envirosphere, 1981). Dames and Moore, Inc., (1979) analyzed the effects of power plant units in Palatka on the St. Johns River and reported entrainment mortality could be reduced with the use of fine mesh screens, allowing the older juveniles, whose natural mortality is probably lower than that of the egg stages, to survive. They also suggested reductions in cooling water volume, changes in intake pipe placement, reductions in approach velocities, prevention of recirculation of discharged water into the plant, and reductions in nearshore dredging. Since fish eggs and larvae generally exhibit extremely high natural mortality rates, impingement and entrainment may either have no impact on natural populations or contribute to a decrease in population size. Dames and Moore, Inc., (1979) concluded that significant reduction in fish catches by commercial or sport fishermen was not attributable to power-plant-induced mortality.

Non-point pollution usually is carried by stormwater runoff during rainfall. The pollutants may run off directly into the estuary or may be transmitted to the estuaries via street flow to storm sewers, ditches, and creeks (Briley, Wild and Associates, 1980). Runoff from city streets, ship yards, and marinas contains oil, grease, and heavy metals. Small oil spills, grease, gasoline, sewage, and trash also are generated where recreational boats are docked. Runoff increases with urbanization because development reduces recharge area. It has been identified as a major contributor to pollution in urban areas and has increased to such an extent that the U. S. Environmental Protection Agency established a National Urban Runoff Program (NURP) to develop the knowledge needed to control associated water pollution (Metcalf and Eddy, 1980).

As mentioned previously, fish, shrimp, and

shellfish processing plants can contribute substantial pollutant loads to the estuary. In addition, the dumping of trash fish from nets of fishing boats at dock areas significantly adds to nutrient loads (Briley, Wild and Associates, 1980).

Another important non-point pollution source is the overflow or leaching of septic tanks with subsequent transport during rainfall. This input results in low dissolved oxygen, high nutrient levels, and increased turbidity and fecal coliform levels.

OTHER CONSIDERATIONS

The impact of sea-level rise on coastal habitats is a growth issue that has more to do with nature's effect on man than man's effect on nature. The following discussion on sea-level rise is a summary from a recent paper by Titus et al. (1984).

For several thousand years, sea level has risen so slowly that, for most practical purposes, the rate can be considered constant. The National Academy of Sciences (Revelle, 1983) and the Environmental Protection Agency (Hoffman et al., 1983) have estimated that "greenhouse" warming is likely to increase this rate and cause a one to five foot rise in the next century. Sedimentation in natural systems has offset the impact of sea-level rise in the past. However, only major river deltas are likely to keep pace with the rate of sea-level rise expected after 2050. Under natural conditions, wetland systems would migrate landward; however, condominiums, houses, roads, and other human developments stand in the way of a migrating wetland. The natural impact of sea-level rise could destroy as much as one-half of the nation's existing coastal wetlands.

Natural impacts fall into three categories: increased tidal flooding, wave-induced erosion, and salt intrusion. The first two primarily affect salt marshes and mangroves; the last is important to freshwater marshes and swamps. Activities such as coastal development and regulation of river flow threaten to disable natural adaptive mechanisms, resulting in substantial losses of wetland areas because of sea-level rise. For example, gently sloping coastal plains could permit landward migration of entire ecosystems. However, coastal development may squeeze the wetlands between an advancing sea and human activities. Thus, while natural wetland processes could partially offset losses, human activities may exacerbate the problem, requiring substantial efforts to ensure that barrier islands do not flood and breach as sea level rises.

The need for increased public awareness is paramount. Property owners need to be informed that their land may eventually be inundated, and planners need to ensure that wetlands have room to migrate landward.

The natural environment also can adversely affect fish populations. Snelson (1979) reported that

temperature is directly correlated with fish abundance, associating the general increase in *Anchoa mitchilli* populations with warmer months in the Cape Canaveral area. Fish biomass/tow was also positively correlated with turbidity. He attributed this to the fishes' inability to avoid collecting gear in more turbid waters. He also found that mean vegetative cover was positively correlated with Margalef's richness factor, a measure of community structure.

Fish kills resulting from natural cold have occurred in the northeast region of Florida. Snelson and Bradley (1978) reported one in the Indian River system in January, 1977. The severity of such fish kills is usually determined by the degree of temperature change, especially as it relates to recent averages, duration of the low temperature, and rapidity of the decrease (Gunter, 1941). Since 1856, 16 cold-induced fish kills have been recorded in Florida waters. However, except for a kill in St. Lucie Inlet in 1962 (Gunter and Hall, 1963) and another in the Brevard County area in 1977 (Snelson and Bradley, 1978), these kills have always occurred on Florida's west coast.

Assessment of fishing impact on fisheries resources is difficult because insufficient data exist on abundance, life history, and population dynamics of fish species, and no information exists for numbers of fishermen and fishing effort. Commercial landings may not adequately reflect trends in abundance. Brice (1897) warned that within the limited fishing grounds of the Indian River lagoon, overfishing was possible unless proper restrictive laws and closed seasons were implemented. Overexploitation has been suggested as the reason for the complete extirpation of a reproducing population of small tooth sawfish (*Pristis pectinatus*) from the Indian River (Snelson and Williams, 1981). This species was abundant in the Indian River at the turn of the century (Evermann and Bean, 1897).

Groundfish, mullet, blue crabs, and shrimp are not highly susceptible to overfishing because of their short life spans, high natural mortality rates, and high fecundity. Their abundances are influenced more by environmental perturbations than by fishing, although heavy exploitation can adversely affect the resource during periods of low abundance.

Spotted seatrout and red drum have been studied in some detail in Florida (Murphy and Taylor, in preparation; Tabb, 1961), so that enough is known to draw a preliminary assessment of the effect of fishing on their populations. The red drum fishery relies heavily on juveniles (300-700 mm fork length) that inhabit the estuary. Fishing may be so concentrated that few juveniles live to reach maturity and reproduce, thus reducing the spawning population to dangerously low levels and creating a high risk of recruitment failure (Murphy, 1985). Yields of red drum could be increased with a larger minimum size limit. Preliminary analysis of spotted seatrout

populations indicate they, too, may be "slightly growth overfished" (fish that are too small are caught). An increase in the minimum size limit may increase yield if hooking-and-release mortality of undersized fish is low. Otherwise fishing effort for seatrout should be reduced.

TRENDS IN HABITAT QUANTITY

COASTAL WETLAND AREAS

The numerous and varied perturbations acting on estuarine ecosystems, as described for northeast Florida in previous sections, result in habitat degradation or alteration. Knowledge of the location and areal extent of specific habitat components is essential to the assessment and monitoring of habitat as an important component of a fishery. The Florida Department of Natural Resources (FDNR) is mapping vegetational and structural components of marine fisheries habitat on a statewide basis and assessing habitat alteration in selected locations; northeast Florida constitutes part of this statewide assessment.

Remote sensing techniques are being developed and utilized in the mapping process. The primary data source is LANDSAT V, a satellite that orbits 508 km in space and passes over any given spot on Earth every 16 days. The primary sensor on board LANDSAT, collecting data for this project, is the Thematic Mapper (TM), an imaging telescope that records the earth's reflectance in several ranges of wavelengths (blue, green, red, three infrareds, and thermal) at a ground resolution of 0.25 acre. Data are transmitted to Earth as digital values ranging from 1-255, representing the intensity of reflectance for each wavelength, and stored on computer tapes.

The computer tapes of raw data are acquired by the FDNR for use within the Marine Resource Geographic Information System (MRGIS). The MRGIS is a mini-computer system capable of analyzing and manipulating LANDSAT data, as well as other geographic data sources. One capability is a process of statistical enhancement to determine extent and location of estuarine vegetation. The system is housed at the FDNR Bureau of Marine Research facility in St. Petersburg.

The LANDSAT imagery used for this project, dated May, 1984, was statistically analyzed to allow delineation of wetlands both visually and numerically. The results depicted (Figure 21) are only one example of information contained on the MRGIS, although various types of information can be displayed. Methods for acceptable dissemination of color pictorial graphics data from the MRGIS are currently under development.

Preliminary area values for different types of emergent marsh have been developed on a county-

TABLE 7. AREAL EXTENT IN HECTARES*, BY COUNTY, OF SELECTED FISHERIES HABITAT FOR NORTHEAST FLORIDA.

	Salt marsh	Mangrove	Total Marsh
Duval	13,163	0	13,163
Nassau	10,541	0	10,541
St. Johns	5,676	+	5,676
Flagler	1,244	++	1,244
Volusia	4,070	2,757	6,827
Totals	34,694	2,757	37,451

*1 hectare = 2.47 acres.

by-county basis (Table 7). Seagrass areas are significant only in Mosquito Lagoon; the tropical seagrasses of Florida grow no further north, except in small or sparse patches. Recent seagrass mapping of Mosquito Lagoon has been conducted by the Environmental Engineering Department of Brevard County (R. M. Willard, personal communication). Seagrass maps for all of Brevard County were done in the early 1970's (Down, 1978); Thompson (1976) mapped seagrasses in the Indian River lagoon south of Cape Canaveral. A recent mapping effort by FDNR completed wetland maps for the Indian River lagoon south of Sebastian Inlet. The Brevard County area mapping was completed in 1986 through a joint project of the Harbor Branch Foundation, Brevard County, and FDNR.

Areal extent of salt marsh and mangroves has been calculated, in the past, with photographs from the early 1970's (Coastal Coordinating Council, 1973) and, more recently, 1984 LANDSAT imagery (Table 7). The bulk of the salt marsh area for northeastern counties is located in Duval and Nassau Counties, comprising 23,704 ha or 68% of the 34,694 ha total in the five-county site. An estimated 304,126 ha of salt marsh exist in Florida (Coastal Coordinating Council, 1973); thus the salt marsh area for the five-county site is only 11% of the State's total. Flagler County has the least amount of salt marsh, because the area lacks both a barrier island system and freshwater input.

Salt marsh vegetation also can be divided into species through the use of LANDSAT data (see Figure 21). This was done for Nassau County as an example. *Spartina alterniflora* marshes occupy 18,011 ha (70%) of wetlands in Nassau County, while *Juncus roemerianus* covers 8,027 ha. *Spartina* dominates the marsh systems of northeast Florida. As

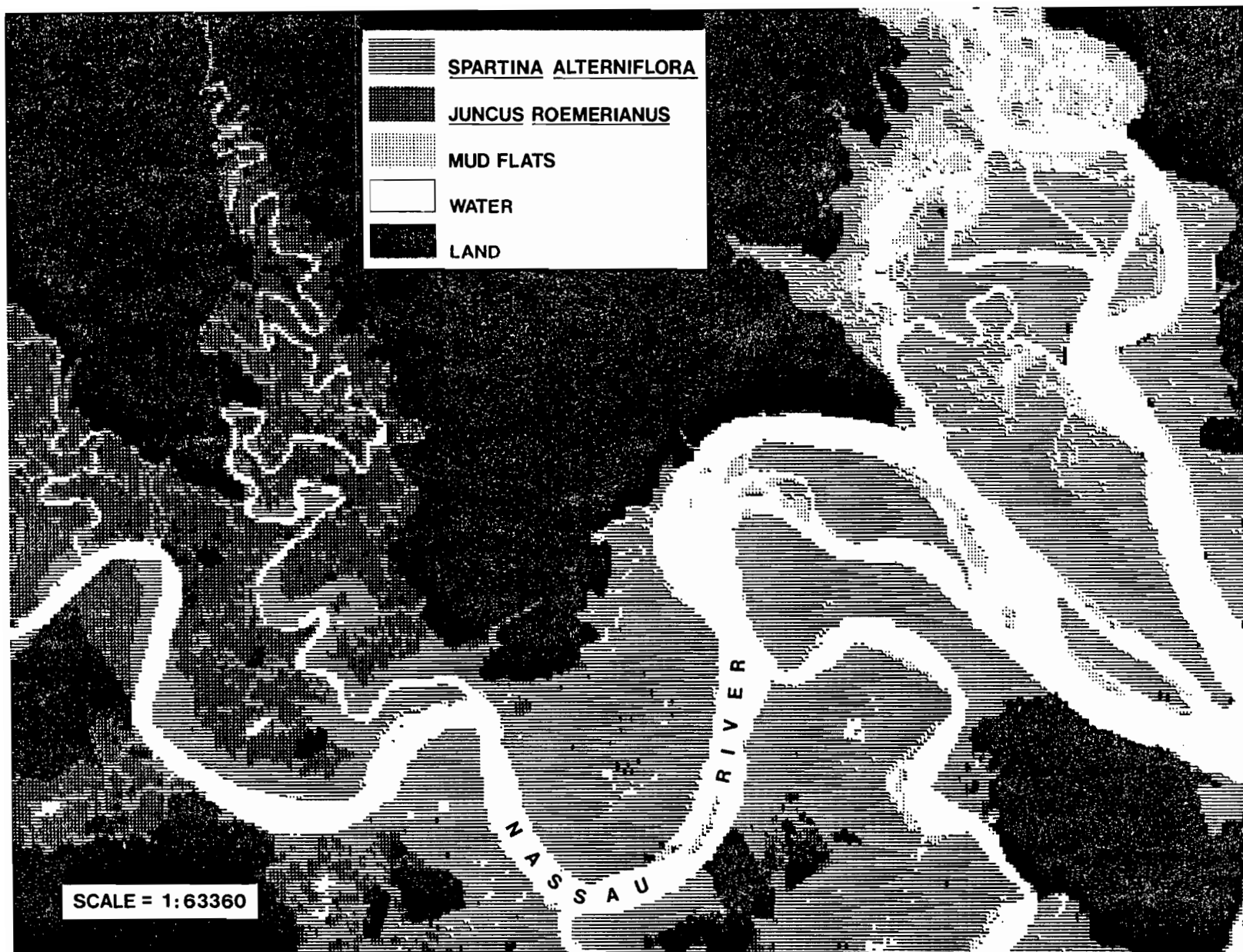


Figure 21. Statistically processed LANDSAT Thematic Mapper (TM) image depicting fisheries habitat in the Nassau and St. Marys Rivers area.

species associations are identified, this type of information may have broad implications relative to fisheries management.

The distribution of mangroves in northern Florida can vary, depending on the amount of freeze damage incurred, and areal coverage may change drastically. The mangroves that existed in lower St. Johns and upper Flagler Counties were confirmed by the satellite imagery; however, these areas were very small. These mangroves have been consolidated into the marsh category. Volusia County had significant stands of mangroves (2,757 ha or 1% of all mangroves in the state), beginning north of Ponce de Leon Inlet and extending to the county's southern border. All mangroves in St. Johns and Flagler Counties and most in Volusia County were killed by the 1984 and 1985 freezes. In Volusia County, the mangrove areas were large; therefore, their areal extent was calculated regardless of live or dead status. Dramatic changes from mangroves to marsh and vice versa will occur with time and depend on climatic events. Unless an active replanting program is instituted, natural mangrove growth will proceed slowly from seeds and propagules that overwinter or drift north via waterways.

Because of mosquito impounding, 638 (9%) of the 6,827 ha of mangrove/marsh in Volusia County (Bidlingmayer and McCoy, 1978) are inaccessible to fisheries, but effects of impoundments can be mitigated. Impoundments in Volusia County are minimal compared to those in other counties on the Indian River, which include at least 76% of the counties' mangrove/marsh habitat. Counties north of Volusia rarely use impounding as a control for mosquitos.

HISTORICAL ASSESSMENTS

Loss of fisheries habitat has become an issue of concern on both state and federal levels. Between 1953 and 1973, approximately 607,000 ha (2,344 sq. miles) of fresh and saltwater wetlands were lost throughout the United States at the rate of 30,000 ha per year (National Wetlands Inventory, 1984). Frayer et al. (1982) estimated that over 33% of this loss occurred in Florida. Legislative action resulting

from environmental awareness has slowed direct destruction of wetlands and fisheries habitat, but the onslaught continues from many directions. Long-term habitat deterioration continues in the form of small, seemingly unrelated projects that, together, impinge on habitats that are important to fisheries production.

Comparisons of aerial photography from the 1940's/1950's and photography and imagery from 1984 were used to analyze habitat alteration at three northeast Florida locations (Table 8). These areas are (1) an 11.3 km coastal segment in Volusia County with Ponce de Leon Inlet as the center, (2) a 12.9 km segment beginning at the north side of St. Augustine Inlet and extending north in St. Johns County, and (3) an area beginning at St. Johns Inlet and extending 5.6 km on either side of the inlet and up the river 16.1 km.

The Ponce de Leon Inlet segment (Figure 22) experienced an overall 20% decline of wetland habitat since 1943 (Table 8). The marsh/mangrove component declined 19%, while 100% (30 ha) of seagrass area was lost. Dredge and fill for development and the Intracoastal Waterway (ICW) were prime contributors to this loss. An estimated 167 ha of spoil were dredged and dumped onto the wetlands prior to 1943.

The development of the ICW has been a major detriment to fisheries habitat throughout Florida. In northeast Florida, most impacts occurred in the early 1900's. If the area of spoil deposits near Ponce de Leon Inlet (1943) is an example of the amount of spoil created per linear km of ICW, then 14.3 ha/km have been deposited. Because approximately 172 linear km of ICW were dredged throughout the northeast Florida marsh by 1943, an estimated 2,460 ha of marsh were altered by the placement of dredge spoil. This does not include the areas actually dredged. Alterations after 1943 occurred to fill wetlands for development. By 1984, many ICW spoil sites were expanded by further spoil dumping. Several spoil islands are now vegetated and have been urbanized with the general population assuming the islands are natural.

Analysis of the St. Augustine Inlet (Figure 23)

TABLE 8. ALTERATIONS IN SEAGRASS AND SALT MARSH/MANGROVE AREAS OF THREE NORTHEAST FLORIDA LOCATIONS. (Areal extent is expressed in hectares.)

	Seagrass	Salt marsh/Mangrove	% Change
Ponce de Leon Inlet 1943-1984	-30 hectares	- 346 hectares	-20%
St. Augustine Inlet 1952-1984	0	- 585	-20%
St. Johns Inlet 1943-1984	0	-1717	-36%

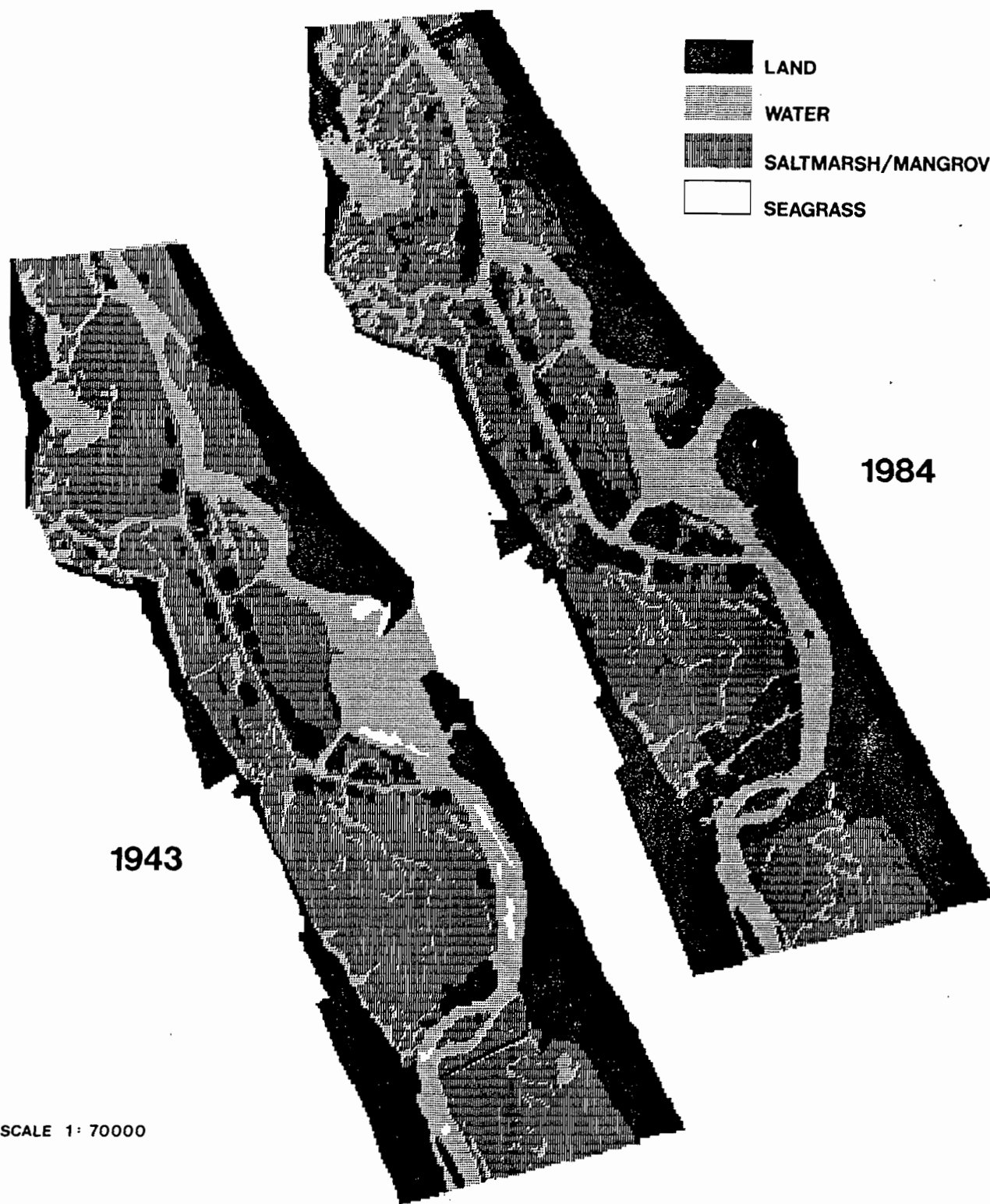


Figure 22. Historical analysis of the Ponce de Leon Inlet area. This illustration was computer-produced from interpretations of 1943 and 1984 photography and 1984 satellite imagery.

TABLE 9. ALTERATIONS IN MANGROVE, SEAGRASS, AND SALT MARSH AREA FOR THREE FLORIDA ESTUARIES.

	Mangrove	Seagrass	Salt marsh
Indian River 1943-1984	-86% -4,575 ha	-30% -856 ha	X
Charlotte Harbor 1945-1982	+10% +2,414 ha	-29% -9,904 ha	-51% -1,244 ha
Tampa Bay 1890-1980	-44% -4,423 ha	-81% -25,182 ha	included in mangrove acreage

indicated a 20% loss of marsh since 1952 (Table 8). The greatest loss occurred in an area that was dammed and converted to a freshwater lake (Guano Lake), totally removing an area that was once a marshland tributary from marine fisheries production.

The Jacksonville/St. Johns Inlet analysis indicated a 36% loss of marsh since 1943 (Table 8). As expected, this area experienced the greatest loss among the five northeast counties, primarily because of intensive dredge and fill activities. Losses prior to 1943 were extensive but, unfortunately, not exactly quantifiable. A large amount of the St. John's River shoreline, located within the study site of this analysis, is composed of spoil that was once a productive marshland.

These three examples may represent "worst case" areas. Early Florida coastal communities centered at inlets to exploit ocean access for fishing and trade. Extrapolation of these losses to obtain a total loss value for the entire northeast Florida region is somewhat tenuous and will not be attempted.

Observations of historical photography indicate that Nassau County has experienced the least amount of marshland alteration, with most loss due to the Intracoastal Waterway construction. Other northeast counties exhibit minimal to severe changes. Loss estimates have been generated for other estuarine areas in Florida (Harris et al., 1983; Lewis et al., 1979; Table 9) and, unfortunately, reveal greater fisheries habitat loss than in sites of maximum loss in northeast Florida.

CONCLUSION

Northeast Florida has lost fisheries habitat and is likely to lose more in the future. These losses must be monitored and minimized to ensure productive and economically important fisheries. Unfortunately, the highest rates of loss have occurred at the inlets that, coincidentally, are the first "habitats" encountered by the juveniles and adults of various marine species entering the estuary. Not only must future impacts be minimized, but knowledge about fishery/habitat relationships must be

acquired. In addition, techniques to enhance the quality of existing habitats and restore degraded ones are critically needed and must be developed.

Regulations prohibiting large-scale wetland destruction should protect the coastal wetlands of northeast Florida, but one major impact still results from growth: cumulative environmental degradation. Environmental degradation does not result from a single act, but is due to "the tyranny of small decisions" (Odum, 1982). The end result is that the important issue (e.g., habitat preservation/quality/quantity) is rarely addressed at higher decision-making levels. We hope that the decision-makers of northeast Florida will begin to assume a large-scale, holistic perspective and avoid the pitfalls of cumulative effects in the future. Only through this approach will future environmental degradation be prevented and the vitality of northeast Florida be preserved.

ACKNOWLEDGMENTS

The authors would like to thank the numerous individuals who responded to our requests for information pertaining to the coastal region of northeast Florida. We also thank Barbara Hoffman and others in the FDNR Bureau of Marine Research staff for providing editorial comments and guidance.

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