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ASSESSMENT AND TRENDS OF FLORIDA'S MARINE FISHERIES HABITAT: AN INTEGRATION OF AERIAL PHOTOGRAPHY AND THEMATIC MAPPER IMAGERY

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ABSTRACT

Florida is currently one of the three fastest growing states in the U. S. with approximately 5,000 new residents entering the state each week. Eighty percent of these residents choose coastal counties for their new homes placing intense pressure on estuarine and lagoonal systems. Over seventy percent of Florida's commercial and recreational marine fisheries species depend on the estuary during all or some portion of their life cycle. Consequently, the alteration and removal of estuarine habitat may have dramatic impacts on marine fisheries.

The Florida Department of Natural Resources is currently mapping and quantifying marine emergent and submergent wetlands as critical components of marine fisheries habitat. The primary data base is developed from LANDSAT Thematic Mapper (TM) imagery using an interactive image processing software package. When submerged vegetation cannot be delineated with LANDSAT data, aerial photographs are interpreted for that submerged habitat and digitized into the georeferenced (UTM) LANDSAT data as an interpretive enhancement.

In addition to assessing current areal coverage of marine wetlands, historical trends at specific sites are being developed. Losses in marine fisheries habitat in Florida's estuaries have ranged from 18 to 81%.

The mapping effort and trend analysis have broad implications for management of the resources. Processing techniques have proven highly successful and the integration of aerial photography has been a key element in providing a data-enhancement approach acceptable to the resource manager.

I. INTRODUCTION

Florida - the word means land of the flowers. Beginning in the 1800's, Florida's warm climate and lush, subtropical vegetation attracted many settlers who traded northern blizzards for warm winters. In doing so, they also battled intense summer heat, mosquitoes, and springtime rains that transformed the State into a giant swamp. Technology soon included ways to beat these elements of Florida's natural environment. Air conditioning was invented. Mosquito control programs were established. And massive canal systems replaced winding rivers and natural sheet flows, draining the wetlands and creating dry land deemed more suitable for agriculture and housing. Since 1950, Florida's population has literally skyrocketed and continues to do so today. Approximately 35-40 people move to Florida every hour. Since over 75% of these new residents have chosen coastal counties to establish homesites, problems associated with exploding growth and development have intensified along Florida's beaches and shores. Before the environmental protection laws of the 70's and 80's, large amounts of raw sewage and other pollutants were disposed into estuaries. Large areas of estuarine wetlands were ditched and diked to prevent the occurrence of a critical reproductive stage of the dreaded saltwater mosquito. Developers dredged, filled, and constructed bulkheads and canals, creating far more waterfront property than Mother Nature thought necessary. The land of the flowers lacked sound growth management and transformed into a land of uncontrolled development.

By 1970, coastal development had reduced or eliminated about 20% of Florida's coastal area (Taylor 1970), areas dominated by estuaries and lagoons. Estuaries are among the most productive ecosystems on Earth, producing, on an average, over three times more vegetation than agricultural land and about four times more than lakes and streams. Estuaries provide food and shelter for a large and diverse group of living resources. In fact, over 70% of Florida's marine commercial and recreational finfish and shellfish depend on the estuary during all or some part of their life cycles (Harris et al. 1983). Additionally, wetland vegetation associated with estuaries provides a natural filter system to cleanse inflowing waters. They also stabilize bottom sediments and shorelines, mollifying erosive forces. Based on these facts, it is obvious that estuaries must be maintained for suitable habitation by all species that contribute to a healthy ecosystem.

The maintenance of estuaries in Florida is not only an ecological concern, but also a sound economic concern. Commercial fishermen harvested seafood worth an estimated wholesale value in 1980 of $175 million and, at retail prices, of $1.25 billion. Approximately 1,278,000 tourist anglers annually fish in Florida waters and Florida ranks third in the nation in resident anglers (2,127,000) (U.S. Dept. of Interior 1982). Sport fishermen alone generate a $1.4 billion industry. In comparison, the Florida phosphate mining industry generates $1.2 billion wholesale, and cattle production, $311 million wholesale. These statistics emphasize the importance of Florida's fishing industry. In addition to sound management, we must realize the long term importance of fisheries habitats to the State of Florida.

Marshes, mangroves, and seagrasses play important roles in estuarine and nearshore environments and are important components of fisheries habitats. These components provide not only food and cover, but also detrital matter which ultimately fuels several food webs. Additionally, the loss of vegetation components of a fisheries habitat has a compounding and long-term effect on the estuary by eliminating the role of vegetation in absorbing flood waters, assimilating waste and excess nutrients, recycling nutrients, controlling shoreline erosion, and trapping particulates that result from erosion. Loss of wetland habitat components can result in reduced water quality and altered circulation patterns that will, in turn, affect the health of the estuary and ultimately the fisheries.

Many Florida fishermen believe that Florida's fisheries are declining. This trend is confirmed for some species by commercial landings statistics (for example, spotted seatrout and shrimp; Florida Department of Natural Resources 1951-1983). A decline in fish populations can be the result of numerous factors (e.g. overfishing, water quality degradation, loss of specific habitat components, natural events) and to identify individual or synergistic processes causing a decline is very difficult. It is possible, however, to map and quantify the estuarine habitat so important to the continued survival of many species. With this information, estuarine habitats can be monitored over future years to identify areas of degradation or change. In addition, habitat information eventually will become an important variable in the assessment and prediction of fisheries populations.

II. MARINE RESOURCE GEOBASED INFORMATION SYSTEM

The importance of quantitatively mapping and monitoring Florida's coastal fisheries habitat has been understood but implementation simply has not been possible due to the almost insurmountable logistical problems encountered when dealing with a coastline of over 2,170 linear kilometers. Standard photogrammetric techniques were prohibitively costly and time consuming, and a minimum ten year cycle in data updates could be expected. This is inadequate for a state whose population is expected to more than double (maximum projected growth) its population by the year 2020 (Smith and Sincich 1984), with the most intense growth affecting the fragile coastal zone and, consequently, the fisheries habitat so important to the state's economy.

Based on results of a Florida LANDSAT demonstration project (Brannon et al. 1981), through National Aeronautics and Space Administration's (NASA) terminated Technology Transfer Program, investigators determined that the LANDSAT series of satellites could provide the primary data base for mapping and monitoring Florida's estuarine and coastal marine fisheries habitat. With support from the National Oceanic and Atmospheric Association Office of Ocean and Coastal Resource Management through the Florida Department of Environmental Regulation, the Florida Department of Natural Resources Bureau of Marine Research has implemented a fisheries habitat assessment program and developed a computer-based Marine Resources Geobased Information System (MRGIS). The MRGIS is designed to process and integrate satellite data and other digital data with environmental and socioeconomic data for resource analysis. The MRGIS is used primarily as a research and development tool for coastal resource management.

Hardware configuration was designed to meet the constraints of the Earth Resources Land Applications Software (ELAS), the primary applications software installed on the MRGIS. ELAS was sponsored and developed by the Earth Resources Laboratory of the National Space Technology Laboratories of NASA.

ELAS has a FORTRAN module overlay architecture with well over 100 modules providing a wide range of statistical, manipulative, modelling, and management routines available interactively to the user. A complete description of ELAS is documented by Junkin et al. (1980).

III. DATA SELECTION

For the development of the initial data base, several specific fisheries habitat components were evaluated for their mapping potential. Three marine wetland vegetative components had high potential for LANDSAT mapping, were considered critically important as fisheries habitat and, in addition, were under intense development pressures:

Seagrasses: a shallow subtidal community represented by seven species. A greater diversity and abundance of organisms within grassbeds than adjacent non-vegetated sites is well documented (Zieman 1982).

Mangroves: an intertidal community represented by three major species. Mangroves are well known for their ability to stabilize shorelines and filter water.

Saltmarsh: an intertidal community represented by two major species. Saltmarshes have been linked to high densities and biomass of marine invertebrates (Zimmerman et al. 1984).

These are the prime vegetative habitat components being mapped, however, site specific vegetated and nonvegetated habitat components also are being mapped (i.e. coral reefs, mud flats, oyster bars, hard bottom, algae beds, etc.).

A. IMAGE SELECTION

When mapping emergent marine vegetation in Florida, imagery selection is not of critical concern because seasonal variation is slight and any good cloud-free imagery typically is acceptable. However, mapping of submerged features such as seagrass requires very careful selection; the primary factor is water clarity. If submerged features are unobservable with aerial photography or TM imagery, they certainly cannot be mapped. The best times for clear water imagery occur in fall and winter during low tides. This rather stringent requirement for seagrass mapping sometimes precludes the use of LANDSAT TM data because of a low potential for having a cloud free, low tide, clear water image. When a clear water TM image is available (Fig. I) the seagrasses are readily observable and easily mapped. Aerial photography is often available, cloud-free, and is usually flown in the winter when the water is clearest. Thus, the integration of photographic interpretations with the TM imagery has become an essential element in the habitat mapping program.

Figure 1. A 1984 TM image (channel 1, .45-.52 μm) of a site near Cape Canaveral, Florida. Submerged vegetation (dark) is easily observed along the shoreline.

B. THEMATIC MAPPER (TM) VS. MULTISPECRAL SCANNER (MSS) DATA

Although the use of MSS data was successful in the initial mapping process, TM data were selected as the prime data source as soon as it became available for the following reasons: (I) better resolution reduces boundary pixel error between statistical classes; (2) the blue reflectance (.45-.52 μm) in channel I provides a better potential for observing water characteristics and submerged vegetation; (3) the infrared reflectance (1.55-1.75 μm) in channel 5 provides better potential for seperating wetland characteristics; (4) rectification of the TM data to an Earth coordinate system is more accurate; (5) more distinct statistical classes of data may be generated by utilizing a greater selection of channels (seven vs four) and optimized bandwidths; and (6) perhaps the greatest asset, the simple fact that higher data resolution (.10 vs .45 ha) is more descriptive pictorally in both the raw and enhanced data. Invariably, TM data have been accepted or selected by the resource manager and even the general public in Florida simply because users can more readily identify visually with features resolved by TM.

Dattavio and Dattavio (1984) have evaluated the potential improvement of TM simulator vs MSS simulator data and concluded that TM data may improve accuracy for mapping wetlands. It may be concluded that, in addition to accuracy, many other features of TM data optimize its use in resource management. Use of TM imagery as the prime data source has virtually assured the acceptance and use of the MRGIS as a tool for managing Florida's coastal resources.

IV. IMAGE PROCESSING TECHNIQUES

A. TM CLASSIFICATION AND RECTIFICATION

Since no specific ELAS TM statistical manipulatives were available in the early days of TM data processing, existing ELAS routines were used to enhance the data. Because such large amounts of data were to be processed, an unsupervised training procedure was used to generate the statistics required for maximum likelihood classification. A standard ELAS module, SRCH, was selected. SRCH is an unsupervised classifier that uses a 3x3 pixel window for homogeneity determination before clustering or discarding the nine pixels to develop a maximum of 64 statistics (stats) for any given data set. By using a 3x3 window, the data variability appears to be smoothed and processing time is significantly reduced. Point classifiers were extremely slow and tended to be overwhelmed by the data variability, often producing unusable stats.

Since the goal for a final processed product was an image emphasizing the fisheries habitat components and also depicting gross upland and land use categories, several TM channel combinations were attempted and evaluated for these criteria. The best results by far were obtained by using channels one through five (.45-.52, .52-.60, .63-.69, .76-.90, 1.55-1.75 μm). Although SRCH is an unsupervised classifier, the training fields can be selected to maximize or skew the statistics generation towards features of interest. SRCH develops an intermediate set of stats which are then merged, based on an interactively set scaled distance (merge radius). The standard approach to stat generation using SRCH is to run it on an entire scene or some unified portion of a scene. However, when developed on small, carefully chosen rectangles of data within a scene, the stats can be biased to better meet the needs of the investigator. The selection of proper training fields is an art/science which requires an ecological understanding of the image contents. A bias towards wetlands classification can be generated by concentrating most of the training on wetland areas and a minor amount on upland areas. If some pertinent wetland feature is not delineated in the original stat generation, either a supervised technique may be used or an unsupervised point cluster analysis may be run on only those categories of confusion.

Using these techniques, rapid, accurate classifications can be developed in relatively short periods of time. Areal comparisons between photoanalysis and LANDSAT analysis have differed as little as 0.4% for wetlands calculation of identical regions (Haddad and Harris, in press). These investigators also found a 69-72% cost reduction and an 83% time reduction by using LANDSAT TM imagery over aerial photography as the prime data base.

After classification, the resultant image is then rectified to Universal Transverse Mercator (UTM) coordinates. A semi-automated point picking routine (courtesy of Fla. Dept. of Transportation) was used to rapidly produce highly accurate rectifications. This program requires the use of a digitizing table and a data file containing UTM corner points for every U.S. Geological Survey 7.5 minute quadrangle (quad) in Florida. The quad sheet is placed on the digitizing table and initialized to the UTM corner points. Control points for image rectification are then generated by choosing a feature on the quad sheet using the digitizing cursor and the corresponding feature from the LANDSAT scene using the screen cursor. The use of TM data greatly facilitates accurate control point generation with root mean square residual errors always less than one pixel. A nearest neighbor resampling is then used to rectify the image to 31m UTM coordinated pixels.

B. PHOTOGRAPHIC ANALYSIS AND RECTIFICATION

It became evident in the early stages of MRGIS development that, in some cases, specific mapping features (i.e., seagrasses) would have to be extracted from aerial photographs and imbedded into the LANDSAT data base. This deviates from the purist approach to machine processing of remotely sensed data but is a practical reality. Since the LANDSAT data provided the mapping base, only those features of interest needed to be extracted from the photography. For example, if seagrasses could not be statistically differentiated in the TM data, existing aerial photography for the given area was acquired and interpreted only for seagrasses as polygons onto mylar overlays. If the photography (regardless of scale) was flight controlled and of high quality, the mylar overlays could be placed directly onto the digitizer, rectified to the UTM-referenced TM scene, and hand-digitized directly into the data base. If the photograph was not flight controlled, the interpretations were first transferred to U.S.G.S. quads and then digitized.

In addition to the TM enhancement, historical photography from selected time periods (i.e., 1940's-1950's, 1970) have been interpreted to determine trends in fisheries habitat change. The various historical analyses were digitized as separate channels of data into the corresponding UTM rectified LANDSAT scene file for direct overlay and numerical comparisons.

V. THE RESULTS AND THEIR IMPLICATIONS TO THE REAL WORLD

Although LANDSAT technology has been available for well over a decade, its acceptance has been slow. In the early days of technology transfer, LANDSAT was oversold as a panacea to the remote sensing world and the resource manager. As a result, the resource manager labelled LANDSAT as a marginally acceptable tool for providing useful data for resource decisions. This attitude is changing in Florida for several reasons: (1) the positive results of NASA's now terminated Technology Transfer Program demonstrated LANDSAT applications and provided a base upon which to mature into the technology; (2) software developments have provided for more accurate information extraction; (3) image processing facilities have become increasingly less costly, and; (4) the advent of Thematic Mapper data has greatly enhanced the interest of the resource manager.

As with all technologies, LANDSAT must demonstrate its capabilities and fill a niche in the real world. This did not occur as rapidly as predicted, but the impetus is now growing and the applications of LANDSAT technology are many. Certainly the LANDSAT founding fathers did not envision that the first programmatically applied use of LANDSAT data in Florida would be to map marine fisheries habitats. However, a systematic approach to mapping fisheries habitat for the entire State of Florida has been initiated and the results have many implications.

A. INDIAN RIVER

The Indian River is actually a saltwater lagoon extending 192km along Florida's east coast. It is separated from the Atlantic Ocean by a series of barrier islands divided by narrow, natural and man made inlets. The Indian River supports a rich abundance of marine flora and fauna which are increasingly subject to coastal development.

Commercial landings of several estuarine dependent species in the Indian River system, i.e. spotted seatrout and shrimp, have indicated a statistically significant decline in harvestable populations since the 1950's. The reasons for declines can be all or one of many factors, i.e. natural population fluctuations, overharvesting, climatological events, loss of habitat, etc. These parameters are difficult to elucidate and quantify, but by knowing the location and trends in the major fisheries habitat components, the resource manager can evaluate and attempt to maintain the estuarine environment as a useful nursery ground for juvenile and adult commercially and recreationally important fisheries species.

The predominant vegetated habitat components in the lower two thirds of Indian River (current study site) were mangroves interspersed with several succulent marsh species and seagrasses. LANDSAT 4 TM imagery for July 1982 was used as the primary data source in the mapping effort. Statistical processing of the TM data easily delineated the mangrove populations in the study area (Fig. II). However, several of the mangrove categories were found to be confused with some

Figure II. A statistically processed TM image of a 12 km site in Indian River, Florida. Mangroves are depicted in black and seagrasses in white. Seagrasses were interpreted from 1984 aerial photography and imbedded into this 1982 image.

freshwater vegetations. Instead of the purist approach to rectifying the data (i.e. further time consuming data reduction), a rapid and practical approach was used: understanding that mangroves simply are not found in freshwater habitats and taking advantage of the interactive capabilities of the MRGIS, the freshwater "mangroves" were changed to a freshwater wetland category. This reinforces a premise maintained in this mapping program: machine processing of LANDSAT TM data must be augmented interactively with information derived from both aerial photography and the investigator's ecological understanding of the system, being mapped.

Within the present 120 coastal kilometers mapped in the Indian River, mangroves comprised 3,198 hectares (ha) of a total 33,425 ha of estuarine habitat. But, based on mosquito impoundment locations (Biddlingmeyer and McCoy 1978), only 767 ha are available to the fishery. Mosquito impoundments are a control measure for saltwater mosquitos that consists of building a dike around the wetland breeding habitat and controlling water levels within the impoundment to prevent adult mosquitos from laying eggs. Unfortunately, this removes access into and out of this critical fisheries habitat component and consequently, 76% of the existing emerged vegetated wetlands in the Indian River are not productive to fisheries.

The Indian River is often turbid and seagrass beds were unobservable by using the acquired TM imagery. Existing aerial photographs (Feb., 1984) with good water penetration were photointerpreted for seagrasses and the results were digitized into the TM data base (Fig. II). Seagrasses were found to cover 2,777 ha of the bottom.

Although the location and aerial calculations of the existing habitat are of prime importance, trends in habitat change also are important in assessing local habitat impacts and areas suitable for habitat restoration. Several areas in the Indian River were mapped for historical coverage (1940/1950 and 1970) and the interpretations entered into the LANDSAT data base. An approximate 30% decline in seagrasses (1,214 ha) can be estimated from the resulting trends. Although an estimated 76% of the existing mangroves are lost to the fishery by mosquito impounding, a total of 86% of the mangrove/marsh has been lost to the fishery since the 1940's.

A visual pattern of seagrass loss for one area in Indian River is depicted in Figure III. This image is the result of digitizing the seagrasses for 1951, 1970, and 1984 into the LANDSAT data base, then removing all other features to dramatize the patterns in seagrass change. This 12 km stretch of estuary surrounding Sebastian Inlet, Fla. experienced a 38% (514 ha) decline in seagrass since 1951, with 16% of that decline occurring after 1970.

B. NORTHEAST FLORIDA

The impacts of growth on fisheries habitat in northeastern Florida have become an issue of focus as federal, state, and local officials attempt to manage a rapidly increasing population. An assessment of this growth and its impacts on the fishery is difficult to interpret but the area has been mapped and assessed for impacts on fisheries habitats (Durako et al., in press).

Three sites in northeast Florida have been analyzed for habitat alteration from the 1940's and 1950's to the present: (1) an 11.3 km coastal segment with Ponce de Leon Inlet (Volusia County, Fla.) as the center; (2) a 12.9 km segment beginning north of St. Augustine Inlet and extending north; and (3) an area beginning at St. Johns River Inlet (Jacksonville, Fla.) and extending 5.6 km on either side of the Inlet and up the river 16 km. The historical interpretations were based on black and white aerial photographs (Soil Conservation Service). A TIPS formatted, May 14, 1984 LANDSAT TM image was used as the primary data base.

The Ponce de Leon Inlet segment experienced an overall 20% decline of marine wetlands since 1943 (Fig. IV). A 19% decline in emergent wetland vegetation occurred while 100% (30 ha) of the seagrasses were lost. In both the photoanalysis and the TM analysis of Ponce de Leon Inet, three categories of emergent wetland were delineated: mangrove, saltmarsh/mangrove (70% saltmarsh and 30% mangrove), and saltmarsh. The areal extent of mangrove declined from 1,290 ha to 951 ha 26% decrease), saltmarsh/mangrove increased from 458 ha to 518 ha (11% increase), and saltmarsh decreased from 172 ha to 104 ha (39% decrease). Several important conclusions

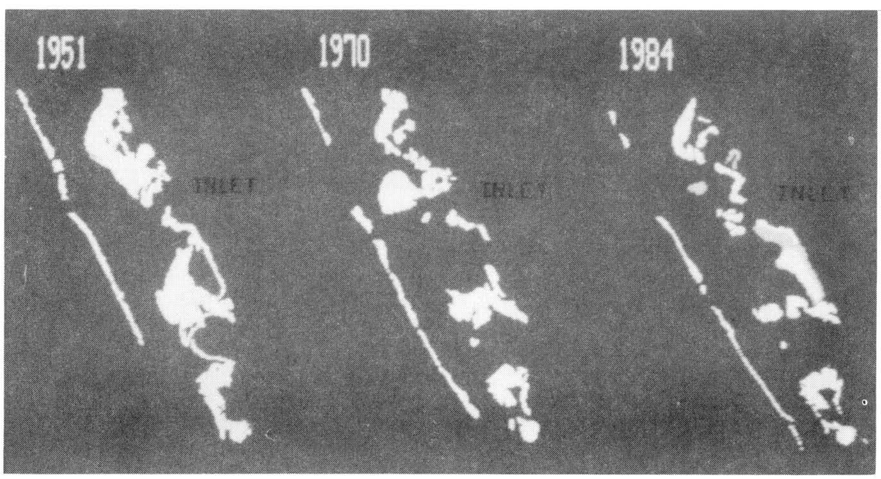
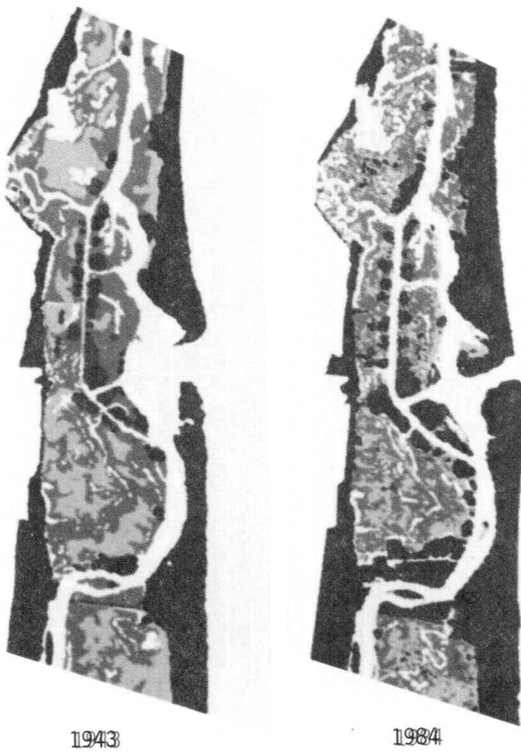


Figure III. A historical analysis of the Sebastian Inlet area showing areal coverage of seagrasses over a 33-year time span.



Upland

Mangrove 1943: 1290ha
1984: 951ha

Marsh/Mangrove (m/m) 1943: 172ha marsh; 458ha m/m
1984: 104ha marsh; 518ha m/m

Water

Figure IV. A comparison between marine wetlands near Ponce de Leon Inlet, Florida for 1943 and 1984. Two categories, marsh and marsh/mangrove, were combined pictorally to create one marsh/mangrove category, but have been addressed as separate numerically.

can be developed from the trends. First, the wetland structure of the Ponce de Leon Inlet area is changing vegetatively, evidenced by the decrease in saltmarsh coverage and increase in the saltmarsh/mangrove coverage. Mangroves are a tropical species; their northern limit (for substantial populations) extends just north of Ponce de Leon Inlet. One can expect the ratio of mangrove to marsh to vary with time, depending on climatological events such as winter freezes. These natural changes in habitat components do not reflect a loss of habitat but merely a change in habitat.

A second conclusion that can be drawn from the trend analysis for Ponce de Leon Inlet is that 347 ha of emergent wetland were lost since 1943 because of direct human impact. Dredge and fill for development and the Intracoastal Waterway were the prime contributors to the total loss of wetlands. An estimated 167 ha of spoil were dredged and dumped onto the wetlands prior to 1943 as a result of construction of the Intracoastal Waterway. By 1984, many of these areas had been expanded by further spoil dumping. Several spoil islands now contain urban development while others are now vegetated. Most impacts occurred in the early 1900's. Spoil deposits near Ponce de Leon Inlet (1943) cover 15 ha of marsh per linear km of Waterway. One hundred seventy three linear kilometers of coastal northeast Florida marsh-lands were impacted by the Waterway. Gross extrapolation of these figures indicates that approximately 3,461 ha of fisheries habitat in northeast Florida already may have been impacted by the placement of dredge spoil by 1943. This includes only areas impacted by spoil; it does not include areas actually dredged before 1943 or dredged and impacted by spoil placement after 1943.

The St. Augustine area analysis indicated a 20% loss of marsh since 1952. The majority of the loss occurred in an area which had been dammed and converted to a freshwater lake (Guano Lake). Once a marshland tributary, this area has been totally removed from fishery production.

The Jacksonville/St. Johns Inlet analysis indicated a 36% loss of marsh habitat since 1943. This area has experienced the greatest loss in NE Florida primarily due to dredge and fill activities related to military and industrial development. Loss prior to 1943 was extensive but immeasurable. A large amount of the river's shoreline is composed of spoil; most of the people living there are unaware that they live on a once productive marshland.

These three locations may represent "worst case" areas, but development is expanding in all directions. Early Florida coastal communities centered at inlets to exploit ocean access for fishing and trade; thus, growth impacts have been greatest in these areas.

Table I. Summary of fisheries habitat alteration for several Florida estuaries.

	Seagrasses	Mangroves	Saltmarsh	Mangrove/Saltmarsh
Indian River	-30%	-86%	-	-
Charlotte Harbor	-29%	+10%	-51%	-
Tampa Bay	-81%[1]	-	-	-44%[2]
Ponce de Leon Inlet	-100%	-	-	-19%
St. Augustine Inlet	NP	NP	-20%	-
St. Johns Inlet	NP	NP	-36%	-

NP = not present
[1]Lewis et al., in press
[2]Lewis 1982

VI. SUMMARY

Florida is undergoing tremendous growth and development pressures, with continual impacts occurring on marine fisheries habitat components that are important in maintaining a viable commercial and recreational fishery. Until the development of the LANDSAT program and, more recently, availability of Thematic Mapper data, no practical method existed to map and monitor a coastline as extensive as Florida's. The use of an unsupervised TM data classification procedure and the integration of photointerpreted supplemental data has proven a simple, cost-effective approach to a potentially complex and costly problem.

The resulting habitat maps are providing a very essential data base for effective management of Florida's resources. The results of habitat trend analyses have suggested substantial losses of fisheries habitat throughout Florida (Table I). The visual and quantitive aspects of the data are providing the public and local and state officials with the incentive to address habitat loss and alteration as a serious issue of Florida's coastal zone.

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