Duplicate

ASSESSMENT OF FISHERIES HABITAT

TASKS II AND III

FINAL REPORT

for contract period 10/1/85 thru 9/30/86

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TASK II

Marine Resource Geobased Information System

LANDSAT data have been acquired to provide coverage of estuarine resources for the entire state. The raw data have been processed and enhanced with a parallel-piped statistical analysis. Seagrass delineation has not been completed in several areas due to the delays in receiving map products from existing state and federal projects. Every attempt has been made to avoid duplication of effort in mapping submerged vegetation. Areas where new data are becoming available are Indian River Lagoon (CZM), Apalachicola (U.S. Army Corp), and the Everglades National Park. These are in the final stages of completion by the respective agencies and the data will be digitized directly into the MRGIS database. The Miami area has not been completed but the data are available and considered low priority because of the excellent graphics produced by Dade County and the availability to the general public.

Several new steps were added to the image processing in order to make the products easier to disseminate. The first step was to reorganize the data into geographic partitions on 300 megabyte removable disk packs. This allows rapid access to the data without having to use data transfer on the slow 9-track computer tapes. Currently, about one third of the state has been reorganized into this format. The second step has been a re-georeferencing of the raw data. Previous analyses used a nearest-neighbor interpolation on the final classified data set. We have determined that a bilinear interpolation of the raw data prior to classifying produces a much more resolved final image and reduces image blockiness. This is important when using the inkjet printer (see TASK III).

With the online capability of the inkjet printer, we have initiated a major effort to complete Aquatic Preserve maps and to respond to an unprecedented number of requests for information from regional and local interests (Table 1). The need for accomplishing the above data restructuring is paramount to maintain our high level of production in accomplishing our stated goals of the habitat assessment program. The data restructuring is expected to continue through April, 1987. At that time, we expect to produce an atlas of vegetated marine fisheries habitat for limited distribution.

Trend analyses have been completed for four areas between Tarpon Springs and Pensacola. The areas are a 15 km length of coast near Hernando Beach, the western half of Choctawhatchee Bay, Big Lagoon of Pensacola Bay, and the mouth of Perdido Bay. Reprint 1 describes the results as presented at the Gulf of Mexico Information Transfer Meeting. Trend analyses for the Keys have not been completed. Review of aerial photography depicted change but the complexity of the change and some of the difficulties in photointerpretation of the historical photographs precluded our ability to produce an assessment of change with a satisfactory level of error. As our techniques are refined, this area will be reassessed for trend analysis.

Trend analyses for the entire Tampa Bay region has been completed in cooperation with the U.S. Fish and Wildlife Service and the results of the 1950/1952, 1970, and 1982 analyses are stored in rastor format on the MRGIS (See Map 1). Methods for updating these data with LANDSAT TM data have been developed and will be presented at Coastal Zone 87 (Reprint 2).

Ancillary data have been digitized into a layered database for a portion of the Tampa Bay area. The layers of data consist of 1) fisheries habitat, 2) open/closed shellfish beds, 3) sediment types, 4) wading bird rookeries, 5) brown pelican rookeries, 6) shorebird rookeries, 7) manatee sanctuaries, 8) oyster leases, and 9) Aquatic Preserve boundaries. Several GIS queries were asked of the database by simple logic algorithm software programs. The results became new files containing a compilation of the query. An example is: "Depict those areas which contain seagrass and mangrove, are over sandy sediment, and are within 3 kilometers of wading bird rookeries." We assumed that all areas which met this condition and which were not within an Aquatic Preserve needed special protection measures because this habitat is important to wading birds as feeding areas during the nesting season. This is a simple example, but much was learned during the entire process of data entry and analysis. A publication describing the concepts of coastal geographic databases as developed on the MRGIS is found in Reprint 3.

A detailed study of Cockroach Bay was implemented to determine the cell size limits of the MRGIS. Tests were conducted at 30 and 15 meter cell sizes. Attempts at 7.5 meter (1/16 acre) cell size proved fruitless because no databases existed at this resolution. If a 7.5 meter cell size were used, creating the database would have been a prohibitively time consuming process. This resolution could be used for localized details in separate files but could not be overlayed effectively with TM data.

The 15 meter cell size (1/8 acre) can be effective in many applications. If the data being entered is 1:24,000 (7.5 minute USGS quad), TM data (normally 30 meter) can be resampled to 15 meters and the acreage accuracies of digitized data can be increased from 90% to 99%. This accuracy is not necessary, in many cases, since the increases in accuracy often exceed map accuracies. We maintain the MRGIS database at 30 meter cell size as a standard, unless we are calculating digitized map data acreages for small areas. This is proving the most effective and efficient approach to database maintenance at this time. Also, reducing the cell size to 15 meters doubles the data storage requirements. When new mass storage devices become available, working with smaller cell sizes may become the norm, but this will have to be reevaluated as the technology improves.

The development of a carrying capacity model was initiated for Cockroach Bay. In order to begin this modelling effort, various sampling gears and techniques need to be evaluated to determine which device best quantifies habitat usage. The initial habitat under study is seagrass.

Drop Net Sampling in Cockroach Bay

Cockroach Bay is located on the east coast of Tampa Bay, north of Port Manatee and south of the Little Manatee River. Cockroach Bay is a shallow estuarine system with mangroves distributed throughout the shoreline and on the numerous islands within the system. Seagrasses are abundant throughout the Bay except along the deeper (>1.5 m) portions of natural channels. The bay is undeveloped and contains no dredged areas. For sampling purposes, Cockroach Bay was divided into three sections: the inner-bay, mid-bay, and outer-bay.

Carrying capacity, particularly of juvenile stages of fish and age at entry into the fishery, is presently unknown for most habitat types, i.e., seagrasses, mangroves, etc. If carrying capacity of a particular system could be modelled and quantified, then habitat loss or degradation could be correlated with yield and stocking capacities (this relates to the DNR five-year plan).

Shallow estuarine areas are important nursery areas for many commercial and recreational fish and invertebrates (Lindall, 1973, 1977). A quantitative sampling method is necessary to determine community structure and constituents.

Hartman (1985) evaluated seven gear types used for sampling fishes and crustaceans in a shallow estuarine marsh area. He found otter trawls were easiest to use, but the fewest fish and the lowest density of organisms of all but a few species were captured. The haul seine captured the most species and generally the most individuals, while the throw trap revealed the highest density of all methods. Gilmore et al. (1978) reported that the drop net captured fewer individuals and species than the seine, and most small demersal and semidemersal forms. However, the total fish density and biomass values of drop net samples surpassed seine sample values per sample area. This has been demonstrated in previous studies as well (Gilmore et al. 1978, Kjelson and Johnson 1973, Kjelson et al. 1975).

Kushlan (1981) compared two sizes of throw nets (1 m^2 and 2.25 m^2) and a drop net and determined that the 1 m^2 throw net required a reasonable number of samples in most cases. In three tests, the accuracies of the 1 m^2 trap for estimating density were similar, encouraging confidence in applying a correction factor for determining standing stock.

Drop nets quickly enclose a known area of seagrass or sand bottom and may be used to quantitatively sample shallow (<1.5 m) estuarine areas. Since most other methods provide unquantified results, drop nets were the best sampling devices for Cockroach Bay.

Sampling Methods

Field sampling began in July, 1986, is ongoing, and occurs three to four times monthly. Two 1 m^2 drop nets are suspended from a boom and mast system which extends 5 m off the bow of a 17' Boston whaler. The boom and mast are constructed from galvanized steel and aluminum inserted into PVC pipes and can be dismantled for traveling (Figures 1 and 2). The mast is held inside an aluminum bowpiece which is attached to the front of the boat (Figure 3).

Each drop net is composed of an upper float frame (2.5 cm, schedule 160, PVC pipe) and a lower sink frame (stainless steel sheet metal, 2.5 x .32 cm). The frames are connected with 3.2 mm cm mesh, nylon ace netting, which allows the nets to expand to a depth of 1.5 m (Figures 4 and 5).

The drop nets are released over seagrass in three different areas of the inner bay, mid-bay, and outer bay. To avoid disturbing a sample site, the boat motor is turned off, allowing the boat to drift to the sample site. Release pins, attached to lines leading into the boat, are pulled, releasing both drop nets simultaneously over the sample site. After releasing the nets, the lower frames are inspected; samples from drops on unlevel surfaces will not be collected since organisms may have escaped. The lower frames are then pressed into the sediment to anchor the nets and prevent escape of organisms. One end of an internal seine (.99 m x .99 m, .32 cm mesh) is scraped along the bottom of the sample area until organisms are no longer captured. Fish, macroinvertebrates, and macroalgae are placed into zip-lock bags and iced, then frozen upon arrival at the lab. Density and species of seagrass and algae, salinity, temperature, dissolved oxygen, turbidity, wind direction and velocity, tidal period, water depth, lunar phase, and cloud cover are recorded at each station.

At the lab, standard length for all fish, carapace width of crabs, and carapace length of shrimp are recorded. Wet weights are recorded for all fish and invertebrates. Macroalage are weighed wet and dry. All data are entered and analyzed using SAS (Statistical Analysis System) programs.

Results

The drop nets captured 25 different species of fish (Table 2) during the months of August and September, 1986. Fish density and biomass values for the inner, middle, and outer Cockroach Bay were calculated (Table 3). These values were also determined for the seagrass species (_Thalassia,_ _Syringodium_, and _Halodule_;

Table 4). The same type data were calculated for fish and macroinvertebrates combined (Tables 5 and 6).

Most of the fish captured were demersal species such as gulf pipefish (Syngnathus scovelli), code goby (Gobisoma robustum), clown goby (Microgobius gulosus), lined sole (Achirus lineatus), and the blackcheek tongue fish (Symphurus plagiusa). Semi-demersal predators also made up a large percentage of captured species, including pinfish (Lagoadon rhomboides), gulf toadfish (Opsanus beta), silver perch (Bairdella crysura), spotted seatrout (Cynoscion nebulosus), red drum (Sciaenops ocellatus), and sheepshead (Archosargus probatocephalus). These results are similar to those of Gilmore et al. (1978) who found mostly small demersal and semidemersal forms.

Conclusion

Drop nets appear to provide valuable quantitative data and may be used as the control sampling method to test other varieties of sampling devices. During the coming year various gears will be designed, constructed, and field tested. Roller rigged shrimp trawls attached to a 17' Boston whaler will be utilized as a semi-quantitative sampling device in the seagrasses of Cockroach Bay. The estimates obtained from the trawl data will be compared with the drop nets to assess the efficiency of each device at capturing different species of fish and macroinvertebrates. Also, stationary drop nets one, two, and four m^2, suspended from a tripod, will be constructed and tested to provide another estimate of fish and macroinvertebrate density and biomass.

To test the application of the above quantitative data an attempt was made to apply a recruitment value to spotted seatrout in the standard Beverton Holt population model. Rudimentary estimates of juvenile populations of seatrout were computed based on average density of seatrout/m^2 multiplied by acreage of seagrass in Cockroach Bay. The Beverton Holt model considers a growth model, mortality estimates, and time parameters in its basic calculations. It also separates male and female populations, and considers recruitment as constant and the actual value as relative. In addition, the recruitment value must remain the same for the life of the model which uses a 6-8 year simulation. This means that yearly variation in recruitment cannot be accounted for in the model. This model has been temporarily discarded for the above reasons. An existing model which can utilize real values and account for yearly variations in recruitment is currently being sought. If such a model in fisheries population dynamics does not exist, then a hybrid will be developed.

TASK III

Geographic Information Dissemination

As the MRGIS has been developed, the need to assess techniques to disseminate data has readily become apparent. Four approaches to dissemination have been assessed.

1. Small format photographic images. A flat screen photographic system was acquired with the original MRGIS acquisition. This system has the capability of reproducing the image on the display screen onto 35 mm tranparencies, 4"x5" instaprints, or negatives. These output products are inexpensive and very good for slide presentation and hard-copy filing of an image. The negatives can be printed and enlarged for journal or other publications. These products are not practical in the field or for utilization as data by the resource manager. In addition, since only a 512x512 pixel output is possible, a data set that is, for example, 1024x1024 pixels cannot be photographically captured without removing data in order to fit the entire image on the screen.

2. High resolution images. An alternative to small format photography is the output from digital, laser optical systems. Image data, on nine track computer tape, were transferred to this high resolution device for photographic hard copy reproduction. Since the system is capable of high resolution output, the need to remove data for entire file reproduction is eliminated. The resulting output product is larger, and since reproduction is not from a CRT, no scan lines are present. The results of this process is an outstanding reproduction of the data. Review of this type of product by the resource manager has received an

overwhelming positive response for its visual acuity. This type of output is not good for field work but can be utilized by the resource manager for geographical reviews and for presentation at meetings where this type of product can be used to demonstrate a regional concept with enough detail for local application. A major drawback to this method of data dissemination is the expense of reproduction. The process is not available within State government and would be costly to initiate. Outside contracts are required with costs ranging from $350 to $1000 per individual photographic output. Only under special circumstances would this type of product be recommended for purchase.

3. Inkjet printer images. An inkjet printer has been interfaced to the MRGIS for paper hardcopy generation. A desktop Tektronix 4696 color printer was chosen as part of a combined software/hardware purchase. The printer interfaces to an IBM AT which is interfaced to the MRGIS (Fig. 6); this was the most cost-effective approach. Data to be printed are downloaded from the MRGIS mainframe to the IBM for printout. The printer has a software driven pallet of 4096 colors and is quite capable of reproducing the color output of the MRGIS. Examples of this product are Maps 1, 2, and 3. The printer uses rolls of paper with a print width of 8.5 inches and is capable of printing approximately 256 pixels across. If the data file is 1024 pixels wide, for example, the printer would automatically print four panels, each containing 256 pixels. The panels can then be manually joined to form the entire image. The data can be output in different scales (i.e., 1:24000, etc.) and can have the map

coordinate system plotted directly on the hard copy. This product is inexpensive to produce, can be accomplished in-house, and can be used in the field and in the office. It has been used succesfully in producing Resource Protection maps for Aquatic Preserve Management Plans (Map 1). The drawback is the time required for a map to be printed. A 512x512 image (approx. 10x10 miles at full 30 m resolution) takes approximately 20 minutes to print. Limited mass production would be possible but not optimal for mass distribution. Production cost for the above product would be approximately $2 per copy.

4. Digitally formatted images. Conceptually, the most efficient and utilizable data output is in digital format. This would allow the resource manager to computer-access the data and use it in more than simple map analyses by incorporating the data into a geographic information system (GIS). Our definition of a GIS and its conceptual applications in coastal resource management are found in Reprint 3 as published in a technical conference proceedings.

To take the applications beyond the conceptual stage, the technological capabilities of downloading data from the MRGIS to a microcomputer were tested. Figures 6, 7, and 8 depict the current MRGIS configuration and Figure 9 describes the flow of data from the MRGIS to a microcomputer at the Lab. Essentially the LANDSAT data are processed on the MRGIS, downloaded via an RS232 serial interface to an IBM AT, and reformatted for distribution. Special software interfaces were required for proper data transfer. One of the problems of dissemination of these of data is the large volume. Files often exceed 5 megabytes and standard floppy disk transfer is not possible. A file-oriented PC 1/4 inch tape back-up unit was chosen as the transfer media from the IBM AT located at the lab to a microcomputer GIS outside the lab. These cartridges carry up to 60 megabytes of data and are easily mailed.

Two micro-GIS systems have been installed outside the laboratory, one at the East Central Florida Regional Planning Council and the other at the DNR Cape Romano and Ten Thousand Islands Aquatic Preserve. The installation at the planning council was accomplished through another DER/CZM grant with our cooperation and advice. Their use of the system is described in their final report and should be reviewed in conjunction with this report. In summary, DNR downloaded wetlands data for Brevard County and GIS analyses were used to target those wetland areas that will be subject to future development pressure relative to population projections.

The Aquatic Preserve GIS system has been installed and LANDSAT data successfully downloaded for their use to build an Aquatic Preserve database for the large Cape Romano and Ten Thousand Islands area. Both management and research data are entered as data overlays to implement the GIS concept.

Prior to the recommendation of which type of microcomputer equipment to install at these facilities, a number of commercial systems were evaluated. The criteria for evaluation were based on user-friendliness, GIS functions, type of graphics display, and various specifics that would allow the technical link necessary to use the data format which we output from the MRGIS.

The evaluation narrowed the possible choice to two systems and the respective vendors were visited on-site to fully understand their product. This process eliminated one vendor because they were unable to display through three image planes. The ERDAS, Inc. GIS system was recommended as the only commercially available micro-GIS which would meet the overall goals of the project. Since then a number of additional commercial products have become available and previously existing companies have upgraded their products. Prior to any further recommended purchases, these new products should be evaluated.

Microcomputer versions of the MRGIS ELAS software are now available but since this software is not user-friendly, it would not fit easily into management applications because of the necessity for simplicity in data query.

Management Assessment

A good overall management assessment for a GIS has been accomplished by East Central Florida Regional Planning Council and that CZM Final Report will not be duplicated in this document. The technological transfer process, data redisplay, and data manipulation have been successfully accomplished, but the acceptance by management has yet to be tested beyond the present demonstrations. Careful selection of the initial installation sites and an unusual collection of abilities and commitments by the persons involved are responsible for the success of the project. However, the GIS concept is not completely guaranteed to be accepted or incorporated into management structure.

Some observations which are pertinent to the success of a GIS and to the potential failure of a GIS are as follows:

1. Personnel with a biological background are imperative to guide the creation of the database. They must be dedicated to attaining the greatest database accuracy possible and must be able to evaluate that accuracy. This requires understanding biological concepts and factors influencing the resources being input into the database.

2. Management must make a commitment to the long-term development of the GIS. A GIS database, by its nature, is continually changing. If a method for incorporating those changes into the database is not scheduled and budgeted, the overall database becomes obsolete.

3. The greatest potential for the failure of a GIS lies within the management structure and the misconceptions that a GIS database is produced out of thin air once the GIS hardware is purchased and turned on. This will be the most difficult obstacle to overcome and is tied into commitment by management to build a GIS. Management is generally starved for decision-making information but is unwilling to commit funds for database creation and access.

4. Once a GIS database is created, the next major obstacle is getting management to use it. Using the database requires some level of training which management often has neither the time nor inclination to accomplish.

5. The GIS must be very simple to use by the manager. This requires a menu-driven component of the GIS to be available on a desk-top computer with a minimal amount of choices for data

access and manipulation.

6. Any GIS development should be instituted on a small-scale pilot project and involve all levels of management.

7. Serious in-house evaluation of the data that comprise the overlays in the GIS structure must be implemented. This should include an evaluation of existing databases. Under no circumstances should the existence and applicability of an existing database be assumed.

Table 1. Examples of some requests to CZM for assistance, cooperative projects, and presentations during the 1985-1986 grant period.

1. Pam Muller, University of South Florida Department of Marine Science: MRGIS use in NSF grant proposal to look at ocean foraminifera distribution.

2. Larry Doyle, University of South Florida Department of Marine Science: Cooperative project through SeaGrant to use TM data to assess sand transport distribution as a result of Hurricane Elena. Presented with co-authorship at the American Geological Society annual conference.

3. Norm Blake, University of South Florida Department of Marine Science: Cooperative investigator to look at scallop recruitment on the Florida east coast, SeaGrant proposal.

4. Nelson May, Louisiana State University Center for Wetland Resources: assistance and use of MRGIS for TM analyses.

5. Don Field, NOAA Office of Oceanography and Marine Assessment: provided acreage data for marine wetlands in Florida and reviewed various techniques in their national data synthesis program.

6. Millicent Quaman, USFWS National Research Center: requested a presentation on the MRGIS database for Tampa Bay at the final USFWS Tampa Bay workshop.

7. Jono Miller, ECOSWIFT of Sarasota County: produce slides of TM data for Sarasota County for educational distribution.

8. Bob Bini's Volusia County Planning and Zoning Department: review performance standards for urban development in critical areas and participate on a steering committee.

9. Anitra Thorhaug, FAO/United Nations Food and Agriculture Organization: presented the MRGIS to a Phillipine group on the first International Coastal Zone Rehabilitation Study tour.

10. Bob Rogers, Department of Interior Minerals Management Service: presentation on trends in distribution of seagrass on the west Florida shelf.

11. George Spinner, citizen: information on value of mangroves.

12. Mara Heesch, Levy County Building and Zoning: estuarine resource information.

13. Dean Jackman, DER: wetland loss information.

14. Bruce Ford, NEFRPC: information on habitats of northeast Florida.

Table 1 - Cont.

15. Janet Fontenot, USF graduate student: information on habitats of Charlotte Harbor.

16. Klaus Meyer-Arendt, Ft. Myers Beach: mapping information for the lower Charlotte Harbor region.

17. FDNR Submerged Lands: presentation on the MRGIS at the Annual Submerged Lands Management Conference.

18. James Thomas, NOAA Estuarine Programs Office: participated in an estuarine remote sensing seminar and workshop.

19. Bill Harding, The Conservancy: assistance on habitats and resources of the Charlotte Harbor and Naples area.

20. Dave Bartlett, NASA Langley Research Center: information on cost analyses for MRGIS mapping.

21. George Ray, University of Florida: support for updating mosquito impoundment information on the Indian River Lagoon.

22. Max Miller, Eart Satellite Corporation: raw data for a Florida TM photographic image series of Florida.

23. Bob Ernest, Applied Biology, Inc.: imagery for the Loxahatchee area.

24. Jan Platt, House of Represenatives/Agency on Bay Management: presentation on Bay Day for the Tampa Bay Region.

25. Wade Stephen, Tampa Tribune: imagery for the Tampa Bay area.

26. Ray Judah, Lee County Division of Planning: briefing on MRGIS and technique to the Environmental staff.

27. James Ward, House of Representatives: information on the Destin area.

28. Presentation at the Conference on Florida's Coastal Future.

29. Don Morrow, Trust for Public Lands: imagery on the Nassau/St. Mary's River area.

30. Douglas Baughman, South Carolina SeaGrant Consortium: information on the MRGIS.

31. Kathy Hasty, Governor's office: participate on a geographic information distribution committee to set standards within the state.

Table 1 - Cont.

32. Carroll Curtis, NOAA National Marine Pollution Program: present a paper on updates of NWI maps using TM data at Coastal Zone 87.

33. Lonnie Ryder, DNR Beaches and Shores: demonstrate MRGIS for applications in resource planning along the beaches.

34. Bob Evans, Florida Chapter of the American Society of Photogrammetry and Remove Sensing: presentation on the MRGIS.

35. Various reporters of the St. Petersburg Times, Tampa Tribune, Orlando Sentinel, The Post, Tallahssee Democrat, Herald Tribune, Florida Today, Bradenton Herald, Miami Herald, Daytona News Journal, and CNN News: supplying data from analysis.

Table 2. List of species captured during August and September, 1986

FISH

Lagodon rhomboides (pinfish)
Archosargus probatocephalus (sheepshead)
Syngnathus louisianae (chain pipefish)
Syngnathus scovelli (gulf pipefish)
Hippocampus zosterae (dwarf seahorse)
Gobiosoma robustum (code goby)
Microgobius gulosus (clown goby)
Chasmodes saburrae (Florida blenny)
Opsanus beta (gulf toadfish)
Anchoa mitchilli (bay anchovy)
Menidia beryllina (inland silverside)
Eucinostumus sp. (mojorra)
Diapterus auratus (Irish pompano)
Chilomycterus schoepfi (striped burrfish)
Cynoscion nebulosus (spotted seatrout)
Sciaenops ocellatus (red drum)
Bairdiella chrysura (silver perch)
Achirus lineatus (lined sole)
Paralichthys albigutta (gulf flounder)
Symphurus plagiusa (blackcheek tonguefish)
Oligoplites saurus (leather jacket)
Floridicthys carpio (goldspotted killifish)
Lucania parva (rainwater killifish)
Cyprinodon variegatus (sheepshead minnow)
Gobiesox strumosus (skilletfish)
Prionotus scitulus (leopard searobin)
Chaetodipterus faber (Atlantic spadefish)

INVERTEBRATES

Penaeus aztecus (penaeid shrimp)
Palaemonetes sp. (grass shrimp)
Alpheidae (snapping shrimp)
Xanthidae (mud crab)
Majidae (spider crab)
Callinectes sapidus (blue crab)
Stenorhynchus sp. (arrow crab)

Table 3. Average density and biomass of fish captured in the inner, mid, and outer bay sections of Cockroach Bay.

	Inner	Mid	Outer
Average Density ($fish/m^2$)	10.5	5.5	4.6
Average Biomass (g/m^2)	12.44	8.37	11.62

Table 4. Average density and biomass of fish captured in three different species of seagrass.

	Thalassia	*Syringodium*	*Halodule*
Average Density ($fish/m^2$)	6.0	5.2	9.3
Average Biomass (g/m^2)	11.60	3.56	11.12

Table 5. Average density of fish and macroinvertebrates captured in the inner, mid, and outer bay sections of Cockroach Bay.

	Inner	Mid	Outer
Average Density ($fish/m^2$)	78.5	31.3	25.5
Average Biomass (g/m^2)	27.29	14.83	20.03

Table 6. Average density and biomass of fish and macroinvertebrates captured in three different species of seagrass.

	Thalassia	*Syringdoium*	*Halodule*
Average Density ($fish/m^2$)	51.3	27.6	36.7
Average Biomass (g/m^2)	23.74	9.74	17.48

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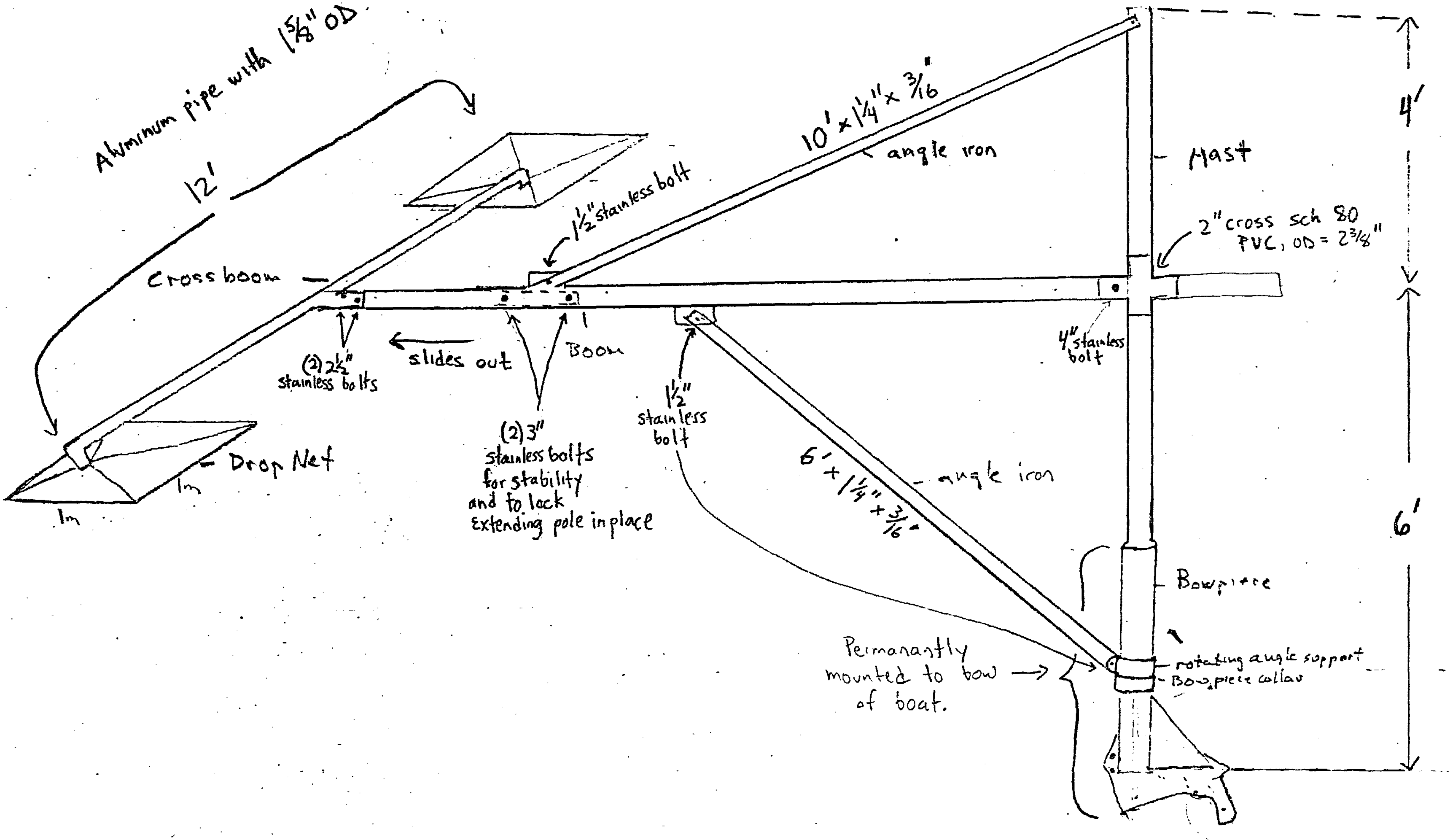


Figure 1. Boom and drop net assembly.

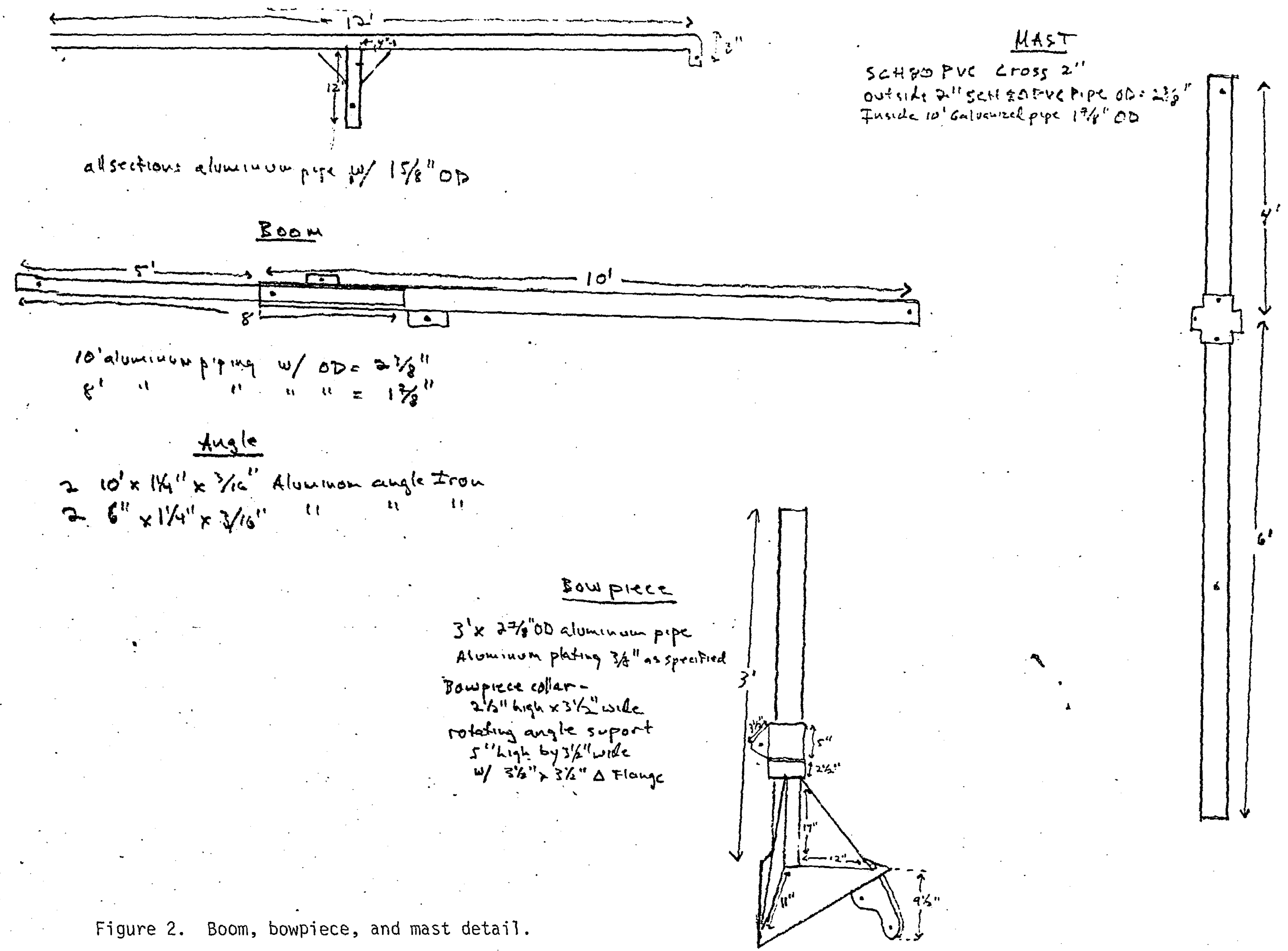


Figure 2. Boom, bowpiece, and mast detail.

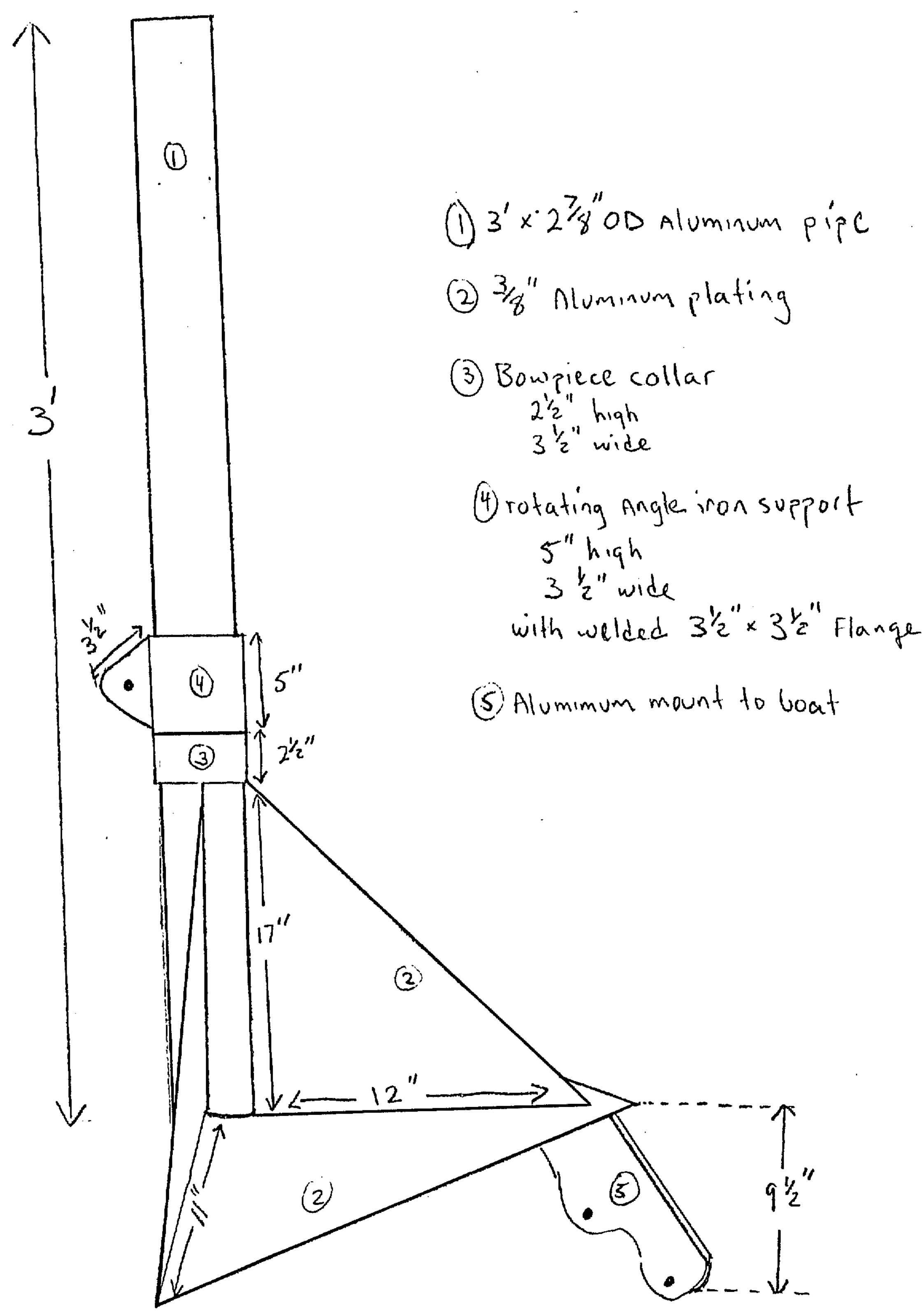


Figure 3. Bowpiece detail.

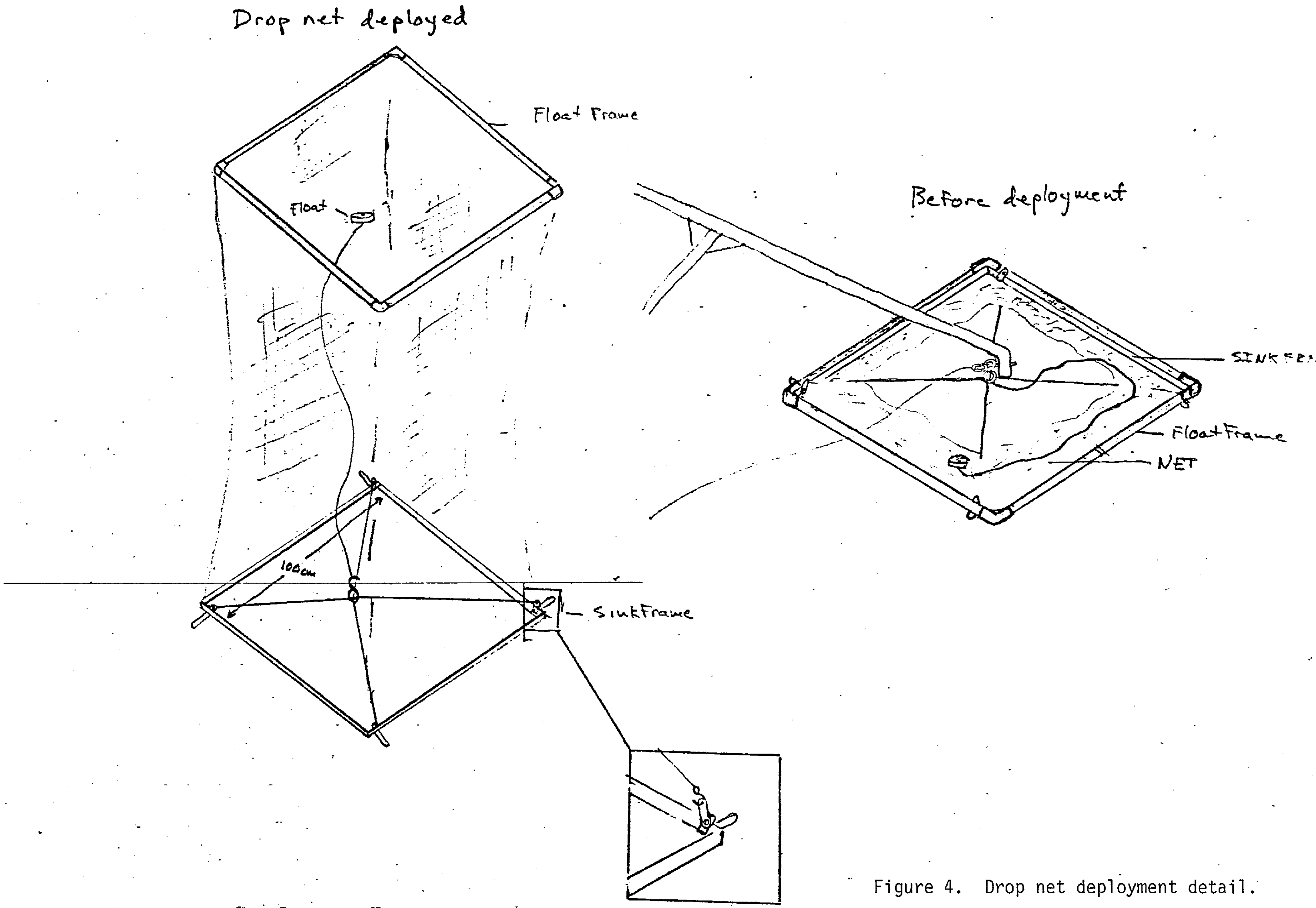


Figure 4. Drop net deployment detail.

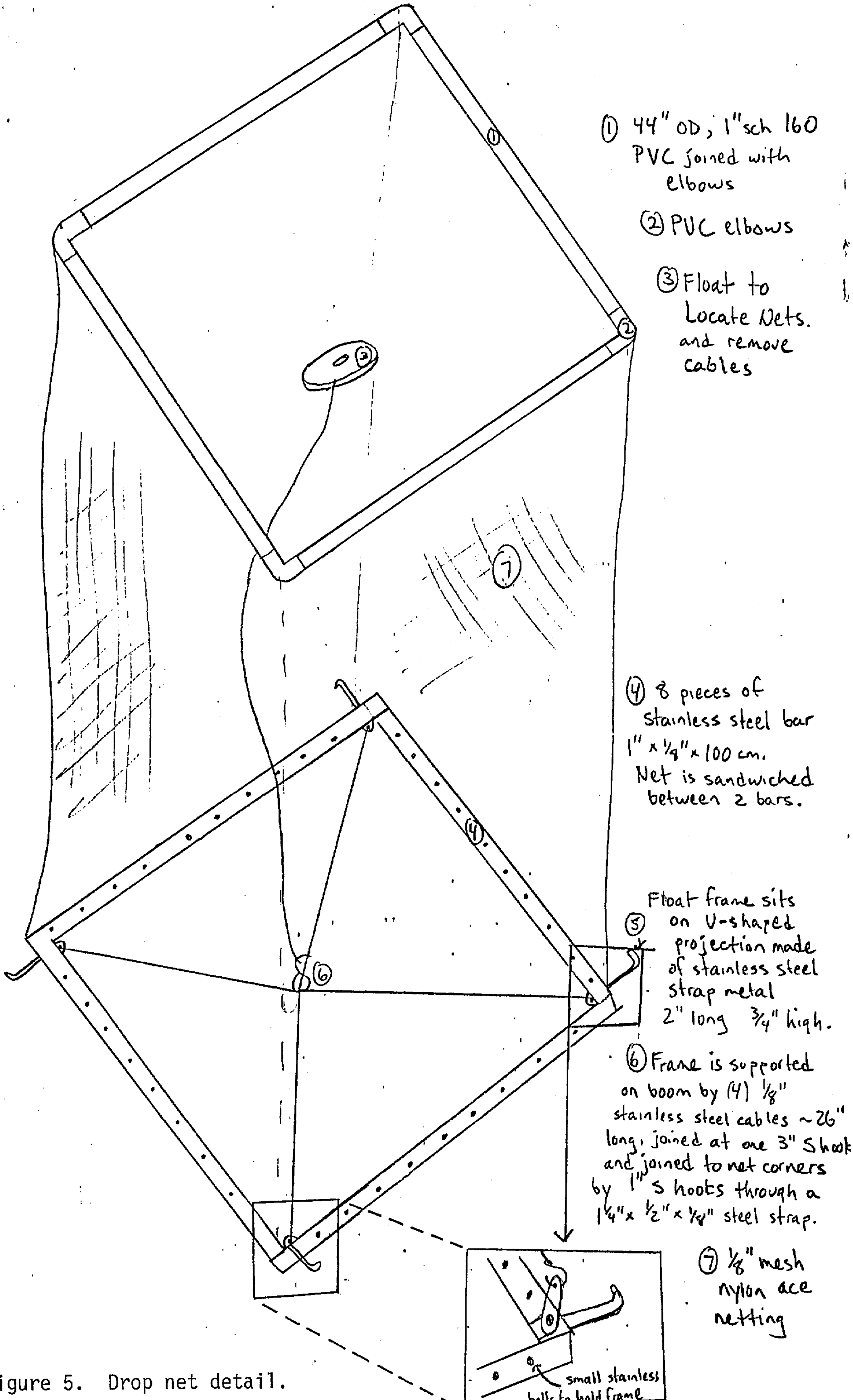


Figure 5. Drop net detail.

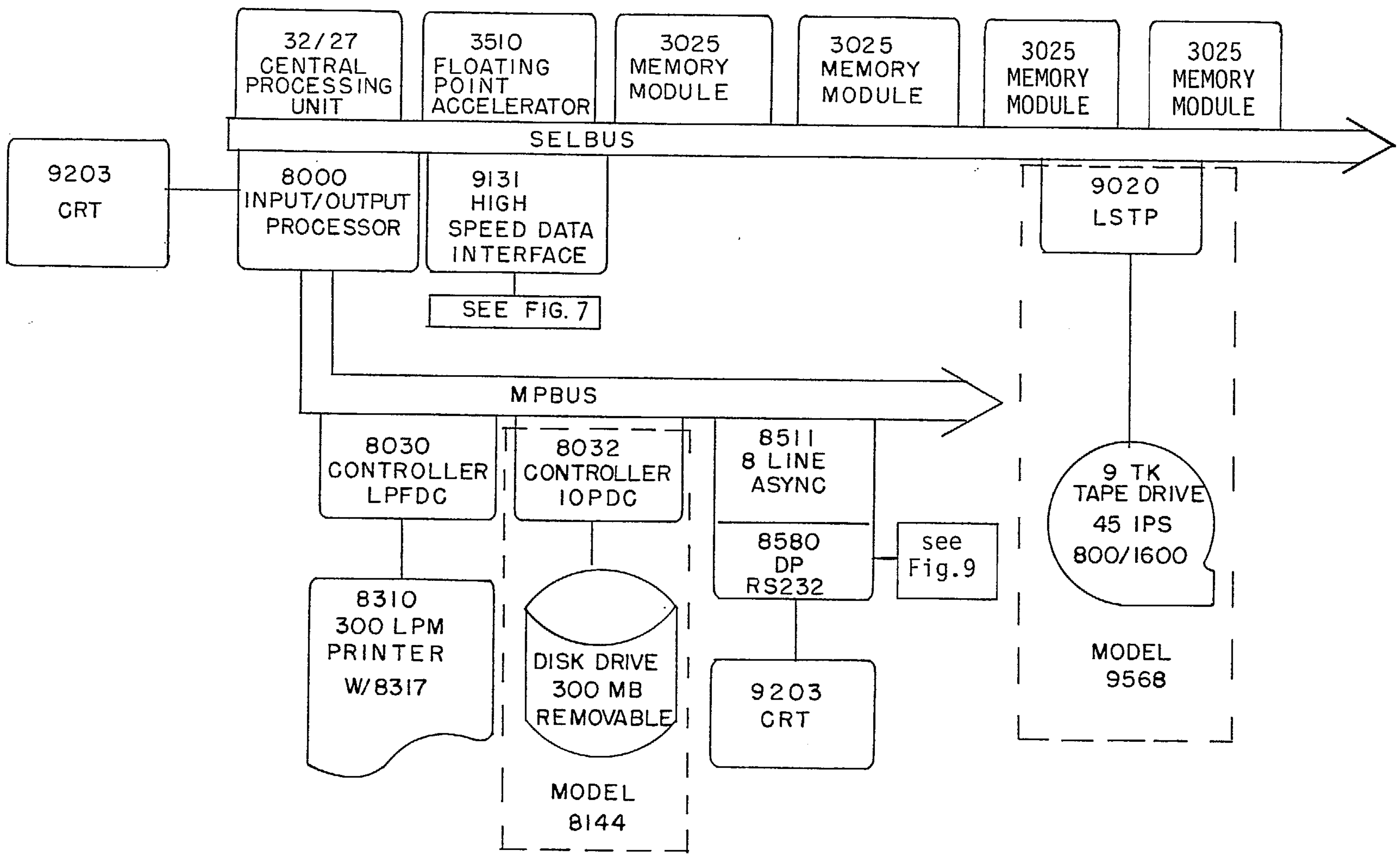


Figure 6. MRGIS mainframe and peripheral hardware.

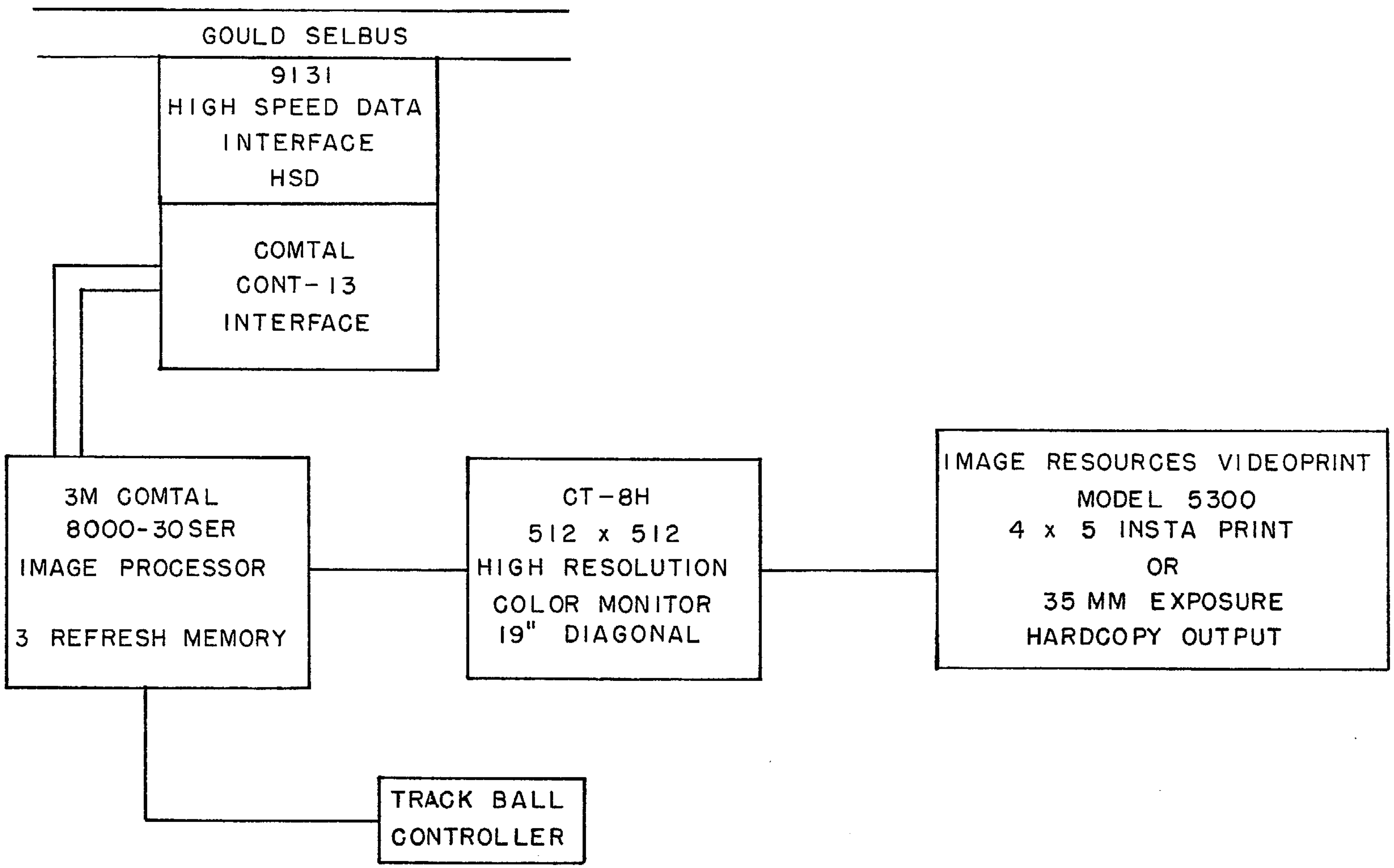


Figure 7. MRGIS graphics hardware.

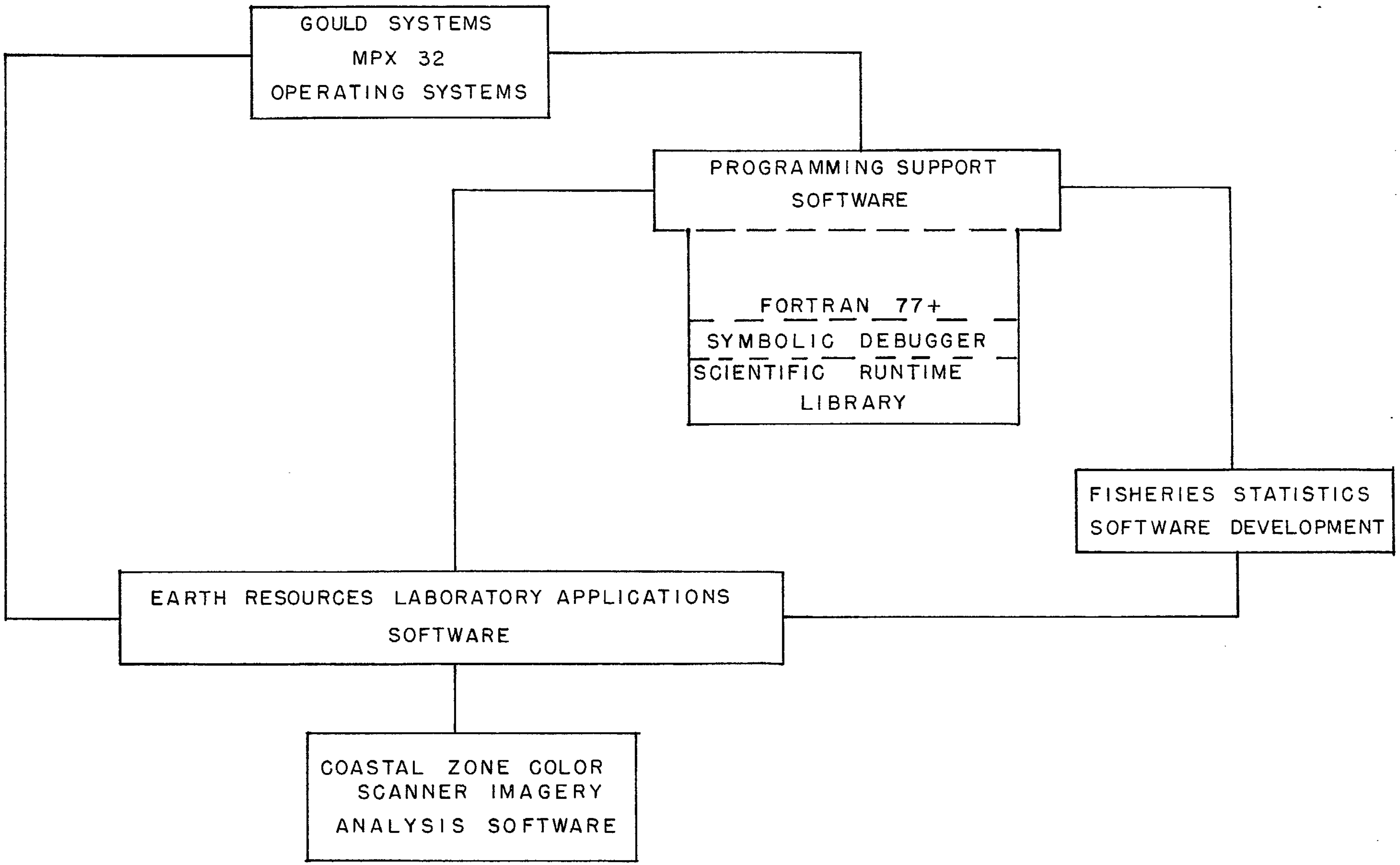


Figure 8. MRGIS software configuration.

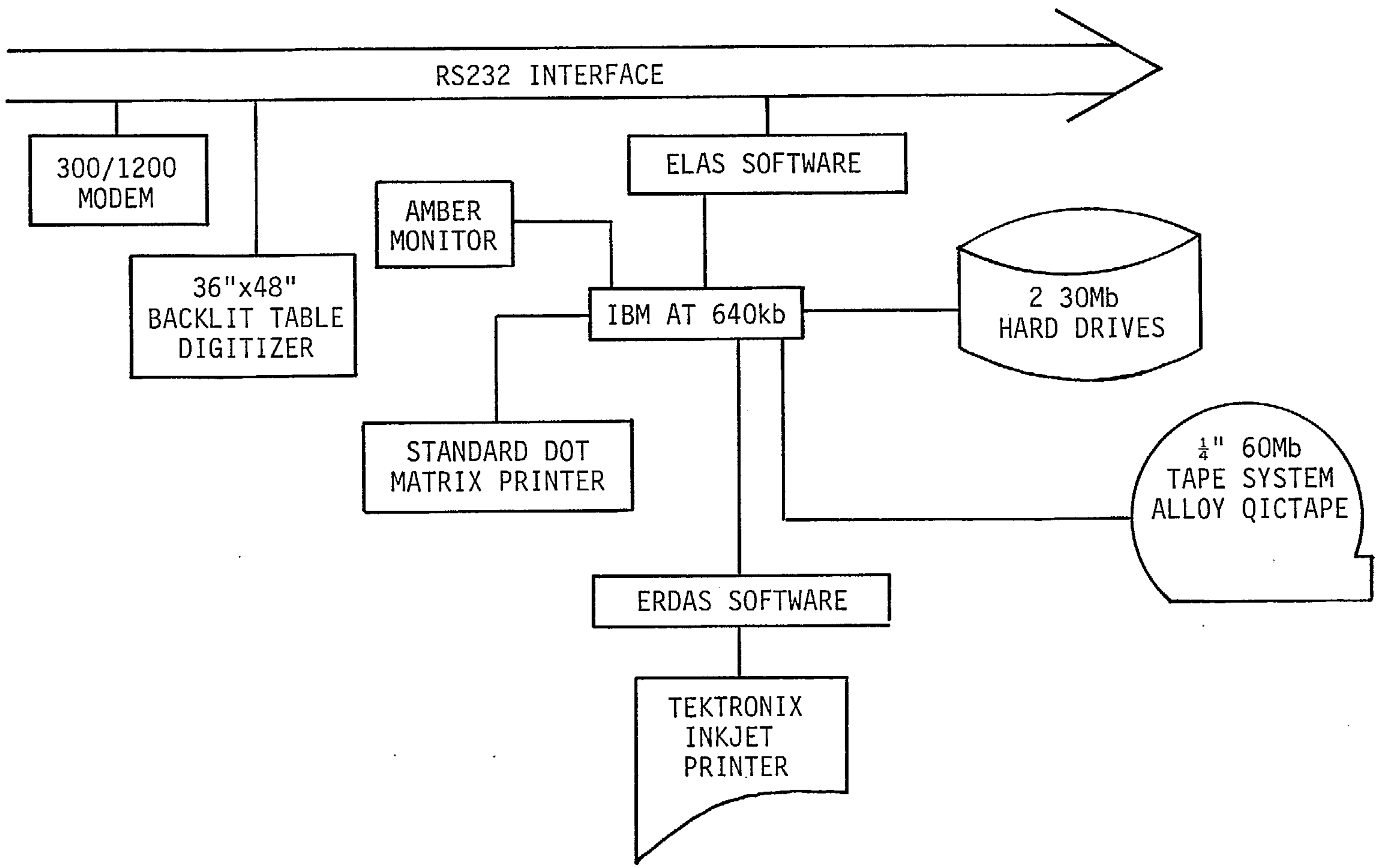
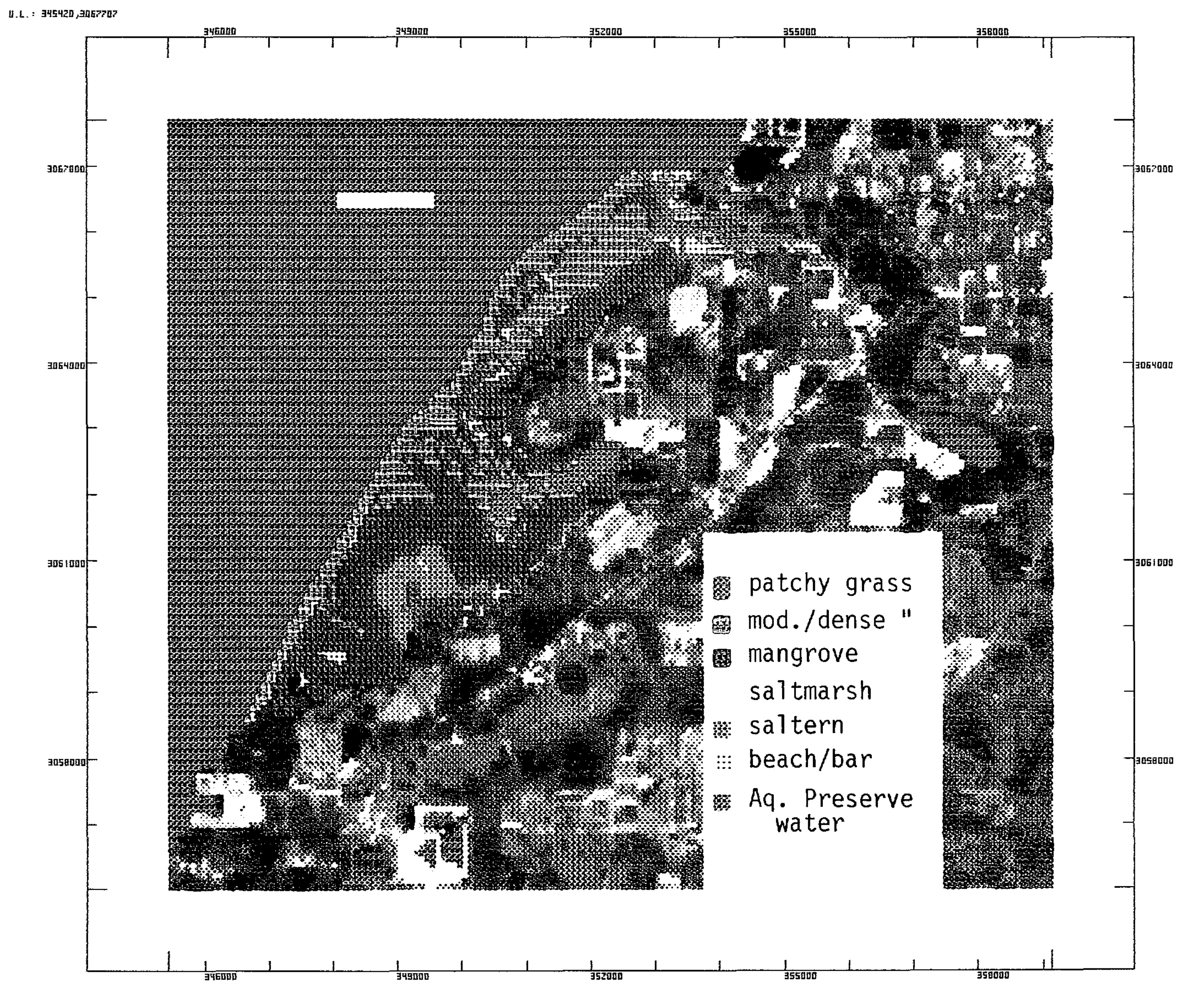


Figure 9. RS232 Interface extension and IBM-AT data transfer system.

MAP 1

This image depicts Cockraoch Bay in Tampa, Florida. The scale of the image is 1:100,000 or 1 inch = 8,333 feet. The legend depicts the vegetation of Cockroach Bay Aquatic Preserve. Those colors not in the legend are outside the Preserve and represent a false color infrared composite of the raw LANDSAT data. The deep blue is water and the reds are vegetation outside the Preserve. The upland light/white colors are barren, urban, or cleared areas. The gridded border of the image is in the Universal Transmercator standard earth reference system coordinates. The resources described in the legend are from data trasnferred from the U.S. Fish and Wildlife Research Center onto the MRGIS. These data and the ability to exchange rastor and vector map data conclude a cooperative project to map the Tampa Bay area and transfer the data to the MRGIS. Data overlay techniques were developed to directly overlay LANDSAT data into a photographically mapped wetlands database. This technique will allow updating of the Tampa Bay database with LANDSAT TM data.



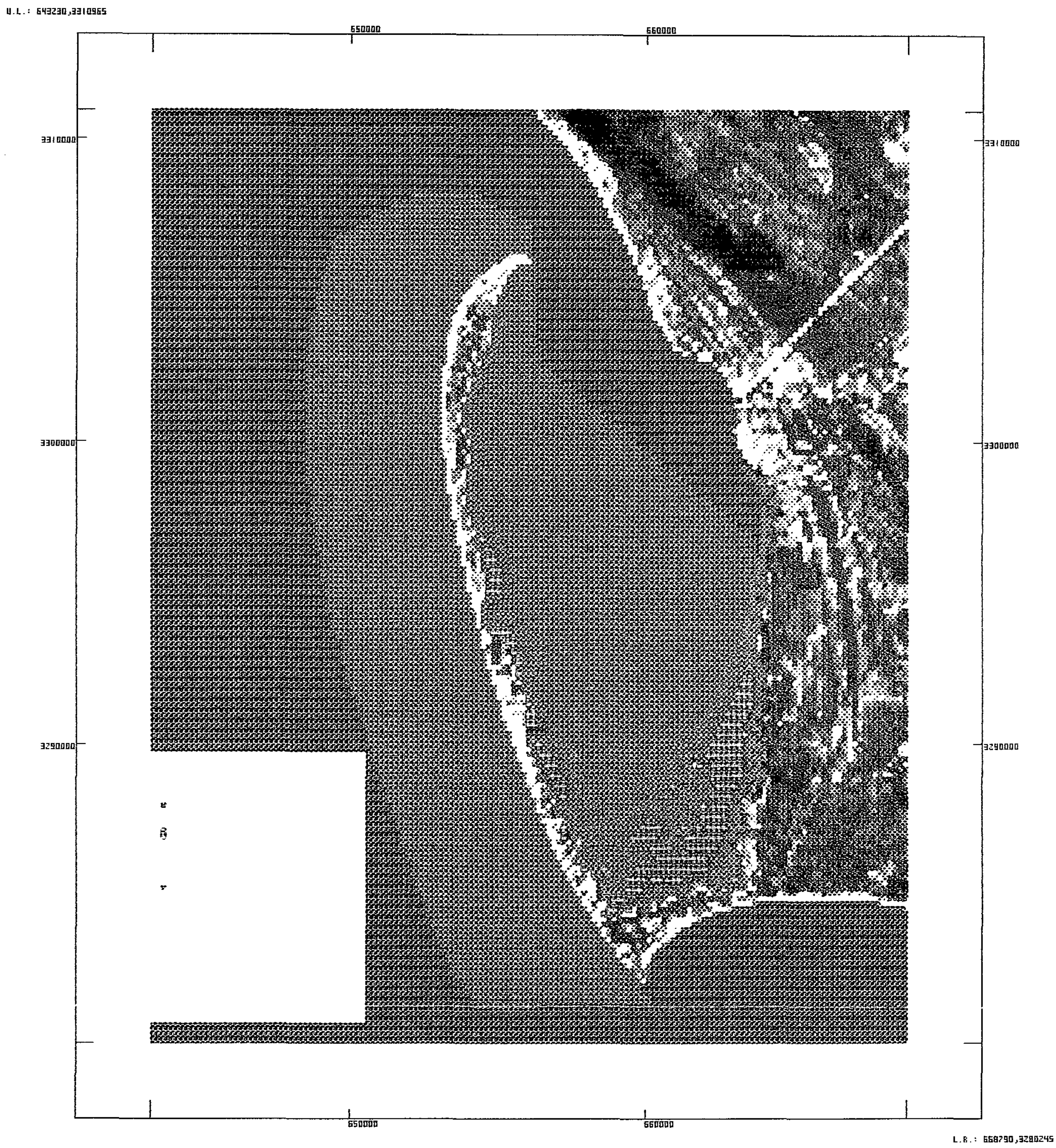
COCKROACH BAY AQUATIC PRESERVE

scale 1:100000 (1"=8333')

Map 1

MAP 2

This image depicts St. Joe Bay in the Florida panhandle. The scale of the image is 1:200,000 or 1 inch=3.15 miles. The legend depicts the vegetation of the St. Joe Bay Aquatic Preserve. Those colors not in the legend are outside the Preserve. The shades of blue adjacent to the Preserve seagrasses are extensions of the grass beds. The very light blue and white in the estuary are shaloow, non-vegetated sites and beach areas. The reds are vegetation and the browns are wetlands outside the Preserve. The upland light/white colors are barren, urban, or cleared areas. The gridded border of the image are the Universal Transmercator standard earth reference system coordinates. See Map 3 for an explanation describing different map scales with the inkjet printer.



The variable name is : ST. JOE BAY (1;200,000)

CLASS NAME

MODERATE/DENSE SEAGRASS

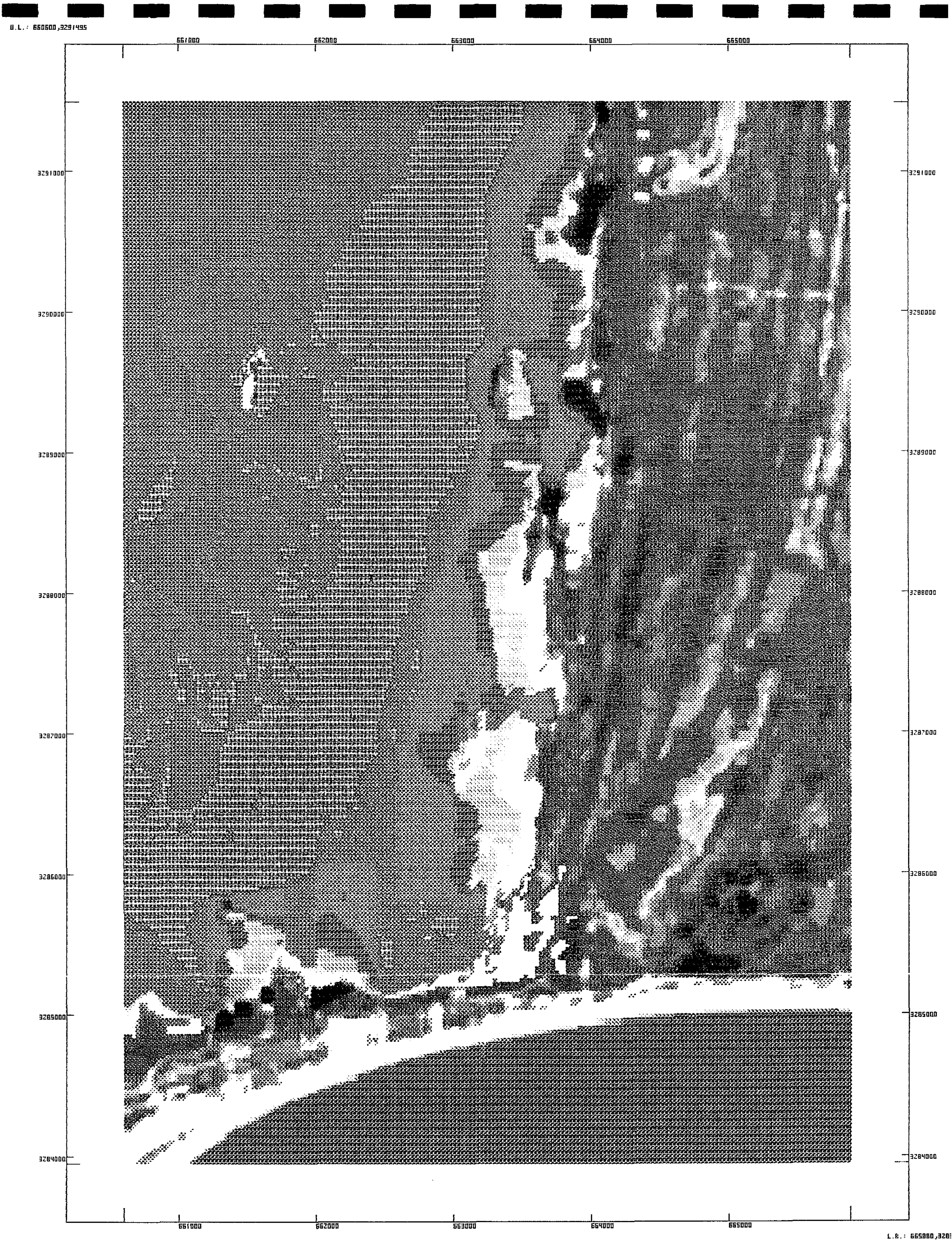
PATCHY SEAGRASS

MARSH

AQUATIC PRESERVE OPEN WATER

MAP 3

This image represents a small subset of the St. Joe Bay area in the Florida panhandle (see Map 2, lower right corner). The scale of the image is 1:33,000 or 1 inch = 2,750 feet. The legend depicts the vegetation of the St. Joe Bay Aquatic Preserve. Those colors not in the legend are outside the Preserve. The shades of blue adjacent to the Preserve seagrasses are extensions of the grass beds. The very light blue and white in the estuary are shallow, non-vegetated sites and beach areas. The reds are vegetation and the browns are wetlands outside the Preserve. The upland light/white colors are barren, urban, or cleared areas. If compared to Map 2 the ability to work with different scales on the inkjet printer becomes apparent. In order to display all of the data on the paper, a minimum scale of 1:33,500 is required. Thus the image in Map 2 has much of the data removed to display the entire area in a small print. The entire image can be printed in panels at 1:33,000 then reconstructed into a large color map at full resolution. The gridded border of the image are the Universal Transmercator standard earth reference system coordinators.



The variable name is : ST. JOE BAY (1:33,000)

CLASS NAME

MODERATE/DENSE SEAGRASS

Trends in Seagrass Distribution on the West Florida Shelf

Abstract for a presentation at the Minerals Management Service Seventh Annual Gulf of Mexico Information Transfer Meeting

Kenneth D. Haddad

Marshes, mangroves, and seagrasses are crucial components of fisheries habitat along the Florida west coast. These habitats may serve as nursery grounds, protective structure, and food sources for many marine organisms. Therefore, quantifying habitat distribution and alteration and documenting the dependency of fisheries on habitat may provide managers with a tool to predict future fishing stocks.

With support from the NOAA Office of Ocean and Coastal Resource Management through the Florida Department of Environmental Regulation, the Florida Department of Natural Resources Bureau of Marine Research implemented a fisheries habitat assessment program. A Marine Resources Geographic Information Systems (MRGIS) was developed which houses a geographically referenced database of fisheries habitat information. The project also includes 1) a sampling program to quantify faunal abundance and diversity within habitat, 2) stable isotope analyses of associated plants and animals to establish habitat dependency, and 3) an assessment of growth and mortality of juvenile fish.

Initially, the project focused on developing techniques for habitat mapping and monitoring. The extent of Florida's coastal zone (2172 km) precluded standard cartographic approaches. Digital LANDSAT Thematic Mapper (TM) data were selected as the optimal base for a statewide assessment effort. Analyses early in the program determined that TM data generally were not sufficient to delineate seagrasses consistently. Aerial photography were photointerpreted for seagrass and digitized into the TM database. Mapping seagrasses of the west Florida coast is currently underway. Recent mapping efforts by various Federal agencies also will be incorporated into the MRGIS database.

Analyses comparing historical with recent data were conducted on selected areas along the west Florida coast to determine trends in seagrass distribution. Initial findings suggested that distribution changed notably in many bay systems since the 1940's. Areas of decline included Charlotte Harbor (29%), Tampa Bay (44%), Bayport (13%), western Choctawhatchee Bay (30%), and eastern Perdido Bay (45%). Big Lagoon (west of Pensacola) increased (55%).

Seagrass declines pose a significant management problem because the factors causing the declines, in many areas, are unknown. Loss has generally occurred in deeper waters suggesting that decreased water quality and light penetration have influenced seagrass distribution. Nutrient enrichment, which promotes phytoplankton growth, and resuspended fine organics and clays may explain reduced water clarity, but its effect on seagrass growth has not been documented. Research is necessary to determine if changes in water quality and light penetration affect seagrass distribution and to identify other possible causative factors. Although this should be a research priority, all facets of seagrass research remain inadequately funded. Seagrass beds are a dominant habitat on the west Florida shelf and certainly contribute to the success of the fisheries. Funding for research to develop the information required for adequate management has not been commensurate with the economic and environmental value of the resource. Federal and State resource managers should address this issue.

Kenneth Haddad is a Biological Scientist with the Florida Department of Natural Resources Bureau of Marine Research. His research has involved the development of applications in remote sensing to coastal and ocean resource assessment. This has included the development of a remote sensing facility at the Bureau of Marine Research.

THE ROLE OF GEOGRAPHIC INFORMATION SYSTEMS IN MANAGING FLORIDA'S COASTAL WETLAND RESOURCES

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Florida is one of the fastest growing states in the nation and this trend is expected to continue into the twenty-first century. The impact of this growth on our wetland ecosystems is difficult to assess and monitor. To deal with these complex issues, coastal resource managers require rapid access to a comprehensive coastal resource database from which they can extract and synthesize pertinent data. A program has been initiated at the Florida Department of Natural Resources (FDNR), with funding through the Florida Department of Environmental Regulation and the NOAA Office of Ocean and Coastal Management, to develop a coastal wetland resources spatial database and incorporate these data into a Geographic Information System (GIS). A GIS may be defined as a computer system or network which has as its primary function the maintenance and analysis of geographical (spatial) data.

The initial phase of the FDNR program has been to institute a Marine Resources Geographic Information System (MRGIS) and develop techniques in remote sensing and image analysis for mapping and monitoring marine wetlands (see Haddad and Harris, Coastal Zone 85). LANDSAT satellite Thematic Mapper data are the primary source for the land cover/wetland mapping and the geographic reference system (in Universal Transverse Mercator units) into which ancillary data are added. The ability to enter ancillary data (such as bathymetry, sediment and soil types, jurisdictional boundaries, etc.) is the feature that gives the GIS such value as a tool in resource management. A GIS is designed to work with numerous geographically co-referenced layers of data to answer queries from the database user. For example, to consider the state regulatory criteria for developing marina sites, the GIS could be queried to display all locations that are not in an Aquatic Preserve, are not adjacent to environmentally sensitive land, are within 600 yards of a secondary road, and are within 50 yards of water depths greater than 4 feet. The system would display these areas for further analysis and assessment.

In addition to the mainframe MRGIS capabilities for data storage and manipulation, microcomputers with GIS capabilities are being installed at selected regional and local planning levels. Data are downloaded onto data cartridges and sent to the microcomputer facility for map display, local planning use, and data upgrading. This strategy for data dissemination will bring rapid access of large volumes of geographic data to the manager. The system is designed for a desktop, user-friendly approach, with a color map-oriented display for resource managers to effectively utilize the best available data in their resource planning and decision making. FDNR also is developing a link between geographically oriented and tabular data (such as fisheries statistics, boat license registration, and permits) to further provide easily interpretable and rapidly accessible computer data to state, regional, and local resource managers and planners.

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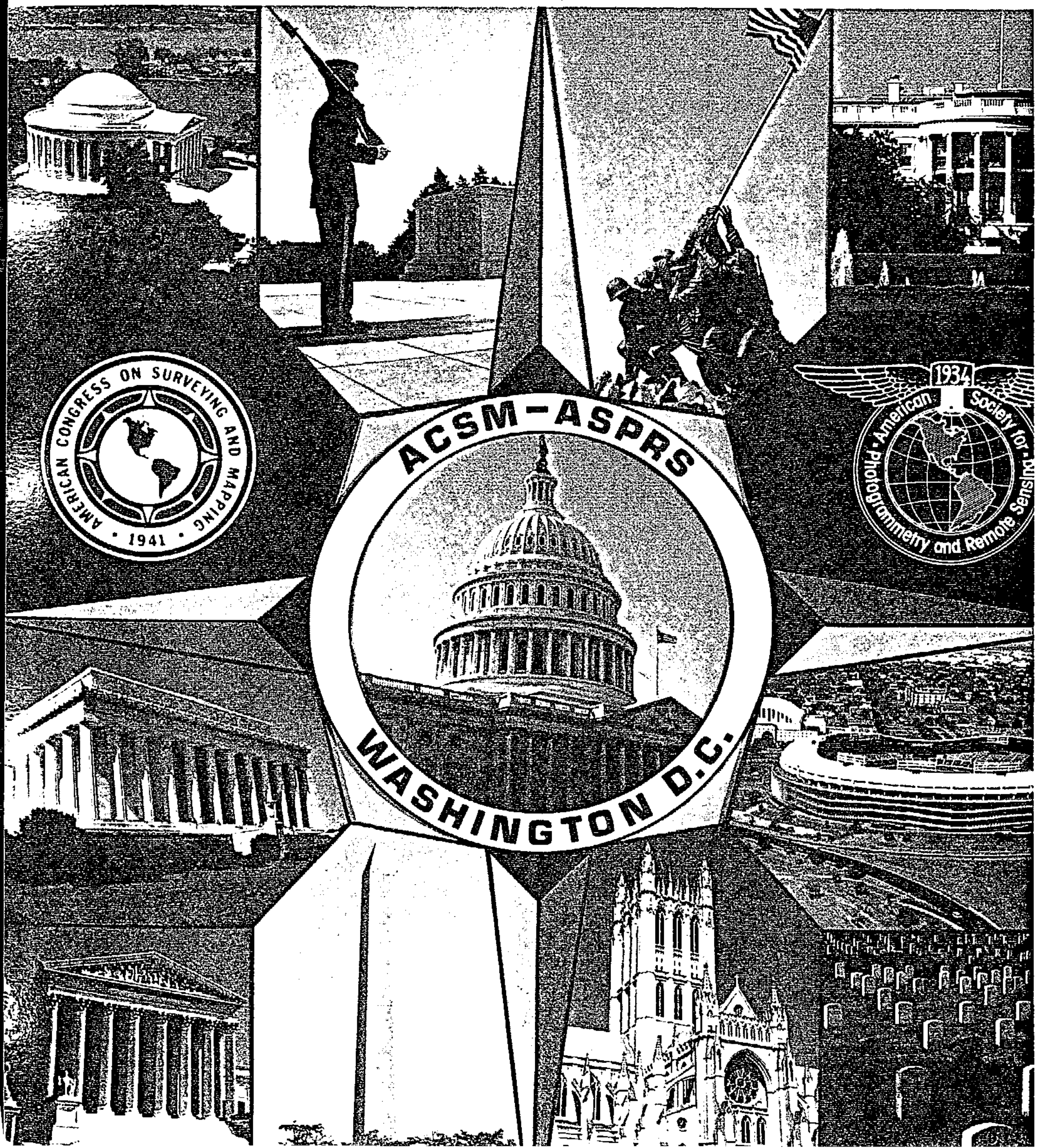

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A FLORIDA GIS FOR ESTUARINE MANAGEMENT

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ABSTRACT

A Marine Resource Geobased Information System was developed within the Florida Department of Natural Resources as a tool for research and management of estuarine and coastal environments. The prime data layer is from LANDSAT thematic mapper data in a UTM map coordinate system. An initial habitat inventory and historical habitat analysis are providing needed information to state, regional and local government and to the public. The concept of ancillary data overlays and GIS manipulations is being applied to the estuarine environment. The initial development of the rastor-based MRGIS has been successful. Full realization of its capabilities will require a long term commitment to the development and enhancement of the data base.

INTRODUCTION

Over 100 species of finfishes, shrimp, and crabs are harvested commercially and recreationally from state or Federal waters off the Florida coast. In 1983, this represented 178 million pounds of commercial fisheries worth a dockside value of $166 million (U.S. Dept. Commerce, 1983). Commercially, Florida's fishery is the sixth largest in the United States and contributes greatly to the State economy. Recreationally, over 30% of Florida's tourists come to fish and generate over $105 million in state revenue. Resident anglers additionally provide over $43.3 million to Florida's tax base (Bell et al., 1982).

Fisheries are a renewable, but vulnerable, resource. Over 70% of Florida's fisheries species of commercial and recreational importance depend on estuaries during some portion, if not all, of their lives. Submerged seagrasses and emergent marshlands provide shelter for young, growing marine animals. These vegetational components indirectly supply abundant food through production of detritus and support a diverse group of non-fishery organisms. These estuarine communities form a complex food web, supported by the vegetation. Without estuarine vegetation, much of Florida's fisheries simply would not exist.

Commercial fisheries statistics for several Florida counties show declines in the amount of fish caught over a 30-year period from 1953 to 1983 for some estuarine-dependent species. These declines usually were associated with estuaries surrounded by highly-developed or developing counties. Tampa Bay, for example, is encircled by two of the most populated counties of the State. From 1950 to 1980, Tampa Bay's surrounding population increased by 243% (Census Bureau, 1982). With this population boom came industry, sewage effluent, massive dredge and fill projects, mosquito control and many more occurrences associated with population growth. Hence,

Tampa Bay lost 44% of its emergent marshland and 81% of its submerged seagrasses (Lewis et al., 1979; Lewis and Phillips, 1982). This vegetation loss and associated problems of low oxygen conditions, poor water quality, noxious algal blooms, and coastal storm erosion affected the survival and availability of desirable fisheries species.

Before growth management was considered important, and natural wetlands were recognized as valuable to a healthy environment, Florida's population exploded. From 1950-1960, population growth was faster than that of any other state. Today Florida hosts the eighth largest population which is projected to double by the year 2010. Five thousand people move to Florida each week and 80% choose coastal counties.

The Florida Department of Natural Resources (FDNR) Bureau of Marine Research recognized the problems that Florida's growth is having on its marine environment and began, in 1982, a project to assess existing estuarine resources of the entire state. In order to generate a map database for Florida's 2,172 linear kilometers of coastline, a remote sensing/Geobased Information System (GIS) approach was instituted.

GIS DEVELOPMENT

Management of Florida's estuarine and nearshore coast required considerable forethought in planning for the development of a pilot GIS. It was obvious that a major type of data to be utilized in the GIS would be digital rastor data from airborne and space platforms and that the ability for image analysis would be a main consideration in system development. NASA, working cooperatively with the State of Florida, demonstrated the potential of the NASA Earth Resources Laboratory ELAS software as a GIS. ELAS is a modular FORTRAN overlay package which is relatively machine independent (Junkin et al., 1981). ELAS may be categorized as a rastor-based information system as described by Marble and Peuquet (1983). ELAS currently does not have the ability to access tabular data, and the ability to manipulate and sort layered data is not based on a "user friendly approach". The exceptional flexibility of the software package, however, makes it an extremely powerful image processing/GIS tool.

A pilot program to develop a Marine Resource Geobased Information System (MRGIS) was initiated within the FDNR and funded by the NOAA Office of Ocean and Coastal Management through the Florida Department of Environmental Regulation. The dedicated purposes of the MRGIS are to (1) develop an initial data base of the extent and location of marine fisheries habitat within the State, (2) look at trends in habitat change, (3) integrate ancillary data from a variety of sources, and (4) demonstrate the potential and effectiveness of an image processing rastor-based GIS for research, management, and education. The MRGIS is a stand-alone minicomputer system operating ELAS as the primary applications software. Several conceptual and successful operational aspects of the MRGIS can provide a basis for GIS development.

1. Stand alone system: Image and GIS processing requires intense computational time. A multi-use system eliminates the interactive potential necessary for operation. The GIS is user-time-intensive and is a

prerequisite for effective operation.

2. Regionalization: The concept of a centralized single system meeting the needs of a state is a questionable approach, again, primarily due to the massive amount of data processing. Regionalization is a viable approach which can be cost-effective and provide greater user access.

3. Dedicated uses: It can be advantageous to categorize systems. For example, the MRGIS concentrates on generating databases on marine resources. This allows for a uniquely specialized approach to developing the needed database for that user community.

4. Data exchange: Perhaps the greatest potential for failure of a decentralized approach is the need for complete compatibility between databases. This ability to exchange GIS data should transcend all but minimal hardware and software requirements and address both vector and rastor data bases. From a statewide perspective, this will be the most difficult issue to address.

Although the above observations are not new, advances in hardware, software, and price structures have given estuarine managers the potential to use GIS capabilities. As GIS capabilities are instituted on state, regional, and local levels, lessons learned from the relatively small group of GIS users throughout the country need to be transmitted effectively to the growing body of potential GIS users.

MRGIS OPERATION

The MRGIS approach was pursued because estuarine management in a state the size of Florida requires the development of a revisable digital database. Since the obvious primary data layer would be land cover information, this requirement guided the approach to generate digital land use data. A standard cartographic approach would include digitizing existing analog maps or acquiring, photo-interpreting, and digitizing new photography. These approaches were discounted, although not totally eliminated, for several, probably universal, reasons.

1. The only commonly formatted analog maps available were those of the National Wetlands Inventory (U.S. Fish and Wildlife Service). These data, although extremely valuable, generally are not available in a digital form and the digitization process alone would transcend the scope of the MRGIS program. In addition, these inventories are now historical data because of Florida's growth. These data may be used as ancillary input into the prime data base.

2. An updated aerial photographic acquisition program with consequent interpretation and digitization does not circumvent the bottleneck of the digitization processes. The associated costs would stifle any attempt at this approach on a statewide basis.

LANDSAT satellite data were considered a viable alternative to standard approaches for primary data base development. In fact, the success of the MRGIS is totally dependent on the transformation of raw LANDSAT data into both a land-cover map and the coordinate reference system for overlays of ancillary geobased data.

LANDSAT Thematic Mapper (TM) data were evaluated for the potential of extracting estuarine wetland and land cover information on a statewide basis, and for the cost of extracting that data relative to standard cartographic techniques. The techniques were approximately 70% more cost-effective and 83% more time-effective on a per hectare basis for large aerial coverage (Haddad and Harris 1985a). In addition, a fully automated approach to TM data extraction was not viable (Haddad and Harris 1985b). The current approach is to use a rapid, biasable, unsupervised classification of the TM data to a level which then requires a skilled interactive and manipulative assessment of the results. The concept behind this approach often is practiced but rarely documented.

1. Due to spectral limitations in TM data, statistical separation of differing land cover types is not always possible.

2. Statistical separation can be enhanced by entering ancillary data (i.e., soils data, bathymetry, etc.) into a multilayer data analysis (Marble and Peuquet, 1983).

3. For final land cover editing, the user, in a highly interactive sense, has the ability to use photointerpretive and ecologically-based cognizance to directly alter and update the digital database. For example, if wet pine flatwoods were statistically undistinguishable from estuarine mangroves, the user, through knowledge of geography, can easily partition them manually. This is the only practical and viable approach to provide high accuracy products acceptable to the resource manager.

4. In some cases, TM data must be enhanced with photointerpretive results of aerial photography (Haddad and Harris 1985a). This was demonstrated in the case of submerged aquatic vegetation where water penetration is dependent on a clear water overflight. These data may be manually digitized directly from a high-quality aerial photo or transferred via normal cartographic methods to a USGS quad sheet for digitization.

Photo data may be merged directly into the TM data which negates the need to attempt data refinement by the more time-consuming statistical methods. Certain scaling factors of the data can increase accuracies for digital input. For example, when digitizing into TM data from 1:24,000 scale photography, acreage computations are much more accurate if the TM data are resampled to 15-meter cell size as opposed to the standard 30-meter cell size. The reasons are obvious and scaling differentials are important.

5. The concept of supplementing TM data with aerial photography was a main consideration in the successful

development of the MRGIS. Besides the obvious data enhancement potential, ease of the process allows rapid and cost-effective data upgrades. Since TM data provide the basic background data base, either as classified data or as a false-color or color-composite, only the features of immediate concern need to be extracted from the aerial photography and digitized into the MRGIS. Without the background TM data, many extraneous features in the aerial photography would have to be extracted to provide (1) a geographic perspective and (2) the estuarine manager with a complete pictorial data display.

Since no GIS-type databases existed for Florida estuaries, the question of whether to use TM data as an ancillary input into a multilayer data set, or to use TM data as the coordinate reference system and enter all other data as ancillary, was not a consideration. It was determined early that TM data could be georeferenced to UTM coordinates with subpixel accuracies. Welch et al. (1985) determined that residual errors for UTM-rectified TM data fall within National Map Accuracy Standards (NMAS) for 1:24,000 scale maps and meet NMAS at 1:50,000 and smaller scales. In fact, in our experience, when entering ancillary map data (various scales) into the TM-based coordinate reference system, errors in geodetic accuracies of local and regional resource information maps become readily apparent.

The development of the MRGIS operations has been an evolutionary process and uses of the MRGIS are evolving with it. The geobased nature of the data is helping to focus research, management, and educational activities on the estuarine environment.

Habitat Analysis

Currently, the major operation of the MRGIS is to develop an initial inventory of marine fisheries habitat within coastal Florida. LANDSAT TM data are being processed to delineate mudflats (where applicable), saltmarsh (to species), mangroves, and seagrasses (submerged aquatic vegetation). Aerial photography is being used for seagrass mapping when water clarity precludes the use of available TM data. This initial comprehensive database will provide the ability to assess changes in these habitat components on a regular basis by using data from existing and future orbital platforms.

The development of this database is coming at an important point in Florida's growth. Legislative mandates require that coordinated growth management plans be developed on state, regional, and local levels. Estuarine wetlands (fisheries habitat) are cited as habitats of special interest and knowledge of the location and aerial extent of these habitat components are required for proper planning and effective management. The Florida Aquatic Preserve Program uses the inventory information to develop management plans and provide information to the public. A multidisciplinary research effort is underway to quantify the association between fisheries habitat and fisheries production. An ultimate goal of this effort is to develop carrying capacities of specific habitats for fishes of commercial and recreational value to Florida. This type of information can then be integrated into fisheries production models and will enhance predictive capabilities useful for regulating

commercial and recreational catch and effort in order to maintain a sustainable yield of specific species.

Historical Analysis

One aspect of the MRGIS program has generated considerable, unexpected interest by managers and the public. In conjunction with the current assessment effort, selected geographic sites are being evaluated for habitat alteration. Aerial photographs from selected time periods (from the 1940's) are photointerpreted and digitized as an overlay directly into the TM database. Both a quantitative and visual presentation of the information from a historical perspective is generated and the resultant knowledge can be used to identify issues requiring management action.

Figure 1 depicts the changes in seagrass vegetation in a portion of Tampa Bay, Florida. As previously discussed, seagrasses often are difficult to extract from TM imagery because of water clarity; this necessitates photointerpretation to develop that aspect of the database. The data in this figure were digitized into a historical overlay representing 1943 and a current overlay representing 1984. The land category for the 1943 overlay is from a 1984 TM image and is presented to provide a geographical reference and to demonstrate the TM-based coordinate reference approach. Seagrass delineation was categorized as dense/moderate, patchy, and sparse, and associated acreages were calculated (Table 1). Significant results of this analysis include (1) a total loss of 53% of seagrass and (2) a significant decline of 82% in the moderate/dense category. This type of information has been, and will be, generated for selected estuarine areas throughout Florida. So far, losses of seagrass have been observed consistently. With the understanding that seagrasses play an extremely important function in Florida's fisheries production, and with pictoral and quantifiable data depicting loss, declines in marine wetlands are being seriously addressed as management issues at both state and local levels.

Figure 2 depicts changes in saltmarsh of St. Augustine Inlet from 1943 and 1984. In this case, the historical data were again digitized into the UTM-referenced TM database as an ancillary data layer. The statistically classified 1984 TM data were then directly analyzed for changes. A 585 ha loss (-20%) of marsh was observed which mostly can be attributed to the placement of an earthen dam across a portion of a tributary observed in the upper right portion of the image. Major habitat alterations have occurred throughout Florida, but present laws are reducing those impacts. This information can be used to develop plans for reestablishing and protecting the natural functions of Florida's estuaries.

Ancillary Data Analysis

Input of photoanalyzed historical data and current TM data provide only the foundation for an estuarine GIS. The input of ancillary databases provides the necessary information to use the GIS as a complete management tool. Unfortunately, no digital databases of important management criteria exist; consequently, a large effort will be required initially (as in all GIS developments) to input these databases.

A data overlay approach is depicted in Figure 3 and differs from

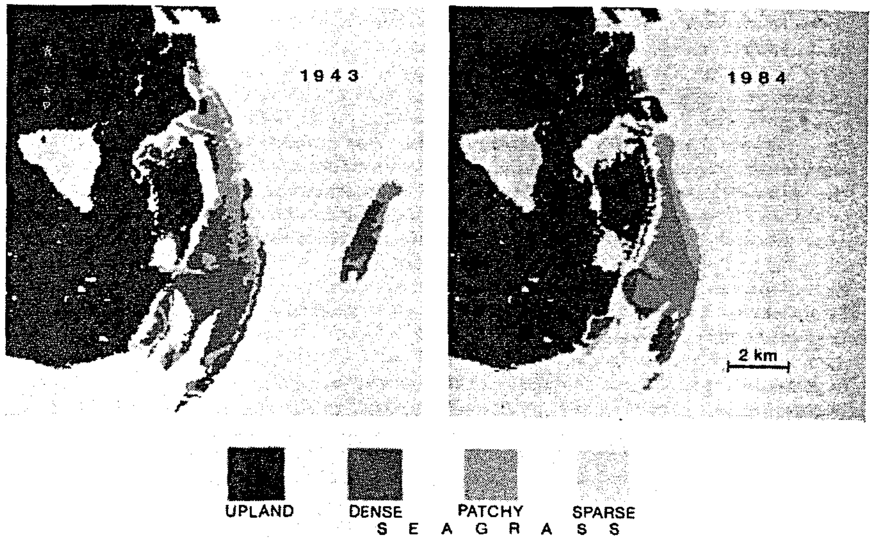

Figure 1. Historical and recent analyses of the Pinellas Point area of Tampa Bay, Florida. Seagrasses (1943 and 1984) were photointerpreted and digitized directly into LANDSAT TM imagery.

Table 1. Results of a historical analysis (Figure 1 above) of a portion of Tampa Bay, Florida.

SEAGRASS	1943	1982	% CHANGE
Dense	428 ha	74 ha	-82
Patchy	203	199	- 2
Sparse	90	67	-25
Total	721	340	-53

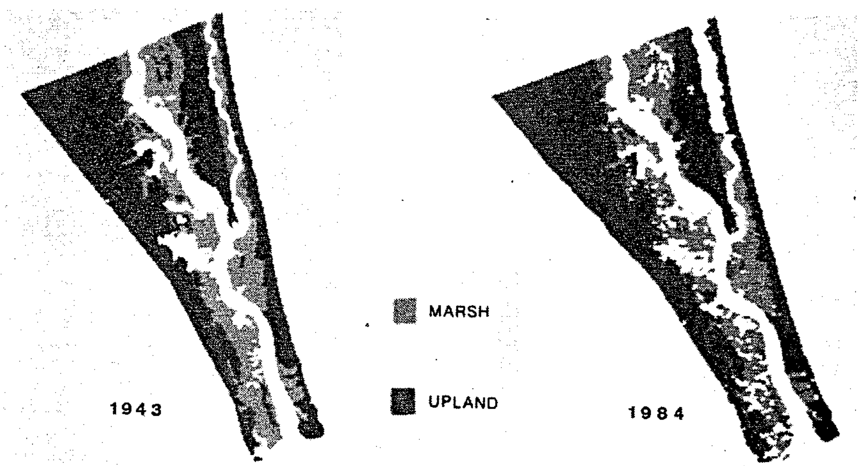

Figure 2. Historical and recent analyses of the St. Augustine, Florida area. The historical image represents a data overlay digitized into the 1984 TM-based UTM-referenced coordinate system.

standard GIS overlays only in the types of parameters being entered. This approach currently is being tested for an Aquatic Preserve in Tampa Bay, Florida. A hypothetical, but practical, management issue might be: the population of snook (a Florida gamefish) has been reduced significantly in southwest Florida. A juvenile stocking evaluation program is underway and it is known that the juvenile snook have the best potential for survival if they are released (1) in isolated depressions (>1.8 m in depth) surrounded by seagrass and mangrove habitat, (2) over organic sediments, and (3) where the average salinity is less than 12 parts per thousand. Where should these releases take place? The conceptual process to answer this and questions like it (Figure 3) is not new by any means. The point to be made is the need for extension of GIS applications into estuarine management practices.

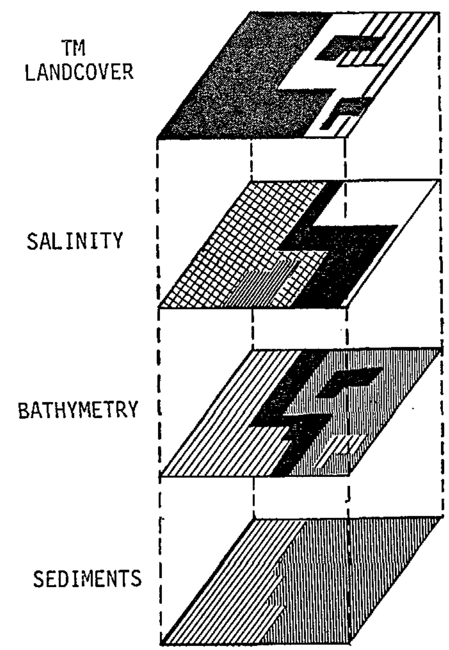

Figure 3. A schematic overlay approach for estuarine management issues. The parameters are numerically unquantified but the overlay concept is apparent. An analysis to determine the best stocking sites for juvenile snook would result in a display of those locations meeting the stocking criteria.

SUMMARY

Rapid growth in Florida and subsequent impacts on its estuarine environment required development of a GIS capability. A Marine Resource Geobased Information System instituted within the Florida Department of Natural Resources is being developed as a useful tool for research, management, and public education. The magnitude of Florida's estuaries stimulated development of the prime database and coordinate reference system from LANDSAT Thematic Mapper data.

Historical analysis of fisheries habitat provided information depicting the previously unquantified loss of seagrass (important to fisheries production) on a statewide basis. This information alone is sufficient to enhance the value of the MRGIS beyond its initial investment.

Some pertinent observations on the operational development of the MRGIS are:

1. Ancillary data required for long-term operations are rarely digital and must be entered through manual or automated digitizing procedures.

2. Rastor GIS data require large mass storage capabilities. One full TM data set for Florida contains 4.2 gigabytes of information. Upcoming technological developments will eliminate this as a logistical problem.

3. Data dessimination from a rastor-based GIS often is based on color and is pictoral in content. Photographic products are not optimal for many uses. Color printers are being improved, but the data layer concept is lost in a flat-plane presentation. Downloading of processed images and ancillary data bases to microbased GISes as a hands-on management tool is currently being tested in a pilot program.

4. Management of natural resources has occurred without the necessary information for effective management. Today, management criteria are not structured to utilize GIS capabilities. As managers are introduced to GIS capabilities and concepts, demands on the capabilities increase.

5. Serious misconceptions can occur in explaining the capabilities of a GIS to potential users. Initial GIS development requires an intensive and committed effort. This is particularly true for estuarine resources where the concept of a GIS approach to management has not been pursued.

The types of information being generated by the MRGIS operations are proving beneficial and, in some cases, the only viable approach for long term management of Florida's estuaries. Its uses will expand as the information base expands - this will remain an ever changing process.

ACKNOWLEDGEMENTS

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USE OF REMOTE SENSING TO ASSESS ESTUARINE HABITATS

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INTRODUCTION

In the early 1900's, Florida was the winter residence for the adventurous who wisely left the state as summer drew near. Though the State offered warmth and comfort during winter months, it became a humid, mosquito-infested swampland during the long, hot summers. Three events occurred near or before 1950 that changed Florida's reputation and future: (1) air conditioning, (2) mosquito control programs, and (3) massive drainage projects that created dry lands suitable for human habitation. Since 1950, Florida's population has literally exploded. Today, approximately 788 people move to Florida each day along with a daily influx of 90,000 tourists (Office of Planning and Budget, personal communication; McGinnis 1983). Rapid development far exceeded planned growth management and, consequently, environmentally unsound development practices were the norm. Because about 75% of Florida's new residents chose coastal counties for their homes, the effects of this growth on coastal and estuarine habitats were amplified. Estuarine dredge and fill practices were rampant. Massive areas of estuarine wetlands were ditched and diked for mosquito control. Upland canals replaced winding rivers and lowlands, expediting the flow of nutrient rich waters (made richer by Florida's extensive livestock and agriculture production) into estuaries. Large amounts of raw sewage and industrial pollutants were released into estuaries. Although laws were enacted to control these effluents, pollutants and treated sewage still affect coastal waters.

Estuaries and lagoons are dominant features in Florida. They are among the most productive ecosystems on Earth and provide food and shelter for a large and diverse group of living resources. This includes over 70% of Florida's marine commercial and recreational finfish and shellfish which depend on the estuary during some part of their life cycle (Harris et al. 1983). Some popular species, such as spotted seatrout, spend their entire life within the estuary. Numerous studies have shown that estuaries are most important for juvenile fishes (Deegan and Day 1984, Miller et al. 1984, Odum 1984, Zimmerman and Minelo 1984, Crowder 1984). Based on this information, estuaries must be maintained for suitable habitation by these species and those that provide for a healthy ecosystem.

The maintenance of estuaries in Florida is not simply an aesthetic or environmental concern; a sound economic concern also exists. Florida's commercial fishermen harvested fish and shellfish

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worth an estimated wholesale value in 1980 of $175 million and, at retail prices, of $1.25 billion. Florida ranks third in the nation in resident anglers (2,127,000) while approximately 1,278,000 tourist anglers annually fish in Florida waters (U.S. Dept. of Interior, 1982). Sport fishermen alone generate a $1.4 billion industry which, when combined with commercial fishing, constitutes an industry worth over $1.6 billion. In comparison, the Florida phosphate mining industry generates $1.2 billion, and cattle production, $311 million. These statistics emphasize the importance of Florida's fishing industry; we must realize the long term importance of fisheries habitats to the State of Florida.

Assessing the relationship between a fishery and an estuary requires detailed knowledge of each life stage of a species and its interaction with the environment for food and cover. Marshes, mangroves and seagrasses play important roles in the estuarine and nearshore environments and are important components of fisheries habitats. These components provide not only food and cover, but detrital matter which ultimately fuels several food webs. The loss of vegetation components of a fisheries habitat has a compounding and long-term effect on the estuary not only by removing food and cover, but also by eliminating their role 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.

Public opinion holds that Florida's fisheries are declining, and commercial landings statistics suggest this trend to be true for some species (for example, spotted seatrout and shrimp; Florida Department of Natural Resources 1951-1983). Many factors can lead to a decline in fish populations (e.g., overfishing, water quality degradation, loss of specific habitat components, natural events) and to single out individual processes causing a decline is very difficult. In many cases, the decline certainly can be man-induced; as Florida's human population increases, pressure on the fisheries and every other resource also increases. Under natural conditions, the percentage of fish eggs hatching and surviving to maturity theoretically is much less than one percent. Man continually reduces that percentage and can even affect spawning regimes and fecundity through selected harvesting pressures or pollution.

REMOTE SENSING

One step in understanding a fishery is to map and quantify the estuarine habitat so crucial to the continued survival of many species. This information can then be used to monitor the habitat over future years to identify areas of degradation. In addition, habitat information eventually will become an important component of fisheries stock assessment and stock predictions.

With support from the NOAA 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, analyze, and integrate satellite data and other digital data with a variety of environmental and socioeconomic data for resource analysis and application modeling. The MRGIS is used primarily as a research and development tool for coastal resource management and for integrating coastal data bases. The system is a research prototype for the State of Florida and is also used to demonstrate regional and statewide applications.

Hardware design was configured to meet the constraints of the Earth Resources Land Applications Software (ELAS), the principal applications software installed on the MRGIS. This software was sponsored and developed by the Earth Resources Laboratory (ERL) of the National Space Technology Laboratories (NSTL) of the National Aeronautics and Space Administration (NASA). ELAS software development began in the early 1970's and was directed towards supervised classification of LANDSAT and aircraft data. Development progressed with the addition of the capability to geographically reference the data to the Universal Transverse Mercator (UTM) grid. Also, the data processing approach was changed from batch to interactive processing. A data base capability was added to allow the storage of numerous parameters, i.e. LANDSAT classifications, soil types, rainfall, elevation, percent slope, slope length, aspect, ownership, oceanographic variables, etc. by a selectable cell size. This permits manipulation of these parameters through selectable application algorithms to produce resource management information. A complete description of ELAS is documented in Junkin et al. (1980).

The initial phases of this program have been to assess and develop techniques using remote sensing and to implement a statewide program to assess and monitor fisheries habitats. The almost insurmountable problem in mapping and monitoring a coastline of over 2,172 km are the time constraint and enormous funding requirement for conventional photogrammetric mapping. For these reasons LANDSAT satellite imagery was chosen as the primary data base in the mapping procedure, supplemented with aerial photography where necessary. Table 1 presents the types and characteristics of the data used. Low altitude photography was not used because of the constraints for large area assessments.

Initial review of both LANDSAT imagery and aerial photography suggested that several structural components of marine fisheries habitat could be accurately mapped. The categories for mapping were:

1. Salt marsh: an intertidal community represented in Florida by the species *Spartina alterniflora* (smooth cordgrass) and *Juncus roemarianus* (black rush). Salt marshes dominate the intertidal zone of Florida's northern coastlines, while mangroves dominate southern intertidal areas. Salt marshes have been linked to high densities and biomass of marine invertebrates, including shrimp (Subrahmanyam et al. 1976, Day et al. 1973, Zimmerman et al. 1984).

Table 1. Characteristics of data types used in fisheries habitat mapping.

Platform/Sensor	Altitude	Resolution	Data	Repeat Coverage
LANDSAT Imagery				
Multispectral Scanner	508-917 km	60m	digital 4 channels	16-18 days
Thematic Mapper	508 km	30m	digital 7 channels	16 days
High Altitude Aerial Photography	3,658- 18,288 km	1-7m	color color-IR transparencies prints	0-10 yrs

2. Mangroves: an intertidal community represented in Florida by the species Rhizophora mangle (red mangrove), Avicennia germinans (black mangrove), and Laguncularia racemosa (white mangrove). Mangroves are well known for their ability to stabilize shorelines and filter water; their significance and contribution to fishery production has been implied.

3. Seagrasses: a shallow subtidal community represented by the species Thalassia testudinum (turtle grass, found only in the southern half of Florida), Syringodium filiforme (manatee grass), Halodule wrightii (shoal grass), three species of Halophila (star grass), and Ruppia maritima (widgeon grass). The presence of a greater diversity and abundance of organisms within grassbeds as compared with adjacent non-vegetated sites is well-documented (see Zieman 1982).

4. Mudflats: an intertidal non-vegetated area represented by several forms of microscopic benthic algae. Diatoms, dinoflagellates, filamentous green algae, and blue-green algae are the primary producers and are observed typically as sediment discoloration. During daylight hours, adjacent seagrasses contain a higher number of fishes, crabs, and shrimp than mudflats (Peterson 1981). Summerson (1980, cf. Peterson 1981), however, found a more even distribution of fish and crabs over mudflats and seagrasses at night.

Since the intent was to use LANDSAT data to map these and other fisheries habitats an initial comparison between LANDSAT and standard photogrammetric analyses was conducted. LANDSAT data was statistically processed using a standard maximum likelihood classifier in ELAS and areal coverage of the habitat components were computed. The smallest mapping unit for both the photo-analyses and LANDSAT analyses was approximately 0.4 hectare (ha). Photographic interpretation was considered the most accurate technique for measuring areal extent of a given fisheries habitat and results of LANDSAT analyses were compared with identical areas photographically assessed (Table 2). This simple approach to comparison is presented

Table 2. Areal comparisons (in hectares, 1 hectare = 2.47 acres) between photoanalysis vs LANDSAT analysis for selected fisheries habitat in Florida.

Habitat Component	Photo-analysis	LANDSAT Analysis	% Difference
Saltmarsh	11057	10541	4.7%
	13914	13164	5.4%
	5130	5677	9.6%
Mangrove	1866	1492	20.0%
	1089	1084	0.4%
	3436	3340	2.7%
Seagrass	523	567	7.6%

[1]National Wetlands Inventory 1984.
[2]Coastal Coordinating Council 1973.
[3]Harris et al. 1983

only as a measure of confidence that the mapping could be conducted on a statewide basis with a reasonable assurance of accuracy using LANDSAT data as the primary data base. LANDSAT TM data was selected over MSS data (see Table 1) as the prime data source for fisheries habitat mapping for some of the following reasons: (1) the potential for error in statistical analysis is decreased because of higher resolution, (2) band one, measuring reflectance in the blue spectral region (.45-.52 μm), provides greater potential for analysis of water characteristics, (3) band 5, measuring reflectance in the infrared spectral region (1.55-1.75 μm) provides a better potential for separation of wetland characteristics, (4) geographical rectification of the TM data to a coordinate system (UTM) is more accurate, (5) the higher data resolution (0.1 ha) is more descriptive pictorally and, consequently, is easily utilized and accepted by the general public and the resource manager. Figure 1 compares data resolution, at identical scale, of an MSS image (Band 2, .6-.7μm) to an identical TM image (Band 3, .63-.69μm) of an area near Melbourne, Florida.

Cost and time comparisons between LANDSAT and photographic analysis are presented in Table 3. Comparisons were based on standard photogrammetric techniques used to fly, photointerpret, and develop a digital data base of Level I land use data (i.e., urban, agriculture, rangeland, forestland, water, etc.) with a Level III classification for marine fisheries habitats (i.e., mangroves, seagrass, salt marsh, mudflat, oyster bars).

Although the exact figures may vary, a 69-72% cost reduction and an 83% time reduction can be realized through using LANDSAT imagery over aerial photography. The real cost saving occurs in the analysis and digitization category. The cost of aerial photographs can be similar to the cost of LANDSAT TM imagery if existing high altitude photographs (i.e. National High Altitude Mapping Program) are used concurrently with the imagery.

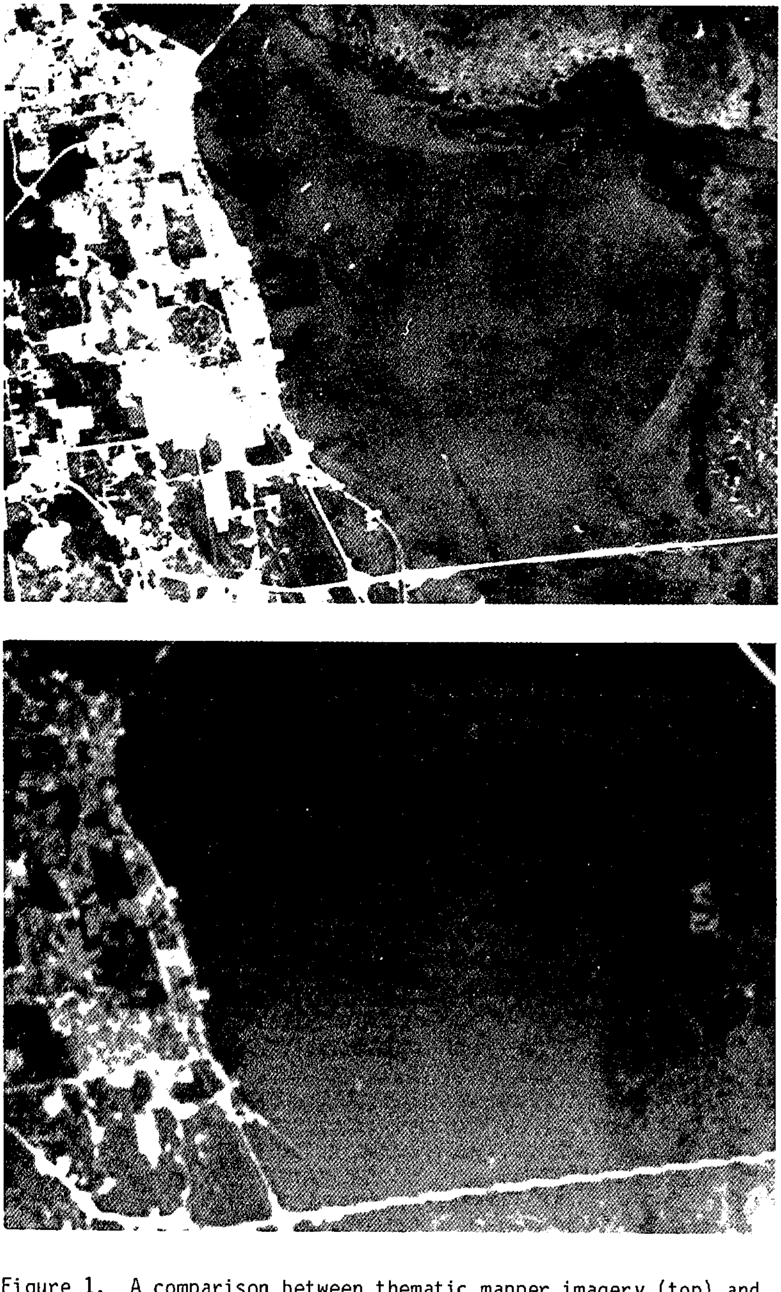

Figure 1. A comparison between thematic mapper imagery (top) and multispectral scanner imagery (bottom).

Table 3. Cost and time comparison (per hectare) for photographic vs. LANDSAT TM analysis for fisheries habitat mapping.

Category	Photography ($/ha)	LANDSAT TM ($/ha)
Imagery	.0002-.0022	.0003
Analysis and digitization	.0151	.0040
Ground truth	.0006	.0006
Total	.0159-.0179	.0049
Production time	3.479 sec/ha	0.588 sec/ha

Based on these initial results, selected marine fisheries habitats are being mapped for the entire state using a combination of LANDSAT TM imagery and aerial photography. In addition to mapping existing habitat, trends in habitat change have been developed by photointerpreting historical aerial photographs ca. 1940-1950's and entering the results into a comparative digital data base and determining habitat change. The results of analysis for several case studies provide examples of types of information generated by the habitat mapping program using various combinations of remote sensing tools.

Case Study: Charlotte Harbor

Located on Florida's SW coast, Charlotte Harbor is one of the State's largest, most pristine estuaries. Recreational and commercial fishermen extensively fish the harbor which supplies, for example, over 50% of Florida's west coast commercial landings of red drum (*Sciaenops ocellatus*) and spotted seatrout (*Cynoscion nebulosus*). Present areal extent and geographic locations of fisheries habitat and a historical comparison of habitat change have been produced for the Charlotte Harbor area. The recent analysis was based on photointerpreted 1982 aerial photography. The major vegetated habitats in Charlotte Harbor were mangrove (22,927 ha), seagrass (23,682 ha) and saltmarsh (1,436 ha). These vegetated components comprised 27% of total intertidal and submerged bottom. In contrast, the same vegetation in Indian River, Florida comprised 16% of the intertidal and submerged bottom. The historical analysis of Charlotte Harbor was based on 1945 photography. Results proved that an unexpected 12,955 ha of estuarine wetlands were lost over the 37 year period. This included 1499 ha of saltmarsh and 9,904 ha of seagrass. Mudflats and oyster reefs also were delineated for Charlotte Harbor of which 3,434 ha and 128 ha were lost, respectively. Conversely, mangroves increased by 2,067 ha. Most of this increase can be attributed to mudflat succession and perhaps rise in sea level. Mangrove loss has occurred in the harbor, mainly due to older waterfront developments that eliminated fringing mangroves. However, the overall trend has been an increase.

The loss of seagrass in Charlotte Harbor has been substantial. Although loss occurred throughout the Harbor, 57% of the loss was in the Pine Island Sound/Sanibel Island area which comprised only 34% of the total submerged bottom mapped in Charlotte Harbor. In the late 1950's and early 1960's, several major alterations to the Pine Island Sound area occurred that appear to have dramatically affected the ecosystem: (1) the Intracoastal Waterway was dredged through Pine Island Sound and up the nearby Caloosahatchee River, and (2) a causeway was constructed restricting the natural flow of water through the Sound. Even before 1960, the Caloosahatchee River was channelized to Lake Okeechobee.

Prior to these alterations, Pine Island Sound was under oceanic influence, with sponges, some corals, scallops, turtle grass and other higher salinity species growing within the Sound. Most likely, construction of the causeway acted as a dam impeding tidal exchange and diverting the natural flow of the channelized Caloosahatchee River into the Pine Island Sound area. The tannins and particulates associated with the river input would increase turbidity. When compounded with increased nutrients, direct destruction, and reintroduction of fine sediments into the environment by dredging, a decrease in seagrasses would be expected. Substantial seagrass loss has occurred in the deeper portions of the Sound and is most likely due to insufficient light penetration for photosynthesis. In addition, after causeway construction in 1962, the area went from a major scallop producer in Florida (as much as 180,000 lbs/yr) to no scallop production by 1964. Circulation alterations caused by the causeway diverting freshwater flow into Pine Island Sound from the Caloosahatchee River were probably the primary reasons for the decline of the environmentally sensitive scallop.

Although exact explanations cannot account for seagrass losses in other portions of the study area, some analogies may be implied. Primary seagrass loss occurred in the deeper portions of the Harbor, at the fringing bars, and in lagoonal-type areas. Very little direct destruction has occurred. It is likely that overall changes in drainage patterns and introduction of sewage pollutants and storm water runoff has served to increase the suspended load in the Harbor. Also, the loss of natural filtration of nutrients probably has increased the phytoplankton production. All of these factors would synergistically act to increase turbidity in the Harbor and eliminate seagrass meadows in the deeper water.

Case Study: INDIAN RIVER

This water body parallels the east coast of Florida, extending approximately 192 km. Indian River actually is not a river but a saltwater lagoon, the longest in Florida. The lagoon is straight and hugs the coast, rarely exceeding more than 3.2 km from the sea. It is separated by a long string of barrier islands separated by narrow inlets. This study included the southern portion of Indian River from Satellite Beach south to St. Lucie Inlet.

Through use of 1982 LANDSAT imagery and 1984 high altitude infrared photography, areal coverage of seagrasses and mangroves was calculated. Indian River water is typically turbid, necessitating the use of the aerial photography as a supplement to the satellite imagery for mapping seagrass. Seagrasses covered 2,777 ha comprising 8.3% of the total submerged bottom (33,425 ha). Mangroves totalled 3,198 ha, however, not all of this is available to fisheries resources as typical mangrove habitat. Much of the mangrove/marsh area has been "impounded" for mosquito control. This process involves building a dike around a mangrove site and flooding it for a large part of the year. This prevents saltwater mosquitoes from laying eggs since they require moist soil (not water) for oviposition. In some cases, impoundments actually encouraged the growth of mangroves. Many of the areas before impounding consisted of high marsh succulents such as Batis and Salicornia interspersed with mangroves; now they are predominantly mangroves. However, we contend that most impounded areas constitute a loss of habitat unless properly managed for fisheries. Approximately 76% of the total mangrove area has been impounded, leaving 767 ha of mangroves available to marine fisheries species.

One area, located north of Ft. Pierce inlet, was analyzed for loss of mangroves and seagrasses over time. Historical black and white aerial photographs (Soil Conservation Service) were interpreted for the years 1958 and 1970. Line drawings were produced (Fig. 2) based on the interpretations depicting areal coverage of mangroves and seagrasses during those time periods. A line drawing also was produced for the 1982 imagery/ photography interpretation. A 25% (217 ha) loss of seagrasses occurred in the Ft. Pierce area since 1958 with 11% of that decline occurring after 1970. Assessing loss of mangroves was difficult because of the large number of mosquito impoundments. A 27% loss of mangroves occurred since 1958 with seven percent occurring since 1970. These losses were primarily due to development and do not reflect loss due to impoundments.

Case Study: Ponce de Leon Inlet

Ponce de Leon Inlet, a site south of Daytona Beach, Florida, also was interpreted for historical areal coverage of estuarine vegetation (Fig. 3). Three time periods were analyzed. The 1943 image (center) is the result of photointerpretation of December, 1943, Soil Conservation Service photography for emergent and submergent vegetation (marsh and seagrass,. The major habitat change in this image is the result of dredging the Intracoastal Waterway and placement of the spoil on the marsh surface. The left image is a hypothetical pre-Intracoastal Waterway portrayal of the area produced by removal of the spoil islands and channels using capabilities within the MRGIS. The image on the right is the current marsh structure delineated through the processing of May, 1984 LANDSAT TM data. This series of analyses visually demonstrates the impact of human impingement upon the coastal marsh system. It also shows that photo-analysis and LANDSAT analysis can be made compatible. The marsh area decreased from 2,119 ha before dredging to 1,920 ha in 1943. Marsh coverage decreased again to 1,572 ha in 1984 or a total decline of 27% in marsh habitat entirely due to dredge and fill activities. Seagrasses were present in the 1943 photos (30 ha) but had disappeared completely by 1984.

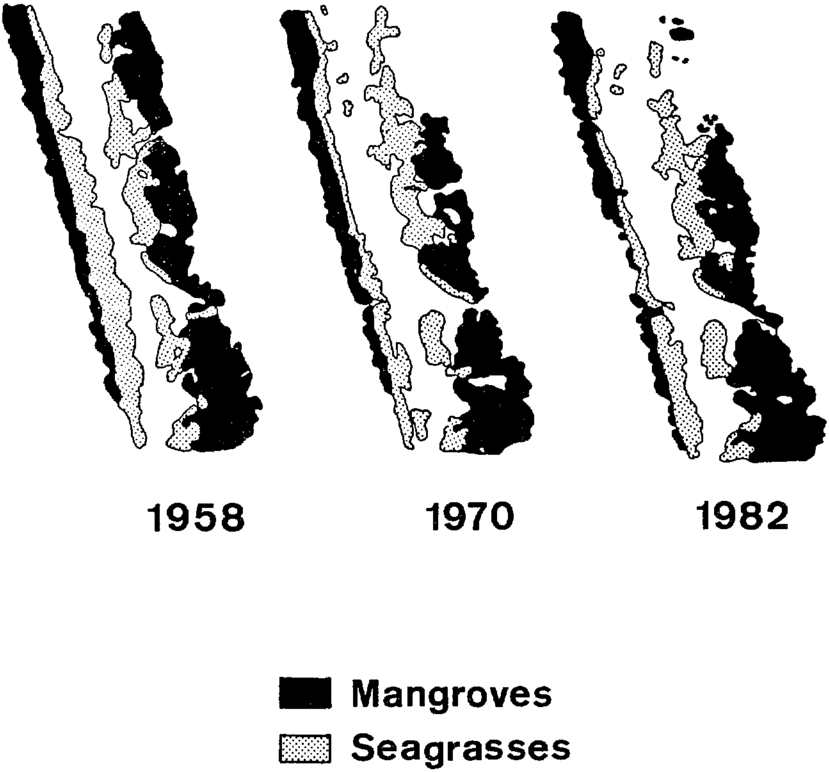

Figure 2. A graphic representation of an area near Fort Pierce Inlet depicting change in areal coverage of seagrass and mangroves over time.

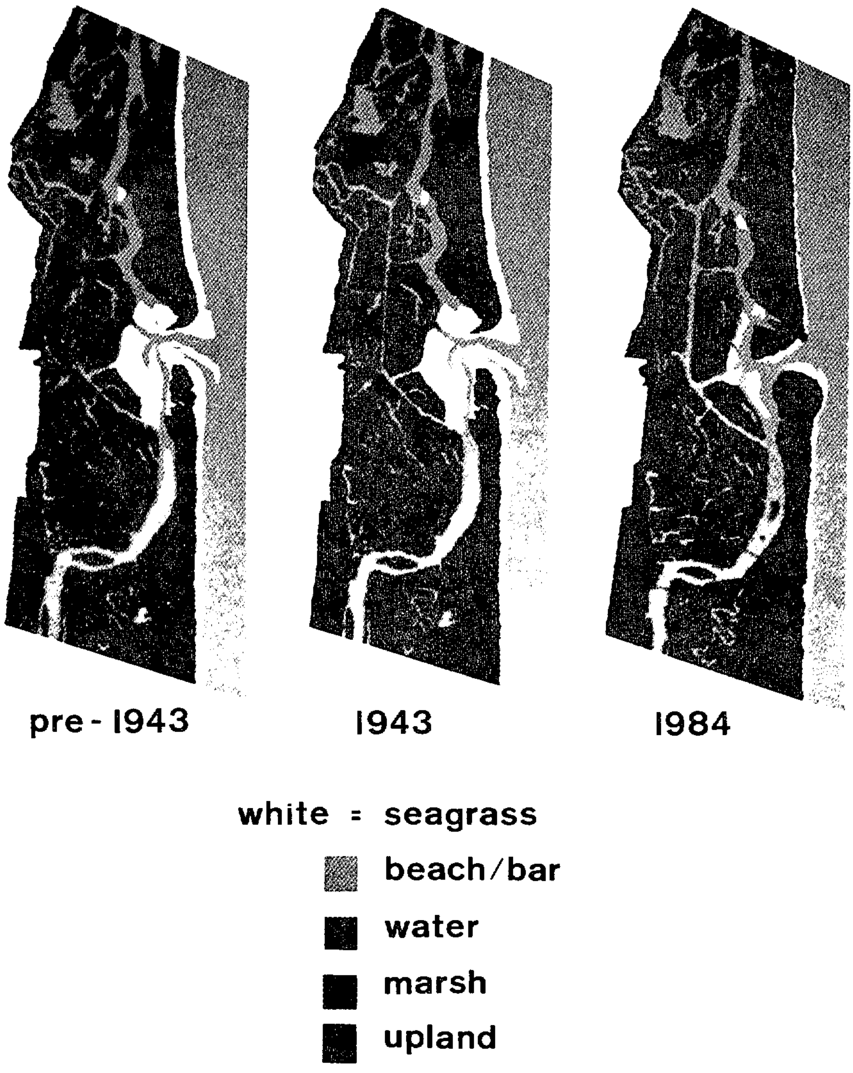

Figure 3. A computer-enhanced reproduction of Ponce de Leon Inlet, south of Daytona Beach, Florida, showing vegetation changes over time.

SUMMARY

A cursory look at the use of remote sensing to map fisheries habitat has been presented. The important aspect of the mapping program is the ability to develop a digital data base and to map and monitor the habitat on a state-wide basis in a minimal amount of time at low cost. LANDSAT TM data effectively have been used as the prime data source for the mapping. When the resolution is insufficient for a given need, higher resolution aerial photography can be interpreted and integrated into the LANDSAT data base.

If Florida fisheries habitats are to be effectively managed, managers need to know the location ofimportant habitat components to monitor and assess those habitat components for natural and man-induced changes. This type of information is also important as a major variable in determining habitat carrying capacities for commercially and recreationally important fish species important to the State. This type of information eventually will become a variable in a fishery production model and will help to provide a predictive capability useful in regulating commercial and recreational fishing pressure on a species in order to maintain an optimum yield.

The resource manager also can more effectively evaluate regional environmental impact statements with an understanding of the location and extent of the habitats in the area. Planners can use the information in planned growth activities such as marina siting, access channels, etc. The Florida Aquatic Preserve Program currently uses the habitat maps in developing management plans and presenting the resources of the preserves to the public.

The habitat component loss information was generated to gain an understanding of trends in habitat change up to the present. This information is important for planned restoration work and provides resource managers with an assessment of impacts already accrued within an area. The general public has made an unexpected demand for this type of information, generated by continuous rhetoric, on habitat loss in Florida. The mapping program has descriptively and quantitatively addressed this issue by positively enhancing public awareness so important in effectively addressing the issues legislatively.

Substantial fisheries habitat loss and alteration has occurred in Florida and statutes have been developed to assist in protecting those resources. Direct destruction still occurs but has been reduced. An overriding concern developed from our initial findings is the loss of submerged seagrasses. Loss has occurred state-wide and often is not due to direct impact but, more likely, to changes in ambient water quality. Water quality has degraded as the human population increased. Since 75% of those people living in and moving to Florida live on the coast, the impact on water quality in our estuaries will continue. This will be an expensive and difficult issue to address and we can expect a greater loss of seagrasses in the future.

The types of information generated from this mapping program will assist in making management decisions. This program is now in the final stages of an initial inventory of marine fisheries habitat in the State. The next steps are to upgrade the map data to a higher resolution and accuracy and to develop a method for rapid data dissemination.

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CHARLOTTE HARBOR HABITAT ASSESSMENT

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ABSTRACT

Charlotte Harbor is one of Florida's largest and least impacted estuaries. The estuarine complex includes the freshwater input of three major rivers as well as expansive areas of mangroves and seagrass. Historical and recent areal extent of mangroves, seagrasses, saltmarshes, mudflats, and oyster reefs, as well as categories of upland use and vegetation, have been assessed for change. The study area included the main harbor complex and adjacent uplands. Urban area increased by 2490%, forest land by 17%, water area by 8%, barren land by 26%, and transportation/utilities by 91%, while agriculture area decreased by 22%, rangeland by 81%, and wetlands by 23%. Of the wetland loss, 90% included loss of marine wetlands. Seagrasses declined by 29%, saltmarshes by 51%, mudflats by 75%, and oyster reefs by 39%. Mangroves, however, increased by 10%. Much of the seagrass loss occurred in the area of Pine Island Sound, where three major environmental disruptions may explain the decline: dredging the intracoastal waterway; building and placement of the Sanibel causeway; and channeling the Caloosahatchee River. Seagrass loss in other parts of the harbor occurred in less shallow areas, probably indicating a decline in water quality which prevented sufficient light penetration to the seagrasses. Most of the harbor fringe consists of mangroves, protected since 1972 by a state preservation program. However, adjacent to the mangrove fringe, thousands of acres of pine forest, freshwater wetlands, and agricultural land have been replaced by clear-cut sites drained by mazes of canals. So far, very few dwellings exist; however, the potential cumulative impacts are great. Charlotte Harbor presents a clear case where

estuarine preservation and management will mean little without concurrent upland management and management of the freshwaters flowing to the harbor.

INTRODUCTION

Charlotte Harbor (Figure 1), located in Lee and Charlotte Counties on Florida's southwest coast, is one of the state's least modified estuaries. The harbor is approximately 56km from north to south, encompassing 92,000 ha of water area. Total shoreline measures 320km, excluding the numerous mangrove islands. Shallow water of 1.8m depth predominates. Tidal range averages 0.5m and the average annual rainfall is 135cm. Recreational and commercial fishermen extensively fish the harbor which provides, for example, over 50% of Florida's west coast commercial landings of red drum and spotted seatrout. In addition, over 40 endangered and threatened species live within the Charlotte Harbor area, including at least 15 bald eagle pairs.

Three major rivers, as well as numerous small creeks, flow into Charlotte Harbor. The Myakka and Peace Rivers together have a drainage basin of approximately 770,000 ha, and the Caloosahatchee River drains about 310,000 ha of land area (Taylor 1974). These watersheds include pasture land, citrus groves, and farmland. In addition, the Peace River flows through expansive phosphate mining areas, and the Caloosahatchee River receives industrial and domestic wastes from Ft. Myers.

During periods of heavy rainfall, flow from Charlotte Harbor's rivers and creeks reduces surface salinity throughout the estuary and several kilometers offshore. During drought periods of low river flow, a saline wedge can occur well upstream in each of the three major rivers.

Charlotte Harbor was formed during the Great Ice Age when radical changes in sea levels, caused by the advance and retreat of glacial ice caps, alternately bound up then released tremendous quantities of water to the oceans. Sea levels varied by as much as 82m above and 160m below present levels. In the last ice age, receding sea levels allowed the precursors of the Myakka and Peace Rivers to erode broad river valleys. As the ice caps melted some 10,000 years ago, sea levels rose once more, creating the estuary we know today as Charlotte Harbor.

MARINE HABITATS OF CHARLOTTE HARBOR

The word 'habitat' refers to the specific physical, structural, and

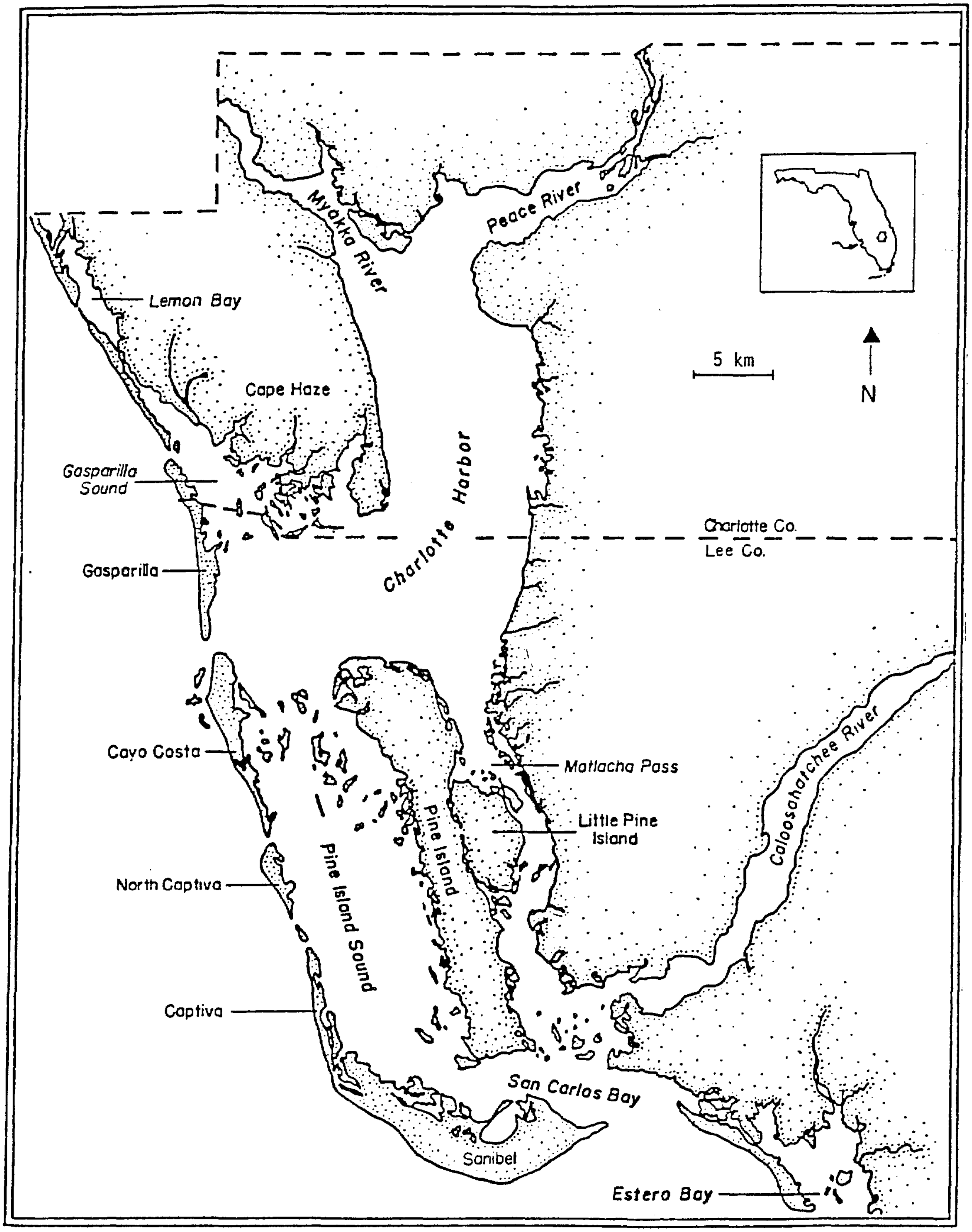

Figure 1. Charlotte Harbor

chemical environment in which an organism lives. Marine habitats often are described by the dominant vegetative or other structural components found within the particular ecosystem. From this point of view, marine habitats of Charlotte Harbor include mangroves, seagrasses, saltmarshes, mudflats, and oyster reefs.

Mangroves are salt-tolerant trees that grow along almost all natural shorelines of Charlotte Harbor, including the numerous small islands. Three species commonly exist within the system. Red mangroves (Rhizophora mangle) are easily recognizable from their prop roots; black mangroves (Avicennia germinans) have characteristic pneumatophores arising vertically from underground roots; and white mangroves (Laguncularia racemosa) have salt glands at the base of the leaves. Mangroves are well known for reducing erosion and providing nesting and rookery habitat for brown pelicans, roseate spoonbills, common egrets, etc. The complex root systems provide hiding places for fishes, crabs, and shellfish, and, additionally, provide a hard surface for attachment by sessile organisms. Some scientists believe that mangroves also provide a tremendous food supply in the form of leaf detritus.

Seagrasses are vascular plants which live in the shallow subtidal zone of estuaries and coastal regions. Four species of seagrasses thrive within Charlotte Harbor. Turtle grass (Thalassia testudinum) has wide, flat leaves with rounded tips. Manatee grass (Syringodium filiforme) has thin rounded blades, while shoal grass (Halodule wrightii) has thin flat blades ending with a forked tip. Widgeon grass (Ruppia maritima) is a freshwater species capable of withstanding seawater; it has thin flat blades resembling shoal grass, but with rounded tips. Seagrasses provide food source to herbivores, such as sea turtles and manatees, and to numerous detritivores. Seagrasses provide shelter for fish, crabs, and shellfish and surface area for epiphytic attachment. Seagrasses stabilize sediments and retard erosion by baffling waves and binding the sediment. They also aid in nutrient cycling. Exportation of seagrass blades provides energy to areas quite remote from source beds, including areas such as beach shorelines and offshore ocean bottoms.

Saltmarshes are herbaceous plant communities that dominate estuarine shorelines in the northern half of Florida where winter temperatures of near-temperate latitudes discourage mangrove growth. In Charlotte Harbor, as in all of south Florida, saltmarshes generally serve as a transitional zone between mangroves and freshwater marshes in rivers. Smooth cordgrass (Spartina alterniflora) and black needlerush (Juncus roemarianus) constitute most of the marsh vegetation; however, marshland is not a prevalent habitat within the Charlotte Harbor system. Like seagrasses and mangroves, saltmarshes provide a concentration of high quality food for estuarine animals in addition to a conducive environment for early life stages. Saltmarshes are also a fundamental part of nutrient cycles, long term accumulators of pollution, and short-term pollution buffers. Animal production is high in saltmarshes, again, providing a tremendous food supply in the form of tiny organisms that are food for fisheries species.

A mudflat is an unvegetated site that becomes exposed at low tide. During daylight hours it serves as a primary feeding ground for numerous species of shorebirds and for wood storks, white ibis, and roseate spoonbills. However, during the night fish, crabs, and shrimp become the major consumers. Primary producers of mudflats include diatoms, dinoflagellates, filamentous green algae, and blue-green algae. Measured primary productivity of 0.9 gC/m2/day (Thayer and Ustach, 1981) is less than half that of estuarine macrophytes, but the food is in a form readily available to consumers.

Oyster reefs are composed of the gregarious American oyster (Crassostrea virginica). Oysters reefs reduce current velocities and waves and provide habitat for animals that require hard substratum for attachment. In fact, every square meter of oyster reef provides at least 50 square meters of available hard surface. The irregular surface creates interstices, providing shelter for small fish and invertebrates. Oysters also help recycle nutrients.

Overlying parts or all of the estuarine habitats, depending on the tides, is the water column. The chemical, physical, and biological composition of the water column influences virtually all aspects of the estuary. Phytoplankton are the primary producers and their productivity is not limited to shallow areas or shorelines as it is for seagrasses, mangroves, and saltmarshes. Phytoplankton are capable of production in the photic zone over the entire area of the estuary. Phytoplankton exist in a state readily available to consumers and are essential components in the food chain that supports larval fishes. But, an abnormal abundance of phytoplankton occurs in many Florida estuaries as the result of increases in nutrient levels above natural ambient levels. This process of eutrophication can have serious implications to the quality of production in an estuary such as Charlotte Harbor.

HABITAT ASSESSMENT

Habitat assessment is just one small contribution to the overall knowledge required to understand and manage the resources. When considering cumulative effects of various perturbations on the Charlotte Harbor system, it is important to measure the perturbations and their cumulative effects.

Habitat alterations have been assessed in the Charlotte Harbor region for the 1940's and the 1980's (Harris et al. 1983). Techniques evaluated in this endeavor are now being employed for a statewide analysis (Haddad and Harris 1985).

The summary results of the Charlotte Harbor analysis are presented in Table 1. The study site was based on those USGS quadrangles which bordered or were within the harbor complex (Figure 2).

Urban area increased by 2490%, a gain of 92,395 acres. Almost 50% of the urban increase was due to massive land boom tracts where huge areas were cleared and roads were built. Few actual dwellings exist, even today. In contrast, the population of Charlotte Harbor has increased by only 1246%.

Agricultural land, mostly composed of pasture and citrus, decreased 22%, a loss of 2,854 acres. Most of this acreage became urban.

In this region, rangeland is typified by a dominance of palmetto prairies interspersed with pine. Rangeland is characterized by fields or brushland with less than or equal to 30% trees. Rangeland decreased 81%, a loss of 85,515 acres. Most of this loss reflected urban gains.

Table 1. Historical and recent acreages of land use and vegetation categories in Charlotte Harbor.

Land use or Vegetation Category	Acreage 1945	1982	% Change
Urban	3,710	96,105	+2490
Agriculture	13,137	10,283	- 22
Rangeland	106,219	20,704	- 81
Forestland	34,583	40,491	+ 17
Water	288,799	312,705	+ 8
Wetlands	160,226	123,903	- 23
Barrenland	6,202	7,826	+ 26
Transportation and Utilities	1,801	3,433	+ 91

Table 2. Historical and recent acreages of marine wetland habitats.

Wetland Habitat	1945	1982	% Change
Seagrasses	82,959	58,495	- 29
Mangroves	51,524	56,631	+ 10
Saltmarsh	7,251	3,547	- 51
Mudflats	11,206	2,723	- 76
Oyster Reefs	806	488	- 39

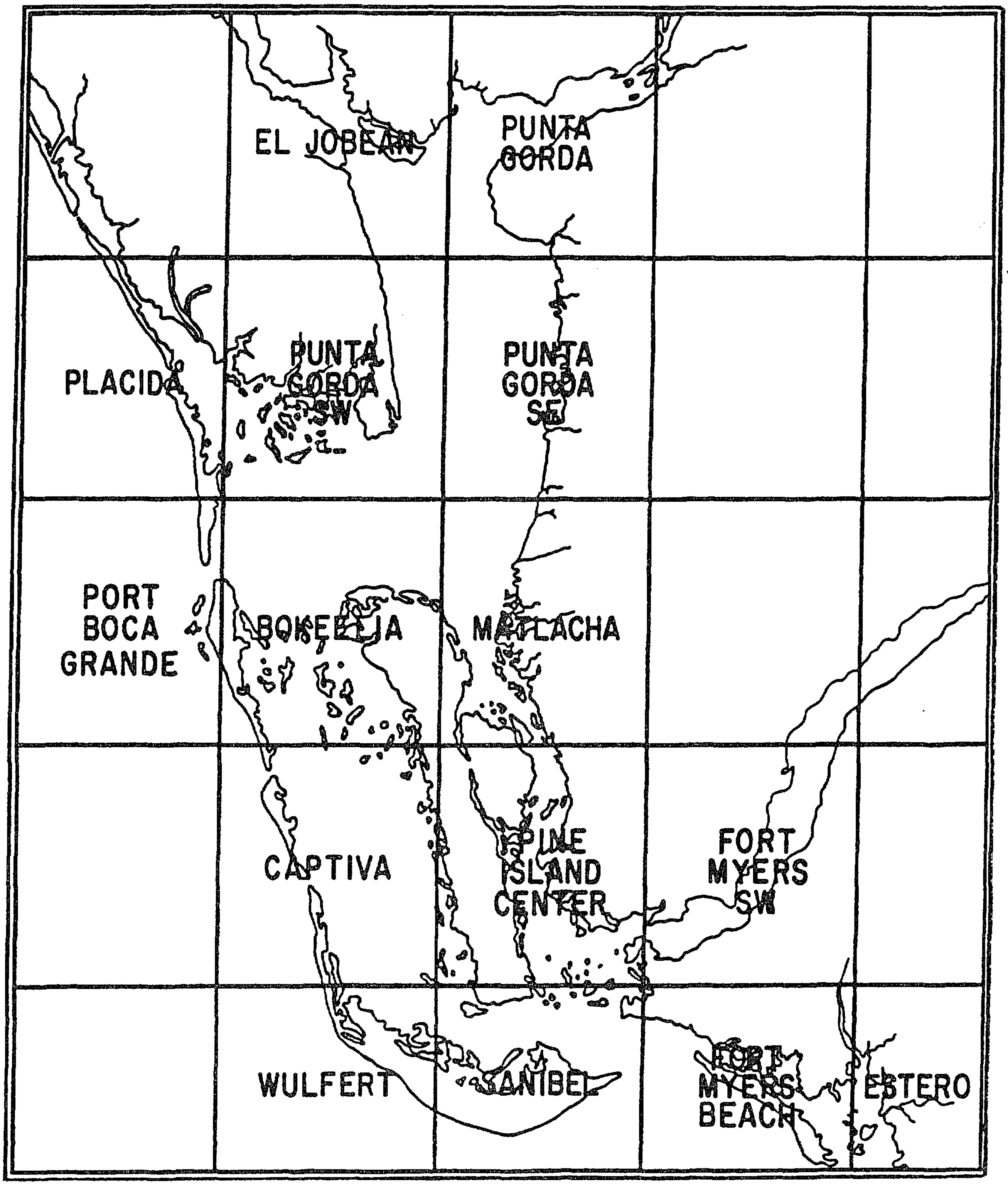

Figure 2. Charlotte Harbor study site and quad locations.

Forestland, defined as non-developed sites with over 30% trees, increased 17%, a gain of 5,908 acres. Forestland was the only general vegetation category to increase; however, the increase was determined to be an influx of exotic species, such as Melaleuca and Australian pine. These species often replace native vegetation.

The water category (non-vegetated bottom) increased 8%, a gain of 23,906 acres. Canal construction and loss of seagrass contributed in large part to this increase.

Barrenland is any non-vegetated area, including cleared sites and beaches. Barrenland increased 26%, a gain of 1,624 acres. Most of this increase was caused by clearing vegetated sites for development purposes.

Transportation and utilities had a tremendous 91% increase of 1,632 acres. This category directly reflects population growth, since increased roads and utilities are results of population increases.

Wetlands, both marine and freshwater, decreased 23%, a loss of 89,923 acres. Included within the wetlands cateogry are the marine habitats: seagrasses, mangroves, saltmarshes, mudflats, and oyster reefs. These habitats also were assessed for historical changes (Table 2).

Seagrasses declined by 29%, a loss of 24,464 acres. Over 50% of the loss took place within the Pine Island Sound and Matlacha areas. Several reasons may explain the loss: the intracoastal waterway was dredged through the Sound; the Sanibel causeway was constructed; and the nearby Caloosahatchee River was channelized. Where seagrasses were not mechanically impacted in the Pine Island Sound area, many probably disappeared because of decreased light levels due to sedimentation and turbidity.

Throughout the remainder of the harbor, grassbeds consistently disappeared from deeper areas, indicating that lower light levels within the water column could be influencing growth patterns. Increases in nutrients, which promote phytoplankton growth, and increases in resuspendable fine organics and clays may explain reduced water clarity, but this has not been documented. This reduction in light could either reduce photosynthesis to a level at which seagrasses could not survive or stress the plant to such an extent that man-induced or natural perturbations could cause loss.

Mangrove acreage actually increased by 10%, a gain of 5,107 acres. Although many biological factors can explain the mangrove increases, the major factor has been management strategy. In the late 1960's the Charlotte Harbor area was the focus for effective state, regional, and local planning. A part of this plan was the acquisition, through purchases, mitigation and donation, of a buffer zone of wetlands around the harbor. This habitat of marsh and mangrove is now maintained as a functioning part of the estuarine system contributing to fish and other wildlife production and helping to maintain water quality. Because mangroves were protected, very few trees were lost due to direct removal for development. The mangrove increase can be explained by natural growth onto mudflats and oyster reefs, spoil island creation, marsh succession, and sea level rise.

Saltmarshes decreased by 51%, a loss of 3,974 acres. In addition to dredge and fill, loss may be attributed to the extensive upland development of canals which may have diverted freshwater away from saltmarshes, allowing saltwater intrusion and inducing mangrove growth.

Mudflats decreased by 75%, a loss of 8,483 acres. Mangrove increase may account for much of this loss.

Oyster reefs were not present in large areas both historically and recently. A 38% decline occurred, representing a loss of 322 acres.

From a management perspective, the development of a wetland buffer zone in Charlotte Harbor has been a success, but the loss of seagrasses suggests a failure in managing the entire harbor as a system. In retrospect, a historical look at the development of the area can provide some insight into probable cumualtive impacts that affected the deeper water seagrasses of the area.

If we assume that seagrass loss occurred because of changes in ambient water quality and sedimentation, a number of man induced perturbations can explain these changes:

1. Dredging and filling have catastrophic direct impacts, but the long-term effects of dredging are most likely seen in migration of spoil deposits

and the release of bound fine organics and clays into the system from all aspects of the dredging activity. These organics and clays contribute to the resuspendable benthic layer and can become resuspended easily by minor currents and wind-driven circulation. In Charlotte Harbor, major dredging activities have included dredging the Intracoastal Waterway and access channels, and placement of bridges and causeways.

2. Increases in dissolved nutrients, due to runoff and effluent discharges, can contribute to a general increase in the phytoplankton concentrations in the water column. Increased phytoplankton populations block light that is normally available to the seagrasses through a clearer water column. Man-induced nutrient inputs occur from discharges such as sewage disposal and runoff from livestock, agriculture, and urban and suburban areas.
3. Alterations of natural drainage patterns could have a significant effect on ambient water quality as well as on the life cycles of various biota utilizing the estuary. The entire drainage basin must be managed for the maintenance of the estuary, but this is rarely accomplished. Riverine and creek discharges are major contributors of freshwater to the estuary. Delivery occurs through a natural percolation and filtration process which both cleanses the water and maximizes the delivery time to the estuary. In the Charlotte Harbor drainage basins, alterations of this natural process have been induced primarily by phosphate mining, agricultural production, cattle production, and urbanization. The impacts of these drainage alterations have not been assessed quantitatively nor have physical, chemical, or biological cumulative impacts been addressed in any comprehensive manner. It is important from a management perspective to define single activities that can be many kilometers upstream from the estuary, but have potential for cumulative impacts within the estuary.
4. Altered circulation patterns induced by structures and channeling also interact with water quality. The synergistic effects of these activities can induce significant biological change. A dramatic example is the loss of the scallop industry in the Pine Island Sound area. As predicted by the USFWS (1959, c.f. Estevez), placement of the Sanibel causeway across

San Carlos Bay precluded the survival of the scallop. Upon the completion of the causeway in 1962, the scallop population indeed collapsed. Because scallops require unpolluted saltwater with little freshwater input, a likely explanation for the population collapse is the synergistic effects of three occurrences: 1) the causeway impeding water circulation and creating a dam effect for waters exiting San Carlos Bay; 2) changes in freshwater quality and flow into the area due to channeling and other alterations of the Caloosahatchee River; and 3) dredging of the Intracoastal Waterway through the area. The results most likely included increased turbidities, increased freshwater delivery (timing and reduction of salinity), persistence of freshwater in the area due to the causeway, and the subsequent demise of the scallop.

5. Drainage alterations in upland areas surrounding the harbor also have occurred and certainly contribute to the water quality of the system. A good example of altered drainage is represented in the Matlacha/Pine Island area of Charlotte Harbor for 1944 and 1982 (Figures 3 and 4). The dotted lines depict boundaries of natural wetlands and flow patterns. These wetland areas served as filtration and retention areas for freshwaters before it percolated to groundwater areas or flowed into the harbor. Major drainage alterations occurred since 1944 and are evident in the 1982 depiction (Figure 4). The natural drainage pattern has been replaced with a system of canals. From the developer's perspective, these canals serve to lower the water table to: 1) reduce flooding potential; 2) provide fill for raising the land to a height above sea level to allow development; 3) provide "waterfront property"; and 4) provide boat access to the harbor by way of a maze of canals.

From a biological perspective, the potential for long-term estuarine degradation has been created by: 1) 100% clearing of vegetation associated with the development tract, including both uplands and wetlands (in some cases "refuges" have been left); 2) poorly designed systems of canals which allow no flushing or circulation and serve as sinks for nutrients (i.e., fertilizers) and other pollutants; and 3) the rapid removal of freshwater from the land by

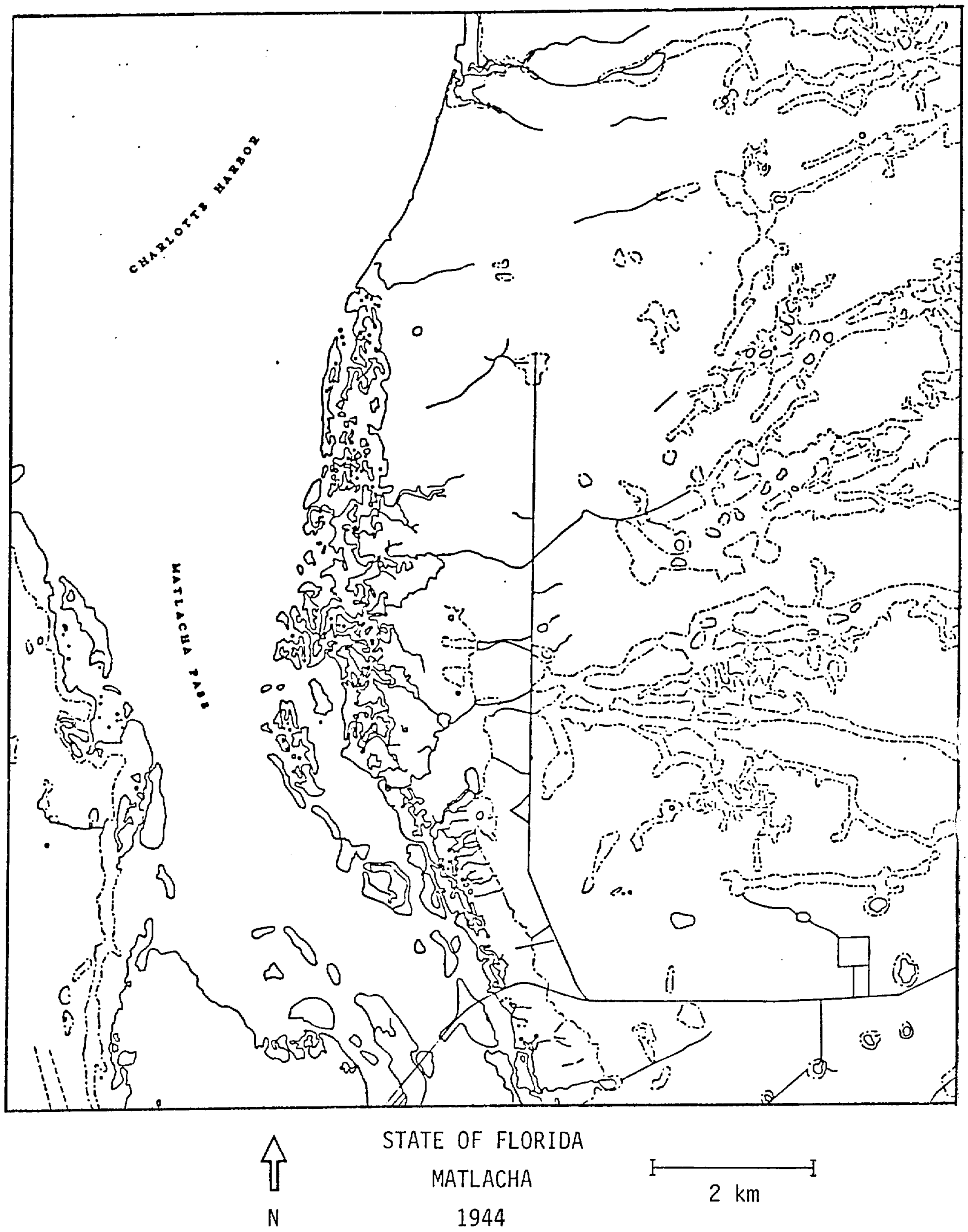

Figure 3. Drainage map of Matlacha quadrangle based on 1944 aerial photography.

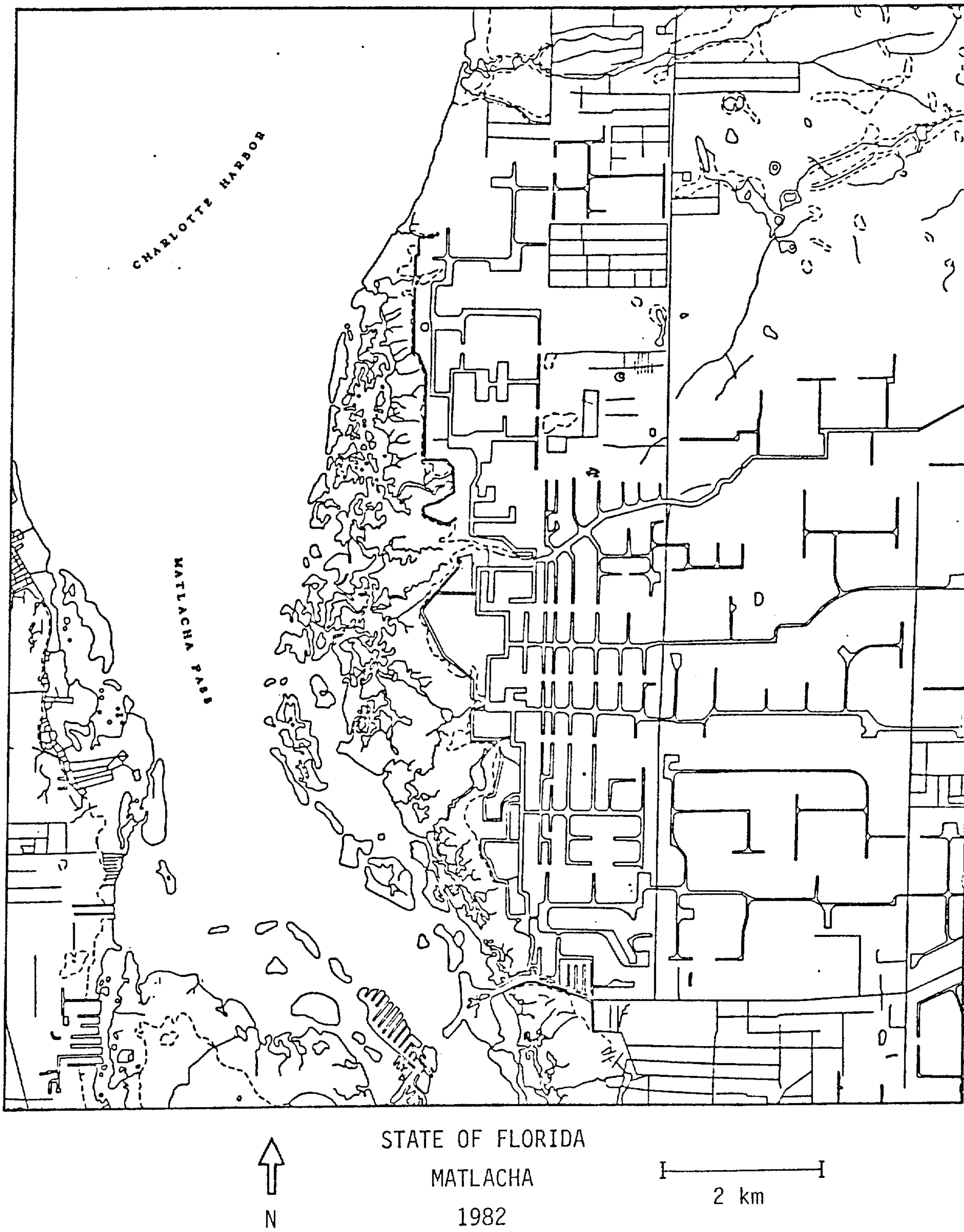

Figure 4. Drainage map of Matlacha quadrangle based on 1982 aerial photography.

the canal systems which deliver it directly to the harbor. When heavy stormwater runoff occurs, the canals are flushed all at once, carrying increased loads of accumulated organics and sediments directly to the harbor. Although a wetland buffer exists along the harbor shoreline, the canal systems often bypass natural wetlands by direct openings to the harbor. The resultant rapidly lowered salinities and increased dissolved nutrients, fine organics, and sediments can impact local areas in the harbor, but additionally can cumulatively affect the entire harbor. Some canal systems within the harbor are designed to minimize these perturbations.

HABITAT MANAGEMENT AND CUMULATIVE EFFECTS

The results of cumulative impacts are difficult and expensive to quantify, and, often the complexity of interactions precludes predicting their effects. In the past this has led to a management strategy that only addresses direct and local impacts, or if cumulative impacts must be considered, the criteria for determining and regulating the impacts are based upon poorly defined models which do not adequately weigh the ecological integrity of the system. Effective management requires a commitment for long-term monitoring of water quality, structural habitat quantity and quality, and their various associations. In addition, this requires a commitment toward research to define quantitative biotic relationships, cumulative effects, and all the intrinsic relationships that affect an ecosystem.

The effects of cumulative impacts in the Charlotte Harbor region are quantifiable if gauged by alterations in vegetative cover. Losses in marsh and mangroves are generally the result of direct impact; consequently, the presence and increase in these types of vegetation reflect an active role by regulatory and planning agencies to minimize losses. Marsh and mangrove losses through man induced perturbations still occur in small increments in Charlotte Harbor. Although these losses can be measured, they still have an unquantifiable cumulative impact on the environment.

Most loss of seagrass in Charlotte Harbor was not the result of direct physical impact. The indirect cumulative impacts which caused the loss have not been specifically identified or quantified, although the loss itself is quantifiable. In fact, no direct scientific data exist that describe the physiological responses of seagrasses (in Charlotte Harbor) to any potential impacts, such as nutrients, pollutants or reduced light penetration. The impacts can be surmised only by deductive reasoning.

This lack of quantifiable, cause and effect information presents a management problem that is difficult to address; in fact, quite often the management process must be instituted without adequate information upon which to develop realistic planning.

With recent support both legally and environmentally to begin addressing cumulative effects of human impacts on systems, the lack of information necessary to assess cumulative impacts becomes acutely obvious. We can no longer target a species or habitat for management without understanding its role in the system. Unfortunately, the commitment to provide the resources to adequately quantify the ecological processes that occur in our wetlands has not been provided in the past and is unlikely to be provided in the near future. This is because of a basic conflict between science and management; management requires short-term responses to immediate problems which require long-term research for adequate response. The long-term research often does not provide the short-term gain of information frequently perceived as necessary in budgetary allocations.

This creates a dilemma for areas such as Charlotte Harbor. Currently, only the wetland changes are known and reasons for their change are speculative. Seagrass coverage has declined, but why it declined is unknown, as is the impact of the loss on the system as a whole. Can a decline in certain fisheries populations be expected? Is there a threshold amount of total cover and food, as provided by certain structural components such as seagrasses, beyond which secondary production is reduced? Are certain fisheries species capable of adaptation to changing habitat availability? Is eutrophication a causative factor in seagrass decline, or is it resuspended organics, or possibly sea level rise, or cumulative effects of these and more?

CONCLUSION

Charlotte Harbor is relatively unimpacted when compared with other Florida estuaries. But the area is undergoing rapid growth which will continue to impact the health of the system, already evidenced by seagrass loss. Water and sediment quality is and will continue to be the most serious issue facing management if the estuarine resources are considered in the planning process. Current Department of Environmental Regulation water quality standards and the Water Management Districts' freshwater management plans do not provide adequate mechanisms to assess cumulative impacts relative to the biological components of the system. Unless this is recognized at state, regional, and local levels, cumulative effects of various water quality parameters will most likely have a serious impact on the future health of the Charlotte Harbor estuary.

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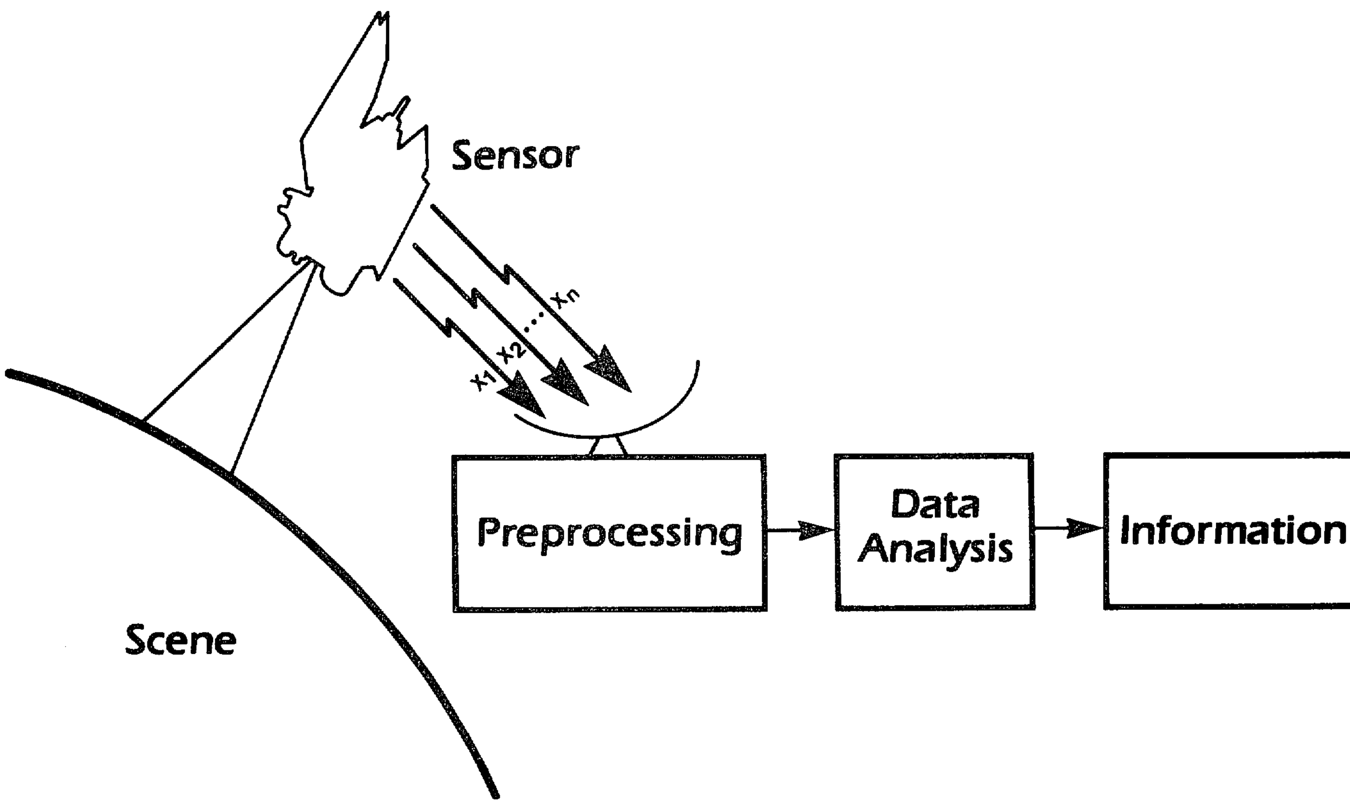

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ASSESSMENT AND TRENDS OF FLORIDA'S MARINE FISHERIES HABITAT: AN INTEGRATION OF AERIAL PHOTOGRAPHY AND THEMATIC MAPPER IMAGERY

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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.

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.

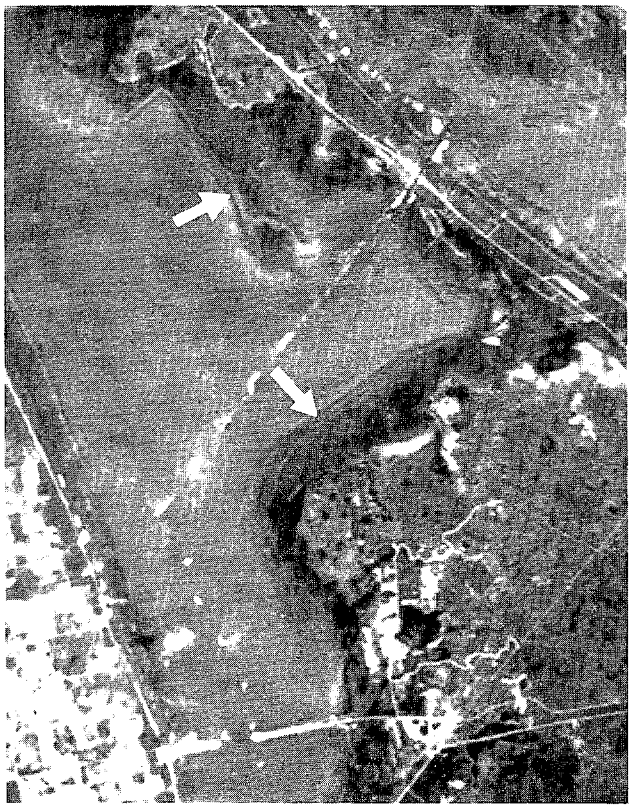

Figure 1. A 1984 TM image (channel 1, .45-.52 μm) of a site near Cape Canaveral, Florida. Submerged vegetation (dark) is easily observed along the shoreline.

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

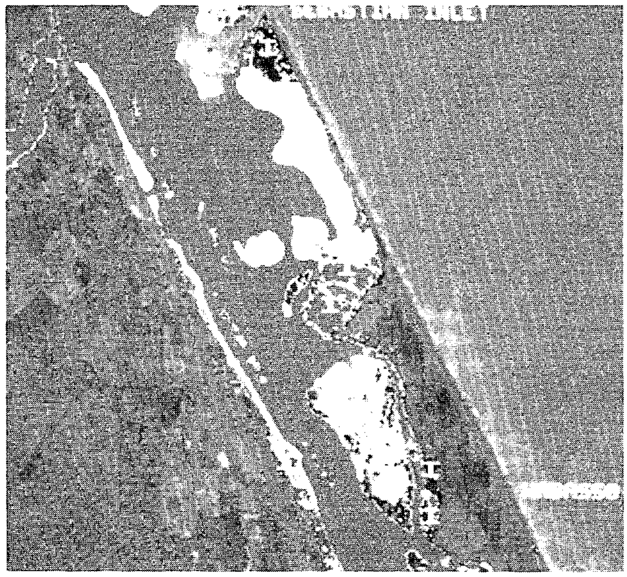

Figure II. A statistically processed TM image of a 12 km site in Indian River, Florida. Mangroves are depicted in black and seagrasses in white. Seagrasses were interpreted from 1984 aerial photography and imbedded into this 1982 image.

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

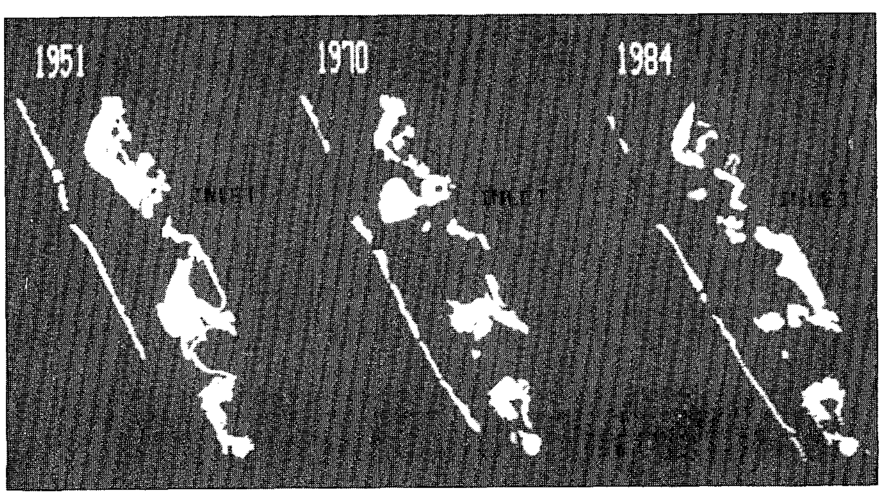

Figure III. A historical analysis of the Sebastian Inlet area showing areal coverage of seagrasses over a 33-year time span.

1943 1984

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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