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USE OF REMOTE SENSING TO EVALUATE THE ECOLOGY OF SAN SALVADOR, BAHAMAS

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ABSTRACT

Landsat Thematic Mapper (TM) imagery of the island of San Salvador, Bahamas was acquired by and processed at the Stennis Space Center by a team of scientists under the direction of Natural Systems Analysts, Inc. in order to develop remote sensing methods to more effectively analyze the impacts of commercial development on "pristine" areas. San Salvador was chosen as the study site because of the extensive coral reefs surrounding the island, the potential threat to the ecology from proposed large scale development activities, and the historical importance of the island in light of the 500th Anniversary of Christopher Columbus' 1492 discovery of America.

A February 1985 one quarter Landsat TM scene was purchased from EOSAT and georeferenced and classified at John C. Stennis Space Center in Mississippi. A second data set dated March 1991 was also acquired, but cloud cover rendered the data set of little value. The 1985 image was also used to developed several commemorative poster concepts for the 500th Anniversary. Other commercial products for the image data and the hard copy print are being pursued for sale this year.

Classification was performed using ERDAS image software. An initially classified image was ground truthed in order to derive a final classified image with 20 classifications, including upland, wetland and marine classes. The data is currently available in ERDAS format on floppy diskettes and/or hard copy.

INTRODUCTION

Some of man's activities on Earth have finally become recognized as very detrimental to the earth's environmental and ecological integrity. Natural Systems Analysts, Inc. (NSA) provides the expertise to analyze some these detrimental impacts. The specialized resources at the John C. Stennis Space Center's Science and Technology Laboratory (SSC/STL) was used to expand NSA's market potential for commercial applications of remote sensing technologies and improve the effectiveness their environmental analysis capabilities.

The purpose of this project was to utilize the specialized resources and existing technologies at SSC/STL to enhance and expand the capabilities of NSA in order to do more rapid and more effective analyses of the impacts of commercial development on "pristine" areas of the world. The island of San Salvador, Bahamas was chosen as a prototype case to develop viable products and information using advanced remote sensing technology. Utilization of this technology should expand the capability of NSA in evaluating the environmental and ecological impacts of commercial development on both local and broad scales and on both near term and long term impacts. In addition, the benefits of this project to the ongoing scientific research on San Salvador could be substantial to the community and to SSC/STL, as described below.

The Landsat Thematic Mapper (TM) satellite provides data in seven spectral bands (from 0.45 to 12.5 microns) with a resolution of 30 meters. Various processing methods exist at SSC/STL which allow features of a scene to be studied, enhanced and/or classified into land use categories. Some researchers prefer using the visible, infrared and thermal infrared spectral bands in processing land surface features. Other channel combinations may emphasize different features such as vegetation cover types, geologic features and water resources.

San Salvador was chosen as the study site for this project. There is an active biological field and research center there. Over 20 years of research and data collection has occurred on the island, providing a historical record of changes that have occurred past and present. The island is widely believed to be the first landing site of Christopher Columbus in 1492 and has significant archaeological sites to be explored and excavated. It served as a U.S. Navy base and target site as well as a U.S. Coast Guard station. It is the easternmost of the Bahamas Island, and so is somewhat remote to mainland United States. Club Med began building a resort on the island and there has been a recent but yet to be explained die-off of coral reefs and urchins. The location of San Salvador is illustrated on the map in Figure 1.

Marine biologists working at the Bahamian Field Station believe that remote sensing techniques will significantly aid their research in determining growth patterns and biomass production of sea grasses. Hydrologist could utilize remote sensing to determine fresh water resources for development uses. Ecological and environmental impacts in pristine areas could be facilitated by comparing historical data with current data and with data following known disturbances, ie., dredging of a marina.

With this baseline of historical "ground truth" type data, research results of 20 years, and the input of new technology remote sensing data, San Salvador is an excellent site not only for this study but as an intensive study site in the NASA Earth Observing System Program, when planned sensors become available.

PROJECT OBJECTIVES

VIP Objectives

Visiting Investigator Program Objectives include providing the opportunity for entrepreneurs and scientists to utilize the specialized resources at SSC/STL to enhance and expand the ability of companies to develop commercially viable products and produce valid assessments utilizing satellite digital data for assessing natural conditions and determining the impacts of commercial development on "pristine" areas using San Salvador, Bahamas, as a prototype study.

Project Objectives

The objectives of this project were:

1. To produce full resolution, false color infrared, research quality images for the entire island of San Salvador so the Bahamian Field Station researchers would have current satellite data of the island,

2. To produce a computer classified, color enhanced and color coded map of the island for research, inventorying and assessing land surface cover features and shallow water features,

3. To produce a commemorative poster of the island linking International Space Year and the 500th Anniversary of Columbus' landing on San Salvador. This and other similar commemorative items will be marketed worldwide,

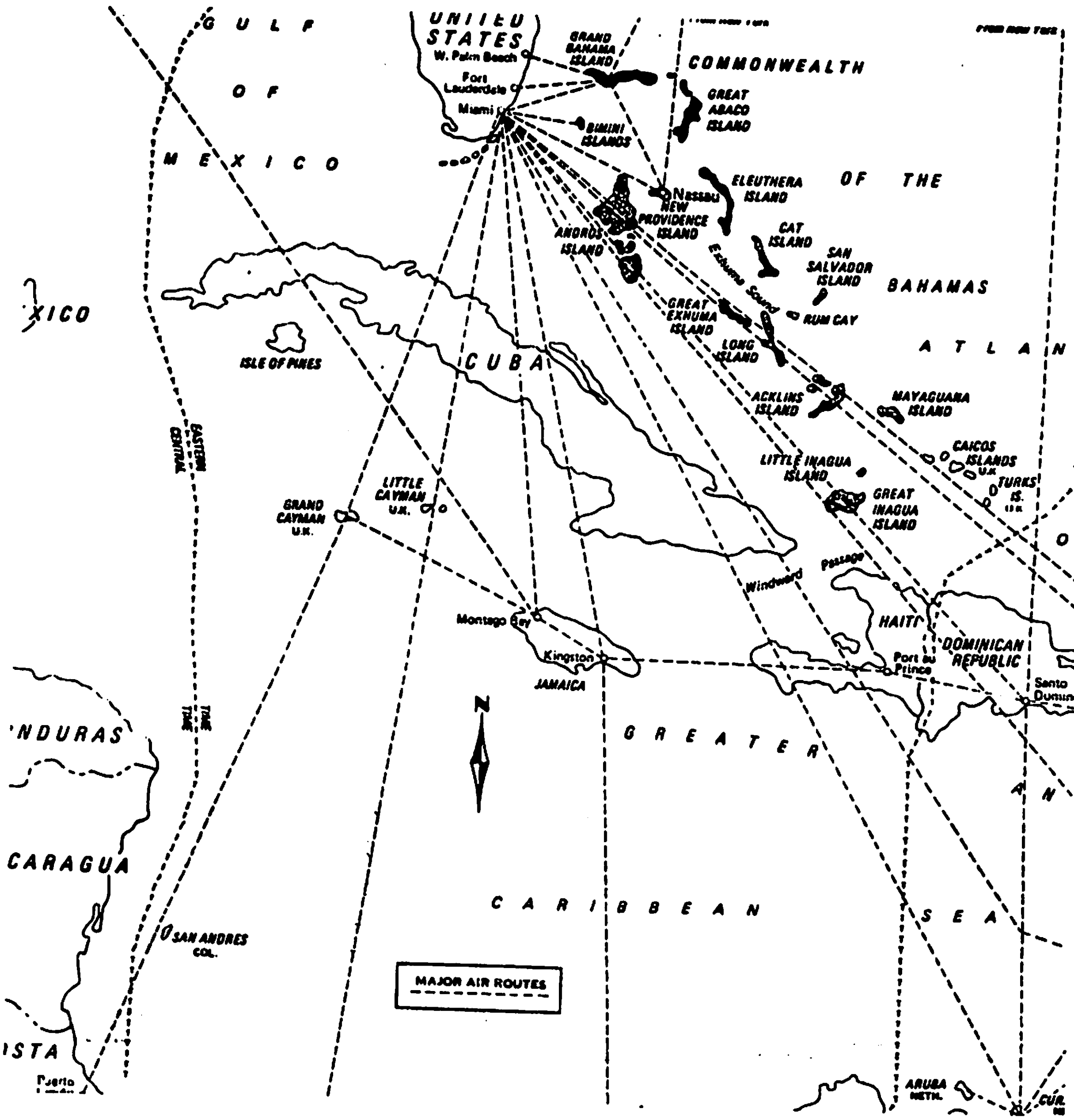

Figure 1. Map of the Caribbean Region and Bahama Islands

4. To develop a prototype remote sensing project in which techniques and methodology developed and utilized in this project may be used in future studies to determine the development on the island and the surrounding marine habitats. (while ground truth was being conducted in June 1991, construction was begun on Club Med Resort on the coast, north of the existing airport.)

DATA AND FINDINGS

Data Acquisition and Processing

A February 1985, cloud-free thematic mapper data set (quarter scene) was obtained from EOSAT to initiate the study and to establish a baseline data set from which change detection and impact studies could be done.

The data set was georeferenced at SSC/STL by selecting 22 control points on USGS 1:25,000 quad sheet maps of the island and "correcting" the data set to those control points.

The full resolution data in bands 4, 3, and 2 were used to produce an unprocessed, false color infrared image of the island (Figure 2). Some of the open water outside the coral reef and sandy bottom shallow shelf surrounding the island was blocked out to highlight the island as the focus of the image. The resolution of this image and the information content of the false color infrared image allowed existing submerged and terrestrial features to be discerned. Some of these fine details were lost in the classification processing of the data to produce the color coded "cluster map."

Data processing was done with ERDAS software, which utilizes an unsupervised training or clustering methodology. This unsurprised training is based on natural groupings of pixels in image data when they are plotted in spectral space. According to parameters specified by the analysts (Drs. Godfrey and Clark and Mr. Schmidt), these groups were later merged into simpler units that could be labeled using "standard" ecological terminology. The 65 classes initially generated by the ERDAS system were named based on the principal investigators' knowledge of marine, land and other surface features. Some of that knowledge was gained by truthing the island using the false color infrared images and annotating overlays on field prints. This naming procedure was done twice; once before ground truthing (60 classes) and again after ground truth was conducted (20 classes). There was so much detail in 65 classes in the image that the ecologists, botanists, and marine biologist had insufficient names for some of the subtle differences in classes. For example, varying depths of water over sand bottom, fossilized reef, or rock gave several different spectral responses and therefore, several classes, but true water depths and bottom combinations were impossible to discern without extensive ground truthing, which time budget constraints did not allow.

The final 20 class map produced by this effort is shown in Figure 3. The names of the classes are discussed in the following section.

Analysis Results

One-quarter scene of thematic mapper data containing San Salvador in a cloud-free acquisition (February 1985) was purchased from EOSAT. It was a full resolution data set that was processed at SSC/STL to form the baseline data set for ecological studies of the island. A second data set was acquired in March 1991, but out of several attempts by EOSAT to acquire a cloud-free scene in late February or early March, the scenes acquired contained so many clouds that the images were of no value if they had been classified. We, therefore, made only a false color infrared image of the south end of the island with bands 4, 3, and 2. With the lack of a good current data set, the project as originally proposed could not be completed. With a good second data set, change detection would have been assessed and other ecological trends could have been assessed.

The marine biologist, Dr. G. Smith, who has several years of data on seagrass beds around the north end of the island observed that the grass beds are definitely mappable using the thematic mapper 30 m resolution data. It is also believed that inventorying and assessing condition and productivity could be done given successive time-lapse images.

Also, with no current data set, there was no way to assess whether or not coral bleachout

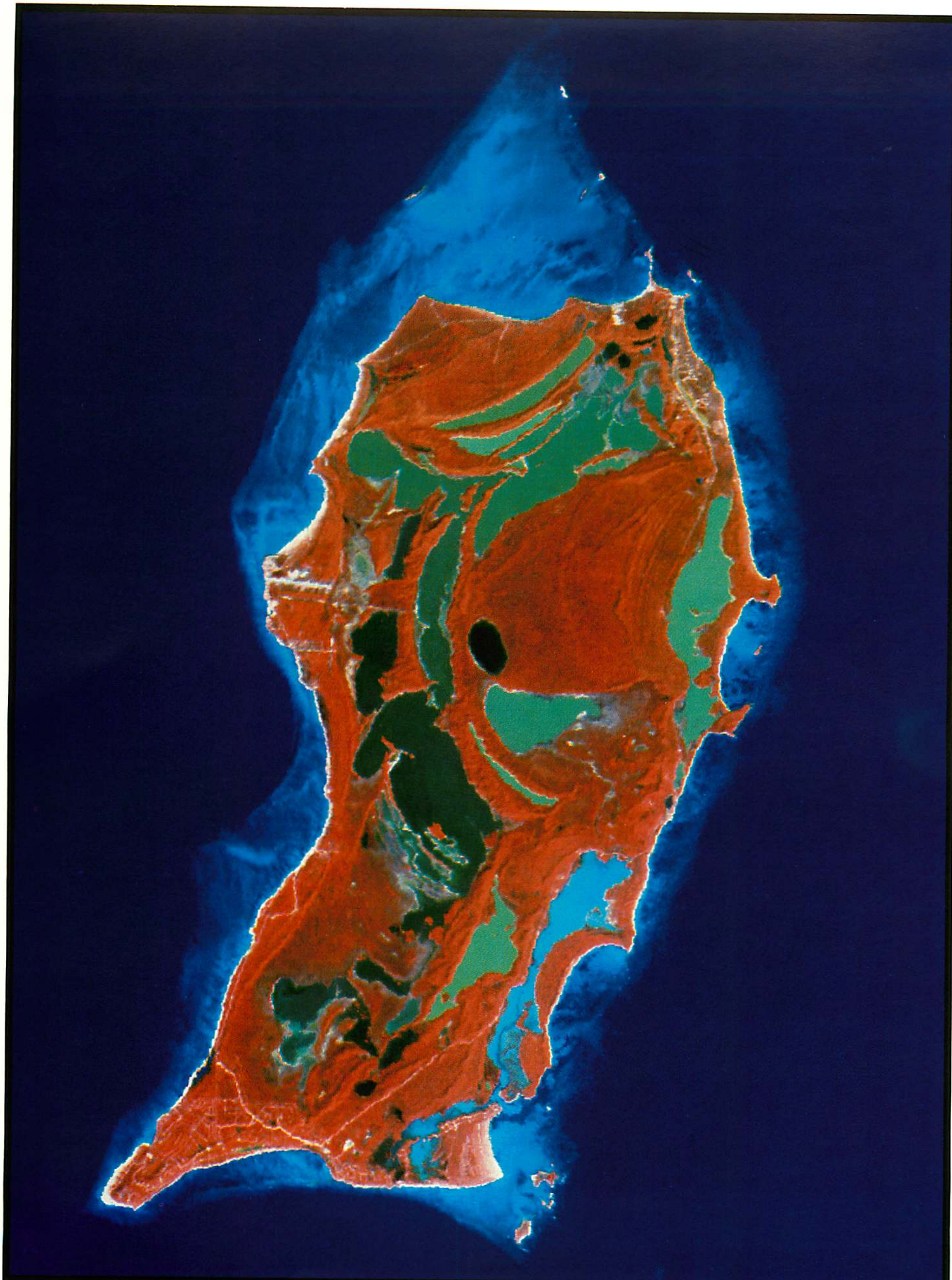

Fig. 2


LANDCOVER CLASSIFICATION
LEGEND
MARITIME TROPICAL WOODLANDS
MANGROVE SWAMPS
SAND RIDGES WITH MANGROVES
SALT MARSHES
COASTAL COPPICE (SHRUBLANDS)
SHRUBLAND TRANSITION
HOME/AGRICULTURE/DISTURBED
AIRPORT
CONCRETE AND BARE ROCK
COAST ROCK/SAND STRAND
BARE SAND
MUD/SAND FLATS/LOW MANGROVES
HYPERSALINE LAKES: <2X OCEANIC
HYPERSALINE LAKES: 2X OCEANIC
HYERPSALINE LAKES: >2X OCEANIC
LAGOON
MARINE: INTERTIDAL/SUBTIDAL
MARINE: INTERMEDIATE/SUBTIDAL
MARINE: REEFS AND SEAGRASS BED
MARINE: BLUE HOLES/DEEP OCEAN
LANDSAT THEMATIC MAPPER
IMAGE DATE: 2/7/85
NASA SSC/STL
NORTH

Fig. 3

could be mentioned by satellite (TM). This monitoring and detection would have required more intensive and more frequent ground truth over period of time.

The final class map, Figure 3, is the result of the unsupervised classification (65 classes) which then supervised and refined by the botanist, C. A. Clark. and ecologist, P. Godfrey, who worked at the CRT at SSC/STL in an interactive mode combining classes which were so similar that they could not be named given the limited number of ecological designations available to define them.

Discussions of the ecosystem or class names and rationale for the class names follow:

1. **Maritime Tropical Woodlands** - Descriptive words were used which more closely define the type of woodland on San Salvador and brings this vegetation more in line with terminology used for other forest communities. Only specialists would recognize "Coppice" or "Blacklands" as by Correll and Smith.

2. **Mangrove Swamp** - Most of the areas actually visited in this class were well developed mangrove swamps suggesting that unobserved sites are also mangroves.

3. **Coastal Coppice (Shrublands)** - Both Correll and Smith use "Coastal Coppice" for the shrublands, so usage of their standard term with some clarification was appropriate. No vegetative text uses "scrub" as an official vegetation type, but Webster's Dictionary does define it as "low trees and shrubs."

4. **Shrubland Transition** - This is clearly a recognizable class, but the transition it represents is not apparent. Comments for #3 apply here as well.

5. **Homes/Agriculture/Disturbed** - These names, "Homes" and "Disturbed" were used because Smith used this terminology on his map. The associated "scrub" is mostly likely the result of human disturbance.

6. **Coastal Rock/Sand Strand** - Terminology used by both Correll and Smith.

7. **Sand Ridges with Mangroves** - This is a meaningful, easily understood description of this surface feature type.

8. **Bare Sand** - Simply bare sand, with very little, if any, vegetation.

9. **Concrete and Bare Rock** - Selected to use the term "Concrete" as opposed to "Cement." "Bare Rock" is used in combination with concrete because its reflectivity would be close to concrete.

10. **Airport** - Runway of concrete and asphalt.

11. **Mud/Sand Flat/Low Mangroves** - This is a broad class combining several similar classes, such as Mud/Sand Flats w/ Sparse Vegetation, Intertidal Mudflats, and Mud Flats.

12. **Salt Marshes** - Correll used "Salt Marsh" to define this type of community, so it seemed prudent to use understood terminology, even though the vegetation does contain several low, woody perennials in addition to grasses and forbs.

13. **Hypersaline Lakes: <2X Oceanic** - This includes Little Lake and Central Great Lake; they contain some phytoplankton.

14. **Hypersaline Lakes: ~2X Oceanic** - This includes the northern arms of Great Lake; contains more plankton than Class 13.

15. **Hypersaline Lakes: >2X Oceanic** - This includes Granny Lake, Stouts Lake, Storrs Lake, Long Lake, and Fresh Lake. Contains maximum plankton, and most areas containing this salinity have stromatolites.

16. **Lagoon** - The ecologists were unable to better define this area, since it is undocumented, but believe it represents variable depths of water over sand bottom. The several classes which were combined into this one occur primarily in Pigeon Creek Lagoon.

17. **Marine: Intertidal/Subtidal** - Intertidal/subtidal and shallow water with sand bottom present a class naming problem without better field information.

The ecologists selected to call this group of classes the intertidal and subtidal because they represent shallow water and wet beaches in the tidal wash.

18. **Marine: Reefs and Seagrass Beds** - The next level below the tide lines are reefs and seagrass bottoms. The term "beds" is frequently used too describe vegetated bottoms. This habitat can be easily explored by snorkeling.

19. **Marine: Intermediate Subtidal** - "Intermediate depth" denotes a deeper subtidal region than classes #17 and #18. This region could be explored by snorkeling at low tide, or with SCUBA.

20. **Marine: Blue Holes/Deep Ocean** - This is the deepest water category and this name is more descriptive than just "deep water," since the blue holes can be identified as well as ocean water. This could be explored using SCUBA or submersible equipment.

COMMERCIAL APPLICATIONS

The greatest potential commercial application of the initial baseline surface cover map of San Salvador made from high resolution satellite remote sensing will be to the ecologists who are looking on the ecological impacts of development on the island and to hydrologists who are modeling the dynamics of the island's fresh water supply. Ecologists working at the Bahamian Field Station have a great need for a false color infrared map of island surrounding waters. Many of the researchers involved in geology marine ecology and systematic botany research have expressed a need for this baseline data as well as subsequent data sets obtained
at seasonal time intervals to monitor change.

In addition, the Bahamian Government will find the imagery to be of value in their mapping, inventorying and navigation operations. Hard copy images will be marketed to Florida marinas and chart stores for use as navigation and recreational aids to hundreds of boaters in the Bahamas. Enhanced false color images showing shallow bottom topography, reefs and potential hazards can be used by recreational and scientific communities.

Since 1992 is International Space Year and the 500th Anniversary of Columbus' first landing in the New World, a high quality image of San Salvador would tie space exploration to Columbus' exploration, thus combining leading edge technology with a very significant historical event. The images of San Salvador would be a great commemorative piece for the International Space Year and the 500th Anniversary of Columbus landing in the Bahamas. Several draft poster concepts are under development. On going discussions with potential financial sponsors of a commemorative poster will yield a commercial product by the summer of 1992.

CONCLUSIONS

This project has yielded numerous benefits to the scientific and educational communities. San Salvador is an important scientific resource area because of the well developed coral reef system surrounding the island and the threats to these reefs from various natural and unnatural diseases and current development plans by Club Med. The application of satellite image processing to data changes in the natural environment has been long documented for land surface features. However, applications of remote sensing technology to submersed features such as coral reefs and sea grass productivity is just beginning. The San Salvador study will provide excellent baseline data and methodology for continued research on the submersed and upland environment of the Bahama Islands.

With the 500th Anniversary of Columbus' discovery of America in 1992, the value of having an image of San Salvador becomes significant to historians, educators, scientists and tourism development professionals. On-going activities to commercialize the image into such products as posters and post cards will continue.