Nearshore Bathymetric Evaluation of Baie du Galion, Martinique Utilizing Landsat TM Data

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ABSTRACT

The use of remote sensing in fish management is primarily dependent on associated phenomena including temperature, chlorophyl content, sediment load, depth to bottom and bottom cover (vegetation). Several of these characteristics - specificially sediment and bottom cover - can relatively easily be detected using the Landsat MSS (multispectral scanner) in the shallow nearshore waters preferred by most artisanal fishermen. The project reported on here is based on an unsupervised classification of Martinique and surrounding waters using the Landsat TM scene obtained July 8, 1984.

While this system was originally designed to obtain terrestrial cover information, a number of algorithms have been developed which successfully have enabled useful classification of the nearshore marine environment in temperate climates. With increased clarity of most tropical and subtropical nearshore waters, this technology can successfully be used not only to identify bottom covers, but also to identify such nearshore phenomena as algae blooms, sediment loadings and other man-induced contributions to the marine environment.

Even with recent increases in costs of the computer compatible tapes (CCTs) large area (small-scale) surveillance in both low- and mid-latitude countries can be a very cost effective fish management tool. This is especially true in those areas which are inaccessible or which have been adversely impacted by environmental degradation.

INTRODUCTION

While Landsat remote sensing has been around for more than a dozen years, most applications have addressed terrestrial non-coastal problems in the mid-latitudes. The utility of the Landsat system for direct fish detection is very limited (Brucks, 1979) primarily because the areal resolution of the sensors is on the order of 1 acre for the multispectral scanner (MSS) and 1/4 acre for the thematic mapper scanner (TM).

Another limiting factor of the Landsat imagery for direct fish detection has been the approaches which the remote sensing community has taken when this technology has been applied to resource identification and analysis. Two approaches have been followed. One is technology-driven while the other is problem-driven. In its classical form the technology-driven project asks what problem can be solved with a given level of technology. To a considerable extent, surveillance of environmental parameters have been influenced more by the capability of the technology and less by the relative importance of environmental indicators and the identification and management of our natural resources.

The problem driven-projects, on the other hand, ask two questions: (a) what is the problem which the resource manager needs to have resolved, and (b) what technology is available or, if unavailable, can be modified or developed to solve this problem. It is clear that the remote sensing research related to fisheries falls into the second category. Remote sensing fisheries related research has largely been conducted by remote sensing experts as opposed to fisheries and/or environmental managers and researchers. The most obvious reason for this is undoubtedly related to the complexity of remote sensing technology as perceived by many resource managers, including those with primary responsibilities in fisheries. Consequently, the few fishing related remote sensing studies which have been conducted in recent years have searched for ways to apply current technology to facilitate the catching of fish. The contrasting approach would be to identify current problems confronting a given inshore or offshore fishery from an ecological perspective and then urge the development of the necessary sensors and software.

With the federal government's growing emphasis on private sector involvement in both research and technology dissemination, there is reason to believe that more private sector efforts will be involved in the future, provided such applications will be marketable. Until such time as the technology capable of providing answers to specific fisheries related problems has been developed, remote sensing research and surveillance will have to rely on what is currently available. This in turn raises questions of how the coastal management community can best serve the needs of the fisheries constituency. It is suggested that the use of existing software when combined with some knowledge of the environmental parameters associated with specific fisheries may stretch the research capabilities of the Landsat system beyond what was originally intended.

Existing scanners are not able to identify fish or even schools of fish except under most unusual circumstances. This raises legitimate questions whether satellite remote sensing can ever make significant and cost effective contributions to the fishing industry. We believe this technology can contribute to making both offshore and especially inshore fisheries more efficient in at least two different contexts. Since direct detection of fish is out of the question, the analyst/fish manager must rely on associated environmental parameters. For discussion purposes these fall under two headings. One relates to those fisheries which are dependent upon emergent vegetation. The second concerns fisheries which are influenced by either surface or bottom characteristics of fisheries affected by matter located within the water column.

The first category includes nearshore area detection and in particular the wetlands (marshes and mangroves). Since upwards of 90 percent of fish stocks spend all or a large portion of their lifecycle in inshore areas, information about the quantity and quality and their rate of degradation are extremely important for the long term viability of the fishery. Considerable research using both the MSS and TM scanners to identify and classify the low latitude wetlands has been undertaken (Carter and Schubert, 1974; Bartlett and Klemas, 1981). Although no cause and effect relationship has been conclusively shown, there is substantial evidence that a strong relationship exists between shrimp larvae production in Ecuador and the rate of mangrove degradation (Norton, 1985).

The project reported on here seeks to address the problems confronting the fisheries manager in the nearshore marine environment. The research is limited in scope to the Havre de la Trinite area extending south from Ste. Marie through the Baie du Galion and the peninsula Presq'ile de la Caravelle' on the island of Martinique (Figures 1 and 2). It is the authors' conviction that the capabilities identified in this paper can be transferred and applied with relative ease to nearshore fisheries problems in other low latitude coastal countries.

The nature of the nearshore marine environment is unique. Much of the vegetation is not clearly separated from the water which makes classification (identification) of the landcover difficult. This is because water absorbs much more of the electromagnetic energy compared to that reflected from bare ground, such as sand, rocks or soil or the vegetative canopy. Nonetheless, much of the wetlands vegetation grows in areas that are well defined on the basis of pedology and hydrology which makes broad wetlands classification possible.

The second area in which remote sensing may contribute to higher catches fall into two categories. One is associated with the bottom cover in the nearshore area, while the other is concerned with materials located either on the surface of the water or within the water column. In both instances the value of remote sensing is based on the researcher's ability to identify those environmental factors which are commonly associated with specific fisheries. In other words, if environmental conditions can be associated with parameters which in the past have suggested high incidences of a particular species, there is reason to believe such associations may be replicable in other areas as well.

Examples include: the 21 degree (centigrade) isotherm which has been found to be associated with a relatively higher number of swordfish appearing very close to the water surface in the New England region. Other correlations between environmental parameters and biological productivity includes areas of upwelling which may be either permanent (Finlay and Baumgarter,

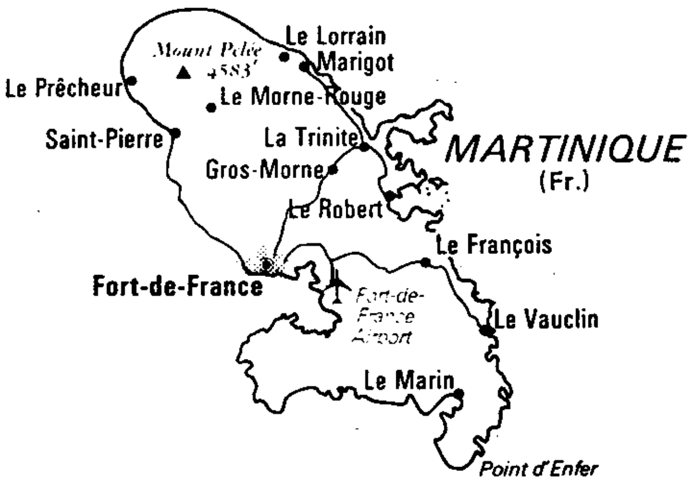

Figure 1. Martinique.

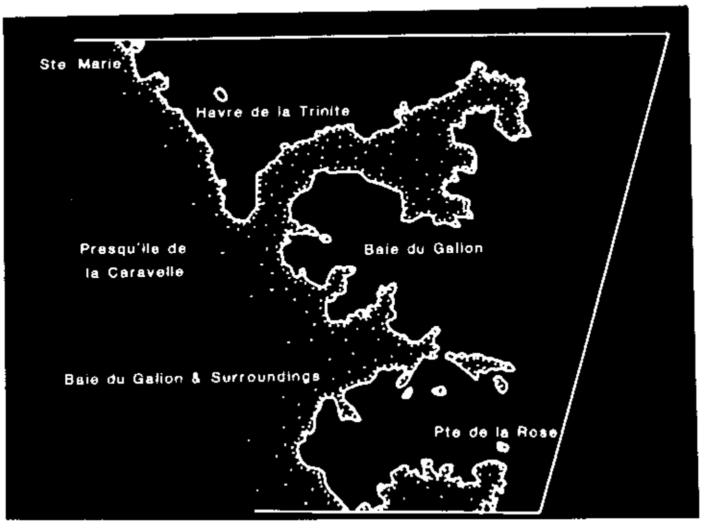

Figure 2. Study areas Baie du Galion and Havre de la Trinité.

1980; Munday and Zubkoff, 1981) or dynamic (Feeley and Lamb, 1981). These oceanic regions are often associated with rich nutrient laden bottom waters on which phyto- and zooplankton and subsequently higher trophic levels feed. Both of these cases are elementary and well known by the fishing community.

Considerable efforts have been made to extend the Landsat technology to the nearshore benthos. While this satellite system was never intended for extensive nearshore surveillance, recent experience indicates that under certain conditions benthic cover can be identified. Reasonable success has been accomplished on an experimental level to detect coral reefs in the Philippines (Anonymous, 1978) while other efforts have succeeded in identifying demersal vegetation in many mid and low latitude coastal areas (Jensen and Estes, 1980).

Other Satellite Systems with Marine Applications

Two additional systems should be mentioned which have particular utility for offshore applications. The Advanced Very High Resolution Radiometer (AVHRR) is a sensor designed primarily to measure electromagnetic radiation in the thermal infrared range while the Coastal Zone Color Scanner (CZCS) is capable of measuring pigment in the green range of the electromagnetic spectrum. This is particularly useful when the object is to identify and measure the biomass of phytoplankton (Khorram, 1981). Unlike the Landsat system with its fine resolution, both the AVHRR and the CZCS have resolutions on the order of 1000 m^2 which is generally much too coarse for detailed nearshore spectral analysis. The advantage of these systems is their almost continuous coverage (every 12 hours). Finally, many researchers, ourselves included, are looking forward to the time when data from the French SPOT system will become generally available. This data will increase surface resolution to 10 m^2.

Landsat Thematic Mapper

Landsat V, launched March 1, 1984, is the fifth of the Landsat series that started collecting land cover data in 1972 (NOAA, 1985). The satellite is in a nearly circular orbit between 80°N to 80°S latitude, orbiting at an altitude of 705 km (438 miles). The period of repeat coverage is 16 days for Landsat V, as compared to every 18 days for Landsat 1-3. When the two systems are operating simultaneously, repeat coverages of every 9 days is theoretically possible. Surface events on the land happen very slowly, making this frequency of repeat coverage satisfactory for most terrestrial applications (Cornillon, 1981). The Landsat V satellite carries two sensor packages. The Thematic Mapper (TM) sensor records electromagnetic radiation from seven different bands, also referred to as channels, as follows:

1) Blue light	(0.45 - 0.52 micrometers)
2) Green light	(0.52 - 0.60 micrometers)
3) Red light	(0.63 - 0.69 micrometers)

4) Near infrared (0.76 - 0.90 micrometers)
5) Near infrared (1.55 - 1.75 micrometers)
6) Thermal infrared (10.50 12.50 micrometers)
7) Mid-infrared (2.08 2.35 micrometers) (NASA, 1982).

The TM has three additional bands compared to the MSS system. The new bands are: blue visible light, mid-infrared and a thermal infrared.

MARTINIQUE DATA SET

The TM data set used for this classification is dated July 8, 1984. Unfortunately, clouds and water vapor cover extensive areas including many coastal regions which makes landcover identification very difficult. The quality of the individual electromagnetic bands was classified mid-range except the near infrared (band 5) and mid-infrared (band 7) which were of high quality. The scene center is located at Lat. 14° 27'N and Long. 61° 29'W. Unfortunately, the availability of TM data for areas outside of North America is still quite limited. The data set on which this analysis is based is one of a relatively few available within the Caribbean basin.

Only two navigational large-scale charts covering all of Martinique have been identified, one by Imray Laurie Noirie and Wilson Ltd., U.K. (Imray) and one by the U.S. Defense Mapping Agency (DMA). The Imray chart is published on a 1:92,000 scale (1 inch to 1.4 mile). Besides identifying coastal drainage basins, it contains more soundings compared to the DMA chart. The Imray chart characterizes the nearshore area in three classes (0 - 6 feet, 6.1-30 feet and depths greater than 30 feet). In addition, areas covered extensively by coral reefs and rock outcrops have also been identified. The chart also includes the 30 foot and 130 foot contours. Most importantly, it includes chart inserts of ports, harbors and significant channels with much greater detail than is included on the main chart. These depth contours have been reinterpolated and graphically represented in Figures 3 through 12. Much of the data has been collected or edited by Don Street, a noted yachtsman who has sailed extensively in the Caribbean. The DMA publishes chart #25524 on a scale of 1:75,000 which also includes coastal river basins. The chart has fewer soundings, and does not include detailed inserts of ports, harbors and significant channels. Consequently, we chose the Imray chart to work from, even though the actual bathymetry may date back to the 19th century, thus leaving open the question about changes in the water depth during the more than 80 years since the areas were last charted.

Unsupervised Classification and Analysis

Land cover information obtained from a Landsat scene may be analyzed in two different ways, referred to as supervised and unsupervised classifications. The supervised classification requires a priori knowledge of the area to be analyzed. In these

Figure 3. Six foot contour, Havre de la Trinité (after Imray).

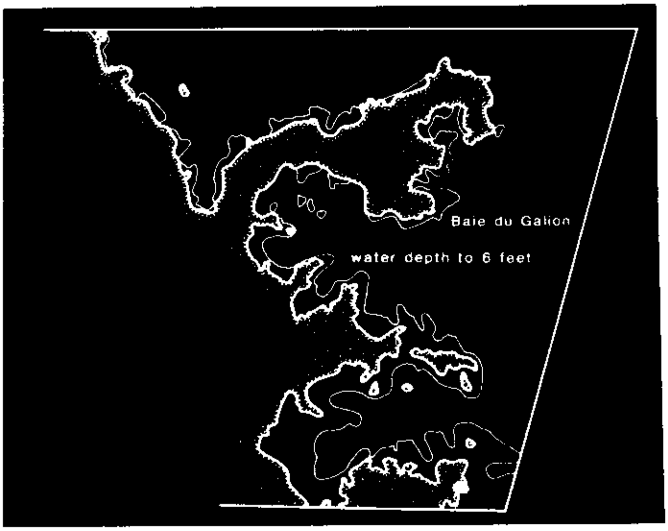

Figure 4. Six foot contour, Baie du Galion (after Imray).

Figure 5. Thirty foot contour, Havre de la Trinité (after Imray).

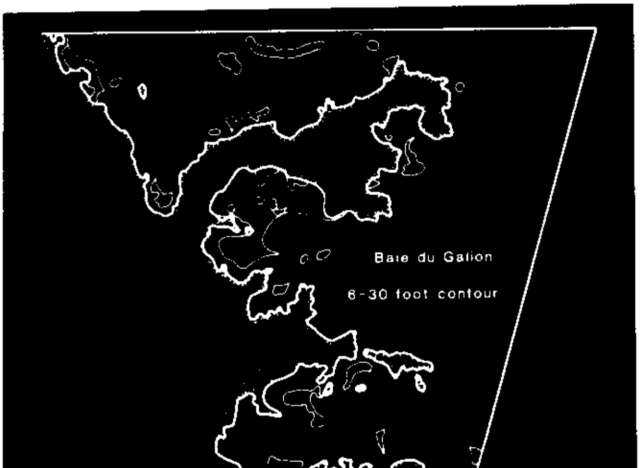

Figure 6. Thirty foot contour, Baie du Galion (after Imray).

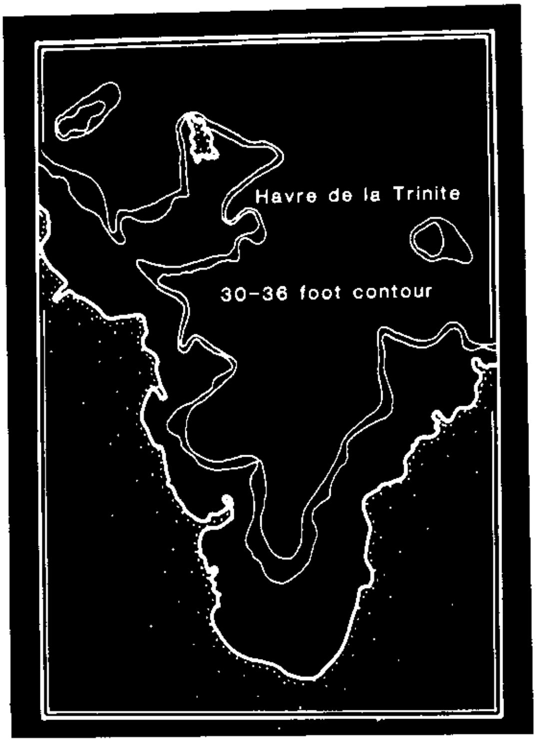

Figure 7. Thirtysix foot contour, Havre de la Trinité (after Imray).

Figure 8. Fortytwo foot contour, Baie du Galion (after Imray).

Figure 9. Thirtysix and fortytwo foot contours, Havre de la Trinité (after Imray).

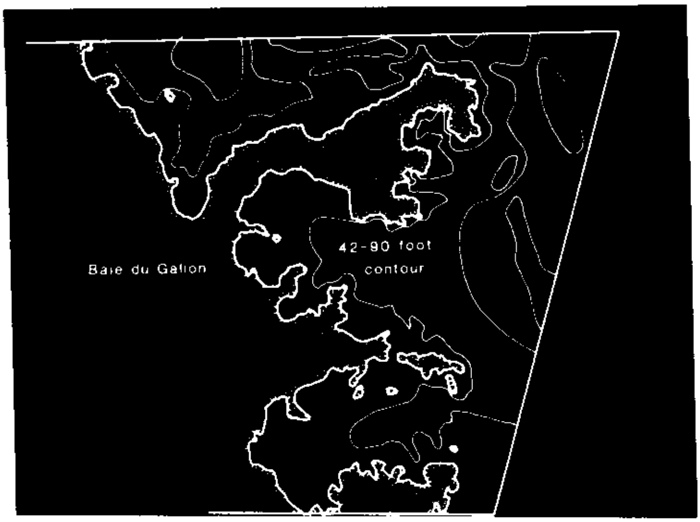

Figure 10. Fortytwo and ninetytwo foot contours, Baie du Galion (after Imray).

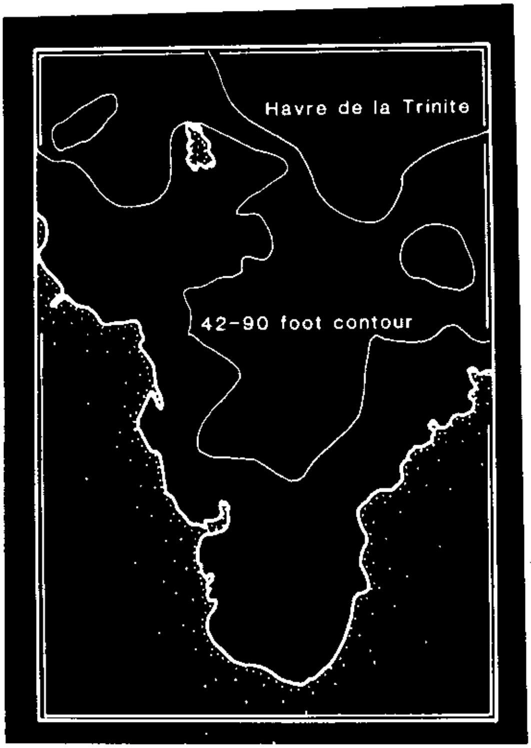

Figure 11. Fortytwo and ninety foot contours, Havre de la Trinité (after Imray).

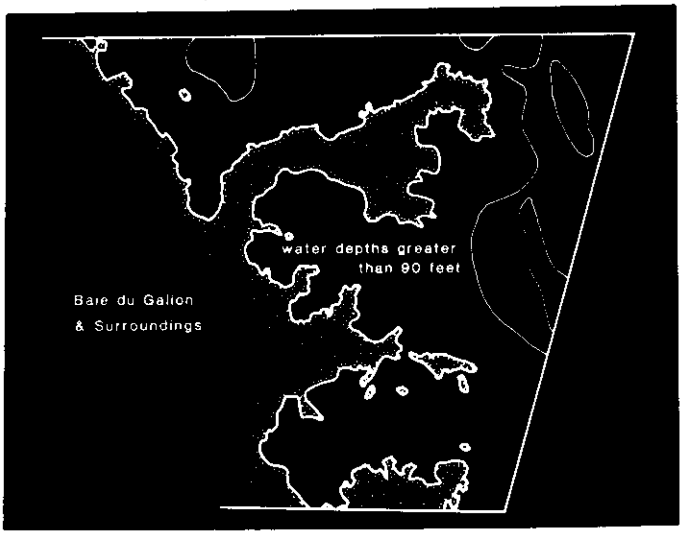

Figure 12. Ninety foot contour, Baie du Galion (after Imray).

Figure 13. Unsupervised Landsat Thematic Mapper classification of shallow waters, Baie du Galion and surroundings.

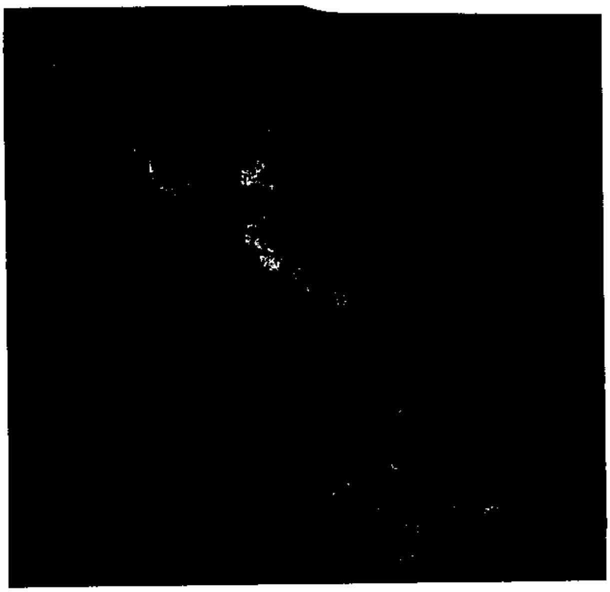

Figure 14. Unsupervised Landsat Thematic Mapper classification of nearshore bathymetry, Baie du Galion and surroundings.

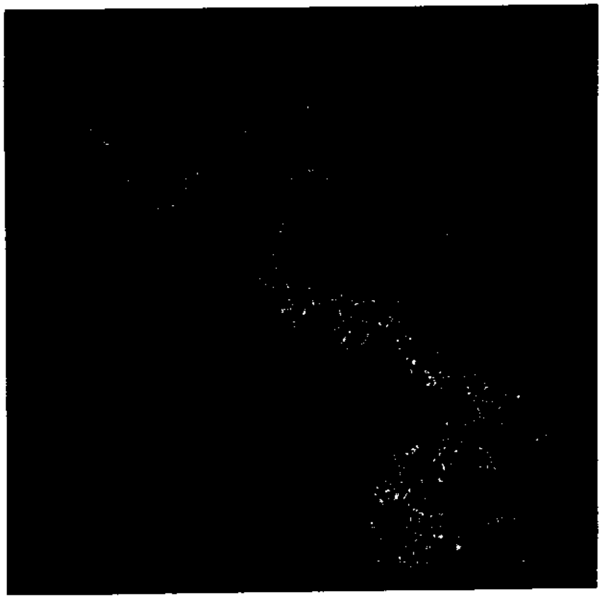

Figure 15. Unsupervised Landsat Thematic Mapper classification of intermediate bathymetry, Baie du Galion and surroundings.

Figure 16. Unsupervised Landsat Thematic Mapper classification of waters with depths between 42 and 90 feet, Baie du Galion and surroundings.

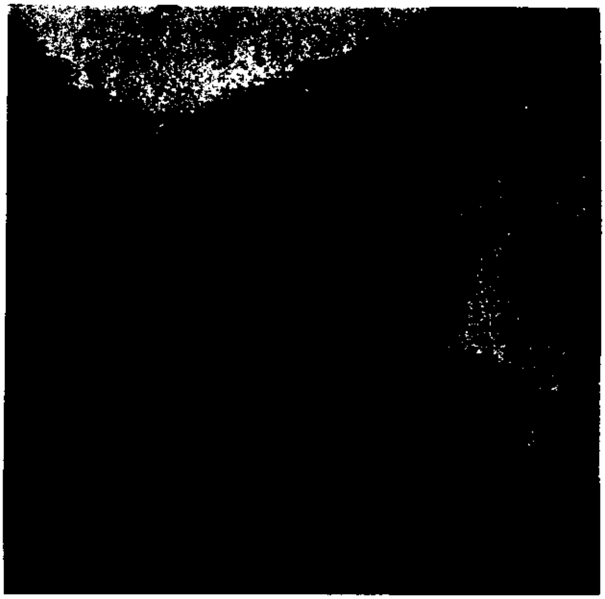

Figure 17. Unsupervised Landsat Thematic Mapper classification of waters in excess of 90 feet.

instances the analyst knows the geographical location of specific land cover types, the reflectance values (electromagnetic energy) of which are being used to classify all other pixels in the scene with similar reflectance signals. The unsupervised classification refers to a procedure by which a classification scheme is developed using the Maximum Likelihood Classification algorithm such that all pixels are grouped without the analyst knowing the associated landcover. This procedure is usually done as a first approximation especially for areas for which accurate landcover information is not available to the analyst, or for areas where ground truth information is either scant or absent. According to Bayes' rule the pixel is assigned a class value in accordance with the probability of its occurrence within that class. The mean vector and covariance matrix from the training site statistics computed by the search routine was used to determine the best fit assignment for classification. Each input pixel is assigned a class from the statistic into which that pixel fits the best.

The Landsat data was processed using the software package ELAS written by the Earth Resources Laboratory of NASA's National Space Technology Laboratory, Bay St. Louis, Mississippi (Junkin, 1980). The software package is made up of more than a hundred modules, each of which is being responsible for a specific type of processing. The software is user interactive and specializes in the use of color image display and manipulation. The ELAS software operates under a control file environment. This control file structure "keeps track" of all processing results from each module that has been used during the processing. This information is stored for the user in the control file for reuse and all values stored in the control file by the user can be used by other ELAS modules as input or intermediate information required to perform its task.

RESULTS

The original analysis was undertaken in two parts, one for the north coast of Martinique and one for the east coast of the island, although only the results from the east coast are included here. The procedures undertaken for both areas, however, were identical. The statistical output represents the suggested land cover classes that were clustered from this window of data. A total of 38 classes resulted from the unsupervised classification covering both terrestrial and marine (nearshore) cover classes. Since our attention is directed towards an analysis of the nearshore region, all terrestrial classes were merged into one class. This "Land" class also includes the several cloud cover and water vapor classes which appeared centered over the land portion of the image. Of the 38 classes, 33 comprised terrestrial and cloud classes. Following this procedure, a total of five water classes were identified. These images are represented in Figures 13-17. In each of these figures the class highlighted is represented in the lightest shade.

Each of the five water classes were visually correlated with the bathymetric contour of the Imray chart with which it was most closely associated and which have been depicted in Figures 3-12. Areas included within each class was measured using standard planimetric procedures and compared with the corresponding areas estimates of the Landsat scene. This measure is computed by the ELAS module PLYA and is based on pixel size of 1600 m^2. The results from this analysis appear in Table 1.

Table 1. Comparative areas analysis of the Baie du Galion nearshore waters

Water Classes	Imray Chart Area (hectares)	Landsat Scene Area (hectares)	Percent Differences
0 - 6 feet	2954	4116	39.3
6.1 - 36 feet	3123	3168	1.4
36.1 - 42 feet	606	1038	71.3
42.1 - 90 feet	4739	599	87.4
greater 90.1 feet	2757	1167	57.7

To a considerable extent, the analysis of the nearshore bathymetry in the two areas under study in Martinique is analogous to identifying the image on the far side of the moon. Neither of the authors had visited the island prior to the analysis. As indicated above, only scant bathymetric information is available. Information on bottom cover and material present in the water column is even more scarce. The relatively poor fit between the information obtained from the Imray chart and the Landsat generated data may be affected by a number of factors, each of which may be significant in a nearshore fisheries context. In tropical waters the clarity of the water is generally much greater than in the high latitudes. The exception occurs when effluents (man-made) and sediments are flowing out into the nearshore marine environment. In these events, the clarity of the water may be adversely affected some distance from the shore. To the extent that the introduced material differs from the reflectance of the receiving waters, this material may be detected by the satellite scanner assuming the minimum areas impacted are larger than 40 m^2. While numerous small rivers and streams drain the northern part of the island, no extensive delta systems have been created in either of the two specific areas under study. The absence of deltas and effluent plumes is no doubt a function of the strength of the longshore drift which in turn appears to be a function of the northeast trades and associated high wave energy dissipated in the nearshore. In addition, the many coastal communities located especially on the east coast of Martinique undoubtedldy contribute effluent to the nearshore marine environment. This additional "load" is likely to contribute measurably to the classes in the inshore areas. Finally, the rapidly increasing depth in this area also contributes to the relatively early dispersal of materials regardless of origin which have been submitted to the nearshore marine environment.

The second problem relates to the presence of bottom covers. These may be influenced by the extent the bottom is covered or ucovered by either emergent or demersal vegetation. Thus, two benthos with similar water depth may reflect different wavelengths depending on the material covering the bottom. From an applied research point of view, this problem can be resolved relatively easily, provided reflectance values can be obtained for the various nearshore ecosystems which the fisheries manager is interested in identifying.

ACKNOWLEDGMENTS

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Endnote

Since presenting this paper, the authors have been in touch with several local scientists who have researched the coral reefs on both the east and southwestern part of the island. Plans are currently progressing to mount a cooperative research effort to develop a supervised classification of parts of Martinique's shoreline using ground truth information obtained by local scientists.