Towards a Management Plan for a Tropical Reef-Lagoon System Using Airborne Multispectral Imaging and GIS

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ABSTRACT

The Ministry of Fisheries and Marine Resources of the Republic of Mauritius, situated in the south-west Indian Ocean, has a requirement to map the coastal lagoons and coral reef areas of the islands of Mauritius and Rodrigues as part of their marine environment management planning. We used a compact airborne imaging spectrometer [CASI] to acquire 11 spectral bands of digital imagery at 4 m ground resolution, on over 115 flight lines averaging 5 km in length. The imagery was radiometrically calibrated, corrected for aircraft roll, pitch and yaw, mapped north-up using differential GPS and mosaicked in groups of 5-25 lines. SPOT panchromatic imagery was used to adjust the final image positioning.

Using *in situ* observations of bottom type, and reflectance spectra of coral and algae specimen as ground truth, the image data were classified and thematic maps of the shallow lagoons and coral reefs were created. These maps were imported to a Geographic Information System (MapInfo) and are being used to train Ministry staff in the use of GIS for marine management and planning.

1.0 INTRODUCTION

The Republic of Mauritius, in the south-east Indian Ocean, is a small (1865 km^2) volcanic island surrounded by an extensive fringing coral reef and lagoon. There is a strong need to improve the management of the coastal areas, as increasing urbanization, tourism, industrialization, fishing, sand mining and other extractive uses of the lagoon are putting pressure on the nearshore marine environment.

The island is also near near a major shipping route from the Persian Gulf to Europe, and increasing ship transportation of oil and other hazardous goods is a concern.

Detailed mapping and ongoing monitoring form an integral part of most management techniques. The Ministry of Fisheries and Marine Resources is implementing a Geographic Information System (GIS) for coastal areas to facilitate such management, and this requires a map base. No bathymetric mapping or suitable recent aerial photographs of the reef area exist.

The Ministry decided to use a more modern digital approach involving objective, multispectral classification which is not possible from film.

Airborne imaging was chosen because of the requirement for high spatial resolution, interest in producing a habitat classification, and because at the time, there was very limited coverage of the island from satellite sensors.

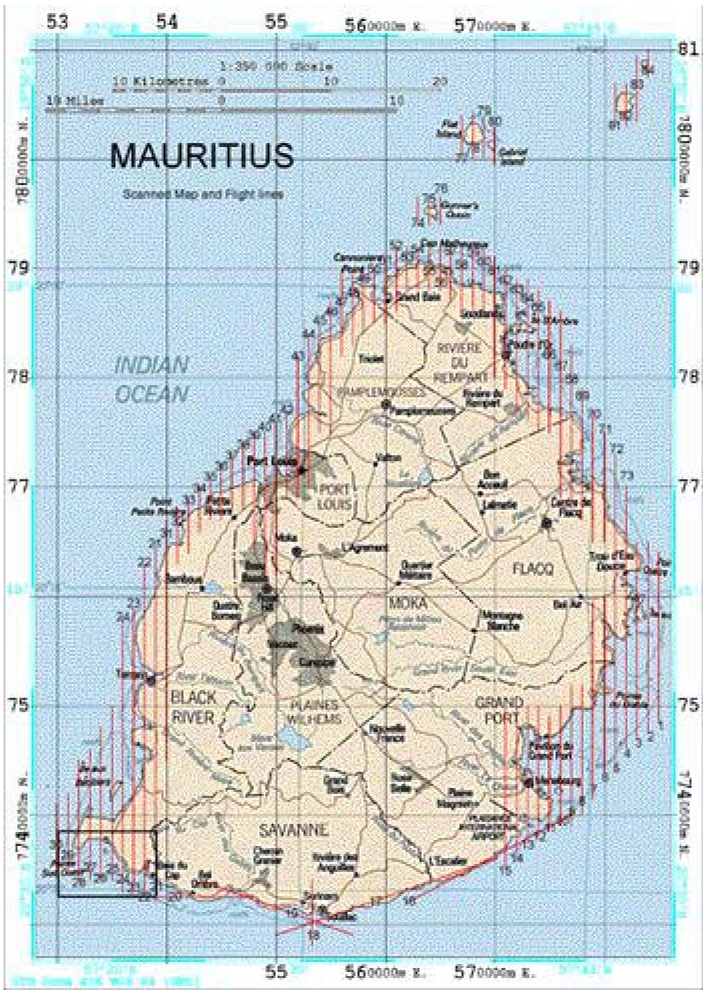

Figure 1. Map of Mauritius showing the flight lines (red) flown during the CASI mission.

2.0 METHODOLOGY

2.1. AIRBORNE MULTISPECTRAL SURVEYS

The airborne package used was based on an Itres Instruments Ltd. 'Compact Airborne Spectrographic Imager' (CASI), which acquires multispectral imagery (Borstad and Hill, 1989; Borstad 1992), and a 80486-based custom built Auxiliary computer which records and synchronizes auxiliary data from the aircraft navigation system, a separate two-axis gyro (for correction of imagery for aircraft roll and pitch), an incident illumination sensor (for reflectance calculations) and a Global Positioning System (GPS) receiver.

The Borstad CASI covers the spectral range 403 nm to 946 nm (the human visual range and into the near infra-red), operating as a multispectral imager with up to 15 spectral bands. Ground resolution for this survey was 4m, as determined by the aircraft altitude (11,000'), ground speed (104 knots), and the instrument instantaneous field of view (35.5 degrees) and integration time (75 msec). The equipment was shipped in 9 luggage size cases, which traveled to Mauritius with the operations crew as excess baggage. The gear was mounted in a twin engine Dornier 220 aircraft, operated by the Mauritius Coast Guard.

Following a series of preliminary flights, a spectral band set was developed to optimize the detection of corals. The bands were selected on the basis of trial airborne data, on-ground spectral data, and previous experience with the classification of intertidal biota. One hundred and fifteen flight lines were then acquired on eleven flights made during the course of the three-week field mission (Figure 1). Because of fast moving low cumulus clouds which are prevalant over tropical islands most of the year, it was not possible to predict which flight lines could be flown on any one day. The mode of operation was to go aloft and look to see which lines could be flown. Many lines were flown on more than one day, as the opportunity presented itself later in the mission.

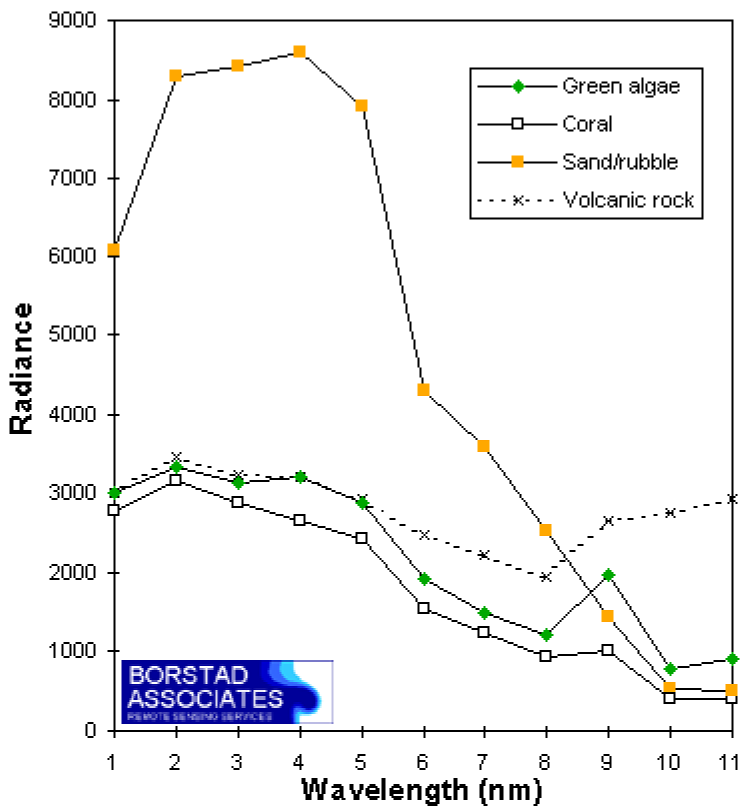

Figure 2. Typical upwelling radiance spectra for four representative classification themes (at 10,900' altitude).

2.2. THE DATA PROCESSING STREAM

Calibration/Navigation: A Sun Sparc5 work station, and data calibration and PCI EASI/PACE image processing software were taken to Mauritius. Calibration proceeded immediately after flying to maintain a close watch on quality control, and most data was processed to a first order mapping before the field crew left Mauritius. Further processing, including mapping of the image data, mosaicking and classification was completed in Canada.

One problem encountered was the lack of good base maps for the coastal zone There was also difficulty in obtaining projection information for existing mapping. In order to facilitate future use of GPS positioning, a move to WGS84 was implemented. Because of difficulties in establishing the correct control of the maps, we carried out a GPS survey by vehicle around the coast road. When differentially corrected, this road survey was used to provide control for a SPOT multispectral image mosaic, which was in turn used to provide the basis for navigational checks on the airborne imagery.

Classification: The coastal area was divided into 14 mosaics of approximately 100-150 km^2 each. Using ground control points, flight lines were first individually corrected to the SPOT imagery, then mosaicked together, colour matching and correcting for atmospheric effects where necessary. In general, colour matching was required only for lines acquired on different flight days.

Classification of each mosaic was performed using a combination of unsupervised (PCI ISOCLUS) and supervised approaches. Following an initial masking of deep water and terrestrial areas, ISOCLUS was run iteratively to develop themes tentatively identified as live coral, seagrass and algal beds, exposed sand and dead reef, and volcanic rock. These identifications were made on the basis of preliminary ground truth surveys of bottom type from various locations around Mauritius Island, from which generalized spectral signatures were developed. As well, spectral data were obtained for live samples of coral and algae taken from the lagoon.

Supervised classification was used to refine the classification in areas of mixed or spatially complex habitat. Spectral signatures used as input were generated from training areas within each mosaic for which the biota were known or easily recognized.

Classification and false colour maps were produced from these preliminary classifications, and used to direct ground truth surveys which were conducted by the Ministry of Fisheries and Marine Resources diving team. Ground truth data were then used to refine the original classifications and produce final maps. These were filtered and vectorized for incorporation into the GIS database.

Table 1. Classification Results for the Imagery Shown in Figure 1.

Class Description	Hectares
Deep water	620.88
Mid-depth water	15.98
Shallow sand/coral rubble	488.26
Deep sand (outside reef)	66.26

Coral	141.06
Deep corals (outside reef)	556.94
Green algae; seagrass	50.36
Other algae, shallow/high density	325.58
Other algae, deep/low density	161.14
Mud/turbid	56.62
Mud/turbid with vegetation	24.28
Black volcanic rock	0.72
Beach; exposedsand	95.44
Land	1233.73
Breakers/cloud/boats	17.43
Unclassified	1.14
Image total	3855.82

Figure 3a. Near true colour imagery of the southwest coast of Mauritius from Le Morne to Baie du Cap. Red (Band 7 639-650nm), Green (Band 4 526-542nm), Blue(Band 1 421-450nm) data are shown.

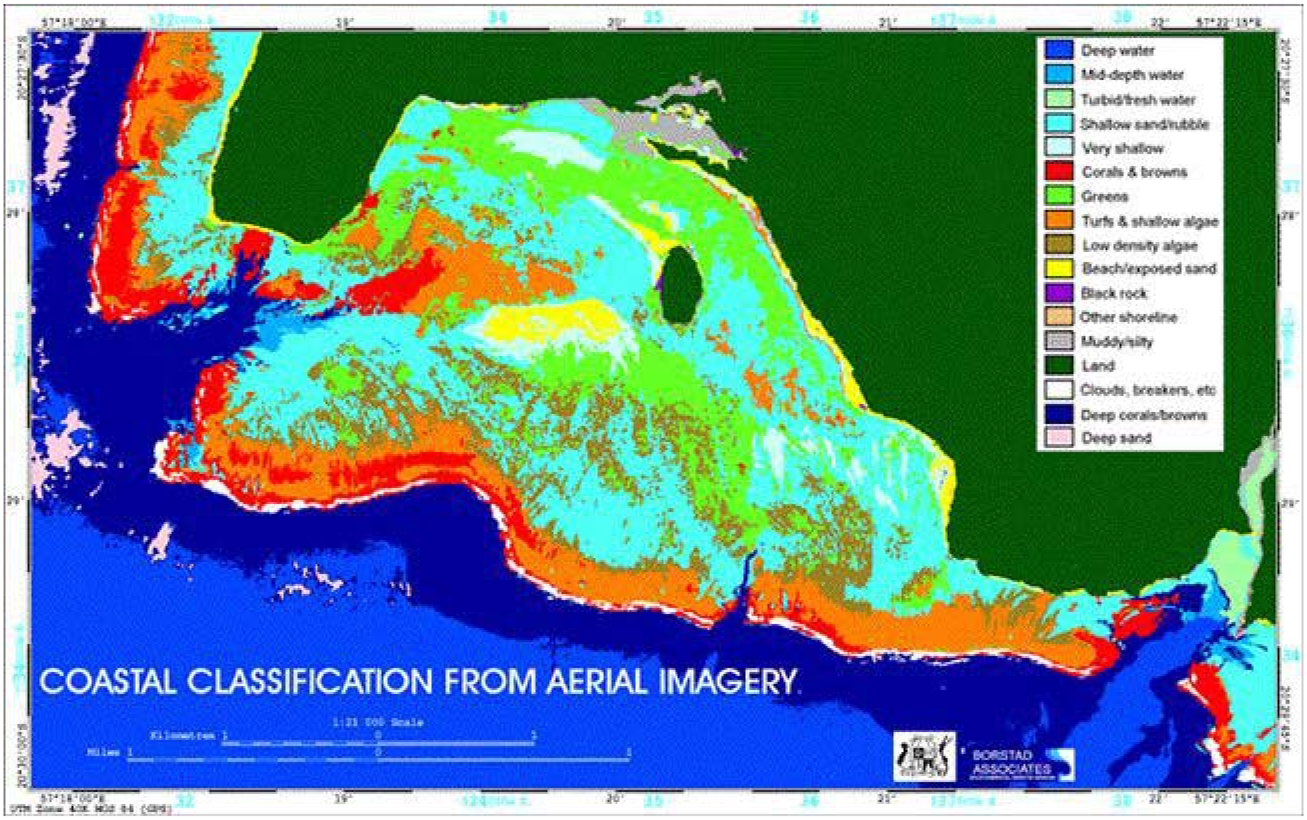

Figure 3b. Preliminary classification map of the same area (illustrative purposes only).

Consistency in classification between mosaics was achieved by a slight overlapping of their extents. Thresholds for class identification (presence vs. absence) were based on signal strength which is a function of class density but also of illumination and water depth (tide). Since these varied between mosaics (or occasionally within mosaics), the overlap areas were useful to correct for these.

<u>Ground truthing</u>: Using image maps produced from the digital airborne data in true colour, false colour, and preliminary classification, a ground-truth (more correctly, sea-truth) team explored several areas in each mosaic by boat, wading, and snorkelling. At points along lines suggested by the image maps, we recorded position, depth, time and date (to allow tidal correction), and estimated turbidity and substrate type and cover. Position was determined by GPS (not differential), and on some occasions GPS and a notebook computer running "The Geographic Tracker" and "MapInfo" were used to follow progress on the image map and find particular habitat themes for verification. Because of the low accuracy of the autonomous GPS positions, points where information was recorded were restricted to the central portions of large areas shown on the image maps.

2.3. GIS TRAINING

A six-week training program was conducted covering use of MapInfo (a simple GIS program for Windows) and an introduction to marine environmental applications of GIS. MapInfo was selected because of ease of use, cost and the ability to integrate vector and image data. On completion of this training the MFMR staff found immediate applications for MapInfo to support resource management decision-making.

3.0 IMAGERY

A mosaic of seven flight lines from the southwest region of Mauritius is shown in Figure 3 (upper illustration). Despite the fact that there is on average 50-60% cloud cover over the island, a nearly cloud free mosaic was acquired for the entire island by flying the lines as they became clear - at different times of day and in different order when the clouds moved away. Using spectra acquired from the air of various known bottom types (Figure 2), the classification map shown in the lower half of Figure 3 was produced. Statistical treatment of the data was then possible (Table 1).

This project is ongoing. An inventory of marine resources, special status areas, and potential sources of marine environmental impacts has been initiated which will contribute to future planning and marine resource management in Mauritius.

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