SHALLOW WATER MAPPING OF CORAL REEF HABITATS: A CASE STUDY FROM THE GREAT BARRIER REEF

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ABSTRACT

A ground truth study at John Brewer Reef, Great Barrier Reef (Australia), was carried out in order to test whether the already established geomorphological mapping of coral reef zones can be extended to the mapping of the living components of the reef substrata. Present results indicate that the spectral and spatial resolution of Landsat MSS data does not permit the distinction of hard coral substrata from algal substrata, which are the two dominant classes of living cover. Shallow coral reef habitats are very heterogeneous over a wide range of spatial scales and therefore the higher spatial resolution of SPOT XS was evident in a classified image. A detailed analysis of feature detection and separability for SPOT is in progress. In addition, the increased spectral resolution of Landsat TM data at the important blue end of the visible spectrum is presently under investigation.

INTRODUCTION

Coral reefs are often remote and difficult to visit regularly for resource monitoring purposes. They are usually large, sometimes many kilometres in length, which adds to the cost of sampling by field observation. The Great Barrier Reef (GBR) of Australia is an archipelago of approximately 3000 individual reefs, extending over 2000km. In the last 25 years, many reefs in the central region of the GBR have been altered greatly by outbreaks of the Crown-of-Thorns starfish, *Acanthaster planci*, which eats the live coral allowing subsequent growth of algae on the bare skeletons of the coral. Reefs that have been severely disturbed by starfish outbreaks have been observed to change from being coral dominated to algal dominated (Moran, 1986). Existing methods for monitoring the effects of this starfish all involve underwater sampling by divers which is very costly. Consequently remotely sensed data are being evaluated as a more cost-effective alternative.

Landsat MSS imagery has already been established as an valuable tool for broadscale mapping of coral reef zones (Smith, 1975; Jupp et al., 1985b) at the geomorphological scale. A reef cover model with classes such as 'reef front', 'outer reef flat' and 'lagoon' was generated by Jupp et al. (1985b) using Landsat data and these classes matched closely the major geomorphological zones for coral reefs defined by Hopley (1982). In order to study effects of starfish outbreaks (COT-CCEP Crown-of-Thorns Study, 1986) the monitoring method must permit the distinction of coral from algae within any particular zone and, for ecological monitoring in general, the mapping of substrata at scales finer than that of the geomorphological zone is required.

Substratum mapping in shallow coral reef areas using satellite imagery is complicated by a number of environmental factors. One of the most important is the confounding effect of varying water depth, both by topographic variation and by tidal variation (Bina and Ombac, 1979; Jupp et al., 1985b).

Corals and algae are the main living occupiers of space on coral reefs but their separability in remotely sensed data is not well known. The brown colour of coral tissues is determined to a large extent by the photosynthetic pigments contained in the zooxanthellae, the symbiotic algae that live within the tissue of hermatypic corals (Veron, 1986). An observer in a small boat over a shallow coral reef with relatively clear water conditions must still actually submerge in order to assess whether the green-brown colour is caused by high algal cover rather than high coral cover. Unfortunately the spectral signatures of the major groups of benthic organisms have not yet been characterised.

This paper reports the results to date of an assessment of Landsat MSS and SPOT XS data for the purpose of measuring the change from high coral cover on a reef to high algae cover after disturbance by *A. planci*. Before tackling the problem of detecting temporal change in the imagery of a reef, the first step must be to assess the information content of the imagery at any single point in time. In terms of ground truth, the main question in this paper is: Which, if any, of the biological or topographic attributes measured by ground observers serve to distinguish the various spectral classes detected in the image data? The substantial historical archive of Landsat MSS data, and the potential to compare these historical data with the past records of starfish outbreaks has meant that the initial emphasis in this study is on the Landsat data.

METHODS

John Brewer Reef is a crescentic reef approximately 50km offshore, in the central region of the Great Barrier Reef near Townsville. It is 5km on its longest axis and was severely disturbed by starfish outbreak in 1984-5 (Moran et al., 1985). One Landsat MSS image and one SPOT image of this reef were obtained through the Australian Centre for Remote Sensing for analysis in this study.

The Landsat MSS (Landsat 5) image was Path 94, Row 73 in Universal Transverse Mercator Zone 55 with the scene centre at 18°49'S 147°37'E, taken at approximately 0930hrs local time on 20th June 1985. The subset analysed here was 128 pixels x 100 lines starting at pixel 2054 in line 609 of the image. Local tide height was calculated as 1.4m using a Queensland Department of Harbours and Marine Co-tidal chart for the Townsville region (Drawing no. 01-155Sh2).

The SPOT XS (multispectral) image (processed to level 1b) was from scene K,L = 373,387 with a subset of 512 pixels x 480 lines, starting at pixel 600 in line 2000. The scene was recorded at approximately 1030hrs local time on 24th July 1987. Local tide height was calculated as 1.2m. Unfortunately this image was acquired in Dec 1987, after the field work had been completed and a detailed analysis of the spectral data is still in progress.

After subsetting the images from computer-compatible tape on a VAX, all image analysis was done using a microBRIAN system (Jupp et al., 1985a). Both images were contrast enhanced and then spatially rectified using 20 control points located on an orthophoto map of John Brewer Reef prepared by the Australian Survey Office (now called the Surveying and Land Information Group, Canberra). During rectification the images were both resampled onto a common 15m grid producing 512 pixels x 400 lines. Locating a pixel that represents a particular ground control point in an image of a reef is sometimes difficult because there are no regular features and most are not sharply defined.

Using a supervised, nearest-neighbour classifier (Jupp et al., 1985a) the Landsat data were classified into 17 themes, and the SPOT data into 25 themes. The supervision of the classification involved the use of a residual image (raw data minus mean values of each class - Jupp and Mayo, 1982) to identify regions of the image that have radiance values widely separated from the means of the existing classes. These regions were then selected as new seeds for the classifier in an iterative process aimed at reducing the information content of the residual image.

Ten ground control sites were selected in order to represent a range of image classes defined by the Landsat MSS classification. These ground sites were located on the rectified images using the Australian Map Grid coordinates provided by surveyors who worked in the field at the same time as the ground samples were taken (April 1987). The Landsat MSS image is shown in Figure 1 and the SPOT image in Figure 2.

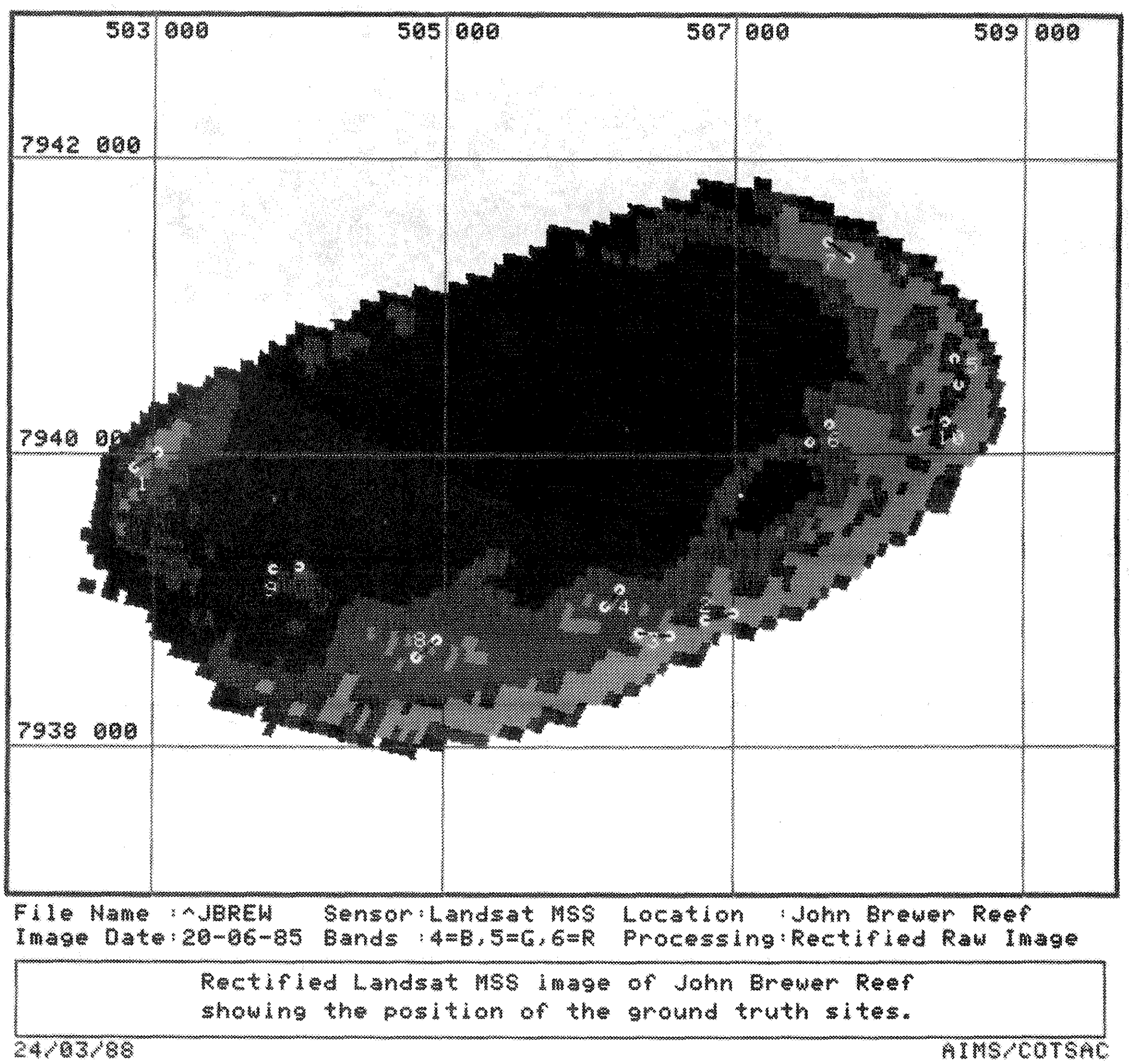

Figure 1. Landsat MSS image of John Brewer Reef showing sample site locations.

Each of these ten sites were sampled by a SCUBA diver using 4 contiguous benthic line transects (Reichelt et al., 1986) each 50m in length with substratum and topographic variation being recorded at every metre. Topographic complexity along the transects was recorded as fluctuation in vertical relief, to the nearest 10cm, from one metre to the next. Details of the sampling techniques are given in Bainbridge and Reichelt(1988). The sites varied in depth from 1m to 3m.

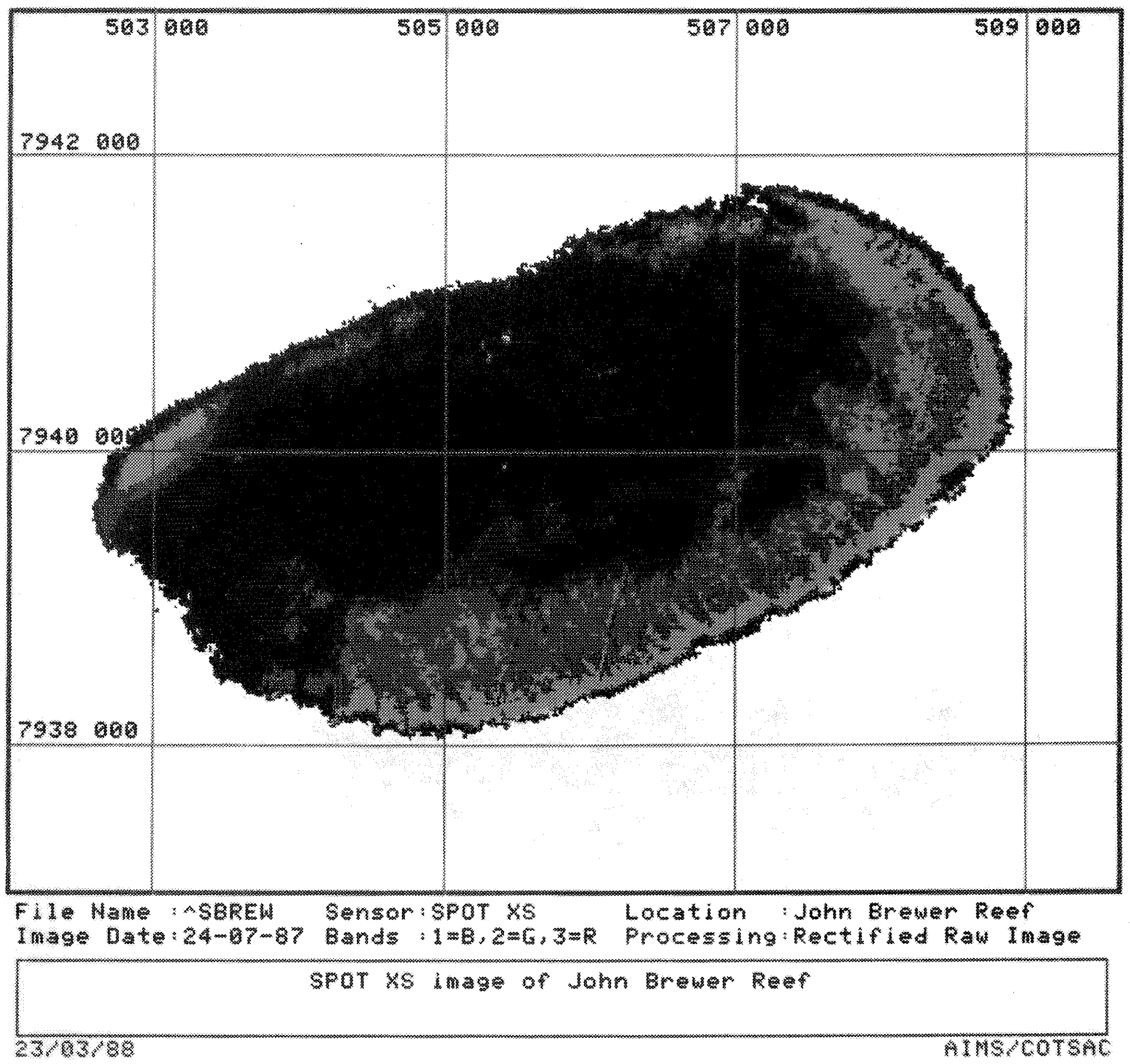

Figure 2. SPOT image of John Brewer Reef showing structure of reef flat habitats including sand channels.

The categories of substratum, which are a very reduced subset from Reichelt et al. (1986), are described in Table 1.

Table 1: Description of the substratum categories.

Category	Description
Hard Coral (HC)	All hard corals, regardless of colony shape or color.
Macro algae (MA)	All large algae that extend more than a few cms above the surrounding substratum (includes *Halimeda* sp.)
Turf algae (TA)	Species assemblage of algae with short, turf-like morphology, projecting less than a few cms above the substratum, including coralline algae.
Sand/Rubble (SR)	Sand and rubble (always composed of calcium carbonate) often occur as inter-grading mixtures on reefs, particularly in areas with strong gradients in wave energy; this category includes the entire range from 100% sand through to 100% rubble.

After classification of the image data, the sample sites can be assigned to particular image classes. The question then becomes, what attributes, if any, within the ground data serve to distinguish the spectral classes from each other? This question is answered using a discriminant function analysis of the ground data, having already assigned the sites to particular groups based on their spectral affinities.

The discriminant function analysis (Dixon and Brown, 1979) was stepwise using the abundance of the particular substratum categories and the abundance of the various topographic categories as input variables that could be included in the discriminant function.

RESULTS

Having declared our main interest in distinguishing sites with high coral from those with high algae, the abundance of these categories at each site must be compared. In order to facilitate this comparison, the results of the 4 individual transects at each site were pooled and the percentage abundance of the 4 substrate categories are shown in table 2.

The ground data, described in detail by Bainbridge and Reichelt (1988), showed that hard coral was present at low levels (<25%) except at site 5 where hard coral accounted for almost half of the total substratum. Sand/Rubble represents the abiotic component of the substratum and values ranged from almost none at site 5 to 48% at site 9, with the other sites containing 20-35%. Although turf algae is not always visually dominant because it may be growing as a thin film on relatively pale backgrounds, it represented a high proportion of the benthos at most sites, ranging from 27% at site 5 to 65% at site 4.

Based on the image classification results, which used only the radiance data and no contextual information, the Landsat MSS pixels at the sites were considered to fall into one of 4 classes. Sites 2, 3 and 9 were in class I; sites 4, 6, 7 and 8 were in class II; sites 5 and 10 were in class III; and site 1 was alone in class IV. Before sampling, the topographic variation at the sites was expected to vary considerably between sites. The results did not show this. The mean variation in vertical relief was between 15cm and 40cm for all sites.

As expected, the classification of the SPOT data, with its greatly enhanced spatial resolution (20m x 20m ground pixels in the XS mode), led to a more complex arrangement of pixel classes and a range of features not represented in Landsat MSS were visible in the SPOT image. These included lagoonal patch reefs, the within-zone structure of the inner and outer reef flat created by linear patterns in the distribution of corals, algae and sand, and even the man-made, floating pontoons anchored in the lagoon of this reef as a tourist attraction.

Table 2: Ground survey results, with the Landsat MSS spectral class derived from the image analysis shown for each site; substratum given as percent abundance; substratum codes from table 1; topography given in cm (after Bainbridge and Reichelt, 1988); other categories that were measured but not included here because of low abundance include coralline algae and soft coral.

		Substrata				Topography		
Image class	Site-nr	HC	MA	SR	TA	min	max	mean
IV	1	6	13	17	43	0	300	35
I	2	7	5	39	31	10	40	12
I	3	24	3	31	42	10	100	23
II	4	1	0	29	65	5	100	16
III	5	50	0	1	27	10	40	17
II	6	3	2	34	31	5	100	21
II	7	5	0	23	60	5	60	20
II	8	1	3	37	35	5	60	12
I	9	6	1	48	36	5	60	12
III	10	21	1	3	52	10	30	18

The discriminant function analysis operates by testing each of the site attributes, adding the best discriminators into a single function one at a time. At the end of the procedure the resulting 'discriminant function' of these variables can be used to classify all of the original transects and assign them to one of the 4 spectral classes. This classification is an indication of the success of the discriminating process and is shown in table 3.

Table 3: Classification matrix arising from the discriminant function analysis; Variable codes are described in table1; the symbol >50 represents a topographic variable - the abundance of vertical relief changes greater than 50cm.

		Image class I	II	III	IV	Percent correct	Reef Zone
	I	10	2	0	0	83	outer reef flat
	II	3	13	0	0	81	inner reef flat
classes	III	0	0	8	0	100	crest + algal rim
	IV	1	1	0	2	50	crest + slope
Discriminating Variables		SR >50	>50	MA HC	--		

Approximate F = 8.2, df = 15,88; $p < 0.001$

DISCUSSION

This study extends the recent work of Kuchler et al. (1986) with regard to ground truth methodology and that of Bainbridge and Reichelt (1988) with regard to substrate mapping in shallow coral reef habitats.

One of the first problems encountered in this study was the time consuming nature of the sampling procedure which resulted in only 10 ground control points being surveyed for benthic cover. This is a relatively small number of points even though the total transect length was 200m, which covers 3 to 4 pixels for Landsat MSS and up to 10 pixels for SPOT XS. The sampling has to be done underwater using SCUBA equipment and in the present study it was carried out during rough seas with 30kts wind.

Another problem that arises when ground-truthing coral reefs is that the area with high living cover extends to deeper parts of the reef (down to about 20m depth) and the very high coral cover region is the reef perimeter, the reef crest and slope, which may be both deep and narrow (only 50-100m wide). These deeper areas are ecologically important, but inaccessible to remote sensing methods such as Landsat MSS.

The SPOT data were acquired after the field work was completed and the transects did not fit exactly within homogeneous pixel classes. Therefore the discriminant function analysis was performed with pixel classes generated by analysis of Landsat MSS. The results indicate that the classes were not being separated *in the image* because of the varying amounts of hard coral versus algae on the ground. The classes were discriminated by the variables shown in table 3. Where hard coral and macro algae were significant variables (for class III, the reef crest and algal rim) macro algae was 0%, turf algae was 27% and hard coral was relatively high at 50%. Site 1 was the only site where coral was low and algae was high but unfortunately none of the variables were strong discriminators of this site and the 4 sub-transects performed at site 1 were not well classified by the discriminant function (50% error) results in table 3.

The Landsat data did separate biotic from abiotic areas which are properties that distinguish broad geomorphological zones also. The patches of coral and algae are mixed together at sub-pixel scales and so unfortunately they are integrated as mixels by Landsat MSS.

Using the raw abundance of the topographic categories is not a particularly sensitive indicator of surface texture and further analyses will be undertaken using a range of texture algorithms (Carleton and Sammarco, 1987) to examine the sensitivity of this parameter with respect to contributing to the discriminant function separating the image classes. Diffuse reflection and shading are almost certain to be important consequences of surface roughness in shallow reef areas and the topographic category, ">50" (abundance of vertical relief changes of greater than 50cm) was a significant discriminating variable for several image classes.

The SPOT image shown in Figure 2 has not been the subject of detailed numerical analysis to date. In fact, feature separability (Richards, 1986) for satellite imagery data of coral reef habitats in general is not well known compared with terrestrial areas (e.g. SPOT mapping, Forster et al., 1987). The lineaments evident in the outer reef flat zone are not detected in the Landsat MSS data because of the difference in spatial resolution. These features are sand channels between the strips of hard substrata which may be covered with either coral or algae. Hopley (1982) has described these and speculates that the width of this zone is a function of incident wave energy. The spacing of the channels

may be influenced by, among other factors, localized sediment transport which is a function of wave direction, period and energy, and the substratum gradient (K. Black, Victorian Institute of Marine Science, personal communication).
In an assessment of ground truth survey methods for coral reefs, Bainbridge and Reichelt (1988) speculated that the improved matching of SPOT data classifications with survey data classifications compared with Landsat MSS (similar methodology to Catt et al., 1987) may be a result of the higher spatial resolution producing fewer mixed pixels (mixels). This will be the subject of further study and indeed, many of the patch reefs and sand patches in shallow reef waters do approximate the size of SPOT pixels. Reefs are patchy over many spatial scales (Reichelt, 1988), however, and high spatial resolution does not necessarily lead to improved performance in producing generalizable thematic maps (Hill and Kelly, 1987).

The implications of the results of this study for environmental management of coral reef regions are that Landsat MSS may well be a valuable tool for general reef zone mapping but that its use for biological monitoring the changes in coral cover on a reef is likely to be limited. Determining the spectral signatures of the major ecological communities would be a major advance. The use of SPOT data for detecting within-zone features on reefs and the increased spectral resolution of Landsat TM in the visible blue are both subjects of ongoing studies of shallow water mapping in coral reef habitats.

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