DEVELOPMENT OF A METHODOLOGY FOR THE APPLICATION OF LARGE SCALE DIGITISED AERIAL PHOTOGRAPHY FOR REEF FLAT MONITORING ON THE GREAT BARRIER REEF

Report on a Project Developed from Research into the Surveillance by Aerial Survey of Reefs Affected by *Acanthaster planci* Outbreaks

David Hopley & Pauline Catt
Final Report to the Great Barrier Reef Marine Park Authority
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1. INTRODUCTION

Coral reefs are dynamic systems in which recurrent natural disturbances such as hurricanes, floods, population explosion such as Crown on Thorns have profound long term influences. At a time when coral reefs are being put under new pressures from human disturbances, it is important to be able to quantify both the natural and human induced change so that effective management procedures can be put in place. This project has aimed at producing a monitoring system using low level digitised aerial photography to scale and resolution suitable for management issues on reef flats of the Great Barrier Reef.

Coral reef surfaces are highly complex being an interaction between ecological and geomorphological processes. From the air there is a clear zonation on reef surfaces largely determined by declining energy conditions from windward to leeward margins. The zonation itself is largely geomorphological, but within each zone is a complexity of repetitive ecological patterns which occur down to minute scales. Zones, though large in total area, may be relatively narrow producing resolution problems for remote sensing techniques. Nonetheless, both satellite data and information derived from aerial photographs has been found to be useful in delineating such zones (see Kuchler, 1984). To date remote sensing techniques have not been able to produce a resolution which is suitable for mapping biological distributions. Most researchers still resort to exhaustive and time consuming ground surveys which themselves cannot be comprehensive and have to reply on sampling distributions with reduced confidence limits. A survey technique which can be carried out relatively automatically and which can be processed to produce comprehensive data across the entire area of interest will be of great value of a range of reef researchers.

The first aerial reconnaissance of the Great Barrier Reef occurred in 1928 and was undertaken by the RAAF. During the 1960's most of the reef was photographed from high altitude. Where available, aerial photography was recognised as a very useful tool for research reef (see Hopley, 1978 for review). When satellite imagery became available, this too was recognised as having great potential (e.g. Smith et al., 1975a,b and more recently Jupp, 1986). However, as highlighted by Kuchler, 1984, there was a paradox in remote sensing techniques. Satellite imagery was produced in a format which could be easily manipulated and automated by computer, but its resolution was such that it could only just be used for mapping reef geomorphological zones and had little application to biological distributions. In contrast aerial photography, depending on scale, could be produced with a resolution suitable for mapping biological distributions but without computer application could not go beyond a subjective interpretation.

This project therefore has tried to research the methodologies of both aerial photography and satellite imagery in an attempt to use the best of both worlds. Fine resolution is produced from aerial photography whilst interpretation is aided by the scanning of this photography and the application of techniques identical to those used for satellite imagery. The advantages of multispectral data produced by satellites are reproduced by the aerial photography using both natural colour and colour infrared film. We believe that the research techniques described here, development of which is still ongoing, produce a valid methodology which can be applied to local area coral reef management problems.

2. HISTORY OF THE PROJECT

Research which has resulted in the project being reported upon here has had a long period of evolution and has been closely associated with the reef studies of one of the authors (David Hopley).

Interest in the use of other-than-normal black and white and true colour photography was developed by a number of 35mm colour near infrared photographs undertaken during the MA thesis work of Ann Smith (Smith, 1975). This showed strong reflectance in the near infrared part of the spectrum from exposed living corals amongst other reef top organisms. Further research was undertaken in the Honours thesis of A. van Steveninck (1976) which compared the qualities for displaying geomorphological features of the reef flats of panchromatic, true colour, colour infrared and black and white infrared film (as reported in Hopley and van Steveninck, 1978). This research determined that the infrared reflectance of corals emanated from the symbiotic zooxanthellae within the coral tissue. Research also identified a number of problems which have been the subject of more intensive investigation recently. These included the problems of attenuation of the infrared part of the spectrum within the water column, problems associated with the atmosphere water content, cloud cover and sun angle, problems of shadow and seasonality of reflectance values.

The reef remote sensing work was extended further in the PhD thesis of Kuchler (1984) which, recognising the limitations of both data sources, attempted to reconcile the information content of both aerial photography and satellite imagery although this work was directed only towards geomorphological features.

During the 1980's, the need for a remote sensing system with a higher resolution than could be obtained from satellite imagery was intensified by the Crown of Thorns problem on the Great Barrier Reef. Initial work suggested that differences in the reflectance in the near infrared part of the spectrum for living and dead corals was sufficient to discriminate between the two reef surfaces. Simultaneously, the commercial availability of scanning systems for aerial photographs allowed for early experimentation with this transformation methodology. Support was provided initially by the Great Barrier Reef Marine Park Authority and simultaneously from a number of internal sources within James Cook University (SRG and URG). Initially research was directed at obtaining a wide range of aerial photography at various heights and under varying weather and tidal conditions and at experimenting with the digitising process. This was largely the pilot stage of the project and is described below and is also the one for which most of the GBRMPA funds were expended together with those from the University.

As it became clear that there were many lines of research which could be undertaken in relation to this project, the project was widened under the support of National Greenhouse funding to incorporate Honours (C. Linfoot) and PhD (T. Thamrongnawasawat) candidates. Although this research is largely ongoing from that funded by GBRMPA it has been difficult to delineate where one starts and the other finishes. An initial final report to GBRMPA on the project covering only the pilot stage produced a number of comments from reviewers which could not be answered purely from the research carried out at the pilot stage. However, the more recent developments and investigations of Linfoot and Thamrongnawasawat go a long way to answering some of the criticisms made and it is for this reason that the more comprehensive coverage is given in this report.

3. PILOT PROJECT

3.1 Development of a Methodology

Satellite imagery is unsuitable for reef monitoring owing to the poor ground resolution (20m at best as multispectral imagery) and problems acquiring data at the optimum time – very low or negative tides. Regular ground truth surveys of large numbers of reefs are not feasible on grounds of cost. Previous work by Hopley and van Steveninck (1976) suggested the possibility of using infra-red air photography for monitoring ecological change over relatively small areas on reef flats. Air photography offered the possibility of control over scale and time of acquisition, and by using both true colour and false colour infra-red film a range of spectral phenomena are recorded. An initial drawback to air photography was reliance on hard copy images with no possibility of digital analysis, but this has now been overcome by digitising the photographs via an Eikonix digitising system, and analysing the resulting data using the microBRIAN system. The Eikonix is preferable to using a video frame-grabber as three-channel data separation is possible.

Air photography was carried out by the authors. A Hasselblad 70mm format camera with Kodak aerial film was used. Both true colour and false colour infra-red photographs were taken to evaluate the information content of each and to determine which is most suitable for long term monitoring purposes. A variety flying heights were used over the sites to establish the most effective scale.

The photographic programme commenced in June 1986 and is still continuing. Flights were timed to coincide with negative tides so that reefs are exposed. To date there is a predominance of winter imagery as negative tides in summer are almost always at night. Some low summer tide flights are being planned although certain reefs will probably be excluded due to water cover.

Photographic prints were initially digitised with reasonably good results. However, problems with reflection from the print surface suggested that in future it may be better to digitise the negatives. In the pilot project the digitising was done commercially.

Analysis of the digitised imagery was carried out using the microBRIAN digital image processing system. The digitised output consisted of 3 channels corresponding to blue, green and red for true colour images and green, red, and reflected IR for false colour images. Standard enhancement algorithms were used, together with band ratioing, classification, derivation of greenness index, and principal component analysis.

In the pilot project only limited ground truth data was collected to assist image interpretation. Reef cover and surface type were recorded along transects located on the photography. Fringing reefs were surveyed at low tide while offshore reef transects were recorded by scuba diving. To date ground truth data have been collected for Pandora Reef, Iris Point, Pioneer Bay, Wheeler Reef, Grub Reef, and Cape Tribulation.

3.2 Site Selection

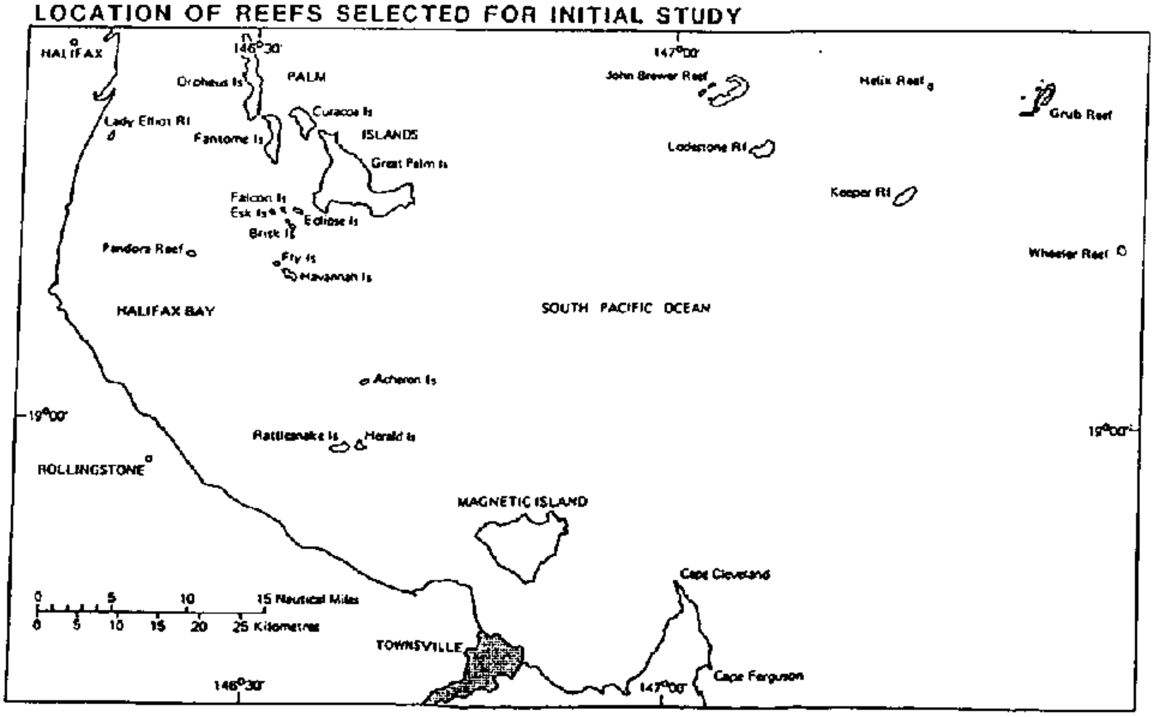
A number of sites were selected to cover a range of reef environments and levels of Crown-of-Thorns infestation. The study sites were chosen in 1986 when the starfish infestation in the Townsville section of the Reef was at its height. Both offshore and fringing reefs were surveyed. Table 3.1 lists the study sites. Locations of sites in the Townsville area are shown on Fig. 3.1.

TABLE 3.1 – Reefs Selected for Survey

Reef	Type	Comments
Cape Tribulation	Fringing	Increasing turbidity affecting coral growth.
Iris Point (Orpheus Island)	Fringing	Algal cover monitored.
Pioneer Bay (Orpheus Island)	Fringing	Algal cover monitored. Coral species discrimination.
John Brewer	Offshore	Recreational impact, starfish outbreak 1983–84. Site of Floating Hotel.
Grub Reef	Offshore	Some starfish present 1988: population treated with copper sulphate 1986.
Wheeler Reef	Offshore	Not subject to starfish infestation until about 1986.
Helix Reef	Offshore	Extensively damaged by starfish.
Bramble Reef	Offshore	Infested by starfish.
Pandora Reef	Offshore	Selected for algal mapping and geomorphological information.

FIG 3.1

LOCATION OF REEFS SELECTED FOR INITIAL STUDY



3.3 Results

3.3.1 Scale

The flying heights used and approximate scales obtained are shown in Table 3.2.

TABLE 3.2

Flying Height	Nominal Scale of Conventional 23cm x 23cm print	Scale on Negative
7000' (2134m)	1 : 6,368	1 : 26,617
4000' (1220m)	1 : 3,646	1 : 15,240
3500' (1067m)	1 : 3,182	1 : 13,309
3000' (914m)	1 : 2,729	1 : 11,407
1000' (305m)	1 : 910	1 : 3,803
500' (152m)	1 : 455	1 : 901

The lowest flying height (500') produces very high resolution imagery so that individual coral heads are clearly visible, but the volume of photography and cost render this scale unsuitable for monitoring large areas. The small scale used (7000' flying height) gives an overall view of the reefs, but is really useful only for mapping reef morphology and limits of coral/algal cover. The most useful combination for monitoring purposes is general coverage flying at 3000' with selected transects at 500' or 1000' depending upon the objectives. In the study area the cloud base offshore is frequently between 2800' and 3500' so that flying at 3000' or just below is generally possible whereas smaller scale imagery is more difficult to obtain.

When images are scanned the ground resolution obtained for study sites is shown in Table 3.3.

TABLE 3.3

Flying Height	Approximate Pixel Size on Ground
4000' (Cape Tribulation)	47.4cm
3000' (Helix Reef)	36.0cm
1000' (Helix Reef)	11.8cm
500' (predicted)	5.9cm

3.3.2 Film Type

Both film types used have value for this type of study. To date evaluation has been based only on visual comparison. Interpretation of digitised imagery has so far concentrated on the use of False Colour IR images, although the digitised true colour images of Helix Reef and Cape Tribulation show good discrimination of coral and algal communities.

The results of the film type comparison using hardcopy prints is given in Table 3.4.

TABLE 3.4

Reef Feature	IR	TC
Living Coral	X	
Algal Cover	X	
Carbonate	O	O
Sand Cay	O	O
Reef Edge Bathymetry		X
Delimitation of Pools	X	
Shingle Features	O	O

X – Indicates better discrimination of feature type
O – Easily discriminated on either

3.3.3 Image Analysis

Initial image analysis involved the visual interpretation of hardcopy prints. In the case of Helix Reef the large scale IR photography showed marked variations in the distribution and intensity of red signatures on a set transect over the period 1986–1989. The intention was to eventually measure change in area, but a major problem encountered early on was that at present rectification of images over most offshore reefs is not possible owing to lack of control points.

The spectral properties of coral are poorly researched and a longer term intention of the authors is to compile spectra for coral species, coralline algae, algae, and coral in various stages of growth, decline and bleaching. In the pilot project interpretation was based on ground truth transects and ground based IR photography over a test site in Pioneer Bay and at Cape Tribulation.

In visual interpretation it is difficult to distinguish between hard coral, coralline algae, turf algae, and macroalgae. On Wheeler Reef the brightest red signatures on the 3000' IR print appear to be produced by coralline algae while at Cape Tribulation fringing reefs macroalgae and hard corals produce the brightest signatures. More fieldwork was clearly required to assist accurate discrimination of ecological communities. Ideally spectral data collection with an instrument such as the GER Infra–Red Intelligent Spectroradiometer (IRIS) is needed.

The attenuation of IR reflectance by water is a problem in all work on reefs and coastal wetlands. In visual analysis areas covered by varying water depths may easily be confused with different cover types, and this problem is more pronounced in digital analysis. All air photography was carried out at low tide to remove the water attenuation problem, but some reefs such as Helix are exposed for very short periods even on negative tides.

Digital image analysis utilised the microBRIAN algorithms for enhancement, ratioing, Principal Component Analysis (PCA), classification and Greenness Index. Both ratioing and Principal Component analysis prove effective for detecting coral/coralline algae communities on Helix Reef and coral/algal communities at Cape Tribulation.

The ratio of infra-red (Channel 3) over visible red (Channel 2) produced clearly defined areas of healthy coral/coralline algae, damaged coral and carbonate reef flat on high resolution imagery of Helix Reef. At Cape Tribulation of 3/2 ratio discriminated areas of coral and algae, and also clearly distinguished rainforest from mangroves.

Principal Component Analysis detected the coral/coralline algae/algae communities in Axis 2 with the data comprising 8.7% of the total. In the Cape Tribulation imagery, Axis 2 clearly maps areas of rainforest and coral/algae, and discriminates between coral and algae. See Figures 3.2, 3.3 and 3.4.

The classification algorithms were less successful, particularly on offshore reefs, owing to the effect of water partially covering some communities. It was possible to detect areas with some water cover versus those without, but this is not particularly useful. When more is understood about attenuation of IR reflectance on the film used following the ground experiments, it is hoped to apply a correction factor to remove the water problem.

The derivation of the Greenness index was not particularly successful. The ratio 3/2 and PCA 2 produced more meaningful results.

3.3.4 Evaluation of Pilot Project and Directions Indicated for Further Research

The advantages of digitising photography were clearly shown. The data can be statistically analysed in the same way as digital satellite and airborne scanner data. Air photography is often the only type of high resolution imagery available and when digitised can be compared and integrated with other datasets.

There is also a very much increased potential for extracting information from air photography to incorporate into a GIS or similar database. The digitising of the photography not only saves a considerable amount of manual labour identifying

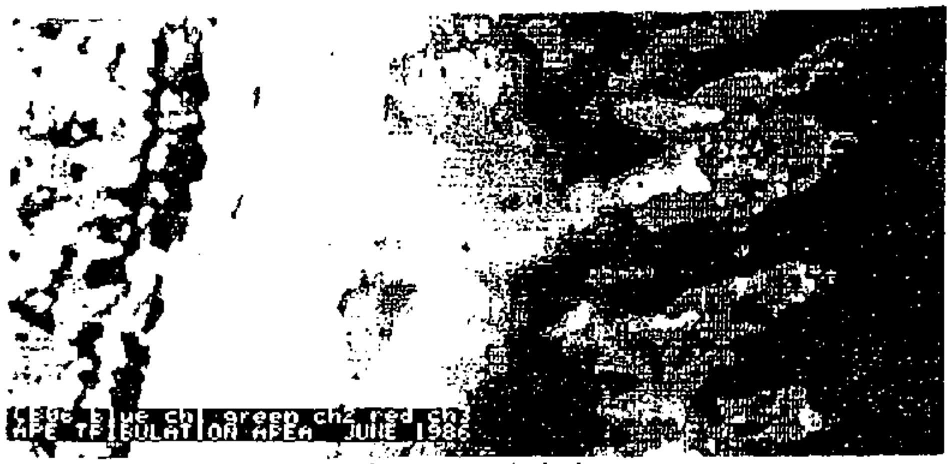


FIG. 3.2

Monochrome copy of 3 colour composite of digitised IR photograph of fringing reefs and rainforest near Cape Tribulation, North Queensland. The centre of the image shows the beach area, with rainforest to the left and fringing reefs with coral and algal communities to the right.

FIG. 3.3

PCA 1 (90.4% of data)

FIG. 3.4

PCA 2 (8.7% of data) showing vegetation features clearly discriminated. Dark pixels in the fringing reef show areas of coral.

boundaries, but also permits the use of image processing algorithms to extract thematic data.

The dedicated low-level air photography discussed in the previous section was more comprehensively digitised using the Eikonix scanning camera obtained towards the end of the pilot project by the James Cook University Centre for Remote Sensing. This has allowed a more comprehensive approach to problems identified in this first stage.

The options available include choice of resolution and choice of a 3-colour or panchromatic image. The lowest resolution possible is 500 pixels x 500 lines which effectively reproduces the original photo scale. Maximum resolution is 4000 pixels x 4000 lines which gives immense detail but may exceed the resolution of the original film emulsion. The dynamic range which can be achieved in the data increases with increasing resolution which is important if any form of statistical processing is to be carried out.

The main considerations in determining a suitable resolution for digitising are the type of information required and the volume of data which can reasonably be handled. A three-colour image 500 pixels x 500 lines occupies less than 1MB of disk space whereas a 4000 x 4000 image occupies 32MB. A resolution of 1000 x 1000 has proved satisfactory in the present project, giving a pixel resolution still within the resolving power of the film used, and the dynamic range within each channel is sufficient to derive spectral signatures for different surface.

In the pilot project, colour infra-red air photography has generally been considered most useful in the discrimination of coral and algae. Digitising colour infra-red photographs permits extraction of the data at the infra-red wave lengths, this being the part of the spectrum under investigation for coral/algae discrimination. The increased dynamic range available in the high resolution scanning is important in attempting to distinguish between ecological communities which have similar spectral signatures at the wavelengths detected by the film. However, considerable more data manipulation and identification of more specific algorithms were identified for further research.

3.4 Pilot Project: Conclusions

The techniques developed showed that valid high resolution digital data could be obtained from air photography. Ground truthing of enlarged digital imagery on Orpheus Island and at Cape Tribulation demonstrated that the data is real and not the result of artefacts introduced during scanning.

The project clearly demonstrated that air photography, particularly when digitised, can be used to detect, map, and monitor features not detectable on satellite imagery. However, considerably ore developmental work, especially in conjunction with ground truthing surveys, is needed. This was taken up in the next stage of the project where the individual tasks were assigned to an Honours student (C. Linfoot) and a PhD candidate (T. Thamrongnawasawat).

4. A METHODOLOGY FOR DETERMINING THE SEPARABILITY OF CORAL REEF SURFACES USING IMAGE ANALYSIS TECHNIQUES ON DIGITISED AERIAL PHOTOGRAPHY

(This part of the report was prepared by C. Linfoot)

This part of the project focuses on developing methodologies for obtaining high resolution and high quality data from digitised aerial photography.

4.1 Introduction

The determination of the separability of environmental parameters from aerial photography, will provide an essential tool for further research and monitoring of the Great Barrier Reef.

The aim of this part of the study was to develop an image processing methodology based on the digitising of aerial photography, and the application of standard image processing techniques to determine the separability of coral reef features, especially the biological components of reef flats.

4.2 Description of Study Site

The project site was at Iris Point Reef, a fringing reef at the northern tip of Orpheus Island. Orpheus Island is a member of the Greater Palm group of islands and is approximately 80 kms north of Townsville, Queensland in the Great Barrier Reef region. The reef extends in a south–south easterly direction from Iris Point at the northern tip of Orpheus Island. The study site was at the southern end of this reef (see Figure 4.1).

Iris Point Reef (North–West) is, in many respects, a typical fringing reef (Hopley 1982) off a near–shore mainland type island. Iris Point Reef is exposed on the sea–ward side of the island, and is therefore subjected to the prevailing wind and weather conditions.

4.3 Data Collection Methodology

The data collection methodologies for this project can be divided into three areas. vis :–

- Collection of Aerial Photographic data
- Collection of Ground verification data
- Collection of Digital data

See Figure 4.2

The methodologies used for each of the areas will be discussed in turn.

4.3.1 Aerial Photography

The vertical aerial photography for this project was sourced from two areas. That is, aerial photography from the Pilot Project was used, as well as specially commissioned aerial photography.

There have been a number of photographic runs made of the study site (North–East reef – Iris Point, Orpheus Island), dating from 1986 onwards. This photography ranges from high level photography (3,000 feet or greater), through to low level photography (2,000 feet or lower). The photography was in both true colour and false colour infra–red

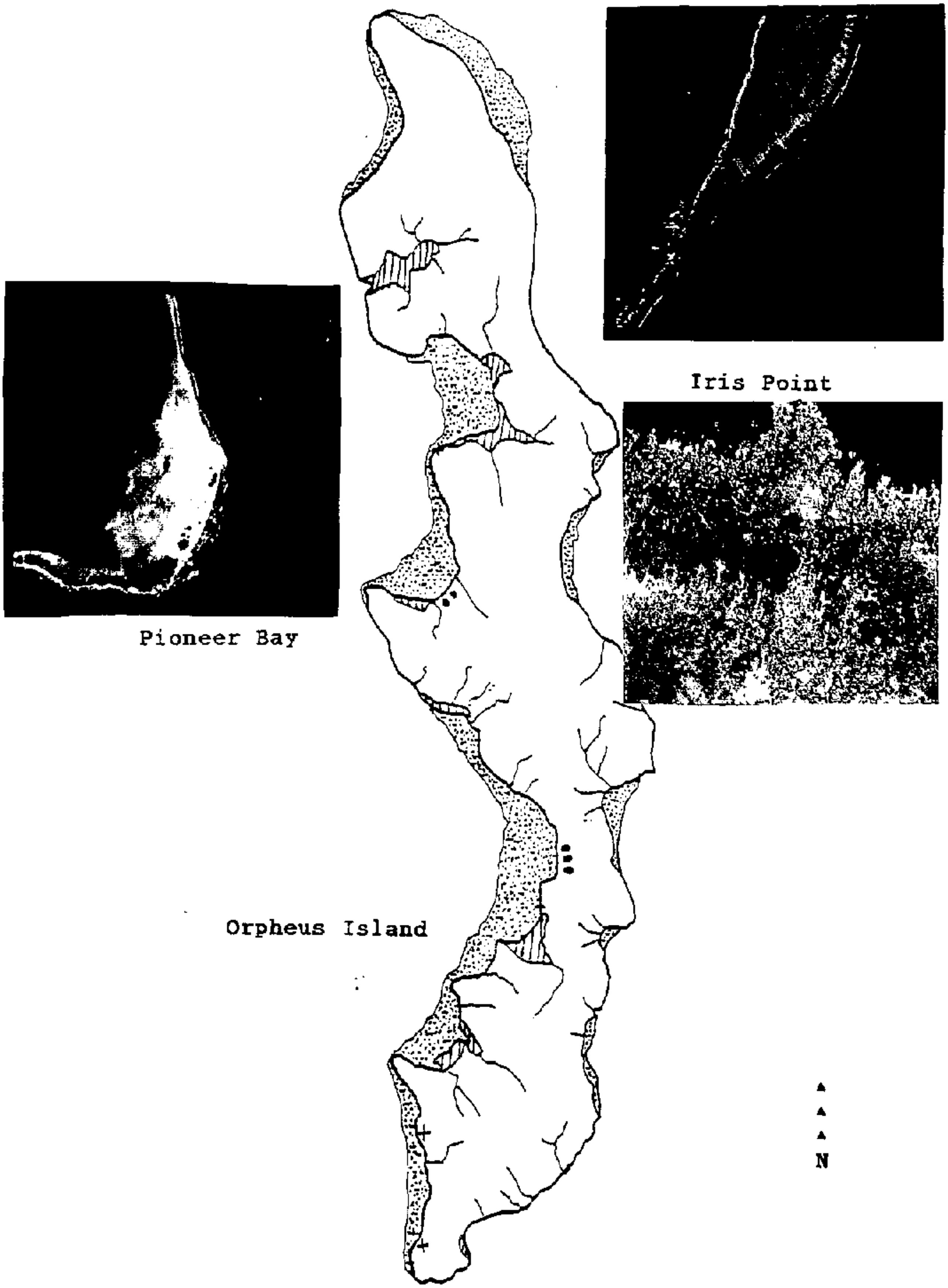


FIG. 4.1 The study sites at Orpheus Island.
(aerial photographs aquired on 7 March 1990)

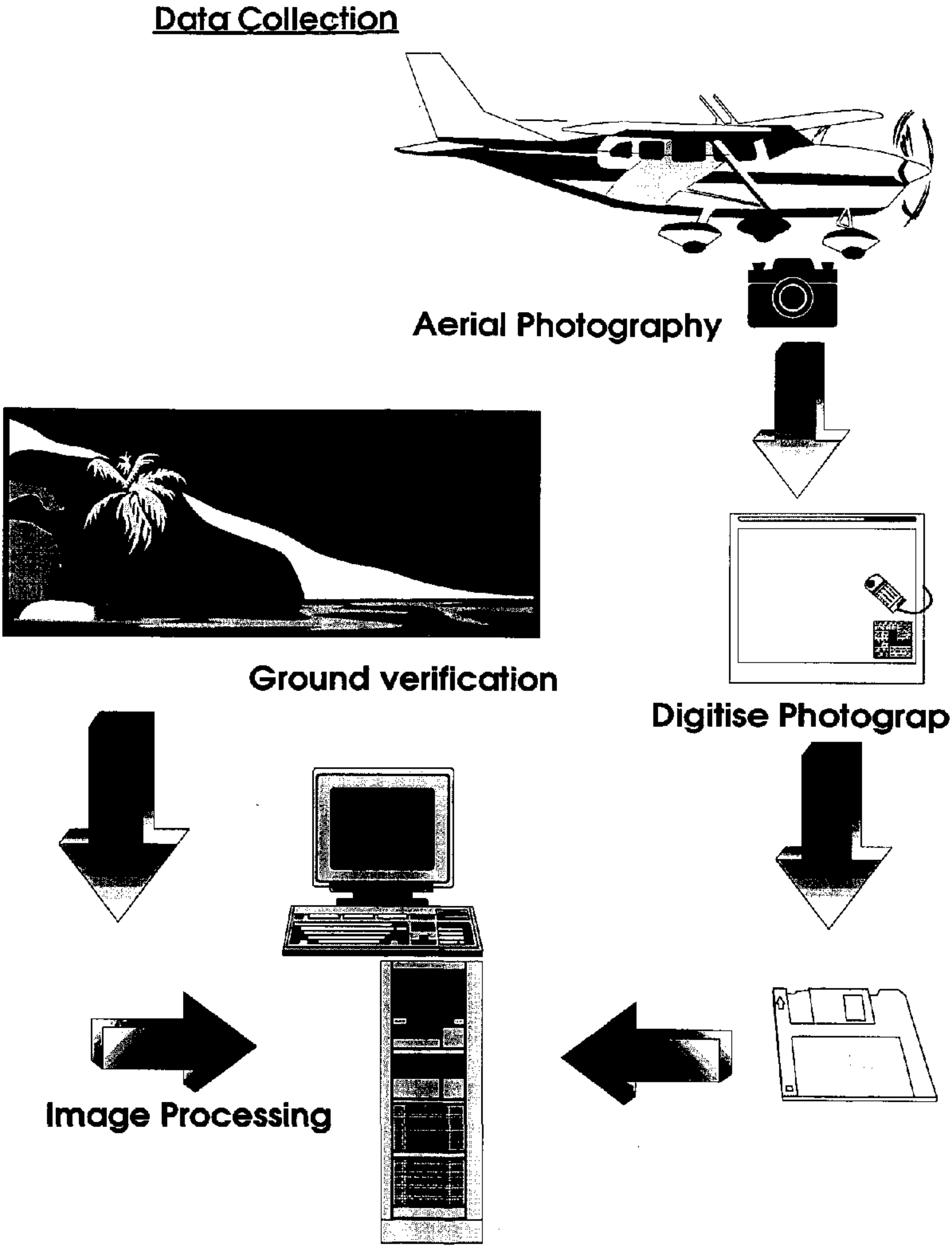


FIG. 4.2 Data Collection Overview

emulsions. This existing photography was used during the initial stages of the project to determine the suitability of the site, and test the digitising and image processing techniques, before further work was done.

The project site was chosen after an aerial reconnaissance of the Greater Palm group of islands. The site was chosen for a number of reasons. Some, not all, are given below. Firstly, there was existing aerial photography of the site over a number of years. Secondly, the site has a prominent bommie feature on the reef edge (see Figure 4.1) allowing for identification of the site from the water, from high level photography and from satellite imagery. Thirdly, the site exhibited good, large, monospecific stands of several species of coral and turf algae, and fourthly, the site was close to the Orpheus Island Research Station which was used as a base.

After some site preparation (see next section), specific aerial photography was carried out on the site. This is detailed below.

A specially modified Partenavia (high–winged, twin–engined) aircraft was hired to carry out the photography. This aircraft was fitted with two viewing ports through the bottom of the fuselage. The first port allowed for the installation of a drift sight, which was used to align and adjust the aircraft along the desired photographic run. The sight was also used to determine when the operation of the camera should start and finish on each run. The second port allowed for the installation of the Hasselblad camera along with its' motor drive into an adjustable mounting cradle.

The crew of the aircraft consisted of the pilot, the navigator/drift sight operator, the photographer, and an observer/assistant. On the ground (at the site) were three personnel in radio contact with the aircraft to ensure the sighting targets remained in place between successive photographic runs (see Figure 4.3).

The flights over Iris Point were carried out on the 26th and 27th of August 1992 from 13:30hrs and 13:45hrs respectively (low tide), this being the time of year (for 1992) when the low tides were at their lowest point during the day for that year, thus exposing the

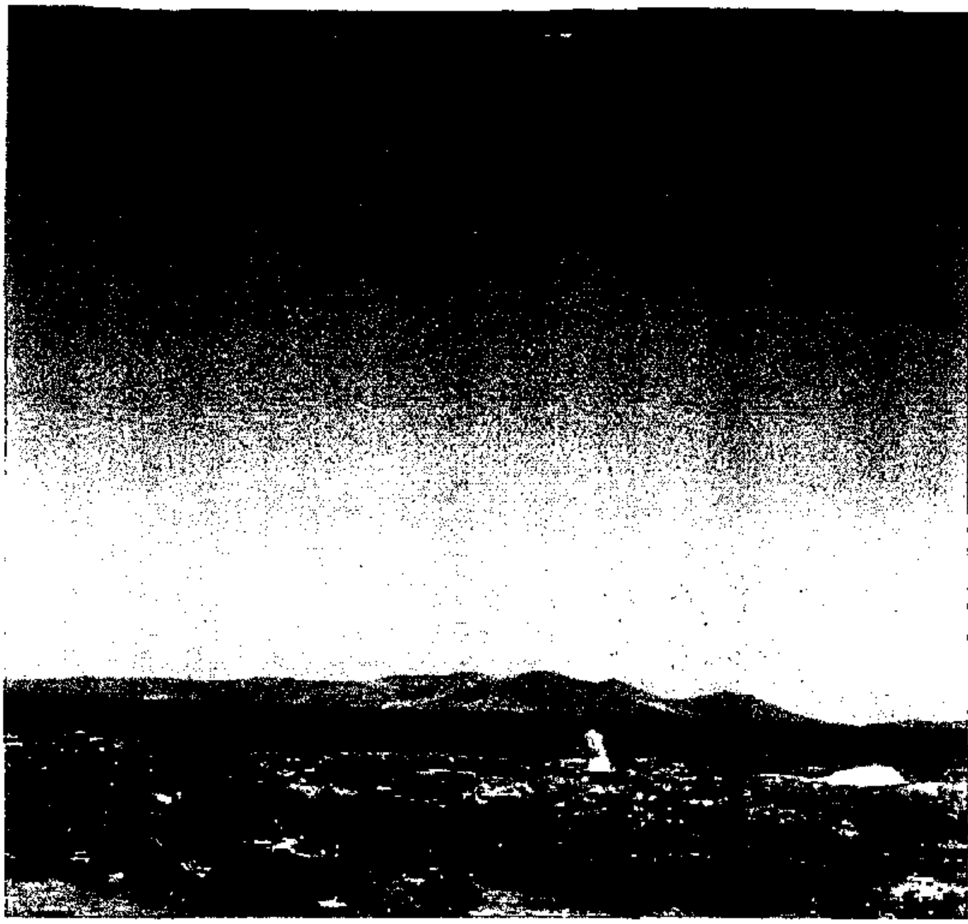


FIG. 4.3 Aerial Photography and Ground Verification

maximum amount of reef.

Several photographic runs were made over the study site at heights of 1,000 feet and 500 feet. The photographic runs were duplicated to ensure that the target areas were included. This was deemed necessary for the lower level (500 feet) runs (and was also done for the 1,000 feet runs as a precaution) as the slowest safe cruising speed of the aircraft was 90 knots. At this speed, at 500 feet, and with the relatively slow speed of the camera motor drive, there was no guarantee that successive photographs would overlap and that the target sites would be included. True colour and false colour infra-red photographs were taken at each of the flying heights.

The film used for the photography was Kodak Aerocolor Negative 70mm film 2445 for true colour and Kodak Aerocolor Infra-red 70mm 2443 false colour reversal film for the infra-red photography. The camera used for the aerial photography was a Hasselblad Single Lens Reflex 500 EL/M body with a 80mm lens and a motor drive. The settings on the camera were an aperture of f5.6 and a shutter speed of 1/500th of a second. For the colour infra-red photography, a Hoya K2 yellow filter was also used to absorb the blue radiation.

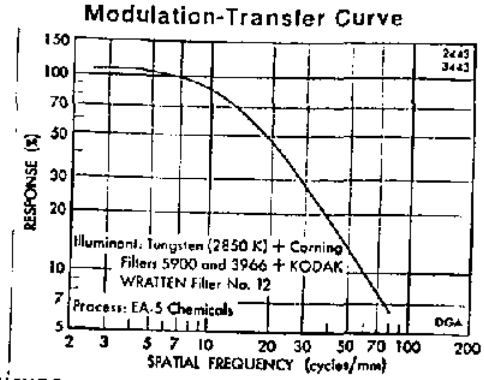
The approximate scales for the large scale vertical photography were calculated using the focal length of the camera and flying height (scale = f/H), and using actual measurements from the processed film and ground measurements (scale = photo distance/ground distance). The approximate scales calculated for the 500 feet photographic runs were 1:1,900 using the focal length method, and 1:2,000 using the actual measurement method. For the 1,000 feet runs, the scales were 1:3,800 using focal length and 1:4,000 using actual measurements from the film.

The spectral sensitivity of the true colour film ranges from 400 to 705 nm, while the false colour infra-red film has a range from 400 to 900 nm., see Figure 4.4. The film was processed by United Photo & Graphics Pty. Ltd., 4/2 Apollo Crt. Blackburn Victoria 3130.

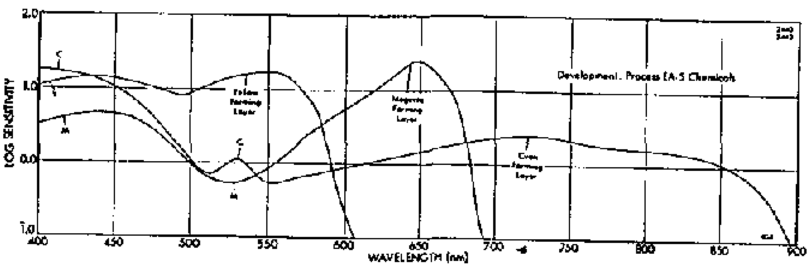
Infra-red Film type 2443 - Film positive.

(Source :- KODAK Aerial Photography Book)

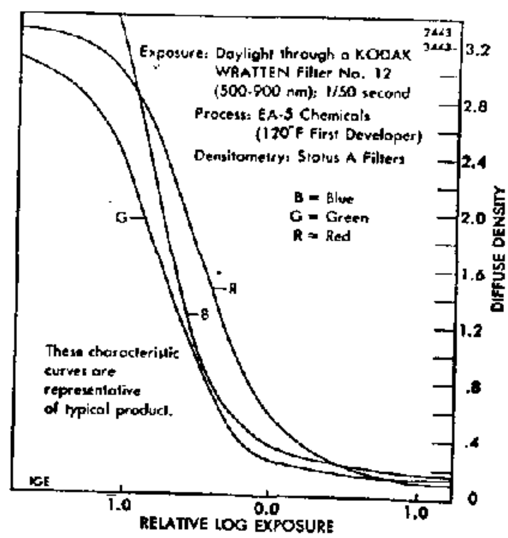
Modulation-Transfer Curve



Spectral Sensitivity Curves



Characteristic Curves



Spectral Dye Density Curves

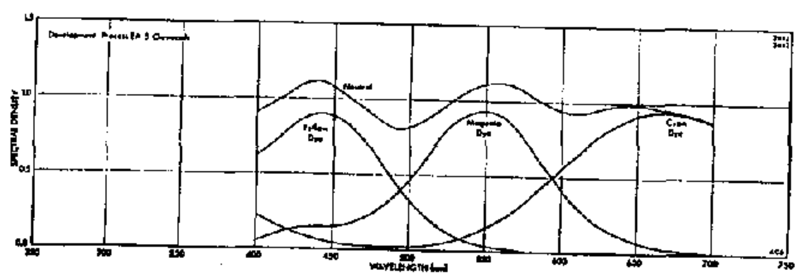
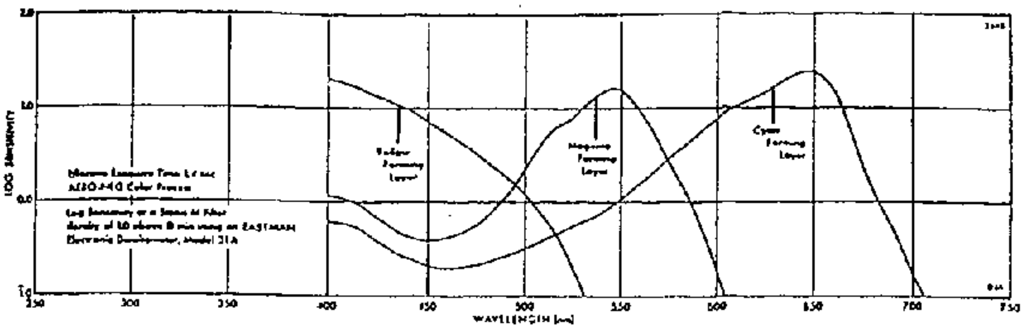
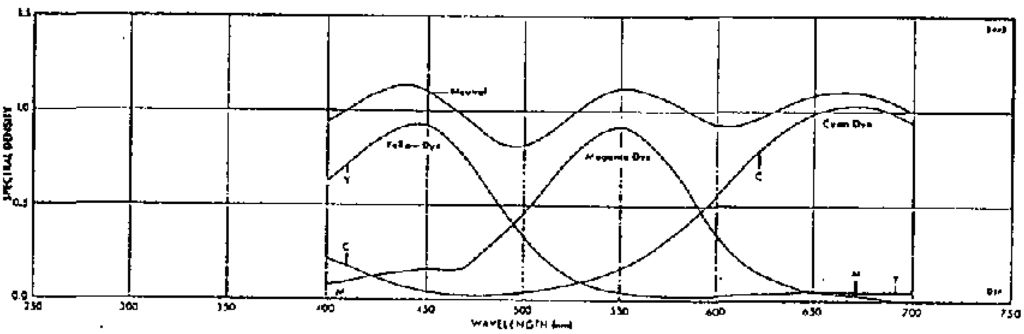


FIG. 4.4 Spectral Sensitivity Curves etc. for Infra-red film and True Colour film (overleaf)

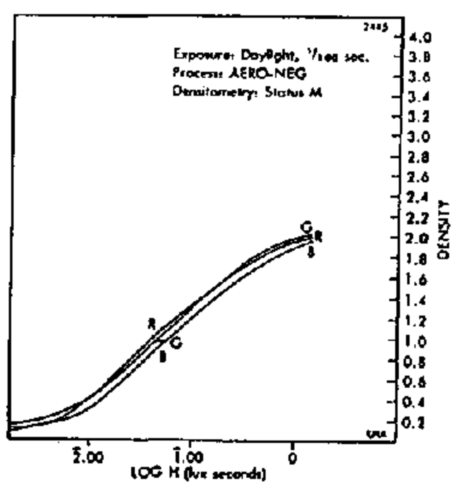
Spectral Sensitivity Curves



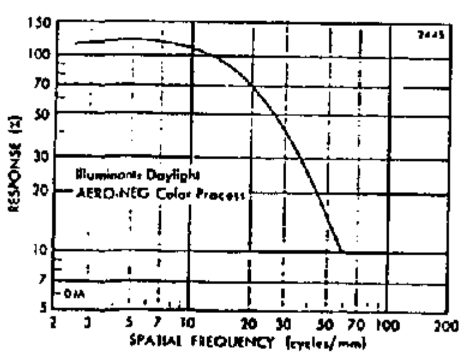
Spectral Dye Density Curves



Characteristic Curves



Modulation-Transfer Curve



True Colour Film Type 2445 - Film negative.

4.3.2 Ground Verification

For this project, the 'ground verification' was done prior to the aerial photography being taken (see Figure 4.3). All field work was done during the low tides during the day. Within the project site, four major areas were identified. These were the Reef–edge zone, the *Acropora* zone, the *Montipora* zone, and the algal turf zone (see Figure 4.5).

From the above zones, representative transects were staked out. Two transects each of 2 metres by 20 metres were marked out for each of the zones described above. This made a total of eight transects for the study site (Figure 4.5). The corners and the middle of the transects were marked with steel pegs hammered into the reef (the steel pegs to be removed from the site the at the end of the project).

Each transect was photographed from the ground using a 35mm camera mounted on a stand. The stand raised the camera 1.6 metres above the surface of the reef. The base of the stand marked a 1 X 1 metre quadrat. Each square metre of all the transects was photographed using this stand. The photographs were then combined into a mosaic for each transect. From the mosaic, identification of the cover type (coral hard or soft, alive or dead, algae, sand) and an estimation of the area of this cover was made.

For the aerial photography phase, the ground crew placed white plastic sheets (1 X 1.32 metres – white plastic tablecloths cut in half) at each corner of each transect. These sheets were used as targets for aligning the aircraft during the photographic runs (Figure 4.3), for subsequent identification of the transects in the processed photography, and as a control for spectral response.

4.3.3 Digital Data

The processed aerial photography was converted into digital data through the use of an Eikonix Model 1412 Digital Imaging Camera System. The primary photographic images containing the transects were digitised at a scanning resolution of 4000 X 4000 pixels (picture elements). The true colour images scanned were contact prints, while the false

FIG. 4.5 The locations of 8 permanent quadrats at Iris Point showed in a digitised infra-red aerial photograph.

Transect 1,2: Acropora Patches
Transect 3,6: Algae Turf Areas
Transect 4,5: Montipora Areas
Transect 7,8: Reef Edges

colour infra-red images were transparencies.

The operation of the Eikonix scanning camera system is through a CCD (Charged-Coupled diode Device) array with a maximum resolution of 4096 X 4096 pixels. The image to be scanned is placed on a stage below the camera, and in the case of prints is illuminated from above by four tungsten lamps. The spectral response from the image is focused through a standard camera lens (Nikkon f2.8 55mm) filtered in turn by blue, green, and red filters, and then sensed by the CCD array. The camera head scans the image line by line (the scanning rate determined by the requested resolution). The analogue CCD array response is then translated into digital data (12 bits per pixel) and sent to the attached PC via a GPIB (general purpose interface board - IEEE-488) (see Figure 4.6).

Prior to scanning, the CCD array is calibrated by using a white standard on which CCD gain and bias calculations are made.

In the case of transparencies, the image is illuminated by a single high intensity tungsten balanced light source below the transparency. The same calibration setup is used in this case as for the prints.

The raw data files created by the scanning camera were in BIL (Band Interleaved by Line) format with a 512 byte header for each colour channel. That is, three data files for each image were created. One file for the Blue response, one for the Green response, and one for the Red response. The data file for each colour channel at a resolution of 4000 X 4000 pixels is 16 Mbytes. When combined into a single 3 channel image file, a file of 48 Mbytes is produced by the microBrian image processing system.

The settings of the scanning camera for the contact prints was an integration time of 65535 integration units (effectively the shutter speed the length of time the CCD's are exposed to the image 65535 integration units equate to 330 msec) and an aperture of f4.0. For the infrared transparencies, the aperture was set at f8.0 while the integration time was set to automatic exposure.

CAMERA SYSTEM OVERVIEW

The EIKONIX 1200 and 1400 series digital imaging camera systems scan transparent and opaque photographs, line art, and three dimensional objects and convert them to digital data that you can store, analyze, and manipulate with your computer. The camera systems have three main components:

- An EIKONIX 1208, 1212, 1408, or 1412 camera: a self-contained unit with black and white capabilities and the option for color capabilities
- Your computer -- which can be DEC Q-bus or Unibus based, IEEE-488 based, VME based, or an IBM PC XT or AT or 100% compatible -- with the appropriate interface and cable purchased from EIKONIX
- A power supply, either 110V/60Hz (USA) or 220/240V/50Hz (International)

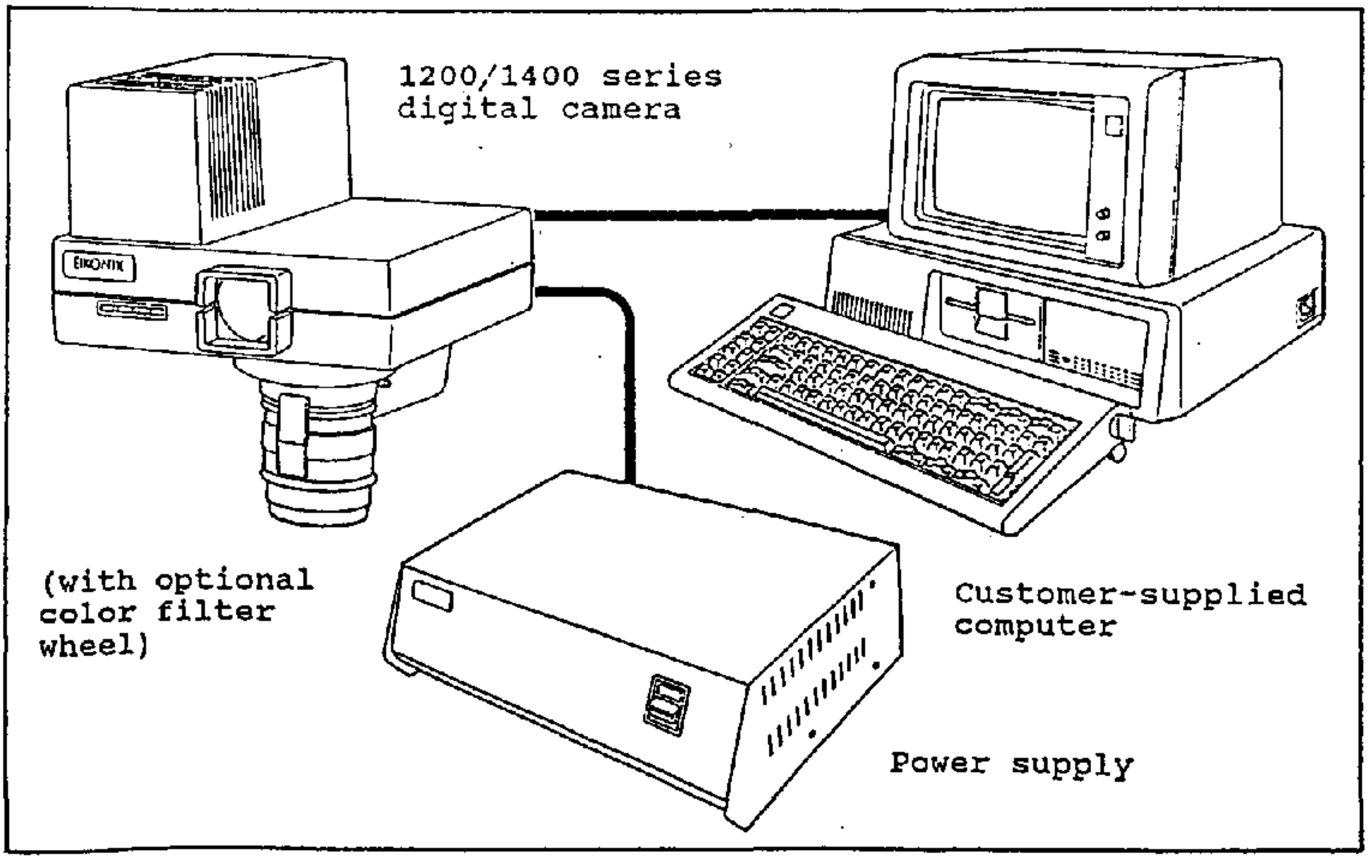


FIG. 4.6 Eikonix Camera (source- Ref. Guide - Eikonix Imaging Systems - 1987)

The three scanning camera output files (*.b,*.g, and *.r) were combined into one data file through the use of the microBrian (version 3.01) 'Combine' module. The resultant single file was in the propriety image file format of the microBrian image processing system (*.img).

These primary images were subsetted (using microBRIAN) cutting out the transects for the study site.

Once the image data was converted into the microBRIAN image format, standard image processing techniques were applied to the images.

The primary images and some of the subsetted images were exported from the microBrian system as ASCII (American Standard Code for Information Interchange) text files. The ASCII files where then loaded into databases (dBase IV ver 1.1) and SAS (version 6.08) for further processing.

4.4 Application of Output

Part 5 of this report discusses the standard image processing that has been applied to the data. For this part of the project the data will be subjected to statistical analysis and treated as data only, not as an image.

There have been two ways this data has been selected from the digitised images. Firstly, the entire image data set (for each primary image) has been exported from the microBrian system and collated into ASCII files for use in the SAS and dBase programs, and secondly, parts of subsetted images of the transects have been extracted for further analysis also using SAS and dBase.

From the subsetted images, data from the transects for each of the cover types has been extracted for each image channel. Using both the true colour and colour infra-red images, this gives four channels, blue, green, red, and near infra-red from which to determine the 'spectral signature' of each of the cover types. There is an overlap in the green and red channels using both film types. This overlap is used to test and adjust the brightness values for pixels from each film type.

The determination of the spectral signatures of each cover type is then used as a 'training set' for the application of a nearest neighbour classification algorithm to the primary images. From the classified image an estimation of the total area of cover for each cover type is made.

The results of this analysis are then compared to the results produced by the image processing software.

4.5 Discussion

Using the paper by Duggin and Robinove (1990) as a basis for the discussion of implicit assumptions made in remote sensing data acquisition and analysis, the following lists these issues and addresses each in turn with respect to the project.

4.5.1 Correlation between Image and Ground Attributes

The assumption was made that there was a very high degree of correlation between the surface attributes, the optical properties of the ground cover, and the attributes of the acquired image.

Through the use of standard photography in the visible and near infra-red wavelengths, recording reflected energy, it was deemed appropriate to make the above assumption.

4.5.2 Sensor Radiometric Calibration

It was to be assumed that the radiometric calibration of the sensor was known for each pixel.

In the case of this project, this was not the case. There was no ground radiometric verification undertaken. Although the need for this was discussed, resources did not permit such verification.

With respect to the digitising of the resultant photography, no reference was made to a sensitometric step wedge. The digitising process was standardised through the use of the same white standard to calibrate the scanning camera for each image digitised. Each of the contact prints were scanned with the same settings for the camera. That is an integration time of 65535 and an aperture setting of f4.0. For the colour transparencies, the aperture setting was f8.0, with the camera set to automatic exposure (for the integration time).

The reason for the difference in treatment between the contact prints and the transparencies, was that the use of the automatic exposure facility for the contact prints produced a digitised image with a very low dynamic range of data (typically a range of 30 brightness values). By increasing the amount of light being registered by the CCD's, there was an associated increase in the dynamic range of the data.

The above treatment of the digitising of the contact prints was considered as a stretching exercise for the data, without affecting the inherent data distribution. Such stretching was not necessary for the transparencies to achieve an acceptable data range.

The use of contact prints, and transparencies as the source photographic material for the digitising process was done to reduce as much as was possible the processing steps (and hence data distortion) required to produce the digital image. From this viewpoint, the use of colour reversal film (positive transparencies) is more preferable to negative film which requires at least one other processing step before a digital image can be created (digitising of the negative film and reversing the channels does not produce acceptable results).

4.5.3 Atmospheric Effects

It was assumed that atmospheric effects did not affect the correlation between the upwelling radiance field and the recorded radiance levels.

As the photogrbphy was low level (500 and 1,000 feet) and the weather conditions were sunny and clear, atmospheric effects (attenuation) on the resultant photography were considered to be negligible.

4.5.4 Sensor Spatial Response Characteristics

It was assumed that the sensor spatial response characteristics were known at the time of image acquisition.

With respect to this project the issue of spatial resolution was of primary concern. Issues of spatial response for this project fell into two main areas. That is, the spatial response of the primary recording media (the film), and the spatial response of ihe digitising process:-

These areas are discussed in turn.

(i) Photographic Spatial Resolution

The film used was Kodak Aerochrome Negative Film 2445 for the True Colour photography, and Kodak Aerochrome Infrared Film 2443 for the infra-red photography.

The granularity value for the true colour film was 13, and the infra-red film granularity was 17. The resolving power of the colour film was 80 lines/mm (contrast 1000:1) and 40 lines/mm (contrast 1.6:1). The resolving power of the infra-red film was 63 lines/mm (contrast 1000:1) and 32 lines/mm (contrast 1.6:1).

The scale of the photography was calculated using the following formula from Lillesand and Kiefer (formula 2.6)

scale = camera focal length/flying height above terrain

As the study site was at mean sea-level, the flying height of the aircraft was used for the scale calculation.

The 500 feet photography yielded an approximate scale of 1:1,900, while the 1,000 feet photography yielded a scale of 1:3,800.

The following formula from Lillesand and Kiefer (formula 2.10) was used to calculate the ground resolution distance (GRD) :-

GRD = reciprocal of image scale/systen resolution (lines/M)

From the above formula, the following ground resolution distances were calculated:-

Photography at 500 feet

True Colour:-
0.0475 metres (contrast 1.6:1)
0.0238 metres (contrast 1000:1)

Infra-red :-
0.0590 metres (contrast 1.6:1)
0.0300 metres (contrast 1000:1)

Photography at 1,000 feet

True Colour:-
0.0950 metres (contrast 1.6:1)
0.0475 metres (contrast 1000:1)

Infra-red :-
0.1188 metres (contrast 1.6:1)
0.0600 metres (contrast 1000:1)

From the above it can be seen that the spatial resolution is primarily a function of the height of the aircraft, and the relative contrast of the area being imaged. The contrast between attributes of interest on the study site was for the most part good. That is, the major cover types could be easily distinguished from one another and the base substrate.

The exception to this was the reef edge transects. The mixture of water (of varying depth), hard coral, soft coral, wet coral, dry coral, and wet and dry sand made differentiation of the cover types difficult, if not impossible, even at high ground resolutions. The variability of this zone of the reef may preclude the use of this type monitoring in the wavelengths used. Longer wavelength monitoring may be required for this area. This aspect is discussed more fully in part 2 of this report.

The advantage of the use of aerial photography (or other airborne sensors) is that' the spatial resolution desired can be chosen by the researcher. This can be achieved by simply altering the flying height of the aircraft. The lower the flying height, the higher the resultant ground resolution. The same is not true for satellite imagery for example.

There are some administrative restrictions to the flying height of the aircraft which may preclude very lowlevel flying. Currently, the minimum legal flying height over the Great Barrier Reef Marine Park is 500 feet, although it may be possible to acquire special permission from the Great Barrier Reef Marine Park Authority to fly at lower altitudes.

Low level flying for aerial photography presents other problems for fixed wing aircraft. Depending on the aircraft, the slowest safe cruising speed will also determine the minimum flying height at which overlapping photography can be taken, along with the film advance speed of the camera motor drive. At low altitudes the effective ground speed of the aircraft platform needs also to be considered to avoid image blurring (thus requiring an appropriate camera shutter speed to be chosen).

All of the above problems can be solved if very high resolution is required. For example, the effective ground speed problem, image blurring, and not enough image overlap can be solved by using rotary wing aircraft. Approvals may be gained to fly at low altitudes. Alternative sensor platforms may be used, for example hot air balloons, ultralight aircraft, and remote-controlled model aircraft to name a few.

(ii) Digitised Spatial Resolution

The process of digitising aerial photography introduced another dimension to the spatial resolution issue. This was because a secondary image was made from the original image by a process not all that dissimilar to the way the original image was captured.

As a result of this, similar considerations as previously described above needed to be taken into account for this process.

The digitising process (as described in Section 4.3.3) allowed many of the spatial parameters to be set to desired levels, this even to the extent where the digitising resolution could exceed the granularity of the original film (or contact print). In such cases where the granularity was exceeded, data gained from the digitising process was of little use. By digitising past the grain of the original image, the resultant digital data would not reflect the original image data, but rather the granular composition of the original emulsion. This aspect became relevant as it was possible to fit macro lens' to the digitising camera in order to zoom in on specific parts of the original images and digitise those parts anywhere up to the maximum resolution of 4096 X 4096 pixels.

The Eikonix Model 1412 Digital Imaging Camera allowed for a maximum resolution of 4096 X 4096 pixels (16.77 X 106 pixels) for each of the three colour channels (Red, Green, Blue). This resolution was delivered by the camera regardless on what the camera was focused. As the camera was mounted on an adjustable stand, the camera could be lowered and raised to focus on any object within the 1 metre range of the adjustable camera stand.

As it was possible through the use of the digitising camera to digitise the original film at a pixel resolution greater than the grain size of the original film, a determination of the maximum practical pixel resolution at which to scan the images was determined.

The determination of the maximum practical pixel resolution was based on the stated resolving power of the film used. The determination was based on the resolving power rather than the grain size to avoid the problems with the inherent variability of grain size in film emulsions.

This was deemed to be acceptable (and conservative) as the resolving power of a film emulsion is ultimately a function of the film granularity.

Using the resolving power also allowed comparison between different film emulsions which is not possible when using the stated RMS granularity values for the emulsions. This was because the stated RMS granularity value is the square root of the grain variance (or the standard deviation) and as such only gives a relative value between emulsions of similar type (Carroll et al 1980).

The physical dimensions of a frame of 70mm film is 55mm square.

Calculations for the maximum practical pixel resolution (MPPR) were made by multiplying the resolving power with the length of one side of the film frame. That is :-

MPPR = resolving power (lines/mm) X width of film frame (mm)

From the above formula, the following maximum practical pixel resolutions were calculated:-

True Colour Photography

- using the 1000:1 contrast
MPPR = 80 X 55
    = **4400 pixels**
- using the 1.6:1 contrast
MPPR = 40 X 55
    = **2200 pixels**

False Colour Infra-red Photography

- using the 1000:1 contrast
MPPR = 63 X 55
= **3465 pixels**

- using the 1:1.6 contrast
MPPR = 32 X55
= **1760 pixels**

From the above, it was noted that in almost all cases the digitising camera could digitise in excess of the maximum practical pixel resolution when the camera was digitising the full frame, as was the case with the primary images.

The effects of the maximum practical pixel resolution became more pronounced when the digitising camera was fitted with a macro lens (focal length 105MM). The macro lens allowed the digitising camera to be focused on a part of the primary image frame, thus reducing the effective frame length (to something less than 55mm X 55mm). This resulted in lowering the MPPR (see Table 4.1).

TABLE 4.1 The effects on Maximum Practical Pixel Resolution (MPPR) of decreasing frame size.

Frame Size	**True Colour - 1000:1 contrast**	**True Colour - 1.6:1 contrast**	**Infra-red 1000:1 contrast**	**Infra-red 1.6:1 contrast**
55 X 55 mm	4400 pixels	2200 pixels	3465 pixels	1760 pixels
45 X 45 mm	3600 pixels	1800 pixels	2835 pixels	1440 pixels
35 X 35 mm	2800 pixels	1400 pixels	2205 pixels	1120 pixels
25 X 25 mm	2000 pixels	1000 pixels	1575 pixels	800 pixels

It was clear that care needed to be taken with respect to the digital resolution when the original aerial photography was digitised for further image analysis.

4.5.5 Sensor Spectral Response Characteristics

The assumption was made that the spectral response and calibration characteristics of the sensing device were known at the time of image acquisition.

The spectral response of the films used for this product were known at the time of image acquisition, and are shown in Figure 4.4. The settings for the camera remained unchanged throughout the photographic runs.

The spectral response characteristics of the digitising camera were known at the time of image digitisation.

4.5.6 Image Acquisition Conditions and Data Types

The assumption was made that the image-acquisition conditions were optimum (or at least adequate) for the discrimination of the features of interest against the background.

As a result of the atmospheric conditions at the time, the extreme low tide, and the prior ground verification work, the above assumption was believed to be correct.

4.5.7 Image Scale and Ground Resolution

The assumption that the scale of the image was appropriate to detect and to quantify the features of interest, was not made in this project.

The appropriate scale was to be determined from the results of this phase of the project.

4.5.8 Correlation Between Attributes of Interest and Optical Properties

The assumption was made that the attributes of interest had a strong correlation, (which was invariant across the images) with attributes of interest on the ground, which controlled the upwelling radiance fields.

As a result of the ground verification work, as well as the use of the white plastic targets, it was believed that this assumption was valid.

4.5.9 Analytical Methods

The assumption that the analytical methods used upon the resultant data from this project, and the sequence in which they were applied were both appropriate and adequate for the task, was the aim of this project. That is, this project was to determine a methodology for the analysis of such data. In this case, therefore, the analytical methods are presented, rather than assumed.

4.5.10 Image Spatial Characteristics

The assumption that the spatial characteristics of the image were adequately explored, at an appropriate scale, was as with the above, one of the main aims of this project. Again this work is presented, rather than assumed.

4.5.11 Accuracy Verification

It was assumed that there was a means of verifying the accuracy with which the ground attributes of interest were mapped/or quantified, and that the process of verification was uniform across the images.

The ground verification work indicated this assumption to be correct.

5. DEVELOPING TECHNIQUES IN GROUND SURVEY AND IMAGE PROCESSING

(This part of the report was prepared by T. Thamrongnawasawat)

5.1 Introduction

The purpose of this part of the project was to develop ground truthing techniques for the digitised aerial photography with specific reference to mapping biological distributions of reef flats. The process focused on designing ground survey methods which could relate results to digitised aerial photography directly, and on modifying existing digital image processing techniques in order to best identify biological distributions contained in digitised aerial photographic data.

Due to the rapid development of remote sensing techniques, there are many technologies which have the potential to give more information (eg. Digitised Aerial Photography, Landsat TM, Airborne Video). Of all remote sensing technologies, low level digitised aerial photography has the highest potential to be developed as a tool for mapping and monitoring biological distributions on reefs. The advantages of digitised aerial photography are illustrated in Table 5.1.

In spite of, the advantages of digitised aerial photography, it is particularly notable that there has been no scientific investigation into the mapping capability of this technology to aid in the monitoring and management biological resources of reef ecosystems.

Based on the work already published, there have been no remote sensing studies on reef ecosystems which concentrate on biological distributions. Previous remote sensing techniques have been used for mapping and monitoring the morphological zonation of the reef, and the results used for monitoring the reef ecosystems. However, the direct remote sensing of biological data on the reef is essential if mapping and monitoring programs are to provide tools for the management of biological resources.

Main Features	Satellite	Normal Aerial Photography	Digitised Aerial Photography
Resolution (one pixel/ground resolution)	30 m (TM) 20 m (Spot)	17 - 55 cm	1 - 26 cm
Bands	6 bands (TM) 3 TC, 3 IR *	3 bands (each photo)	6 bands (combined data)
Techniques	image processing	visual identifying	image processing
Acquired Times	fixed, not dependent on user define	user definition	user definition
Water Disturbance	high, dependent on tides	low, selecting the lowest low tides	low, selecting the lowest low tides
Time Consuming	low, using themes	high, re-do each photo	low, using themes
Processing Errors	low, dependent on statistics	high, bias	low, dependent on statistics
Potential for studying reefs	not enough resolution, only processing for reef geomorphology	time consuming, bias, limited data	suitable for most cases

* In fact, Landsat has 7 bands however, Band 6 of Landsat TM is a thermal infra-red which does not provide information for reef mapping.

TABLE 5.1 **Advantages of digitised aerial photography compared with satellite and aerial photography**

Previous scientific works have also concentrated on mapping reefs at a regional scale (eg. Kuchler, 1984). These are only of a broad scale planning interest to management bodies such as GBRMPA. An investigation of the capability of remote sensing technologies for mapping individual reef components is urgently required. These are the true indicators of reef health and therefore are the prime interest of managers and marine biologists.

Reef monitoring programs using satellite remote sensing techniques have been previously conducted (eg. Kuchler, 1984). However, the disadvantage of past studies has been the concentration on geomorphological features. The results from such projects have been used to indirectly map biotic distributions. For example, the living coral areas could be located by mapping reef slopes, using reef knowledge that living corals occur on reef slopes. However, satellite remote sensing techniques cannot directly map biological components themselves due to the low resolution of the data. Moreover, reef benthic cover changes more quickly than reef geological patterns (eg. seasonal changes in algae). Therefore mapping reef geomorphology cannot be used for monitoring changes in reef biological components.

In contrast, digitised aerial photographs can give information at a fine enough scale to directly map the biological distributions of reefs. Thus, it should be possible to establish a monitoring program to detect changes in biological distributions using digitised aerial photography.

From the current data, it will be shown that there is a possibility to develop a digitised aerial photography technique for detailed mapping and monitoring of biological distributions. In addition, this project provides the groundwork for the establishment of reliable and efficient techniques for research and management of reefs of the Great Barrier Reef region.

5.2 Methods

The digitised aerial photography technique is a new approach using an EIKONIX digitising camera to scan the reef aerial photographs. This technique has been tested in the Pilot Project as a tool for studying reefs. However, there was little testing of the image processing techniques in order to identify biological distributions in detail. Moreover, there was no ground truthing technique designed to be used with the digitised aerial photography.

This part of the project consisted of 3 processes; data collection, data analysis, and data comparison.

5.2.1 Data Collection

The data collection process was very important since there have been no previous scientific investigations of digitised aerial photography from reefs. Moreover, this project aimed to collect data at the lowest low tide (for exposed reefs) which occurs only few times per annum. Therefore, the data collection process had to be designed and developed carefully. There were 3 aims of the data collection process which are listed as below:

- Data should be collected from a selected area which has exposed biological components. The areas of biological components should be big enough to be separated in many individual distinct areas.
- Digitised aerial photographs should contain data both in true colour and infra-red. Data should be collected from different flying altitudes. Therefore images will consist of various resolutions, which can be compared to determine which is most suitable.
- Ground data should be collected at the same time and sites as the digitised aerial photography.

Following these concepts, the data collection process was separated into 3 major parts, namely survey methods, aerial photography, and ground data collection.

Survey Methods

An aerial survey gave broad data recorded on camera and video recorder. Firstly, the acquired data was analysed in order to locate exposed areas of living corals on various reefs. Then, a ground survey was conducted at selected sites in order to establish whether these areas were suitable for use as study sites.

Aerial Photography

Digitised aerial photography was obtained using a 70 mm camera (more detail in Part 4).

Ground Data Collection

The ground data collection methods in most remote sensing research projects are usually referred to as "ground truthing". Many types of ground truthing methods have been conducted in reef mapping programs (eg. Kuchler, 1984; Thamrongnawasawat, 1992), but techniques have been created for the purposes of each individual project. Hence, there is no standard ground truthing technique for reef remote sensing studies.

For the purposes of this paper "ground truthing" will be defined as referring to methods which focus only on broad scales. They aim to obtain general data for a whole study area. The surveyed areas are only parts of a whole area studied and hence, this type of data is only a representative. Moreover, most ground truthing occurs after remotely sensed data have been acquired. Hence, there are time errors in ground truthing results.

In this project there were two types of ground data collection techniques, namely "ground truthing" and surveys of permanent transects.

(i) Ground Truthing: This technique was adapted from previous satellite ground truthing techniques (eg. Kuchler, 1984; Thamrongnawasawat, 1992). However, there were some important modifications. For instance, Global Positioning System (GPS) is an essential piece of equipment for satellite ground truthing techniques. However, for the digitised aerial photograph ground truthing technique, a GPS is useless because of the different resolutions of the two data sets. A GPS may have an accuracy of 10-20 m which is enough for the satellite imagery, but it is useless for aerial photography with 20–50 cm resolution. The modified ground truthing technique used a camera and a video recorder as major data collection equipment.

(ii) Permanent Transects: There were two major parts of this technique which were different from ground truthingas defined above. Firstly, the studied area of both remote sensing and the permanent transects was the same. Hence, the ground data represented a whole area. Secondly, ground data were collected at the same time as remotely sensed data. Hence, there were no time errors.

This method was modified from the permanent quadrat technique. It was developed in order to collect two data groups, namely data used for the ground data analysis, and data used for the image processing. Eight permanent transects were conducted in four selected areas: reef edges, Acropora patches, Montipora areas, and algal turf areas. In each area two permanent transects were laid. Each transect covered an area of 40 m^2 , 20 m in length, and 2 m in width. Photographs were taken over the whole quadrat, then used in the ground data analysing process. Each transect had 4 ground control points, which were white plastic sheets laid at each corner (Figure 5.1). These ground control points were used as indicators for aerial photography (more detail about the operation in Part 4).

Although this technique has been used successfully for the mapping project, the ground control point technique requires some further modification in order to give better results. The major problem of the permanent transect technique was the defining of the borders of the transect. Plastic sheets could not give exact borders along the transect. This problem made it difficult to cut the transect area out of surrounding areas during image processing. A detailed inspection of the ground data could solve this problem but is very time consuming. Subsequent surveys may need more transects with more time consumption. Moreover, if the technique was to be developed for a long term monitoring program and should be sensitive enough to detect small biological changes, it needs exact borders in order to compare percentage of coverage of biological components from time to time. A suggested modification for the ground control points is illustrated in Figure 5.1.

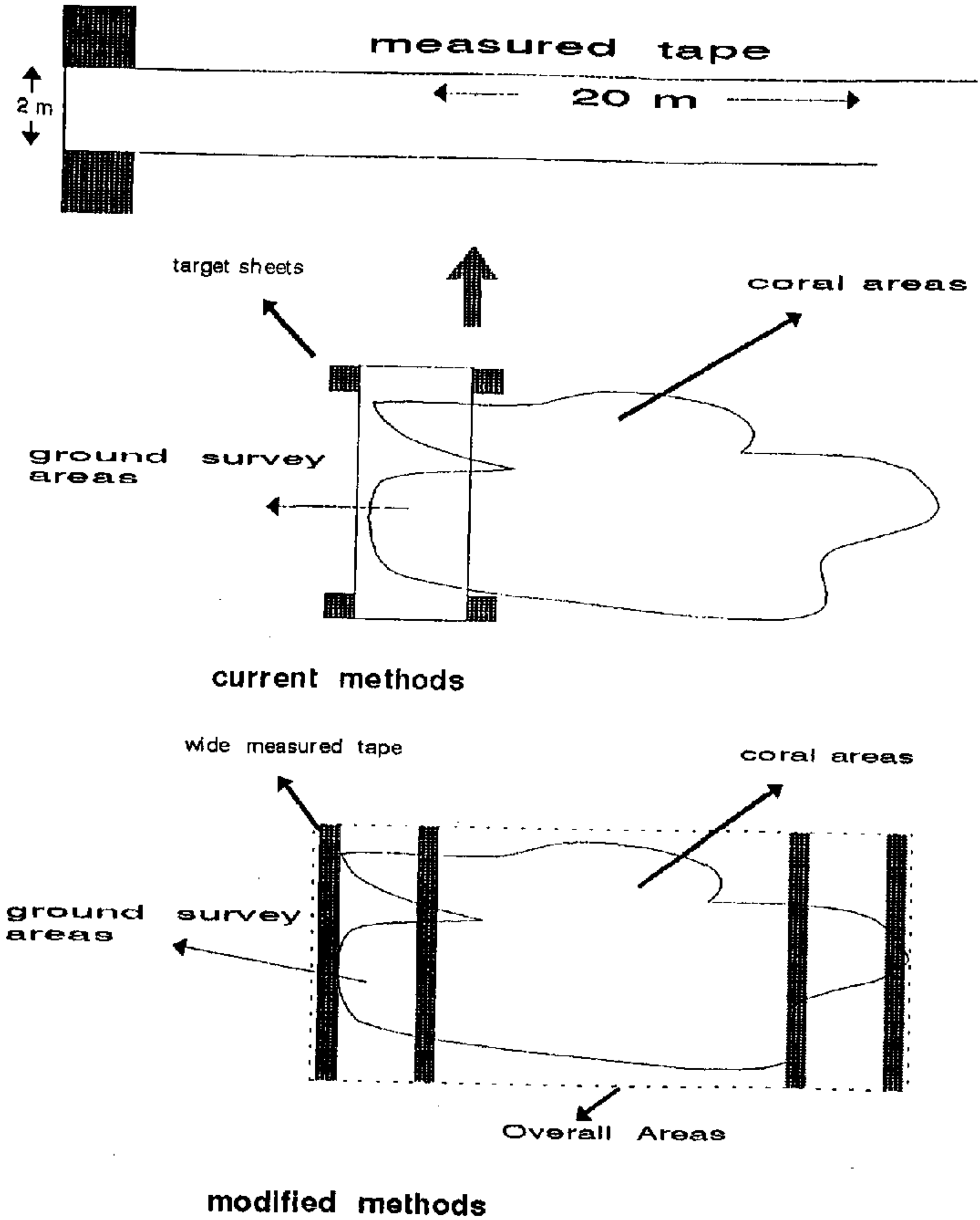


FIG. 5.1 Designed (above) and modified permanent transect methods

In this newly designed technique, white thick plastic tapes (approximately 25 cm in width) were used instead of white plastic sheets. Two tapes were laid along borders of the transect. Other operational techniques were the same as in previous methods (detail in Part 4). Measuring tapes indicated exact borders of the transects in image processing.

5.2.2 Data Analysis

The data analysis process was divided into 2 processes: ground data analysis and digitised aerial photograph analysis.

Ground Data Analysis

Data for this process was produced by ground photographs taken from permanent transects, 80 prints for each transect (total 640 prints). Photographs from each transect were mosaiced together. The percentage coverage of each biotic component was then calculated from weights of paper cut from each transect. Details of each component in each transect may be different depending on the major dominant living features. However, percentage coverage of living corals were calculated from all transects, and used for comparison with results from image processing.

Digitised Aerial Photograph Analysis

This process was separated into 2 major operations; image enhancement, and image analysis.

(a) Image Enhancement: This aimed to enhance and clarify raw images in order to give better results. The results from image enhancement had 2 objectives. Firstly, the results were used as data for image analysis. Secondly, the results can be directly presented as end products. Image enhancement was generated into 3 minor processes.

(i) Enhancement: Raw images were enhanced using contrast stretching in microBRIAN (more detail in Harrison and Jupp, 1990). The results were directly used as end products, or else, they were used for later analysis. In this project, most of the results were used for the second objective because aerial photographs can be visually interpreted more easily than digitised images.

Enhanced images used in the second objective were used only for visual interpretation which is required in several image processing techniques. Data analysis operated only with raw image data. For instance, training areas for image classification were selected by visual interpretation of a stretched image, but raw image data were analysed in computer classification.

(ii) Combination: Image combination is an essential method for using different sources of data. Although this project concentrated only on the digitised aerial photography, two types of film were used: True colour and Infra-red. Hence, image combination was used in order to merge both data sets together. This resulted in a new combined image which has 6 bands, 3 in true colour and 3 in infrared. The ground control points of each transect were very important in this process. Two factors require particular consideration:

- Both data sets have to be collected at the same time, sites, and flying altitudes.

- Both data sets should have ground control sheets set up especially for this purpose. At least 16 ground control sheets should be contained in both datasets.

Mapping Infra-red to true colour images is easier than vice versa because ground control points were detected more easily in true colour images. The results from this process were important for identifying mixed biotic areas using a band ratio technique and image classification.

(iii) Masking: Although most aerial photographs were taken from exposed areas, some ground photographs were taken from areas close to the sea. Those areas were reef edges which had dense biotic components. Therefore, this project had to identify some areas covered with water. Moreover, reef edges had a three dimension relief so there were many shadows in the photographs. A masking process was used for solving errors from water and shadows which affect biotic reflectance values. Using microBRIAN, themes of water and shadows were created and used in order to cut and mask water and shadow areas from images. The results of this process were used directly in classification procedures.

(b) Image Analysis: Image analysis is different from image enhancement because image analysis performs calculations which change the raw data, while image enhancement is used only to improve raw data. Image analysis in this project was separated into 3 processes listed below:

(i) Principle Component Analysis (PCA): This technique was used for enhancing major or minor reflected components in images. This project used PCA as a testing method for a few selected images.

(ii) Band Ratio: This technique was used for calculating reflectance values in images. In order to use band ratio technique products, reflectance values have to be studied in detail. However, reflectance values of digitised aerial photographs taken from reefs have never been previously studied in detail, and a comprehensive study is time consuming. Therefore, this project used only a band ratio technique for enhancing some target areas before using a classification process to identify biotic components.

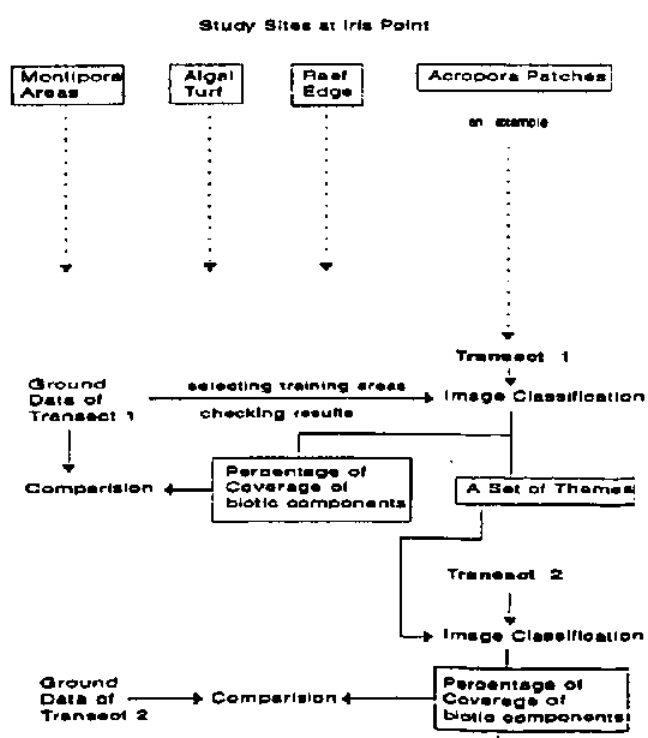
(iii) Classification: There are 2 types of classification used in remote sensing, namely unsupervised and supervised classifications. An unsupervised classification is mostly run by an image processing program, while a supervised classification needs user definition for details, such as training themes. This project used mostly a supervised technique, hence, ground data became very important both in selecting training areas and in checking thematic results.

5.2.3 Data Comparison

This process focused on testing the accuracy of digitised aerial photography of the studied reefs. The results from image processing techniques were compared with results from the permanent transect technique. The differences between the two techniques provided an estimate of the accuracy of digitised aerial photography for mapping reef benthos.

The comparison technique was applied to each zone separately. All substrates in one transect of each zone (there are 2 transects in each zone) were classified using training themes selected from ground data. This set of themes consisted of major reef biotic components: hard corals, soft corals," and macro algae. The first classified results were then classified again by selecting more training themes from areas which had not been mapped correctly in the first classification. This process was conducted again until all biotic components in the first transect were classified. Therefore, the percentage coverage of reef biotic components in this classification indicated the accuracy of the set of themes created from ground data at the first transect.

A set of themes from the first transect of each zone was applied for image classification of the second transect of each zone. The classified results were compared with the results from the permanent transect in order to determine how accurately it portrayed the actual distribution of biota. The whole comparison process is summarised below:



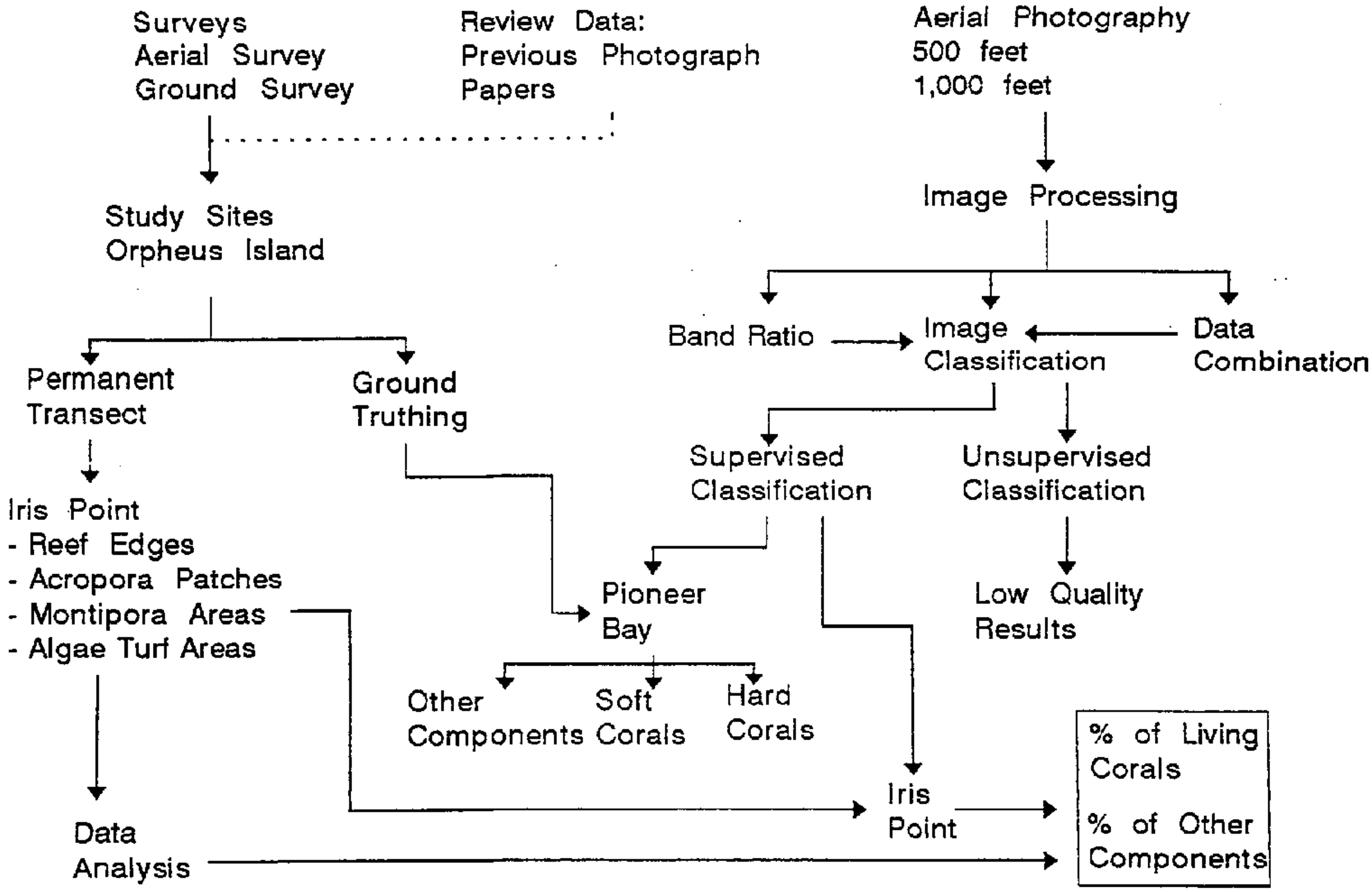


FIG. 5.2 A result framwork

5.3 Results

The results of this project are separated into 2 parts, namely results from ground data, and results from image processing. Most results concentrated on explaining development techniques. Results are summarised in Figure 5.2.

5.3.1 Ground Data

Survey Results

The results from aerial and ground surveys showed that Orpheus Island, Palm Group, was suitable for use as a study site. The specific study sites on this island were at Iris Point and at Pioneer Bay. Iris Point has an exposed fringing reef at the southern end of this reef there is an exposed area with high density of biotic components (Figure 5.3). Hence, this area was selected as a major study site for the permanent transects. Pioneer Bay has a sheltered fringing reef. Although this area had many biotic components, they were mixed together over wide areas. As a result, this area was selected as a minor study site for developing ground truthing methods. Orpheus Island and both study sites are illustrated in Figure 4.1.

Permanent Transect Results

The results of the permanent transect technique are shown in Table 5.2. It is noted that this technique can give all necessary data. Therefore, the permanent transect technique is suitable for use as a major data collection technique in later stages.

Ground Truthing

The ground truthing results were of minor interest for this project. The results from a camera and a video recorder gave broad information for use with general image processing results. However, these results could not be used for locating small biotic components exactly. Therefore, the digitised aerial photography study could not depend only on the

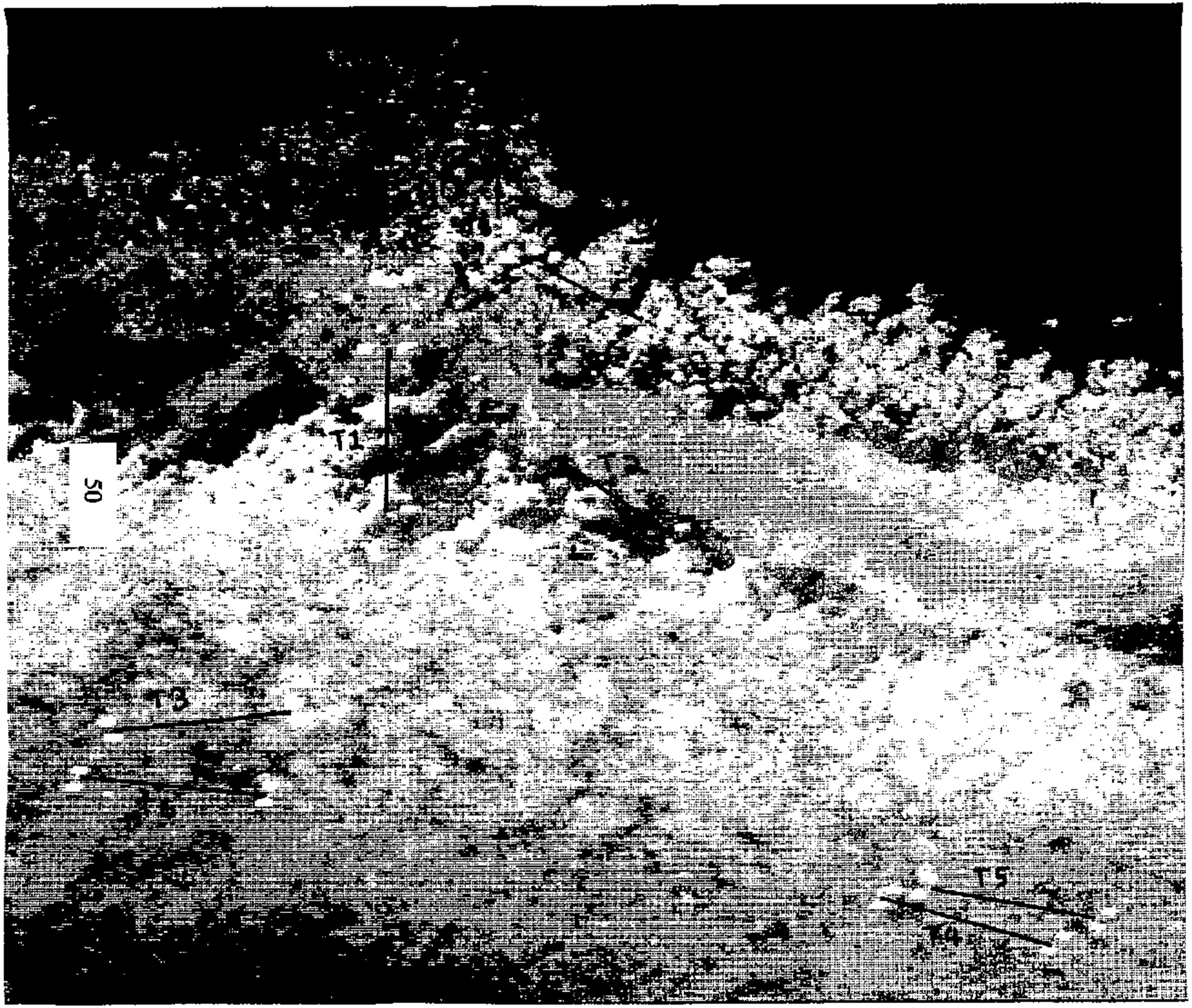


FIG. 5.3 The locations of 8 permanent quadrats at Iris Point showed in a digitised infra-red aerial photograph.

Transect 1,2: Acropora Patches
Transect 3,6: Algae Turf Areas
Transect 4,5: Montipora Areas
Transect 7,8: Reef Edges

ground truthing data. The permanent transect technique is essential for setting up a technique for mapping and monitoring biological distributions of reefs.

5.3.2 Image Processing

Image Enhancement

The results of this part were separated into 3 minor processes:

(i) Enhancement: As discussed in the Methods Section, most results of this process were used in image processing. Hence, there were not many end products from this process. However, the results from the enhancement process produce some interesting features using stretched values and gamma adjustment. Raw aerial photographs cannot be used in this way. Figure 5.4 shows an enhanced digitised aerial photograph compared to the raw photograph.

Visual identification of the raw infra-red photograph (Figure 5.4) could identify 3 major areas: black as water, red as living organisms and other non-biotic components, white as sand, dead corals and wave breaking. Although individual coral heads could be located by their structure, there were only a few in this photograph.

In contrast, visual identification of the enhanced infra-red digitised aerial photograph (Figure 5.4) enabled a categorisation of the reef (the same site but different acquisition times) into 5 distinct areas: blue as water, white (inner part) as sand, light blue as coral rubble, red as living corals at reef edge, and dark red as Acropora patches.

(ii) Combination: The results of image combination are very important for the band ratio process. A combined image can be presented in many different ways depending on purpose. Ground truthing is required in order to identify the results. More technical information is given in APPENDIX I.

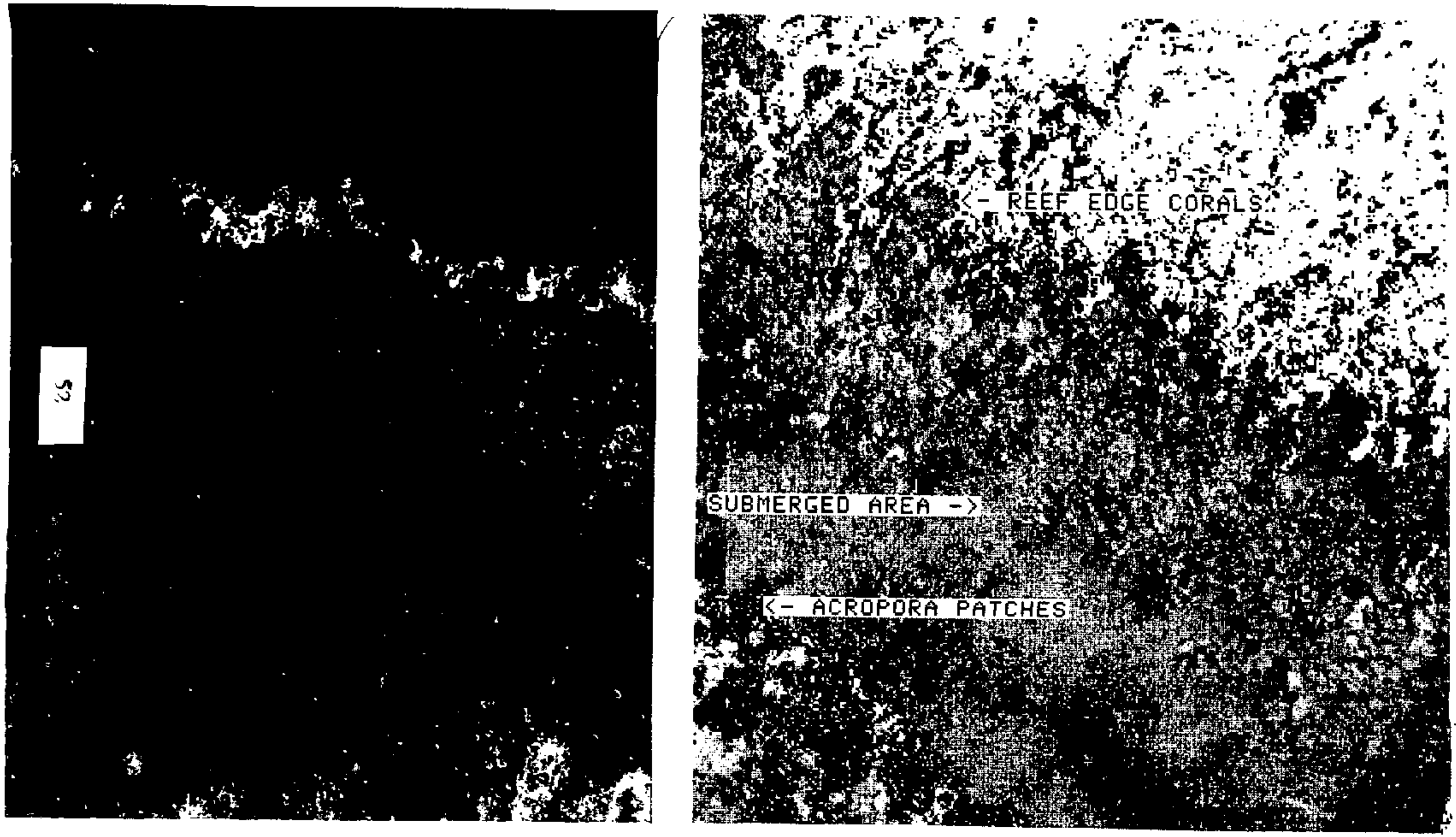


FIG. 5.4 Normal (left) and enhanced digitised (right) low level infra-red aerial photographs of reef edges at Iris Point.

(iii) Masking: Most results from this process were used as a data base for an image classification process. There was no end product in this process. However, results confirmed that this process was very useful especially for mixed biotic component areas such as reef edges.

Image Analysis

(i) Principle Component Analysis: PCA was developed in order to reduce the data from the original image. It uses spectral statistics of the image in order to remove similar responses of two or more original channels, and create new channels which are computed by an affined transformation of the original data. These new data are arranged along axes which incorporate a decreasing proportion and the total image variance (Harrison and Jupp, 1990). In the study of PCA in MSS satellite data, the first principle component usually represents at least 90% of the total variation. In terrestrial scenes most data in PCl represents image brightness (or topographic shading). PC2 usually represents vegetation greenness and PC3 is related to soil colour (Ahmad, 1987). PCA is usually used as an intermediate step in other processes especially image classification. it gives fewer channels with increasing colour saturation in composite images (Gillespie et al., 1986). Hence, PCA helps in selecting training areas.

The image classification of this project was based on ground data. Therefore, PCA was not very useful in this case. Each training area could be identified by ground data. Hence, the patterns of living organisms in images were far more important than colour shades. The new PC channels had many colour shades which made the selection of training areas difficult.

Water and shadows were further problems in developing PCA in this project. The high resolution digitised aerial photographs of reefs have considerable areas of both. They reflect light in low values which are similar to some biotic components (eg. corals, algae). When PC1, which represents image brightness, is used for identifying reef components, waters and shadows may be incorrectly mapped as corals or algae.

In the pilot project, Catt and Hopley have used PCA and suggested that this method was successful in their studies of reefs near Cape Tribulation (Catt and Hopley, 1990). However, the processed images were collected at 3000' flying altitude which were completely different to images taken from 500' of flying altitude used in this project. For instance, water and shadows did not appear significant in high altitude aerial photographs. Moreover, they used PCA as a separate process for enhancing biological data, while this part of the project used PCA as an intermediate process for helping image classification. Therefore, PCA may be used in some cases depending on scale, resolution, and techniques.

(ii) Band Ratio: The results confirmed that this technique is very useful. For instance, it was difficult to separate hard corals and soft corals at reef edges. Image classification and combination could not solve this problem since hard corals and soft corals were displayed in the same colour of green (Figure 5.5). However, this problem was solved by using a band ratio technique of an infra-red band divided by a blue band. Comparing this image (blue, green, infra-red/blue) with a true colour image (blue, green, red), hard corals displayed in red, while other reef components included soft corals displayed in colour composites of blue and green (more in APPENDIX II).

(iii) Classification: Image classification was the most effective technique for identifying biological distributions in this project. Two procedures were followed in order to obtain an image classification:

Creating Sets of Themes: The major concept of this procedure is to develop sets of themes which can be applied for classifying biotic components in the study sites (detail in Section 5.2.3). There are 4 study sites therefore there are 4 sets of themes developed in this procedure. The creating process runs separately in each study site because biological distributions in each site are different.

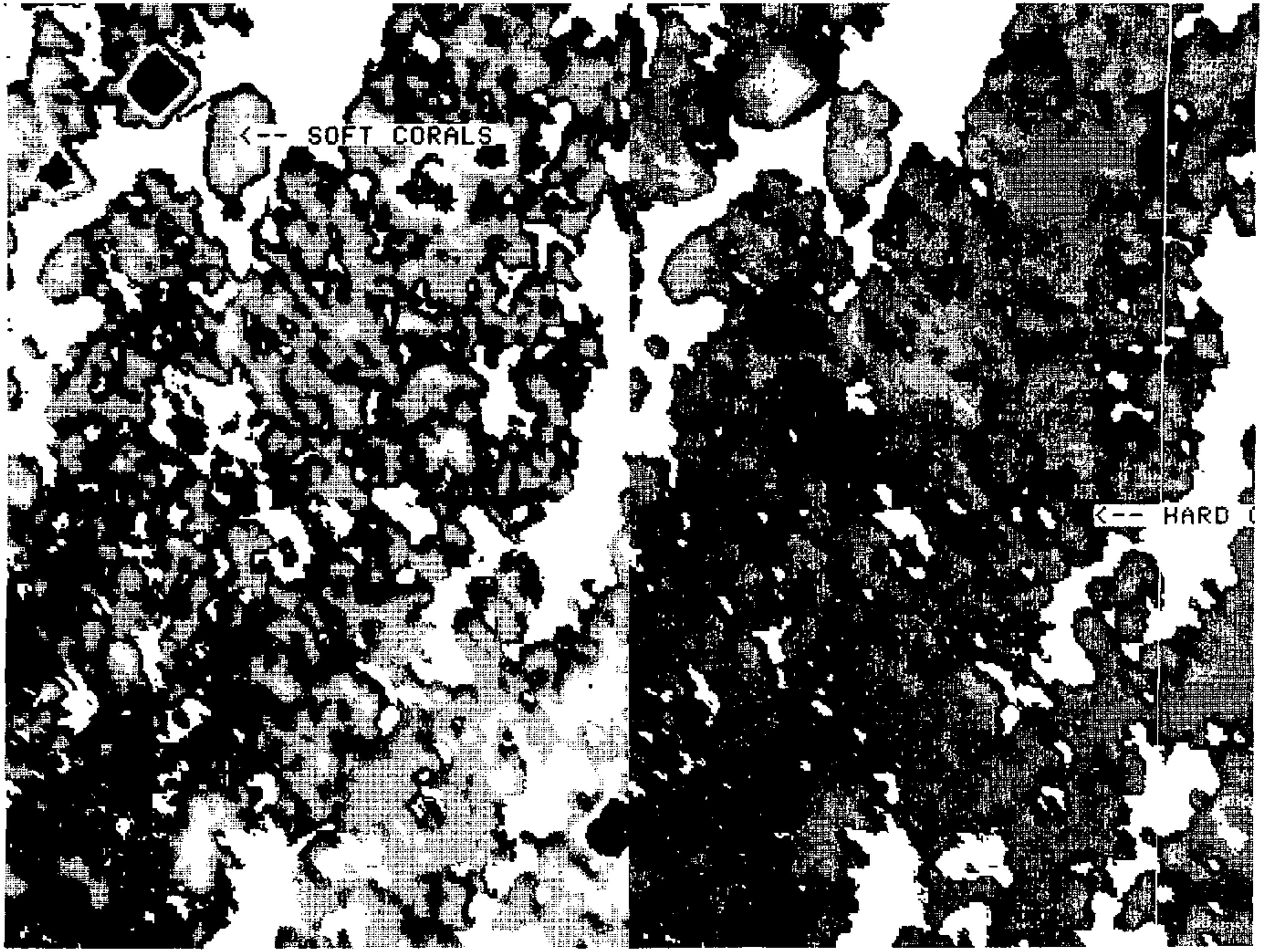


FIG. 5.5 Normal (left) and band ratio (right) digitised aerial photographs of Transect 7. Hard corals are enhanced in red.

This process began with selecting an interpreted image (results from other processes such as enhancement, masking). Next, one transect was cut out from other areas. This transect image was used for selecting training areas. Ground data were very important in this process because they showed real substrates located in training areas. Hence, themes of reef components could be created by this technique. This process concentrated on biological distributions, therefore most themes were selected from biotic components. However, some non-biotic components were also selected in order to differentiate biotic components from non-biotic components. Results from this process ended with a set of themes which usually contained 12–15 themes, 8–12 themes of biotic components (eg. 4–7 themes of hard corals, 4–5 themes of soft corals, 1–2 themes of free-living algae), and 3–5 themes of non-biotic components (eg. 1–2 themes of sandy substrate, 2–3 themes of dead corals).

This set of themes was applied to classifying an image. A group of feature classes, which was presented in a dendrogram, was calculated by clustering basic spectral signatures of each theme. This dendrogram was applied for use in taxonomic clustering of classified results. It assumes that substrate covers are spectrally homogeneous clusters (Harrison and Jupp, 1990). Low altitude digitised aerial photographs have very high resolution, therefore one biotic component reflects light in many pixels (eg. one coral head contains 4–5 pixels). Each pixel in a digitised image and has a homogeneous value reflected only from one substrate. Hence, the dendrogram clustering technique is suitable for use in this project.

Results from the computer classification did not have the same number of classes as the input themes. The reason was that themes created by training areas could not classify all substrates in the transect (it is possible to create a set of themes from training areas which can classify all areas, however, it is very time consuming). In areas which could not be classified into input themes, the computer will create new themes for those areas. For instance, a input set of themes from selected training areas in the first transect of Acropora patches contained 12 themes, but the classified results contained 25 classes, 13 themes had been created by computer. All computer created themes were non-biotic classes. However, these themes might map some biotic components which are not mapped by themes created from selected training areas. All computer created themes were not included but only used in a taxonomic clustering and labelling process.

Results from the first classification were checked against ground data. More biotic training areas were selected from the areas which had been incorrectly mapped in the first classification. These newly selected themes were included in the first set of themes, hence the process still had one set of themes. This was used in the second classification and the process was conducted again until the set of themes mapped all biotic components correctly. Finally the number of pixels in each class were counted and calculated for percentage coverage of reef components in this transect.

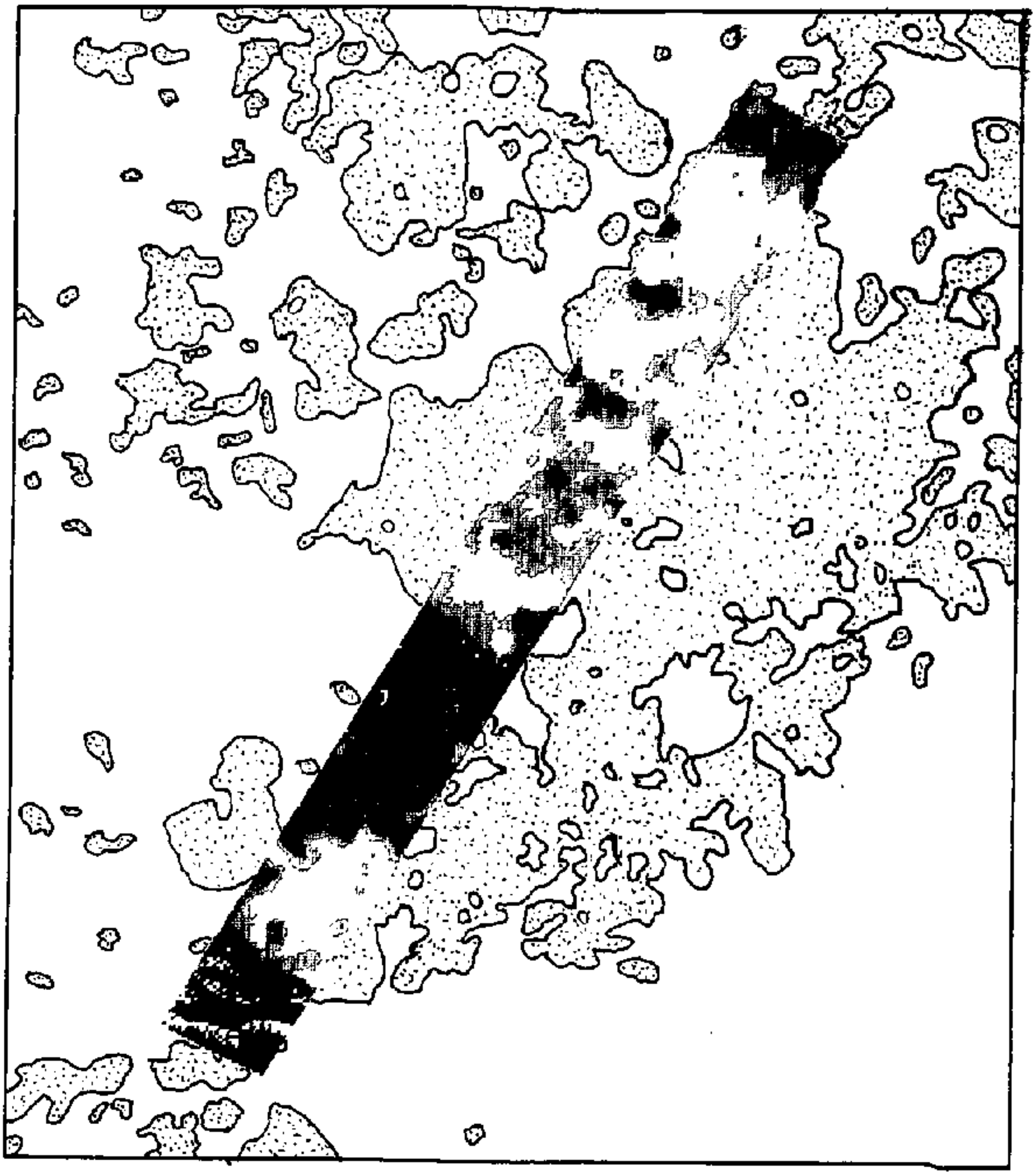
A good example of this process is the classification of Transect 1 consisting of Acropora patches. This process is summarised:

```
                a cut image of Transect 1
                          ↓
                selecting training areas
                          ↓
            a set of themes contained 12 themes
              -  8 themes of biotic components
              -  4 themes of non-biotic components
                          ↓
                the first classification
              -  25 classes, 13 classes mapped by
                 computer created themes
                          ↓
            taxonomic clustering and labelling
              -  4 classes, 3 classes in biotic
                 components, 1 class in other non-biotic
                 components
                          ↓
                checking with ground data
                          ↓
  selecting more training areas with uncorrectly mapped
                          ↓
  new themes added in a set of themes, total 15 themes
              -  11 themes of biotic components
              -  4 themes of non-biotic components
                          ↓
```

```
                    the second classification
                  - 24 classes, 9 classes mapped by
                    computer created themes
                              ↓
               taxonomic clustering and labelling
                  - 4 classes, 3 classes in biotic
                    components, 1 class in other non-biotic
                    components
                              ↓
     checking with ground data, the classified results
                     correctly mapped
                              ↓
         counting number of pixels in each classes
                              ↓
     calculating percentage coverage of reef components
                              ↓
  results ended with percentage coverage of reef components
                   and a set of 15 themes
```

Sets of themes from this process were used in mapping the second transect in each site. Each group of themes had to be used only in its site. For instance, themes from Acropora patches could not be used in classifying biotic components at reef edges. The percentage cover data from the classified results were then compared with the results from the permanent transects. The differences were used in order to confirm the accuracy of sets of themes used in later processes.

Testing The Accuracy: The second transect was used as an unknown area to be mapped using the sets of themes created from the first process. Hence, this process involved only one classification which ran without any information from the ground data (eg- selecting training areas, checking classified results). Taxonomic clustering and labelling techniques were used in classified results. The percentage coverage of reef components was then calculated from the number of pixels in the transect. The results were compared with the results from the permanent transect. The differences between these results were true indicators of the accuracy of the digitised aerial photography for mapping unknown areas.



Hard Corals

High Density Coral Areas

Moderate Density Coral Areas

Low Density Corals Areas

Other Abiotic Areas

FIG. 5.6 A digitised aerial photograph thematic image of Transect 1, Acropora patches. (Transect length: 20 metres)

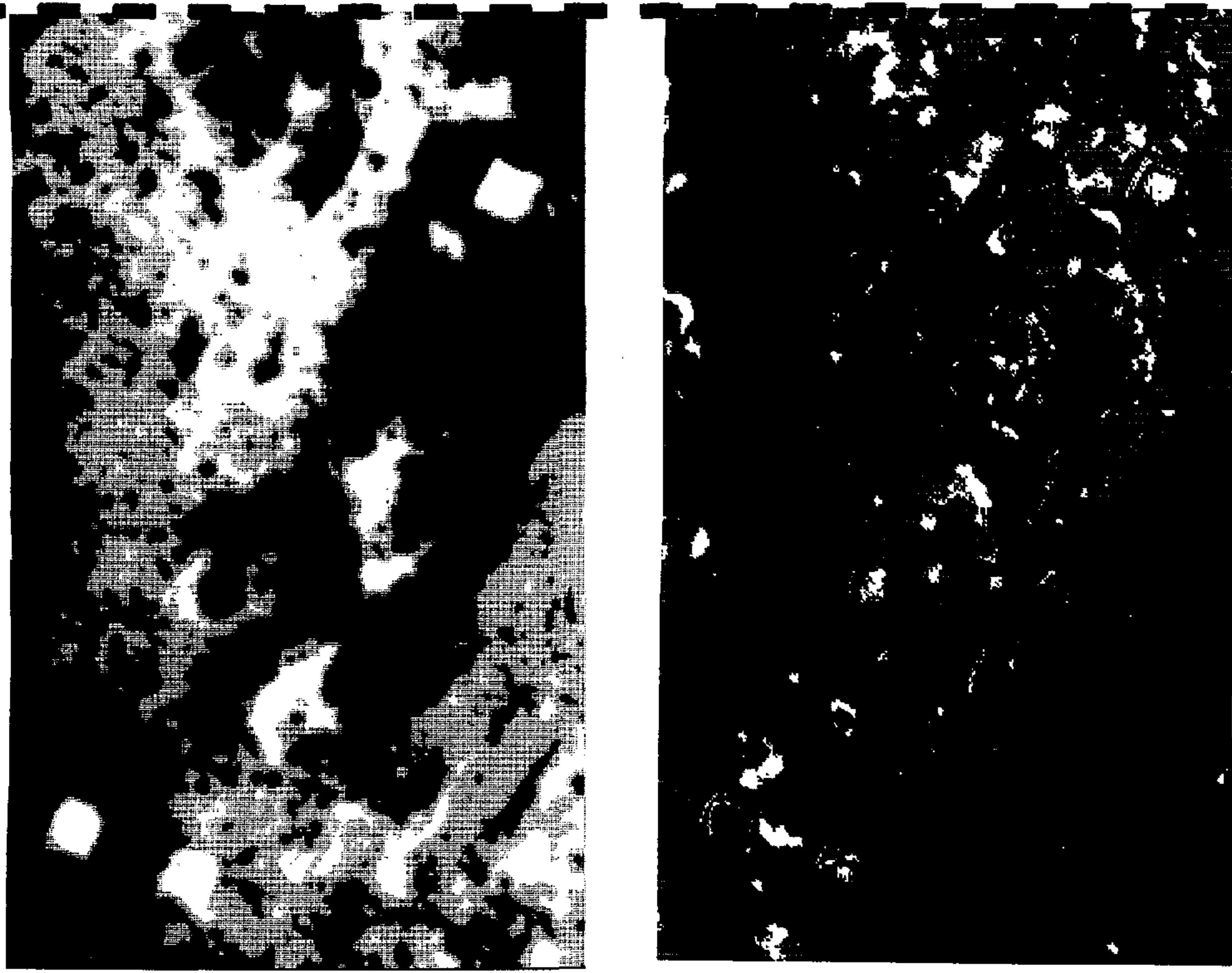


FIG. 5.7 Normal (left) and classified (right) digitised aerial photographs of Transect 2.

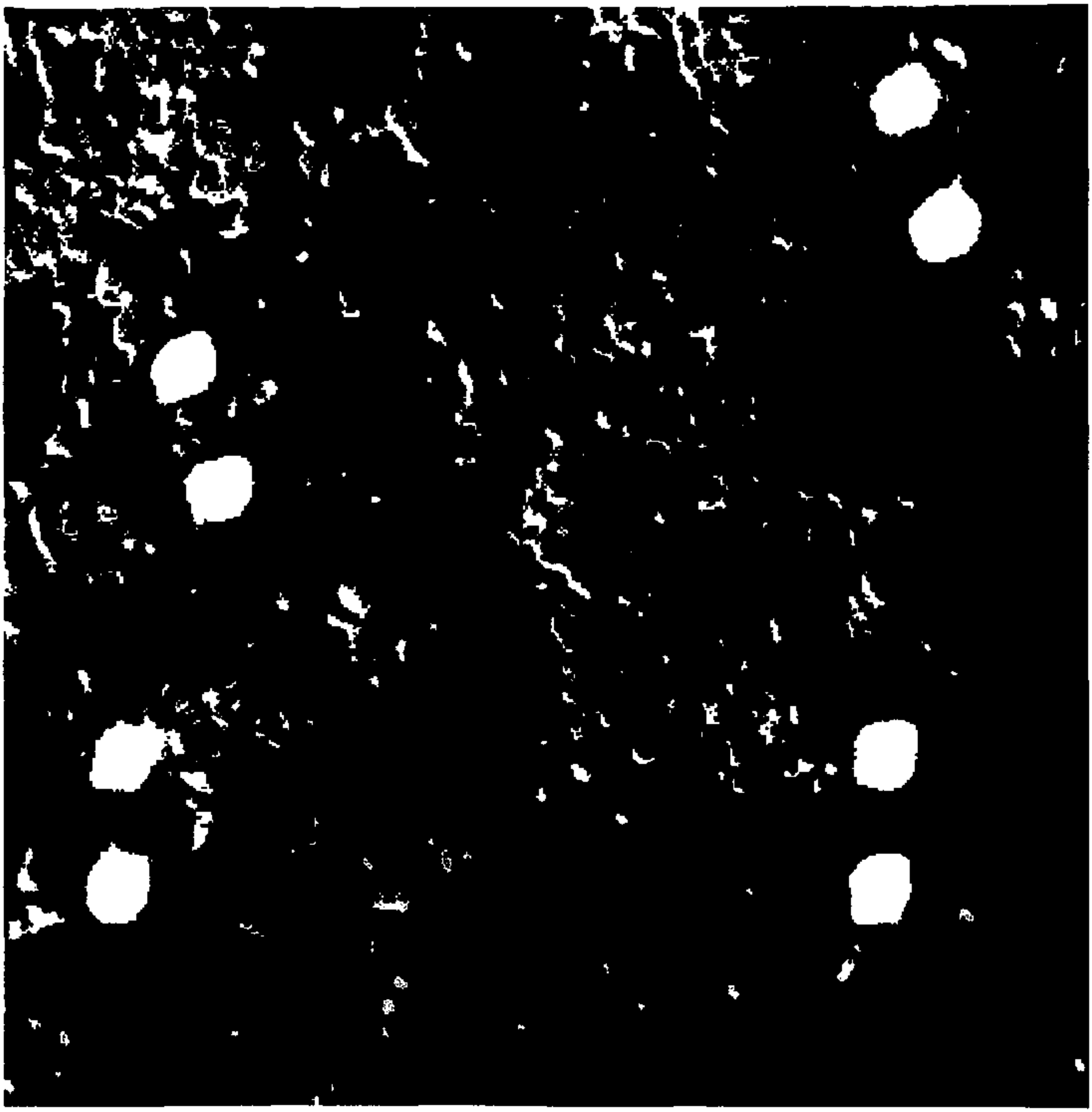
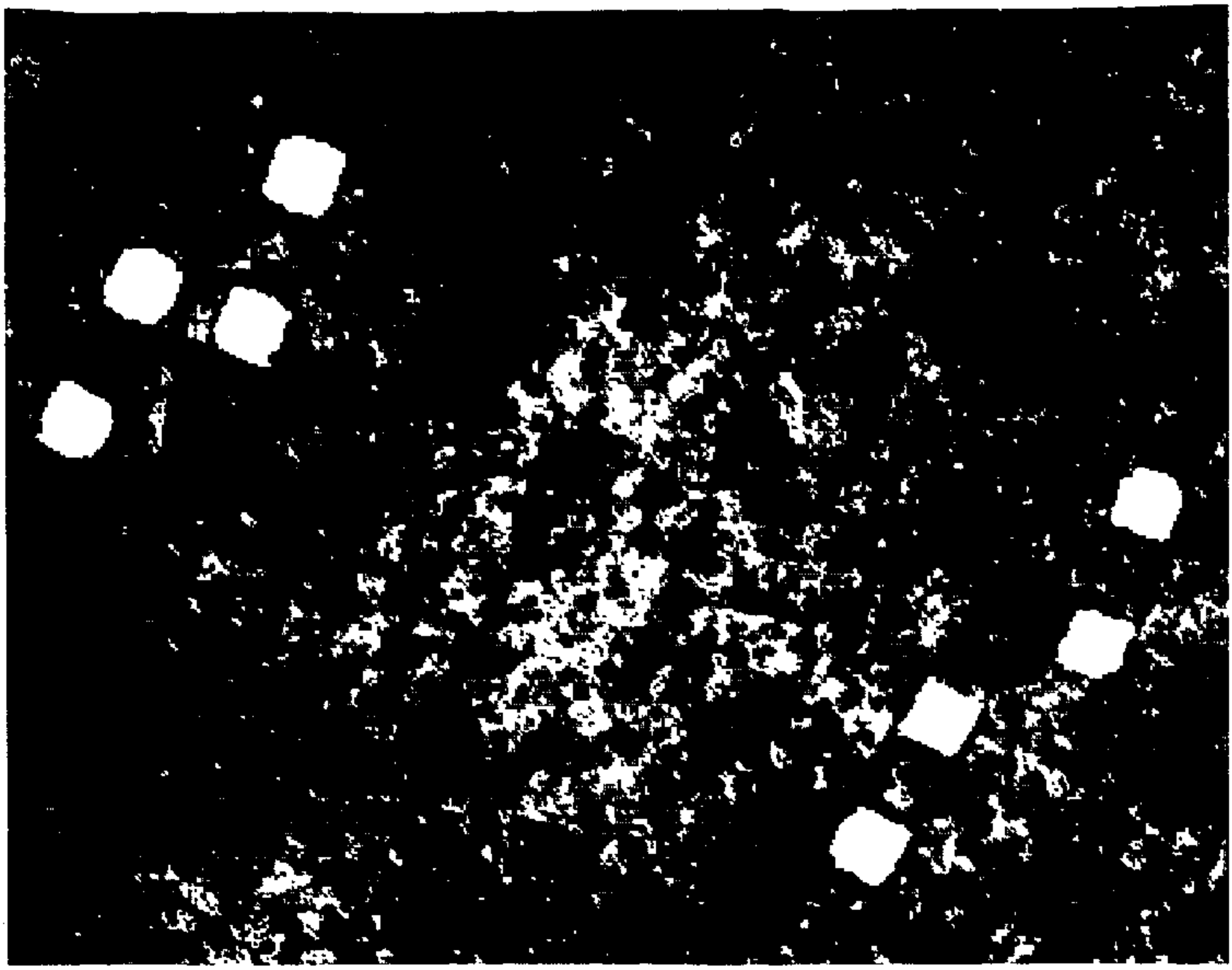


FIG. 5.8 A digitised aerial photograph thematic image of Transect 3 (above) and 6 (below), algae turf areas. (Transect length: 20 metres)



☐ High Density Coral Areas

■ Low Density Coral Areas

■ Free-Living Algae

■ Other Abiotic Components

☐ Ground Control Points

FIG. 5.9 A digitised aerial photograph thematic image of Transect 4 (below) and 5 (above), Montipora areas. (Transect length: 20 metres)

Hard Corals

Soft Corals

Other Abiotic Components

Water

FIG. 5.10 A digitised aerial photograph thematic image of Transect 7, reef eges.
(Transect length: 20 metres)

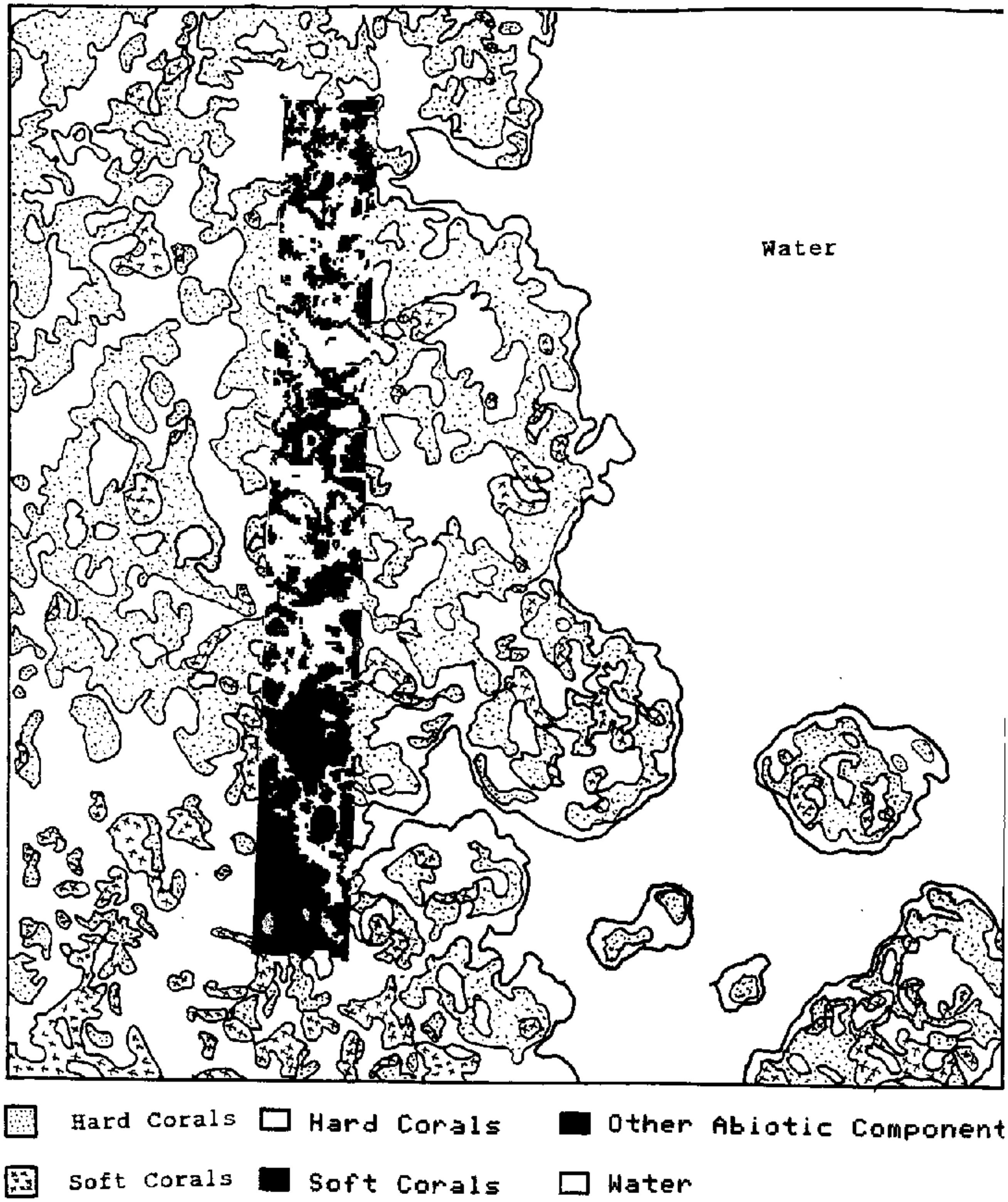


FIG. 5.11 A digitised aerial photograph thematic image of Transect 8, reef edges. (Transect length: 20 metres)

The classified results and calculated accuracy are illustrated in Figure 5.6 – 5.11 and Table 5.2 and 5.3. Results indicated that there were 2 types of biological distributions in the study sites which are listed below:

- Areas with One Dominant Biological Component: These areas included quadrats of Acropora patches (Transect 1,2), algal turf (Transect 3,6), and Montipora areas (Transect 4,5). Other biological components, for example macro algae, occurred in these areas but only in very small amounts.

- Mixed Biological Components Areas: Reef edge areas (Transect 7,8) were identified as this type of biological distribution. There were at least 2 biological components dominating this area (eg. hard corals and soft corals).

In contrast to results at Iris Point, results from Pioneer Bay were classified using image processing only (a supervised classification), then the ground truthing was conducted in order to test the image processing results. However, the small biological components could not be located and identified exactly. Figure 5.13 shows a thematic image of Pioneer Bay. The classification techniques are also described in APPENDIX III.

5.3.3 Comparative Results

Percentage coverage of reef components calculated from image processing were compared with results calculated from permanent transects (Table 5.2 and 5.3). The differences of percentage coverage of reef components indicated the accuracy of both techniques. According to standard techniques in image processing, comparison of results are separated into two parts: comparison of results calculated from image classification with ground data, and comparison of results calculated from image classification using sets of themes:–

(a) Image Classification with Ground Data

Results showed that the differences of coverage of all reef components calculated from both techniques were lower than 3.14%. However, the compared results in each zone are

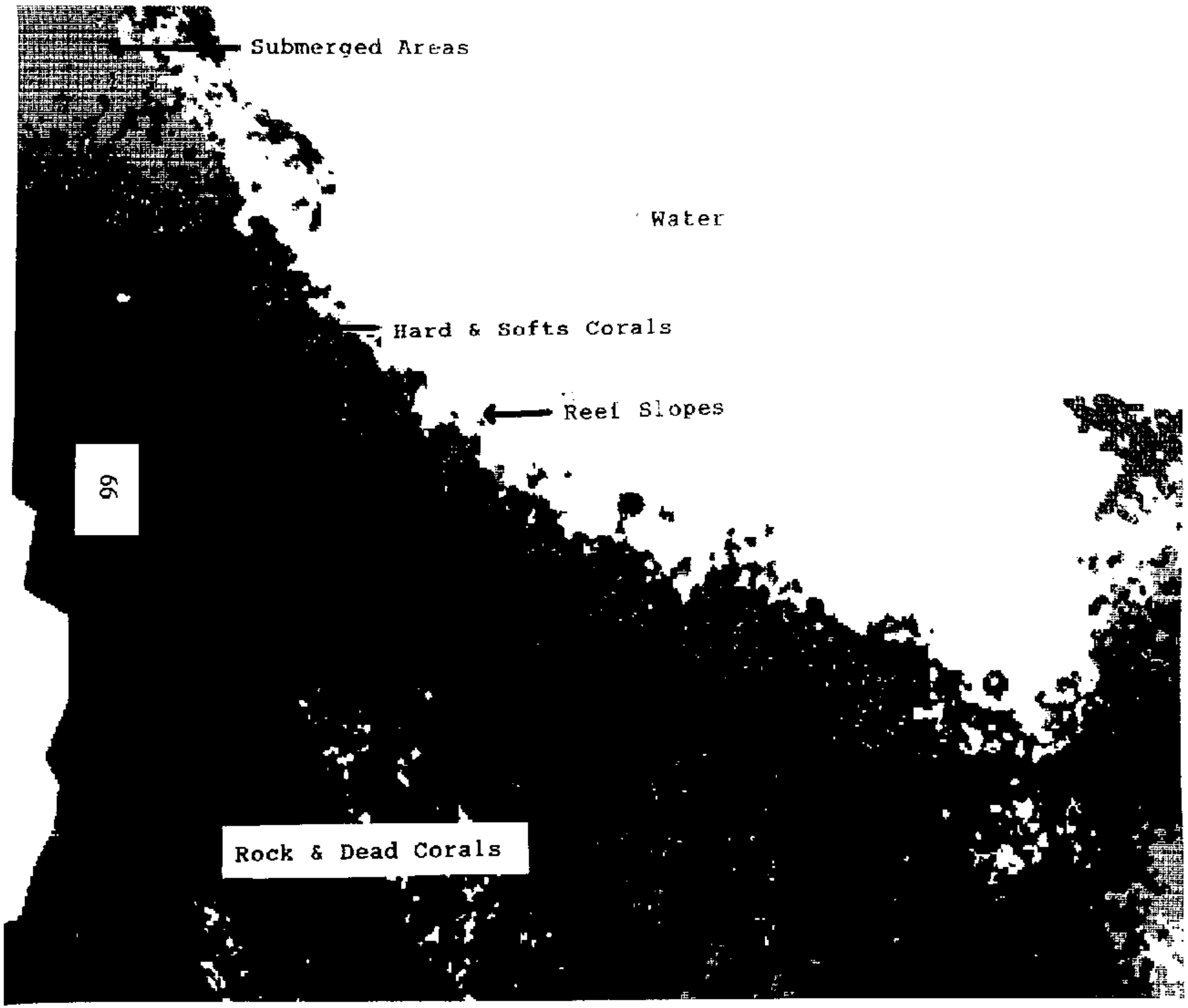


FIG. 5.12 **A digitised aerial photograph thematic image of Pioneer Bay, which was identified by a supervised classification.**

different. The conditions of reef component distributions in studied areas affected results and there are 4 important conditions:

(i) The pattern of biological distributions in each area affects classified results from digitised aerial photography., The reason is some biotic components have reflectance values close to other biotic components (eg. hard corals and soft corals: APPENDIX IV). Themes, which were selected from biotic components, may overlap. Hence, a computer might map one biotic component as other groups of biotic components. For instance, the differences of percentage coverage in T7, reef edges, are high in hard corals and soft corals. The classified results and ground data showed that the computer mapped some soft corals into hard coral classes. Hence, the percentage coverage of soft coral classified from image processing is lower than results calculated from the permanent transect. Conversely, the percentage coverage of hard corals in image processing is higher than results calculated from permanent transect (Table 5.2).

This problem rarely occurred in separating biotic components from other non-biotic components because reflectance values of each group were very different (eg. hard corals and sand: APPENDIX V). Therefore, areas with only one dominant biological component showed smaller errors in percentage coverage estimates compared to mixed biological component areas (TI, T3, T4 lower than T7; detail in Section 5.3.2).

(ii) Waters and shadows disturb the image classification process. Although the masking process (see Section 5.2.2) helps in reducing water and shadow disturbances, this process may cut small amounts of biotic components out of the image.

Turf algal areas (T3) and Montipora areas (T4) have only few water areas and shadows because these areas are flat and distant from the sea (Figure 5.3). Therefore, there were no water and shadow disturbances in the image data. Results in Table 5.2 show that the difference in these areas was lower than areas which have more water and shadows (TI: Acropora patches and T7: reef edges).

(iii) The types of biotic and non-biotic components in each area may affect the accuracy of the classified results. Some biotic components may reflect light in values close to some non-biotic components. This means that the reflectance values of both groups are difficult to separate. Hence, a computer may incorrectly map some biotic components as non-biotic component groups. Transect 7, reef edge, has this problem. Some soft corals showed reflectance values close to reflectance values of dead corals (APPENDIX V). This is one reason why the differences of percentage coverage in T7 are higher than results from other transects.

(iv) The types of homogeneous substrate distributions in each studied area affected results from image classification. Algal turf areas and Montipora areas are located close to each other (Figure 5.3) and both areas have similar conditions as discussed above. However, the differences in percentage coverage in algal turf areas are lower than Montipora areas. The reason is algal turf areas have only two major reef components: algal turf sand, and hard corals, while Montipora areas have mixed non-biotic components (eg. sand and coral fragments). Reflectance values of algal turf areas separate into two groups which are more contrasted than reflectance values of Montipora areas (APPENDIX VI). Hence, algal turf areas are more homogeneous than Montipora areas. The image classification process used in this project is based on taxonomic clustering which assumes that the categories of reflected substrates are homogeneous (more detail in Section 5.3.2). Hence, the differences of percentage cover in algal turf areas are lower than the differences of percentage coverage from Montipora areas (Table 5.2).

(b) Image Classification Using Sets of Themes

The classified results in this section were obtained using only the sets of themes calculated from the first type of classification (detail in Section 5.3.2). Classified results were not checked against ground data. Therefore, in each zone the differences in results in

# Transect	Image Processing (%)	Permanent Transect (%)	Percent of Difference	Image Types
T1: Acropora	LC: 67.99 OT: 32.01	LC: 66.10 OT: 33.90	1.89 1.89	True Colour
T3: Turf Algal	LC: 6.82 OT: 93.18	LC: 7.55 OT: 92.45	0.73 0.73	Infra-red
T4: Montipora	LC: 32.64 AL: 3.34 OT: 64.02	LC: 31.15 AL: 3.38 OT: 65.47	1.49 0.04 1.45	Infra-red
T7: Reef Edge	LC: 28.23 SO: 21.73 OT: 50.04	LC: 26.42 SO: 24.87 OT: 48.71	1.81 3.14 1.33	Combined Image & Band Ratio

TABLE 5.2 Percentage coverage of biological components, which were calculated from image classfication with training areas and re-correcting process, compare with results calculated from the permanent transect technique.

# Transect	Image Processing (%)	Permanent Transect (%)	Percent of Differences	Image Types
T2: Acropora	LC: 70.17 OT: 29.83	LC: 72.78 OT: 27.22	2.61 2.61	True Colour
T6: Turf Algal	LC: 7.99 OT: 92.01	LC: 8.93 OT: 91.07	0.94 0.94	Infra-red
T5: Montipora	LC: 68.92 AL: 0.27 OT: 30.81	LC: 67.18 AL: 0.22 OT: 32.6	1.74 0.05 1.79	Infra-red
T8: Reef Edge	LC: 33.94 SO: 8.56 OT: 57.50	LC: 31.11 SO: 13.82 OT: 55.07	2.83 5.26 2.43	Combined Image & Band Ratio

TABLE 5.3 Percentage coverage of biological components, which were calculated from themes of the first transect of each zone, compare with results calculated from the permanent transect technique. This classification run without re-correctting process.

NOTE:
LC: Hard Corals
OT: Other Substrate Types
AL: Free-Living Algae
SO: Soft Corals

# Transect	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Rank of Maximum Percent of Disfferences (lowest to highest)
Acropora Patches: T1		xxxxxxxxx		xxxxxxxxx		# 5
Acropora Patches: T2		xxxxxxxxx		xxxxxxxxx	xxxxxxxxx	# 6
Turf Algal Areas: T3						# 1
Montipora Areas: T4				xxxxxxxxx		# 3
Montipora Areas: T5				xxxxxxxxx	xxxxxxxxx	# 4
Turf Algal Areas: T6					xxxxxxxxx	# 2
Reef Edge Areas: T7	xxxxxxxxx	xxxxxxxxx	xxxxxxxxx	xxxxxxxxx		# 7
Reef Edge Areas: T8	xxxxxxxxx	xxxxxxxxx	xxxxxxxxx	xxxxxxxxx	xxxxxxxxx	# 8

NOTE:

Factor 1: mixed biological components
Factor 2: high water and shadow disturbances
Factor 3: reflectance values of non-biotic and biotic components close to each other
Factor 4: less homogeneous reef components
Factor 5: results were classified without ground data
xxxxxxxxx: a factor occurred

TABLE 5.4 Factors affected the percent of differences in each transect percentage coverage classified without ground data are higher than the differences in results of percentage coverage classified by ground data (Table 5.2 and 5.3).

The differences in percentage coverage in this type of classification was also affected by different conditions of reef component distributions as explained above.

(c) Factors Affecting The Differences in Percentage Coverage of Reef Components

Five factors affected differences in percentage coverage in all the studied areas and are summarised in Table 5.4. Four of these factors come from the different conditions of each of the study sites. The fifth factor results from techniques used in the image classification being different.

The differences in percentage coverage of reef components in each transect relate to the number of factors involved. The differences in transects which have more factors, are higher than in transects which have fewer factors (Table 5.4).

The results also showed that each factor has different effects on the differences of percentage coverage of reef components. Taking Transects 6 & 4 as an example, both transects have one affected factor but the differences of percentage coverage are unlike (Table 5.4).

Results from Table 5.4 showed one important feature about the effects of different factors. Transect 6 and Transect 4 both have conditions similar to Transect 3 except T6 which has an affected Factor 5 and T4 which has an affected Factor 4 (Table 5.4). However, T6 has lower differences of percentage coverage (rank #2) than T4 (rank #3). Hence, Factor 5 has a lower effect than Factor 4.

The effectiveness of other factors cannot be explained because one factor may have different effects in each zone. Therefore, effectiveness of each zone cannot be compared. For instance, results from T5 (Montipora) and Tl (Acropora) showed that both transects had two factors (T5: Factor 4&5; T1: Factor 4&2) but one factor was the same (Factor 4). However, the effects of Factor 4 in Montipora areas may be different to the effects in Acropora areas. Hence, the effectiveness of Factors 2 and 5 cannot be compared.

Although results from Table 5.4 cannot provide all information, they are still very important in the selection of study sites. In addition, they also provide information about factors affecting the mapping of reef components using digitised aerial photography.

5.4. Conclusions and Recommendations

This part of the project represents an initial stage in the development of techniques to map and monitor changes of biological distributions of reefs. The objectives focused only on mapping techniques. The next stage will involve the repetition of data collection and analysis techniques, and the testing of these techniques at different locations and at different times.

5.4.1 Developing Techniques

Although this project was successful in mapping biological distributions of reefs, some important techniques have to be further developed. Recommendations include:

(i) Ground Data Collection

The permanent transect technique should be modified with respect to ground control points (more detail in Methods Section). This newly designed technique must then be tested.

The number and size of permanent transects in this initial project aimed only in proving the capability of digitised aerial photography in distinguishing different cover types. It did not concentrate on using the permanent transect technique to give representative information for whole reef areas. Hence, later stages should study the number and size of permanent transects required in order to represent more accurately ground data of whole reef areas.

(ii) Ground Truthing

The ground truthing used in this project was a simple technique. Later projects should consider developing ground truthing techniques further, including ground truthing techniques to support previous image identification.

(iii) Band Ratio

The band ratio technique should be developed in greater detail using results of this project. Further studies should investigate the ability of the band ratio technique to map corals at large and small scales. Moreover, the band ratio technique should be tested with other biotic components.

(iv) Classification

The classification developed in this project was successful. However, further projects may consider gathering classified sets of themes from many biotic components and grouping them as a single major theme set for use with various biological distributions.

(v) New Study Sites

Although Orpheus Island was a suitable study site for this initial project, more study sites are required in order to complete this whole project.

More study sites are required in order to develop techniques suitable for identifying other biological distributions. Two major reef biotic components that should be investigated are seagrass habitats and macro algae. Thamrongnawasawat (1991) reported that satellite remote sensing techniques were very useful for mapping the morphology of seagrass habitats. However, he noted that separating seagrass density areas was a major problem with respect to satellite data because of low resolution. This problem might be overcome using digitised aerial photography techniques, and might enable different densities of seagrass areas to be mapped. (n.b. further work has now been carried out in the Greenhouse Project concentrating on macroalgae on Cape Tribulation reefs and seagrasses at Green Island).

(vi) Investigation of Previous Data

There are many earlier aerial photographs which could be digitised and studied for long-term changes. Hence, selected reefs with good previous aerial photographs should be included as study sites in this project.

(vii) Developing a Monitoring Program

Orpheus Island is a suitable site for a long-term monitoring program. Therefore, the study should continue on this island.

Reefs on which there are extensive human activities should also be selected for developing a monitoring program. The advantage of selecting such reefs is that there is a greater chance of real changes occurring during the early stages of the project. The results could then be used for developing techniques suitable for monitoring longer term changes in biological distributions in which the human influence may be less direct.

APPENDIX I: IMAGE COMBINATION

Two sets of digitised image were selected for analysing in this process. The first set of images, with lower resolution, was the outer reef areas which covered 2 transects at reef edges (T7 and T8) and 2 transects in the Acropora patches (Tl and T2). Another set of images was from the reef edge areas which covered 2 transects (T7 and T8) with higher resolutions. Both sets of images contained digitised aerial data both true colour bands and infra-red bands. This process can be explained as follows:

(i) Two aerial photographs, both infra-red and true colour, were selected from the mixed study sites as they could not be classified by simple image processing techniques. These areas included both hard corals and soft corals.

(ii) Both photographs were digitised with the highest resolution (detail in Part 4). Then, study sites were subsetted from major images. This process provided smaller images which could be processed much faster (eg. from an image of 4000 pixels by 4000 lines, a 48 Megabytes file, to an image of 1000 pixels by 1000 lines, a 6 Megabytes file). The size of each images might be different but within small ranges. For instance, an infrared subsetted image was 800 pixels by 1050 lines, while a true colour subsetted image was 690 pixels by 1080 lines.

(iii) Image transformation programs (eg. MAPPER, MODEL) were then used in order to rectify both images together. One image acted as "map", another image acted as "image". The coordinate points from each image were selected from ground control points around transects.

(iv) The process used a program "REMAPPER" to map an "image" to a "map". Size of a new "image" had to be selected as the same size of a "map". The result from this step was an image which was referred to as a rectified "image". This image had a size and location similar to a raw "map" image.

(v) Using an image combination program (COMBINE) both images were combined. The result was one image which had all bands of the infra–red and true colour digitised aerial photographs.

Results suggested that combined images were very useful for later processes such as classification. Without this process it may not be possible to identify the mixed biotic component areas.

APPENDIX II: BAND RATIO

This process conducted on two images was developed from image combination. Both images were calculated and created new bands. Each new band had new reflectance values calculated from the raw values of 2 bands. For instance, reflectance values of a new band were calculated by dividing reflectance values of infra-red band 3 (called band 6) blue band (called band 1). Interesting results are listed below:

1. Band 6/Band 1 (Infra-red band 3/blue band)

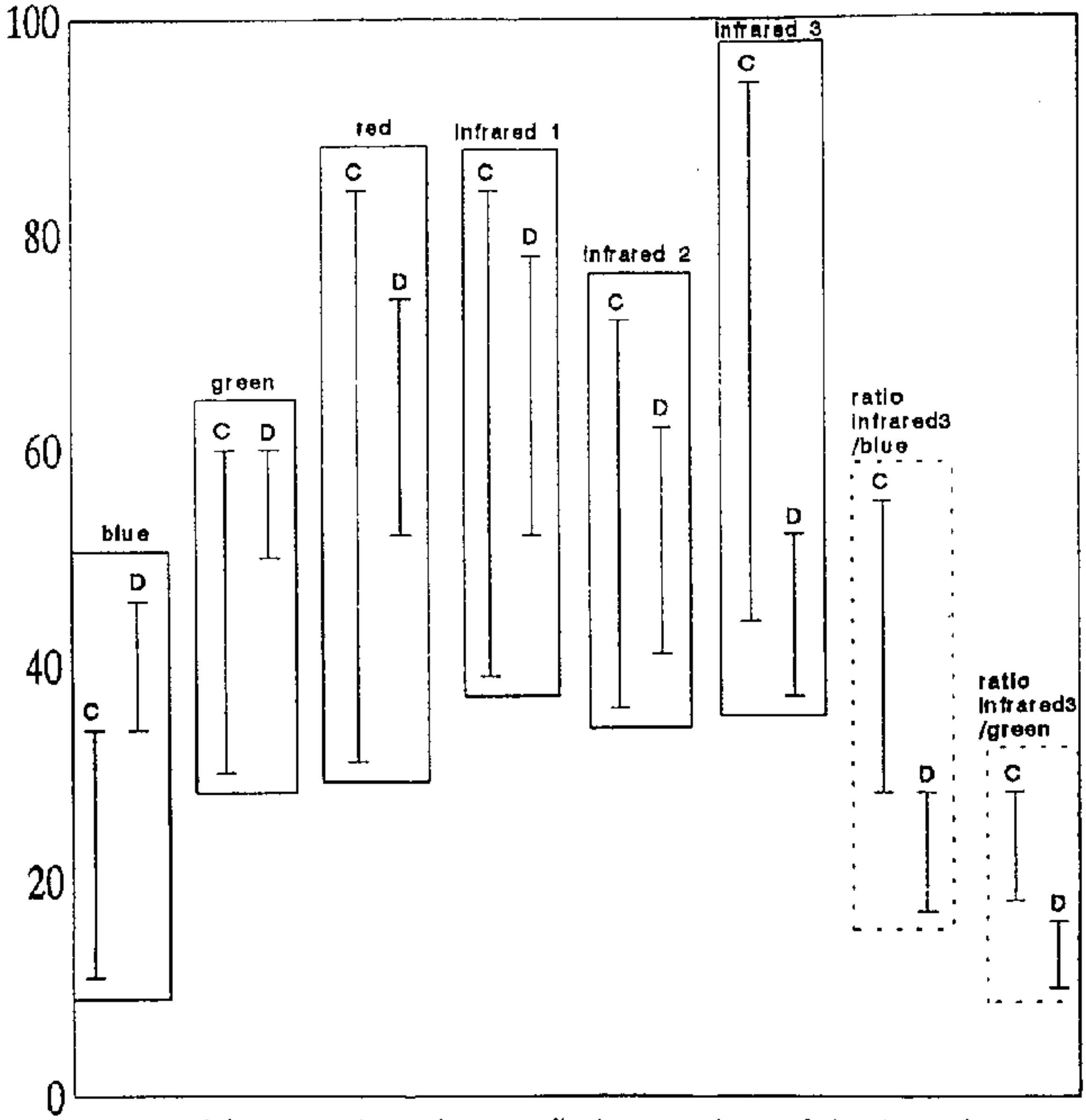
Divided results of these two bands were very important for identifying biological distributions of mixed biotic areas. Results displayed in this ratio (1,2,6/1 in a colour composite image of blue, green, red) enhanced living corals in red (data in band 6/band 1) while other substrates showed lower reflectance values in band 6/band 1. Hence, other components (including soft corals) still showed in shades of blue and green. Therefore, locations of living corals could be carried out using this ratio. A problem was that a few biotic components such as algal turf, dead corals might show close ratio values to hard corals. This problem was not serious in a colour composite image, but it might cause small errors in a classification process.

2. Band 6/Band 2 (Infra-red band 3/green band)

Results from this ratio represented a similar pattern to above results. However, reflectance values of living corals in band 6/band 2 were lower than band 6/band 1. This ratio aided in classifying biotic components which could not be classified in ratio band 6/band 1 because such biotic components showed separated ratio values.

Although there were only two distinct results from the band ratio process, both results gave efficient data which were used in classification process. The graph of minimum and maximum reflectance values of hard corals and algal turf/dead corals shows overlapping values in band 2,3,4,5, and 6 (green, red, infra-red 1, infra-red 2 and infra-red 3) which means that these sets of data are not suitable for creating themes for use in classification.

Only raw data in band 1 (blue band) did not overlap. However, this band could not be used in classifying an image because it did not allow for a categorisation of biotic components. This project used band ratio techniques creating two new bands of infra-red3/blue and infra-red3/green. Resulting data separated minimum and maximum values reflected from hard corals and algal turf/dead corals. Therefore, these data provided opportunities to create two separated themes, and used them in the classification process.



minimum and maximum reflectance values of hard corals and algal turf dead corals at Transect 7
C = Hard Corals D = Algal Turf Dead Corals

APPENDIX III: CLASSIFICATION

Results from classification process one major end products in this project. As indicated, results from image classification were in two parts: an unsupervised classification and a supervised classification.

1. Unsupervised Classification

This type of classification was run by computer alone. Detail of standard input of an unsupervised classification used in this project are listed below:

Enter channels to select from [image name]>
<u>input</u> all channels

Enter Maximum Number of Classes>
<u>input</u> 20–40 classes (depended on image)
if it looks uniform: 20–30 classes
if it looks variable: 30–40 classes

Enter [number of channels] Percent Tolerance Values>
<u>input</u> 20,20,....

Enter Maximum Number of Iterations>
<u>input</u> 2

2. Supervised Classification

This type of classification was separated into two parts dependant on study sites. The following descriptions will explain techniques in image classification with ground data only. The techniques of image classification using sets of themes have already been described in the RESULTS section.

According to the differences of study sites, the classification process could be separated into 2 types.

(i) Classification of Areas with One Dominant Biological Component: This type of classification used basic techniques because the study sites consisted of one dominant biotic component. Hence, the main objective of this classification was to separate a dominant living component from non-biotic components. This classification ran as 3 steps as follows:

- Pre-Classification: Images were enhanced in order to clarify living organisms from non-biotic components. Then, the best image, either true colour or infra-red, was selected as a preclassified image.

- Classification: Training areas were selected using ground data. Next, classification programs were used with standard input indicated in an unsupervised section.

- Post-Classification: Classified results were then checked with ground data again. If some biotic areas were missed, results had to be re-processed, and the missing areas added as training areas.

As there was only one dominant biotic component, living corals, sometimes classification results could provide further detail, such as identifying conditions of corals. For example, Acropora patches could be classified into 3 different types of coral density. Consequently, classification process could be separated into two operations:

- General Image Classification: This technique was used for identifying living corals from other substrates.

- Separating Coral Densities: This method was conducted in order to identify different coral densities. Classified results consisted of 3 classes as high, medium, and low coral densities. Other non-biotic components could be separated into 3 classes as dead corals, coral fragments, and sand. Number of classes in each substrate may be adjusted depended on patterns of reef component distributions of each areas.

(ii) Classification of Mixed Biological Component Areas: This method was more complicated than the first method due to the study sites having more than one dominant biotic components. Basic classification techniques could not initially identify them correctly. Digitised images had to be enhanced by image analysis techniques as listed below:

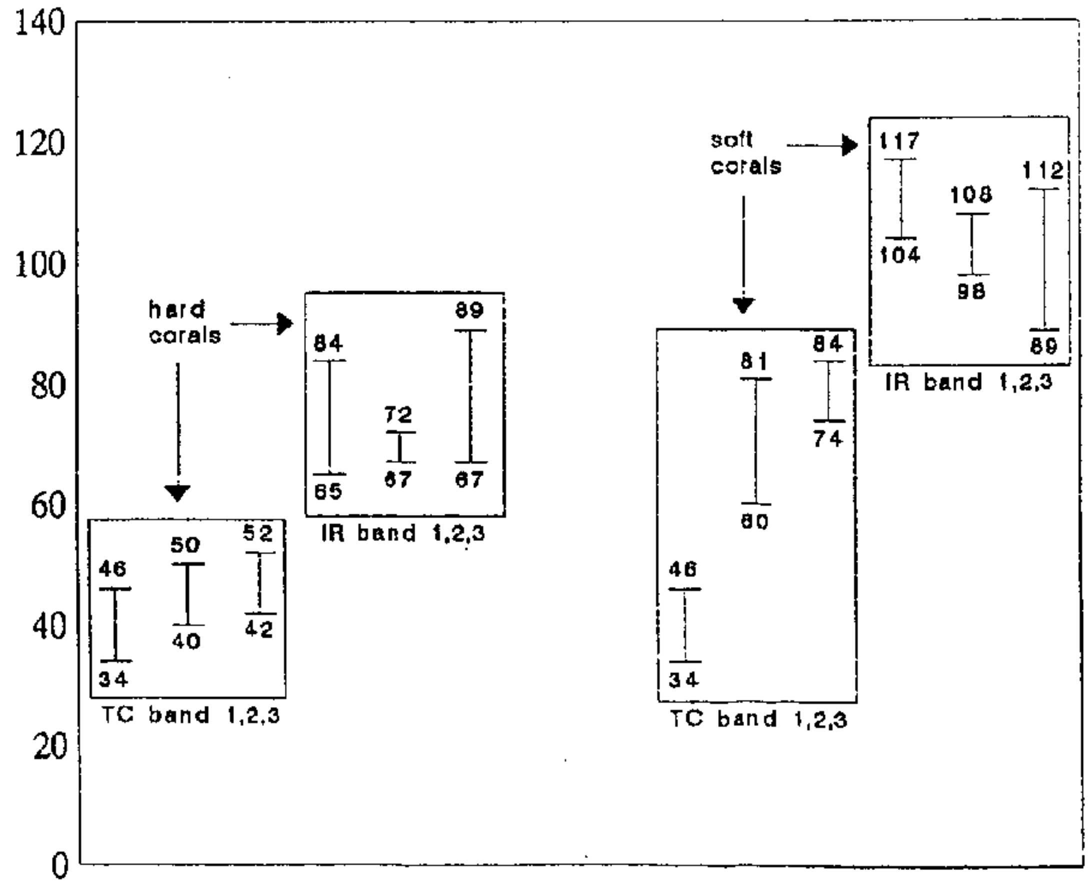
- True colour and infra-red images had to be combined together.
- Band ratio techniques were used in order to separate one dominant biotic component from the others (in this study, hard corals were highlighted).
- The image was ready to be classified by basic classification techniques as indicated in the first classification.

APPENDIX IV: REFLECTANCE VALUES BETWEEN BIOTIC COMPONENTS

These sets of data (APPENDIX IV and V) were extracted from digitised aerial photographs at Iris Point using image processing techniques. Biotic components, which were located by visual identification of ground data, were selected as training areas. Then, themes of these areas were run through statistical and classification programs. Results from both programs were minimum, maximum, medium, and means of reflectance values of biotic and non-biotic components.

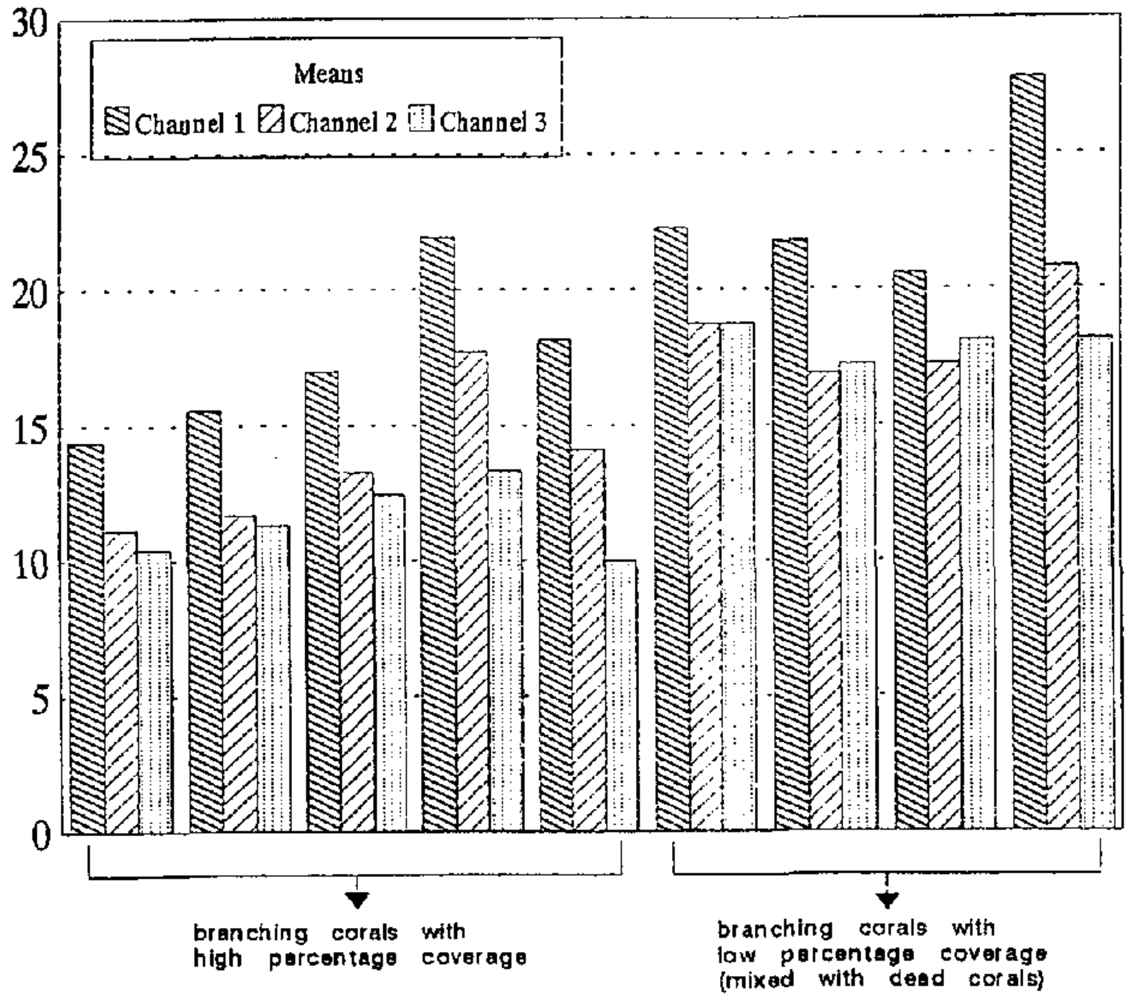
1. Hard and Soft Corals

This graph below shows minimum and maximum reflectance values of individual hard and soft corals selected from an image of Transect 7. These kinds of hard and soft corals presented close minimum and maximum reflectance values which might cause errors of miss-mapping in the classification process.



2. Hard Coral Groups

This graph shows mean reflectance values of hard corals selected from an infra-red image of Transect 2. Means of this set of hard corals separated into 2 groups. Hence, the classification process of separating coral densities (APPENDIX III-2-i) used this type of data from classified coral densities.

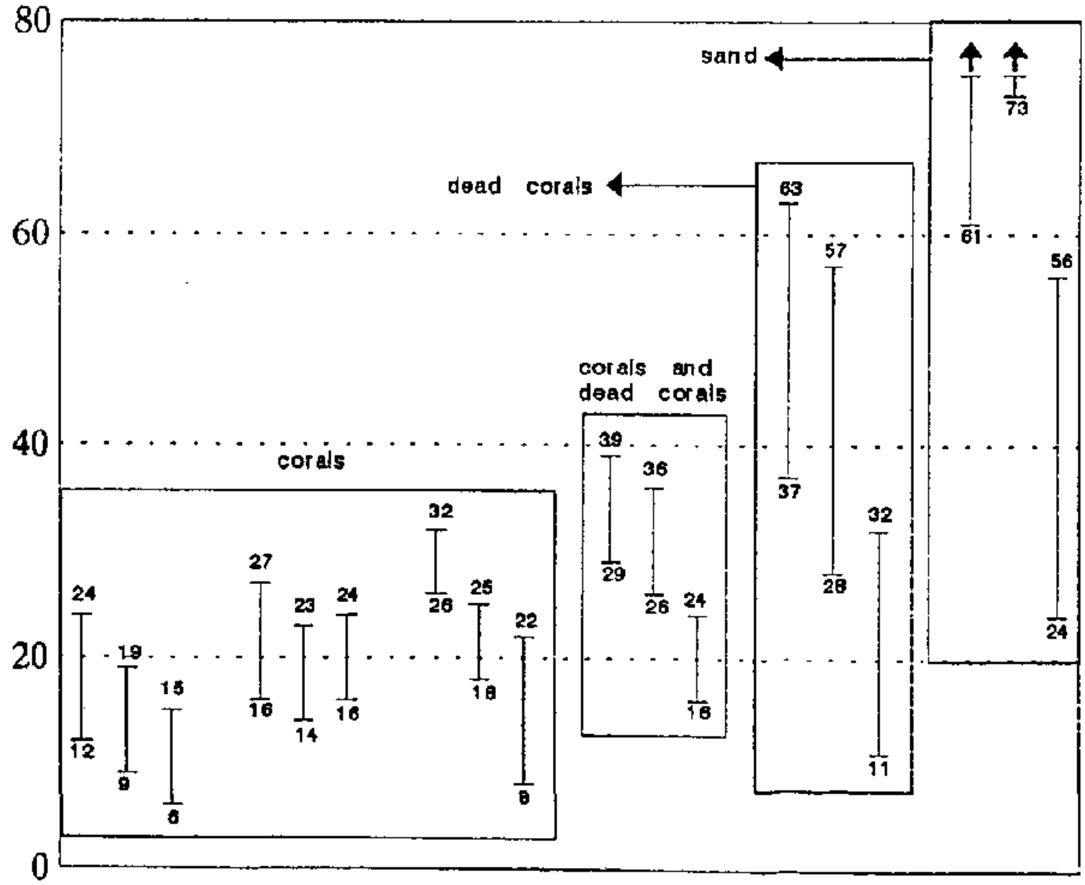


APPENDIX V: REFLECTANCE VALUES BETWEEN BIOTIC AND NON-BIOTIC COMPONENTS

This process used similar techniques as described in APPENDIX IV, two examples are illustrated below:

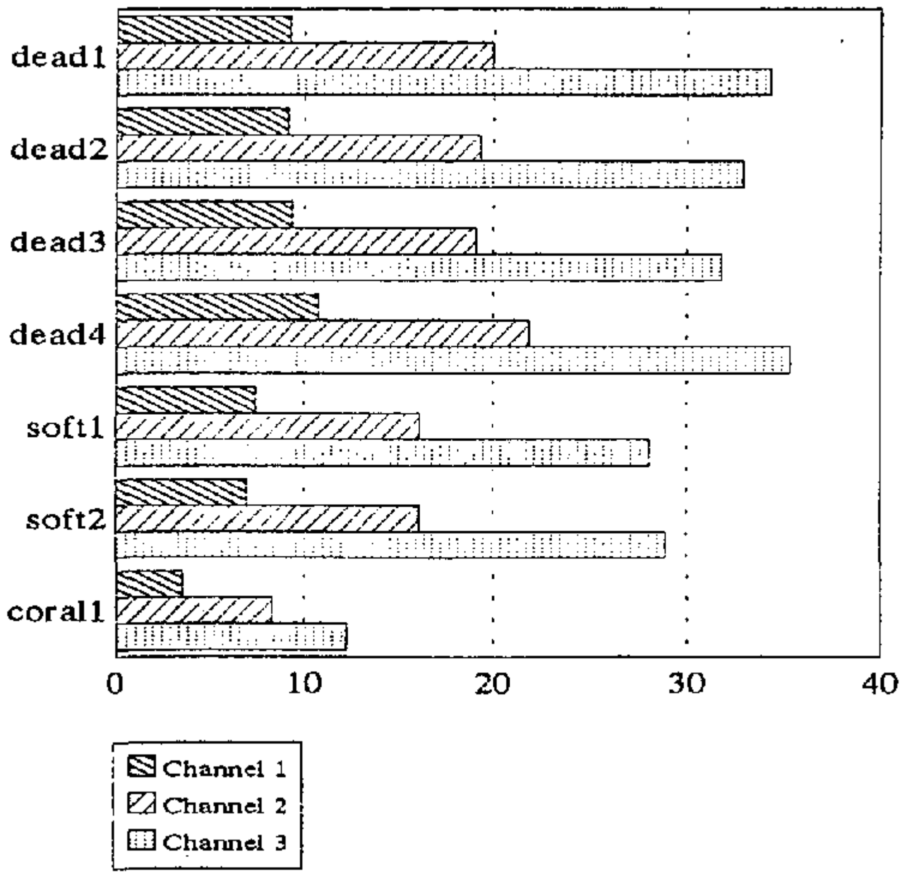
1. Hard Corals and Non-biotic Components

The graph below shows minimum and maximum reflectance values of themes created from an infra-red digitised aerial photograph Transect 1. Reflectance values of the hard coral group definitely separated from values of dead corals and sand. Even the areas with mixing hard corals and dead corals also separated from other groups. Hence, classified results had low errors.



2. Dead Corals, Soft Corals and Hard Corals

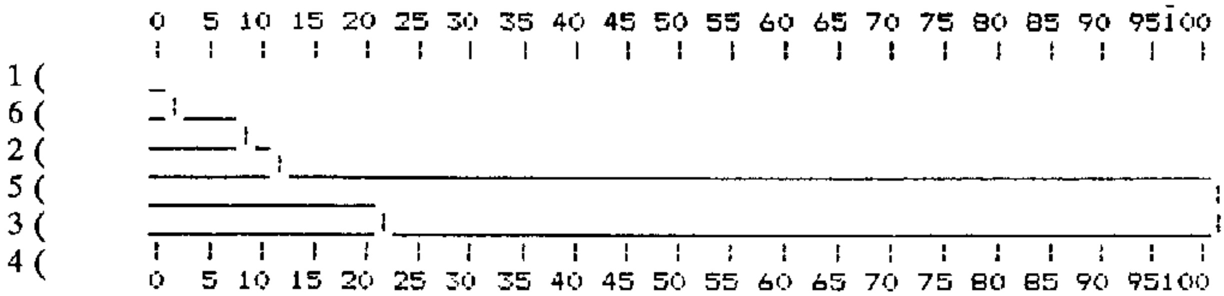
This example of mean reflectance values is between selected types of dead corals, hard corals, and soft corals from Transect 7 in true colour bands (blue = channel 1; Green – channel 2; Red = channel 3). Soft corals presented mean reflectance values close to dead corals. Hence, soft corals were difficult to separate from dead corals, and classified results may contain some errors.



APPENDIX VI: REFLECTANCE VALUES BETWEEN ALGAL TURF AREAS AND MONTIPORA AREAS

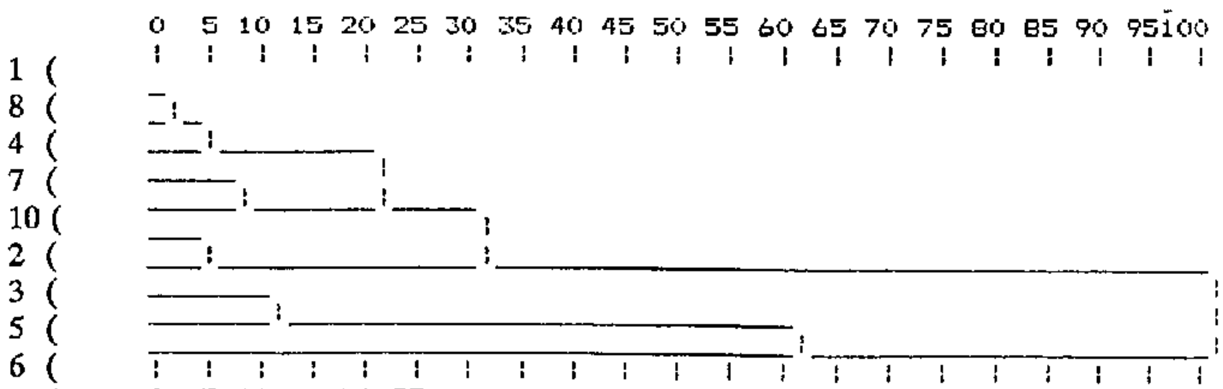
Two clustering graphs selected from statistical infrared data used in clustering and classifying reef components at Transect 3: algal turf areas and Transect 4: Montipora areas.

Objective function ranges from I.0010 to 2.9846 using a log stretch
These values are scaled from zero (0) to one hundred (100) on the dendrogram



Transect 3: Algal Turf Areas
1,6,2,5 = corals 3,4 = algal turf sand

Objective function ranges from I.0009 to 3.9792 using a log stretch
These values are scaled from zero (0) to one hundred (100) on the dendrogram



Transect 4: Montipora Areas
1,8,4,7,10 = corals 2,3 = coral fragments
5,6 = algal turf sand 9 = white dead corals

Reef component distributions in Transect 3 were more homogeneous, hence, clustering processes classified data in this transect better than data in Transect 4. Hence, errors contained in classified results of Transect 3 should be lower than in classified results of Transect 4.

6. SUGGESTED USES FOR DIGITISED AERIAL PHOTOGRAPHY

The results from this study suggest that the uses of digitised aerial – photography for reef studies and management purposes may be listed below:

1. Reef Survey

This technique will be very important for use as a tool in reef surveys. Other broad-scale reef survey techniques such as those from satellite imagery cannot map locations of individual biotic components. The newly developed techniques could thus provide a new scale of data.

2. Reef Monitoring

Monitoring programs for biological distributions on reefs have been previously developed. However, most methods have used only ground techniques which cannot map and monitor large areas with small resolution. The results from ground methods are only representative of the studied areas. For instance the life form line transect technique, which is widely used in reef monitoring programs, gives results of percentage coverage of reef components under the transect line only. These results are then considered as representative of reef components in the general area. However, since the results are not gathered from the whole area, they cannot be used to draw conclusion regarding changes in the area unless a very large number of transects are measured. In contrast to the ground techniques, the digitised aerial photographic technique is a true indicator of changes of biological distributions in a whole area. Providing that proper studies are conducted to establish the statistical reliability of classified images, this technique will be very important for short–term and long–term reef monitoring programs.

3. Reef Management

Recently, small scale tourist/commercial developments on reefs have increased. These developments (eg. marinas, resorts) affect reefs in one particular area. Moreover, many developments are constructed on or adjacent to reef flat areas. Present monitoring techniques concentrate mostly on detecting environmental condition changes, such as sediment discharge. However, there are few techniques which monitor biological changes directly. Digitised aerial photography can provide this type of data, particularly on reef flat areas. This technique has potential to provide valuable data for designing ecologically sustainable developments on reefs.

4. Reef Biological Studies

Studies, which integrate biological data with habitat conditions, are important. For instance, studies of reef fish focus on integrating fish census data with habitat conditions. However, current techniques concentrate only on gathering data for the target organism (eg. fish census studies). In contrast there are only a few techniques for gathering habitat information. The habitat data collection techniques are usually based on modified ground techniques which cannot give all necessary data. Digitised aerial photography can provide the required habitat information over a larger area.

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