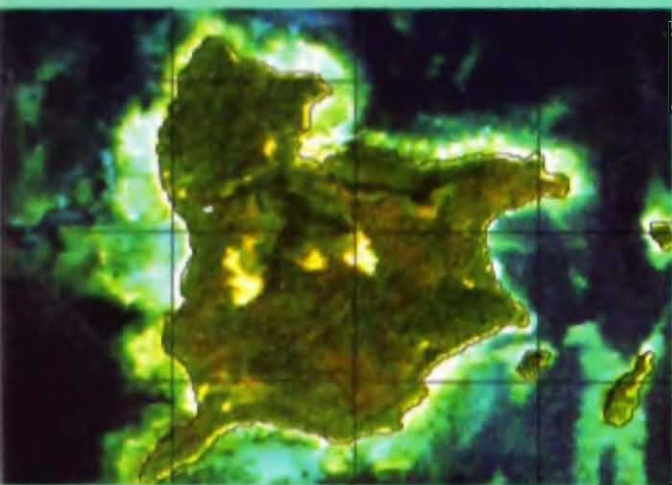




Occasional Paper No. 301

Coral Reef Ecosystem of Andaman Islands

Remote Sensing and Rapid Site Assessment Survey

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ZOOLOGICAL SURVEY OF INDIA

RECORDS OF THE ZOOLOGICAL SURVEY OF INDIA

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CONTENTS

1.0. INTRODUCTION	1
Classification	1
Fossil History	2
Geographical Distribution	3
Growth of Corals	3
Structure of Coral Reefs	4
Importance of Coral Reefs	4
1.1. Objectives and Approach	5
1.2. Background	6
2.0. METHODS	12
2.1. Image Processing Stage I	12
2.2. Field Survey	19
2.3. Data Analysis	27
2.4. Image Processing Stage II	27
3.0. RESULTS	37
3.1. Terrestrial Biotopes of the Andaman Islands	37
3.2. Marine Biotopes of the Andaman Islands	38
3.3. Site Description	57
3.4. Diversity of Corals	108
3.5. Pre- <i>tsunami</i> Status of Corals	109
3.6. Post- <i>tsunami</i> Status of Corals	110
3.7. Status of new coral recruits	112
4.0. DISCUSSION	112
Threats to coral reefs of Andaman and Nicobar Islands	119

Management Strategies	120
5.0. SUMMARY	121
6.0 ACKNOWLEDGEMENTS	126
7 0 REFERENCES	126

1.0. INTRODUCTION

Appearing as solitary forms in the fossil record more than 400 million years ago, corals are extremely ancient animals that evolved into modern reef-building forms over the last 25 million years. Large wave resistant structures of reef have accumulated from the slow growth of corals. Coral reefs are the largest structures on earth of biological origin. They are the most diverse and beautiful of all marine habitats. The development of reef is aided by algae that are symbiotic with reef-building corals, known as zooxanthellae. Coralline algae, sponges, and other organisms, combined with a number of cementation processes also contribute to reef growth. Corals and coralline algae precipitate calcium carbonate, whereas the framework-building sponges may also precipitate silica. Most of these organisms are colonial, and the slow process of precipitation moves the living surface layer of the reef upward and seaward. The reef is topographically complex. Much like a rain forest, it has many strata and areas of strong shade, cast by the over towering coral colonies. Because of the complexity, thousands of species of fish and invertebrates live in association with reefs, which are by far our richest marine habitats. Of all ocean habitats, reefs seem to have the greatest development of complex symbiotic associations.

CLASSIFICATION

The corals are classified as follows :

Phylum CNIDARIA

This diverse invertebrate (invertebrates are animals without spinal columns) group includes corals, sea anemones, hydras, jellyfishes, and their relatives. All cnidarians are radially symmetrical (the body is symmetrical around a central axis), lack a head, usually have a crown of tentacles around the mouth, and possess nematocysts. About 9,000 living species are known.

Class ANTHOZOA

Anthozoans include corals, sea anemones, sea pens, and sea pansies. These animals are either solitary or colonial polyps that live attached to a substrate (surface). Of the 6,000 known anthozoan species, corals comprise about 2,500 species.

The Class Anthozoa is further divided into three subclasses : Octocorallia, Zoantharia, and Tabulata (extinct colonial corals).

Subclass OCTOCORALLIA (ALCYONARIA) : Polyps are characterized by having eight *pinnate* (side- branching) tentacles. Octocorallians include gorgonian corals, sea pens, sea pansies, organ- pipe corals, and soft corals (order Alcyonacea). Most are colonial. The Octocorallian orders are as follows :

Order STOLONIFERA (organ-pipe coral and tree fern coral)

Order TELESTACEA (*Telesto*)

Order ALCYONACEA (soft corals such as leather corals and tree corals)

Order COENOTHECALIA (Indo-Pacific blue coral)

Order GORGONACEA (gorgonian corals including sea fans, red coral, sea whips, and sea feathers)

Order PENNATULACEA (sea pens and sea pansies)

Subclass ZOANTHARIA : Polyps are characterized by having tentacles in multiples of six. Zoantharian tentacles are rarely pinnate. Black corals and reef-building corals (order Scleractinia) are members of this subclass. Reef-building corals are also known as “hard corals” or “stony corals.” Zoantharians may be either solitary or colonial. The Zoantharian orders are as follows :

Order ZOANTHIDEA (anemonelike anthozoans)

Order ACTINIARIA (sea anemones)

Order SCLERACTINIA or MADREPORARIA (reef-building corals such as star corals, brain corals, staghorn corals, mushroom corals, and bubble corals)

Order RUGOSA or TETRACORALLA (extinct solitary corals)

Order CORALLIMORPHARIA (resemble true corals but lack skeletons)

Order CERIANTHARIA (anemonelike anthozoans)

Order ANTIPATHARIA (black corals)

Subclass TABULATA (extinct colonial anthozoans)

FOSSIL HISTORY

1. The earliest reefs developed two billion years ago in the mid- to late Precambrian era. These reefs were built by colonies of calcareous algae, not corals.

2. Corals, sponges, bryozoans, and calcareous algae enhanced the growing reef community in the Paleozoic era, 245 to 570 million years ago. During this era, natural environmental changes led to periodic reef demise.
3. Hard corals developed into the prominent reef builders during the Mesozoic era, 65 to 245 million years ago. Coral reefs flourished until a devastating demise at the end of the era, when many coral families disappeared.
4. The species of corals that made up the reefs of the Tertiary period, 2 to 65 million years ago, were similar to today's species.

GEOGRAPHICAL DISTRIBUTION

Reef-building corals are scattered throughout the tropical and subtropical Western Atlantic and Indo-Pacific Oceans, generally within 30°N and 30°S latitudes. This is because the algal-cnidarian symbiotic machinery needs a narrow and consistent band of environmental conditions to produce the copious quantities of limestone necessary for reef formation. The formation of highly consolidated reefs only occur where the temperature does not fall below 18°C for extended periods of time. This specific temperature restriction 18°C does not, however, apply to the corals themselves. In Japan, where this has been studied in detail, approximately half of all coral species occur where the sea temperature regularly falls to 14°C and approximately 25% occur where it falls to 11°C (Veron 2000). Many grow optimally in water temperatures between 23° and 29°C, but some can tolerate temperatures as high as 40°C for limited periods of time. Most require salinity ranging from 32 to 42 parts per thousand. The water must also be clear to permit high light penetration. The corals' requirement for high light also explains why most reef-building species are restricted to the euphotic (light penetration) zone, approximately 70 m (Lalli and Parsons, 1995).

The number of species of corals on a reef declines rapidly in deeper water. High levels of suspended sediments can smother coral colonies, clogging their mouths which can impair feeding. Suspended sediments can also serve to decrease the depth to which light can penetrate. In colder regions, murkier waters, or at depths below 70 m, corals may still exist on hard substrates, but their capacity to secrete limestone is greatly reduced (Barnes, 1987). In light of such stringent environmental restrictions, reefs generally are confined to tropical and semitropical waters. The diversity of reef corals, i.e., the number of species, decreases in higher latitudes up to about 30° north and south, beyond which reef corals are usually not found.

GROWTH OF CORALS

In general, massive corals tend to grow slowly, increasing in size from 0.5 cm to 2 cm per year. However, under favourable conditions (high light exposure,

consistent temperature, moderate wave action), some species can grow as much as 4.5 cm per year. In contrast to the massive species, branching colonies tend to grow much faster. With suitable conditions, these colonies can grow vertically by as much as 10 cm per year. This fast growth rate is not as advantageous as it may seem, however, mechanical constraints limit the maximum size that branching corals can achieve. As they become larger, a heavier load is placed on the relatively small area attached to the substratum, rendering the colony increasingly unstable. Under these circumstances, the branches are prone to snapping off during strong wave action. The opposite is true of the massive-shaped corals, which become more stable as they grow larger (Barnes and Hughes, 1999).

Although various types of corals can be found from the water's surface to depths of 19,700 ft. (6,000 m), reef-building corals are generally found at depths of less than 150 ft (46 m), where sunlight penetrates. Because reef-building corals have a symbiotic relationship with a type of microscopic algae, sunlight is necessary for these corals to thrive and grow. Reefs tend to grow faster in clear water. Clear water allows light to reach the symbiotic algae living within the coral polyp's tissue. Reef development is generally more abundant in areas that are subject to strong wave action. Waves carry food, nutrients, and oxygen to the reef; distribute coral larvae; and prevent sediment from settling on the coral reef.

STRUCTURE OF CORAL REEFS

Coral reefs begin to form when free-swimming coral larvae (planulae) attach to the submerged edges of islands or continents. As the corals grow and expand, reefs take on one of three major characteristic structures—fringing, barrier or atoll. Fringing reefs are the most common, project seaward directly from the shore, forming borders along the shoreline and surrounding islands. Barrier reefs also border shorelines, but at a greater distance. They are separated from their adjacent land mass by a lagoon of open, often deep water. If a fringing reef forms around a volcanic island that subsides completely below sea level while the coral continues to grow upward, an atoll forms. Atolls are usually circular or oval, with a central lagoon. Parts of the reef platform may emerge as one or more islands, and breaks in the reef provide access to the central lagoon (Lalli and Parsons, 1995; Levinton, 1995; Sumich, 1996). In the 1830s, Charles Darwin distinguished between the three main geomorphological categories of reefs, and suggested that fringing reefs, barrier reefs, and atolls were all related stages in the sequence of atoll reef formation. All three reef types—fringing, barrier and atoll share similarities in their biogeographic profiles.

IMPORTANCE OF CORAL REEFS

Coral reefs are the most valuable marine habitats for over 100 countries around the world. Coral reefs contain the largest variety of species of marine life

in a very tiny area, and produce more living biomass than any other marine ecosystem. It provides many free economic and environmental services, including fisheries, tourism, generation of sand for beaches, and protection of the shore from waves, which make them the most valuable of all marine ecosystems in most countries where they occur. The importance of corals is as below :

1. Corals remove and recycle carbon dioxide. Excessive amounts of this gas contribute to global warming.
2. Reefs shelter land from harsh ocean storms and floods.
3. Reefs provide resources for fisheries. Food items include fishes, crustaceans, and molluscs.
4. Coral reefs attract millions of tourists every year.
5. The coral reef is an intricate ecosystem and contains a diverse collection of organisms. Without the reef, these organisms would die.
6. Some evidence suggests that the coral reef could potentially provide important medicines, including anti-cancer drugs and a compound that blocks ultraviolet rays.
7. Coral skeletons are being used as bone substitutes in reconstructive bone surgery. The pores and channels in certain corals resemble those found in human bone. Bone tissue and blood vessels gradually spread into the coral graft. Eventually, bone replaces most of the coral implant.

1.1. Objective and Approach

The objective of the present investigation was to conduct a rapid assessment of reef sites around the Andaman Islands to identify the level of importance of the reef systems to global biodiversity, and to assess the status of the reefs with respect to their general condition. The stepped approach adopted involved: (1) reviewing relevant literature; (2) processing satellite imagery of the region; (3) field surveys to 'ground truth' imagery and record coral diversity at selected reef sites; and (4) production of satellite image classification maps for future survey and management.

The initial satellite image processing was conducted in March 2001 followed by the field survey in April 2001. The field data were analysed in July 2001 and reclassification of the satellite image has been done in August & September 2001. The survey mainly focused on providing an inventory of the reef builders, and so coral species growing on reefs and associated habitats were compared at different sites.

The coral fauna mainly consists of the zooxanthellate scleractinian corals, which are those that contain single-cell algae and contribute to reef building. Also

included are a small number of zooxanthellate non-scleractinian corals which also produce large skeletons which contribute to the reef (e.g., fire coral *Millepora*, blue coral *Heliopora* and organ-pipe coral *Tubipora*), and azooxanthellate scleractinian corals (*Tubastrea*), and a few azooxanthellate non-scleractinian corals (*Distichopora* and *Stylaster*). All produce calcium carbonate skeletons that contribute to reef building to some degree. The survey allowed a comparison of the faunal richness of the Andaman Islands with other parts of Southeast Asia and adjoining regions.

1.2. Background

Coral reefs are ecologically important fragile ecosystem restricted to warm seas, essentially between the tropics of Cancer and Capricorn, where minimum water temperature do not fall below 20°C. Although coral reefs are geographically restricted to tropical seas and their occurrence limited to 0.2% of the ocean area on the earth's surface (Smith, 1978), have globally important implication for their amazing marine biodiversity. There has been a growing concern in recent years, over the status of reefs for the sustenance and survival of living corals associated with them. As a result, there is an increasing awareness now-a-days, for coral reef conservation and management along with long term research monitoring programmes at the national and international levels.

Coral reefs are highly productive marine ecosystem in the world with annual gross production rates in the range of 2000-5000g Cm⁻² through efficient retention and recycling of nutrients (Mann, 1982). Coral reefs of the world cover an estimated area of 600,000 km² (Smith, 1978; Klepays, 1997). Over half of this (54%) lies in the Mediterranean Indian Ocean. Of the remaining, Pacific reefs account for 25%, Atlantic reefs for 6%, Caribbean reefs for 9%, Red Sea reefs for 4% and Persian Gulf reefs for 2%. Majority of the coral reef areas are concentrated on western sides of these oceans (Scheer, 1985). The growth rate of coral and a coral reef depends on the factor such as light intensity, water temperature, salinity, turbidity, food availability, competition for space and predation. Upward growth of coral colonies is generally between 1 and 10 cm per year under favourable conditions (Lalli and Parsons, 1997).

A number of threats have caused serious declines in the distribution and condition of the coral reefs during recent decades. In particular, the El-Nino event of 1997-98 produced extremely high water temperature that caused bleaching and mortality of corals on a global scale. The Indian Ocean was said to be particularly badly affected by this event and most of the corals of East Africa and in central and northern Indian Ocean corals bleached and died due to this effect (Linden *et al.*, 2002).

In India, coral reefs are distributed in Andaman and Nicobar Islands, Lakshadweep Islands, Gulf of Mannar and Gulf of Kachchh; and in patches off Malwan on west and Gopalpur on east coasts. Indian coral reefs together with shelves, lagoon and submerged banks have a fishery potential of 0.2 billion tonnes per year or about 10% of the total production (Wafar, 1990). Reefs around Indian waters also represent all geomorphological forms. Fringing reef occurs in Andaman & Nicobar Islands, Palk Bay, Gulf of Mannar and Gulf of Kachchh. Forms of barrier reefs are also present in Andaman & Nicobar Islands and Gulf of Mannar. Reefs of Lakshadweep are represented by atolls. Besides these prominent reef forms, patchy reefs occur in some submerged banks and intertidal areas along the west and east coasts of India. The total area of various reef features as deduced from the satellite imagery is about 2,300 km², but extent of coralline shelves below one optical length (detection limit of satellite-borne sensors) could be several times higher, especially in the shelves of Andaman & Nicobar reefs (Wafar, 1999). In Indian reefs a total of 235 species of corals belonging to 73 genera have been reported. The 1998 bleaching event affected all the Indian reef areas to varying degrees. The Andaman & Nicobar reefs appear to have suffered the most followed by Lakshadweep, Gulf of Mannar and Gulf of Kachchh reefs (Wafar, 1999; Pet Soede *et al.*, 2000; Arthur, 2000).

The Andaman-Nicobar islands are a low mountainous chain of islands, which rise from a submerged north-south trending ridge separating the Andaman Sea from the Bay of Bengal between 6°-14°N and 92°-94°E (Figure 1.1). There are approximately 572 islands in the chain, some of which are volcanic. The islands occupy an area of 8,293 km² with a coastline of 1,962km and account for 30% of the Indian Exclusive Economic Zone (Jeybaskaran, 1999). The islands probably formed during the Mesozoic period (about 110 million years ago), and have undergone submergence and emergence events. The Andaman and Nicobar islands are in a mid-oceanic position, being separated from continental landmasses by deep water on both the east coast by the Andaman Sea, and on the west coast by the Bay of Bengal. The Andaman Sea is bordered by Myanmar (Burma), Thailand, the northern end of the Strait of Malacca, and the northwest coast of Sumatra. The waters of the Andaman Sea connect to the Indian Ocean through the Great Channel, a passage in the submerged ridge characterised by rugged sea bottom topography and depths greater than 2000m.

There is relatively little information on the coral reef ecosystems around the Andaman and Nicobar Islands, when compared to many other island groups in the Indian Ocean. The studies on taxonomy of Indian coral reef started in India as early as 1847 by Rink in Nicobar Islands. Alcock (1893) conducted the earliest recorded survey of the islands, and the general topography was described by Kloss (1902). Later Alcock (1902) described 25 species of deep sea Madreporaria dredged by Royal Indian Marine Survey Ship *Investigator* from depth of more than hundred fathoms, around Andaman Islands. Sewell (1922) provided the first

account of the ecology and formation of reefs in the region after visiting the Nicobar Islands. He subsequently visited the Andamans (Sewell, 1935), reporting that the coastline was edged by fringing reefs and that there was a barrier reef, 350km in length off the west coast between 10°-12°N. Reef structures have since been described by : Reddiah (1977); Pillai (1983b); Mahadevan and Easterton (1983); and Jeyabaskaran (1999). Pillai (1983b) described *Acropora* dominated seaward reefs, and *Porites* dominated leeward reefs. Sheltered areas close to mangroves were colonised by *Porites* and *Favia* on sand, except in flood channels. Jeyabaskaran (1999) conducted the most recent quantitative survey of benthic cover, around the Andaman and Nicobar Islands, incorporating sites at: Cinque Island, Little Andaman, John Lawrence, Henry Lawrence, Great Nicobar and North Reef.

The diversity of marine flora and fauna around the Andaman and Nicobar islands has received attention: Matthai (1924) listed coral species from the Andamans based on collections in the Indian Museum in Calcutta; and Pillai (1983a) listed 135 coral species from the region, and found that the Andaman islands were less diverse (31 genera with 82 species) than the Nicobar Islands (43 genera and 103 species). The latest Status Report (Wilkinson, 2002) sources that 203 hard coral species occur in these islands. The faunal studies other than corals have also been carried out at different reef locations of the Andaman and Nicobar Islands. More than 1200 fish species have recorded around Andamans and Nicobars (Rajasuriya *et al.*, 2002). Quantification of reef areas has been carried out by Space Application Centre (MWRD 2000) using Landsat TM, IRS LISS II and SPOT satellite imagery. The reef area calculated by this study comprised 795.7 km² in Andaman Islands, 30.81 km² in Great Nicobar, 15.53 km² in North Reef, 27.15 km² in Rani Jhansi Marine National Park, 6.78 km² in Cinque and 58.29 km² in Little Andaman. In-depth information on coral reef ecology and community structure are limited to few studies on some specific reef sites only: The percentage cover of live corals has been estimated for the islands of the Mahatma Gandhi Marine National Park (Dorairaj and Soundararajan, 1997; Arthur, 1996; Kulkarni, 2001) and North Reef, Cinque Island, Twin Islands reef, West Rutland Island, Tarmugli Island, Flat Island, South Button, Outram Island, Henry Lawrence, Minerva ledges, and Neil Island (Turner *et al.*, 2001). These studies also listed species wise distribution for these reef areas. In addition, Kulkarni *et al.* (2001) addressed several ecological parameters in their study, which include sedimentation, terrestrial zone influence and other anthropogenic factors.

The reef corals of the Andaman Islands belong to the Indo-west Pacific faunal province. The Andaman Islands are just northwest of the central area of greatest marine biodiversity, referred to as the 'Coral Triangle', an area enclosing the Philippines, central and eastern Indonesia, and northern and eastern Papua New Guinea (Hoeksema, 1992). Areas of lower diversity include Eastern Australia's Great Barrier Reef, Southern New Guinea, western Indonesia and the Ryukyu

Islands of Southern Japan. The biodiversity of corals falls off from the Coral Triangle in all directions, reaching 80 species at an island near Tokyo, 65 species at Lord Howe Island southeast of Australia, 45 species in Hawaii, and 20 species at Pacific Panama. Reduction in species diversity is less to the west in the Indian Ocean and Red Sea. Some 300 species may currently be known in the Red Sea, though this area, like many others, is insufficiently studied to provide accurate data. Corals are habitat-builders and appear to have less niche-specialization than some other groups. Some zonation occurs by depth and exposure to waves or currents. Thus, there are a few corals that are restricted to zones such as very shallow areas, protected areas, deep water, shaded niches, soft bottoms, or exposed areas. However, many corals can be found over a relatively wide range of exposure and light intensity. Shallow water corals are primarily autotrophic, relying on the products of the photosynthesis of their symbiotic algae, supplemented by plankton caught by filter-feeding and suspension feeding. Most require hard substrate for attachment, but a few grow well on soft substrates.

Macroalgae were surveyed by Jagtap (1985, 1992), Soundararajan (1997), and Rao (1999) who listed 182 species. Reddiah (1977) commented on the distribution of algae, such as *Lithothamnion* conspicuous on windward reef edges, *Turbinaria* on windward reef fronts and *Halimeda opuntia* on reef flats. Jagtap (1985, 1992) identified 7 species of seagrass, and a further 2 species were found by Das (1996), and all 9 species are known to occur off the coast of mainland India (Ramamurthy *et al.*, 1992). Jagtap (1985) found that seagrass growth was poor relative to the Lakshadweep Islands and that seagrass diversity is higher in the Andaman Islands than in the Nicobar Islands.

Previous mapping projects to quantify the marine habitats using remote sensing data have been undertaken in the Andaman Islands. Wafar (1986) calculated the reef area around the Andaman to be 11,000 km² (taken as all lagoon and submerged banks together) and 2700 km² around the Nicobar Islands. Nayak *et al.*, (1994) (cit. MWRD, 2000), mapped the Andaman and Nicobar group of islands using Landsat TM, IRS LISS II and SPOT satellite imagery, and calculated reef area as 959.3 km². Menon and Pillai (1996, cit. Bakus *et al.*, 2000), in a study mapping total reef flat around India calculated 813 km² of reef flat round the Andaman-Nicobar Islands. MWRD (2000) produced a series of maps at 1:250,000 scale derived from SPOT satellite images recorded between 1988-1993. Although the maps show coral, mangrove, sand, mudflats and vegetation categories, it is not known whether these maps were ground truthed. Area estimates from these maps are shown in Table 1.1 and Fig. 1.2. 84% of the islands were forested.

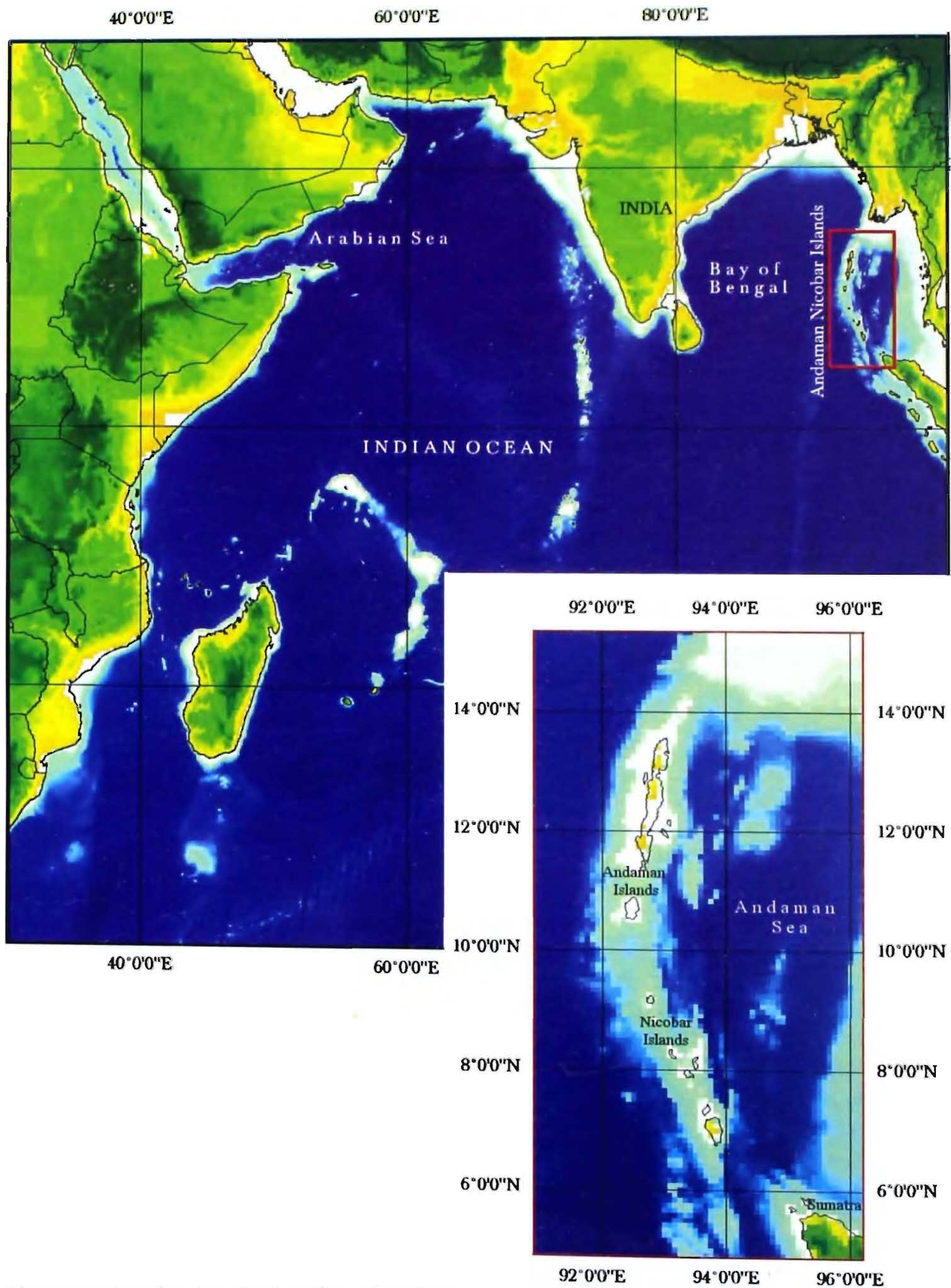


Fig. 1.1. Map showing the location of Andaman and Nicobar Islands.

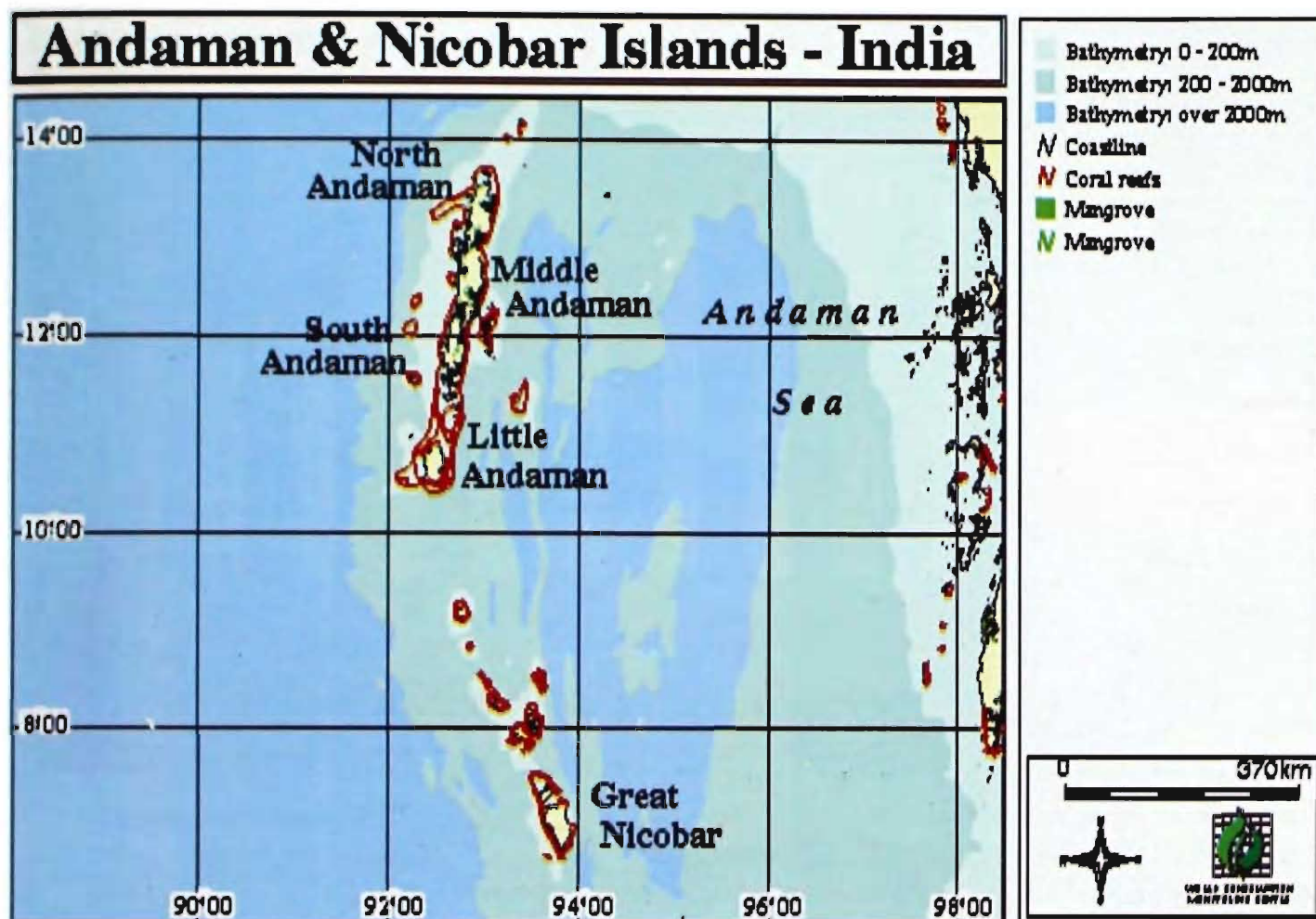


Fig. 1.2 Distribution of corals reefs and mangroves of Andaman & Nicobar Islands.

Table 1.1. Terrestrial and marine habitat area estimations (km²) for the Andaman and Nicobar Islands group and specific sites as given by MWRD (2000) and derived from SPOT satellite imagery 1988-1993.

Habitat	Andaman & Nicobar Islands	Great Nicobar Island	North Reef Island	Rani Jhansi Marine National Park	Cinque Island	Little Andaman Island
Habitation	—	0.09	—	—	—	—
Barren	159.4	—	—	—	0.62	—
Agriculture	108.64	—	—	—	4.55	—
Forest	4526.3	935.21	2.58	86.13	4.55	618.75
Plantation	2.81	—	—	—	—	—
Mixed Vegetation	221.61	0.17	—	0.058	2.46	—
Mangrove	750.82	16.88	—	18.89	0.86	39.05
Mangrove Andaman	679.9	—	—	—	—	—

Habitat	Andaman & Nicobar Islands	Great Nicobar Island	North Reef Island	Rani Jhansi Marine National Park	Cinque Island	Little Andaman Island
Mangrove Nicobar	70.92	—	—	—	—	—
Other Vegetation	43.32	—	—	—	—	0.16
Sand	82.89	10.56	1.11	7.45	0.67	7.27
Coral reef	795.7	30.81	15.53	27.15	6.78	58.29
Mudflats	49.47	0.25	0.14	—	—	11.25
Water body	17.46	—	—	—	—	—
Lagoon	20.52	—	—	—	—	—

2.0. METHODS

The following section details the preliminary image processing (Stage I) of a Landsat 7 Enhanced Thematic Mapper (ETM) image of the Andaman islands, including the selection of satellite scenes and the initial computer generated classification of terrestrial and marine habitats; the field survey and field data analysis, and finally the post survey image processing (Stage II).

2.1. IMAGE PROCESSING STAGE 1

2.1.1. Satellite Scene Selection : The Landsat 7ETM+ world reference system (WRS) for the Andaman Islands is shown in Figure 2.1. Scenes 134-051 and 134-052 covering the northern Andaman Islands were selected on the basis of location and extent of cloud cover. Sequential coverage for adjacent scenes and are listed in Table 2.1. The 'quick looks' of the scenes finally selected are shown in Figure 2.2.

Table 2.1. Specifications of the selected Landsat 7ETM+ scenes for the northern Andaman.

Data Granule	Start date	Stop date	Centre point	WRS path	WRS row	Dataset
E1SC L70RWRS.002 2000743789	07 Feb. 2000, 04:01:48	07 Feb. 2000, 04:01:48	13.01 Lat. 92.70 Lon.	134	51	LANDSAT-7 LEVEL-1 WRS-SCENE V002
E1SC L70RWRS.002 2000743792	07 Feb 2000, 04:02:12	07 Feb 2000, 04:02:12	11.57 Lat, 92.38 Lon;	134	52	LANDSAT-7 LEVEL-1 WRS-SCENE V002

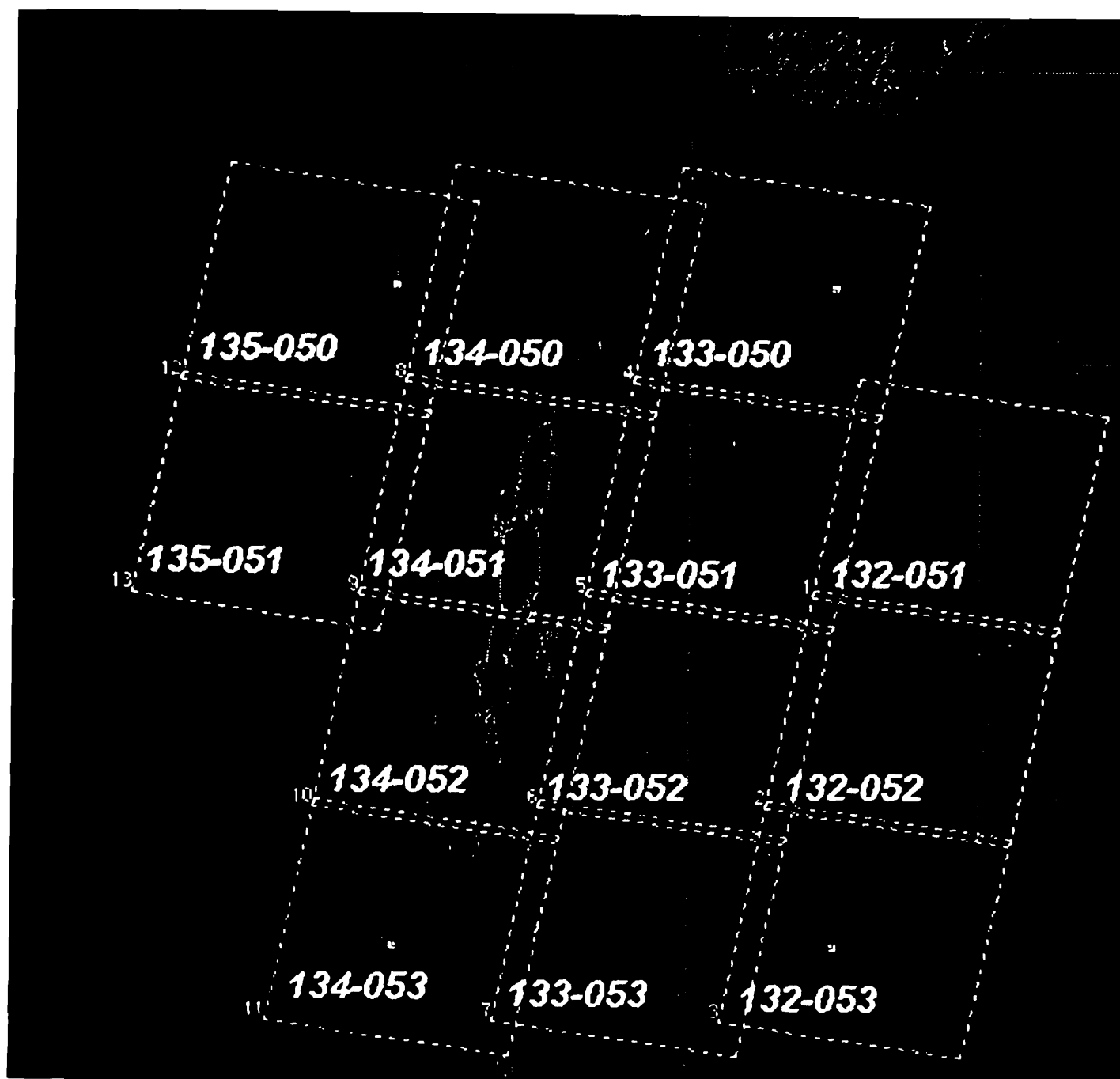


Fig. 2.1. Chart showing the WRS scenes for the Andaman Islands.

2.1.2. Image Enhancements : The two Landsat 7 ETM+ scenes were corrected for radiometric and atmospheric variation using the 6S atmospheric model in ERDAS Imagine. The scenes were mosaiced and georeferenced to Latitude Longitude WGS84 using GIS vector data.

2.1.3. Terrestrial and Mangrove Vegetation Mapping : The vegetation of the northern Andaman was mapped using a Normalised Differential Vegetation Index (NDVI), a ratio of the Landsat 7 bands ETM3 and ETM4. The NDVI image was classified into 10 classes, which represent different levels of 'greenness' or vegetation cover. Figure 2.3 shows the NDVI classification for Landfall and East Island to the north of the Andaman Islands. The Landsat 7 bands ETM4, ETM5

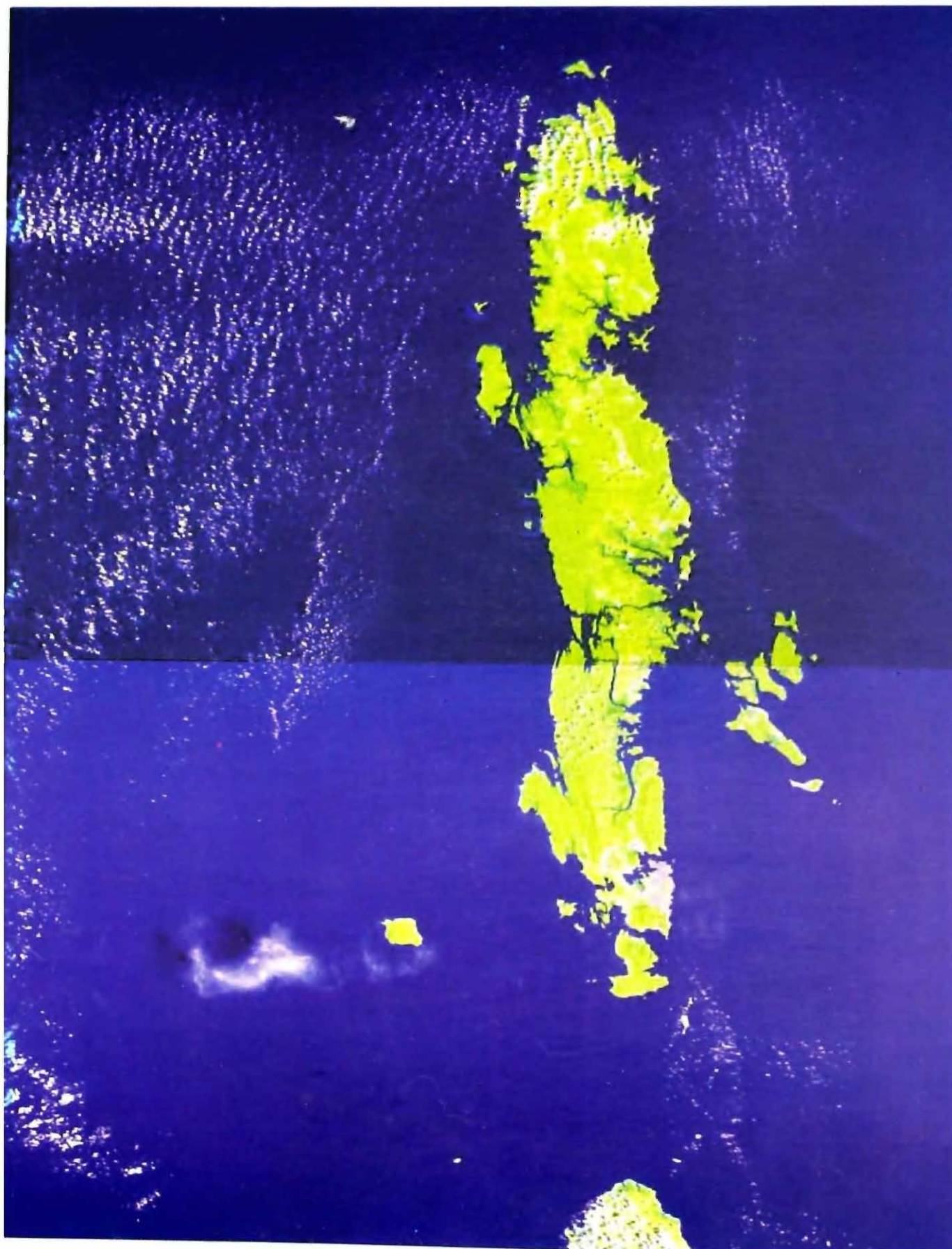


Fig. 2.2. Landsat 7ETM+quick looks of the Andaman Islands on 7th February 2000.

and ETM3 distinguish mangrove or wetland vegetation from terrestrial vegetation (Figure 2.4). Ratios of these bands, $ETM3/ETM5$ and $ETM4/ETM5$, were created and classified to map the mangrove areas. The NDVI image was then subdivided using the classified mangrove image into mangrove and terrestrial vegetation areas. The NDVI values, in both the mangrove and the terrestrial vegetation areas, range from low NDVI in sparse vegetation such as bare or cleared areas of mud, sand and agricultural land, to higher NDVI values over densely vegetated areas such as primary tropical or deciduous forest or mangrove. The preliminary terrestrial vegetation classes are listed in Table 2.2. An example of the final vegetation map, which includes both terrestrial and mangrove vegetation divided according to the NDVI or 'greenness', is provided in Figure 2.5.

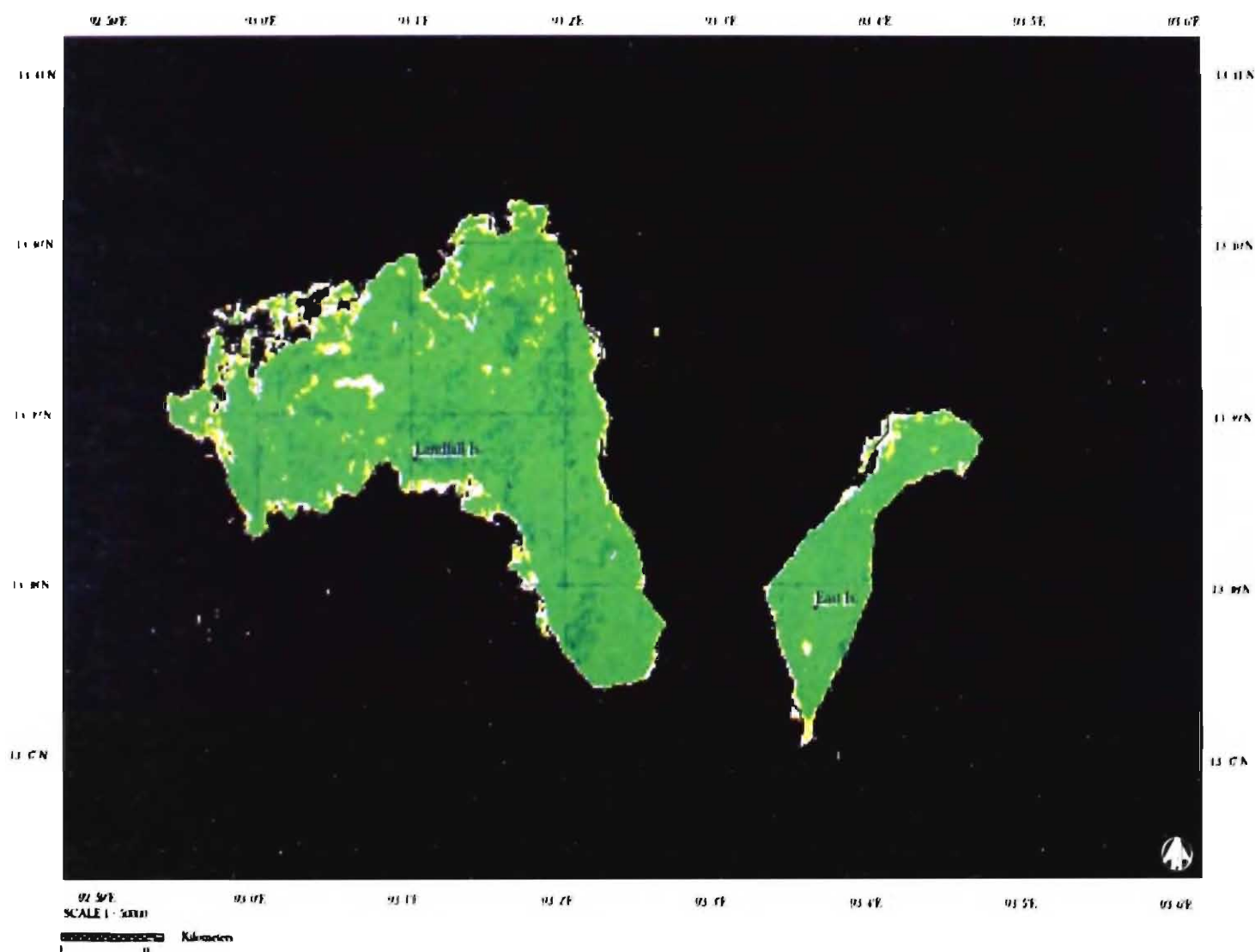


Fig. 2.3. Landsat 7ETM + NDVI images of Landfall and East Islands, North Andaman. (Green colour – vegetation; Yellow/white/pale brown – sand or mud).

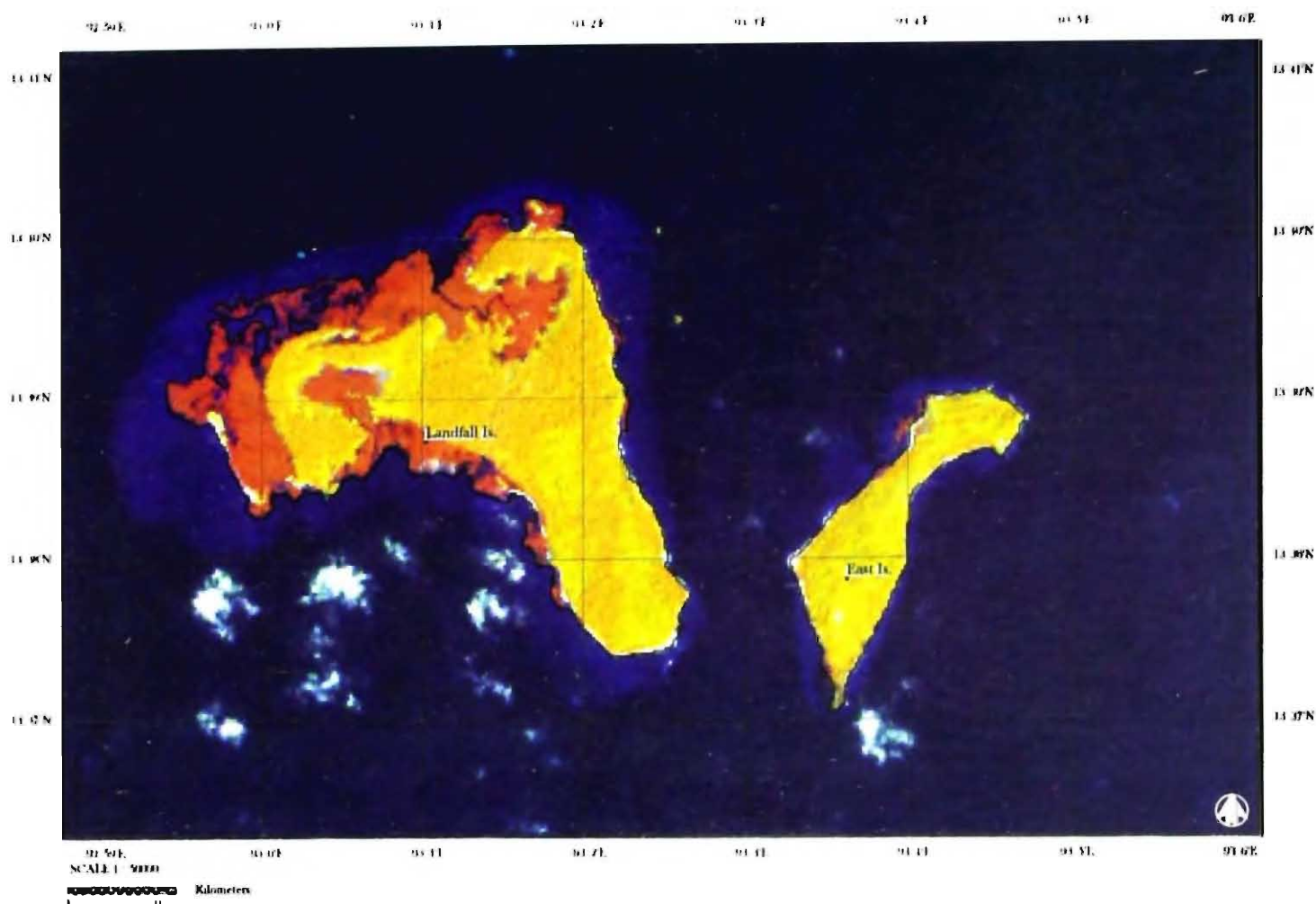


Fig. 2.4. Landsat 7ETM+ NDVI images of Landfall and East Islands, North Andaman. (band combination)

R:ETM4 G:ETM5 and :ETM3). Red areas – Mangrove or wetland vegetation distinct from terrestrial vegetation and non-vegetated areas.

2.1.4. Marine Biotope Mapping : The Landsat 7 bands ETM1, ETM2 and ETM3 were masked to exclude land and cloud. Images showing band ratios ETM1/ETM2, ETM2/ETM3, and ETM1/ETM3 were also created using an arctan transformation to adjust for between scene differences not accounted for during radiometric and atmospheric correction. The masked scene and band ratio scenes were iteratively classified using an unsupervised classification algorithm tested with different numbers of classes e.g. 12, 25 and 35 classes. The preliminary marine biotope classification eventually used 21 classes (Table 2.2) based on experience of using similar satellite data, since prior to the field survey, no suitable georeferenced data was available to define classes. One of the intended objectives of the field survey was to collect data to use in validating the preliminary classification, and where possible, to conduct a supervised classification.

2.1.5. Terrestrial and Marine Biotope Maps and True Colour Composite Maps : The Terrestrial and Marine Biotope maps were combined (Figures 2.6, 2.7), and then sectioned into 11 regions (Figure 2.8) for hard copy map output, each map at a scale of 1:200,000. A true colour composite of marine

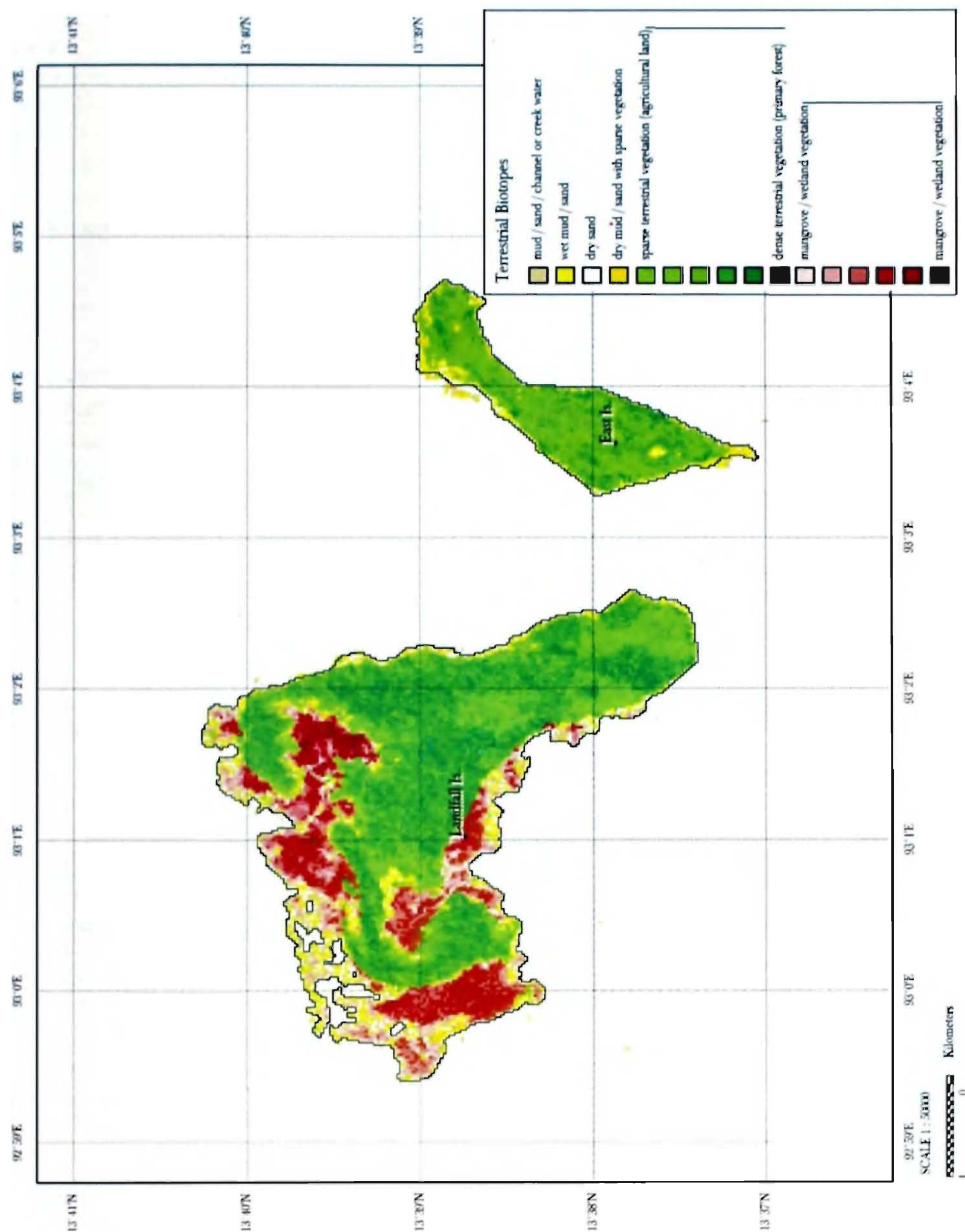


Fig. 2.5. Subsection of Terrestrial Biotope map for the Andaman Islands created using a combination of NDVI and unsupervised classification of band ratios from Landsat 7ETM+.

areas, using bands Red: ETM3, Green: ETM2 and Blue: ETM1 combined with a natural colour composite of terrestrial areas was used to create a second set of hard copy maps covering the same subsections. In addition, 34 higher resolution subsections, at a scale of either 1:50,000 or 1:60,000, covering areas of probable interest (reef flats, lagoons) were created, and examples for North Reef are shown (Figures 2.9, 2.10).

Table 2.2. Preliminary classification of Terrestrial and Marine biotopes as illustrated in Figure 2.7.

Terrestrial Class	Notes
Mud/sand/channel or creek water Wet mud/sand Dry sand Dry mud/sand with sparse vegetation	Non vegetated areas. Classified using NDVI.
Sparse terrestrial vegetation 01 Sparse terrestrial vegetation 02 Sparse terrestrial vegetation 03	Terrestrial vegetation, classified using the NDVI measure of 'greenness', and will include agricultural, tropical and deciduous forest.
Dense terrestrial vegetation 01 Dense terrestrial vegetation 02 Dense terrestrial vegetation 03	
Mangrove/wetland vegetation 01 Mangrove/wetland vegetation 02 Mangrove/wetland vegetation 03 Mangrove/wetland vegetation 04 Mangrove/wetland vegetation 05 Mangrove/wetland vegetation 06	Mangrove or wetland vegetation. Classified using the ETM4, ETM5, ETM3 band combination and separated using NDVI classification of 'greenness'
Terrestrial cloud shadow	Areas covered by cloud shadow may cause misclassification.
Cloud	Areas covered by cloud.
Marine Class	Notes
Deep open ocean 01	Water ~> 50m depth
Deep open ocean 02	Water ~>30m depth
Deep open ocean 03	Water ~>20m depth
Open water/reef slope 01	Water <~20m depth and reef slope
Open water/reef slope 02	Potential reef slope spectral confusion with deep sand and in turbid areas.
Reef slope/reef crest/turbid water	Potential reef crest spectral confusion in turbid areas.
Reef flat 01 Reef flat 02	

Table contd.

Terrestrial Class	Notes
Reef flat 03	All the reef flat classes are expected to be in water <10m depth and will include some silt, sand, and rubble areas, as well as macroalgae, seagrass, soft coral and hard coral dominated areas.
Reef flat 04	
Reef flat 05	
Reef flat 06	
Reef flat 07	
Reef flat 08	
Reef flat 09	
Reef flat 10	
Reef flat 11	
Reef flat 12	
Reef flat 13	
Reef flat 14	
Sand	Clean shallow sand

2.2. FIELD SURVEY

A rapid site assessment of reef sites around the northern Andaman Islands was conducted between 14th and 24th April 2001 from the SY 'Ilala' (Figure 2.11). Surveys were conducted at representative and accessible reef sites in the south, west, north and east of the northern Andaman Island group, selected using the satellite imagery. At each site, a brief reconnaissance was conducted of the area using an inflatable boat, from which depth was measured using a Plastimo Echotest sounder, and the seabed viewed where possible using a glass bottomed viewer. The geographic position of sites selected for underwater surveys were recorded using a global positioning system (GPS, Magellan 315) and downloaded to a GEBCO base map using DataTrack software (Magellan). In addition, position, depth and seabed type were recorded at other sites in the locality, for use in assessing the accuracy of the classified satellite image. The geographic positions of distinctive landmarks visible on the satellite image (such as rock promontaries, mangrove outcrops, shorelines, exposed rock ridges and reef flats) were recorded as Ground Control Points (GCP) for the geometric correction of the satellite image. The location of the GCPs, survey sites and accuracy assessment sites are shown in Figure 2.11 (as red stars and blue diamonds respectively). The list of survey site and waypoint locations are given in table 2.3.

Post Tsunami survey : Post tsunami survey has been conducted in selected islands of Andman and Nicobar during the the year 2005-08 to assess the impact of tsunami on coral reef ecosystem.

A rapid site assessment survey technique was used to assess benthic physical structure and biological composition over an area of approximately one hectare

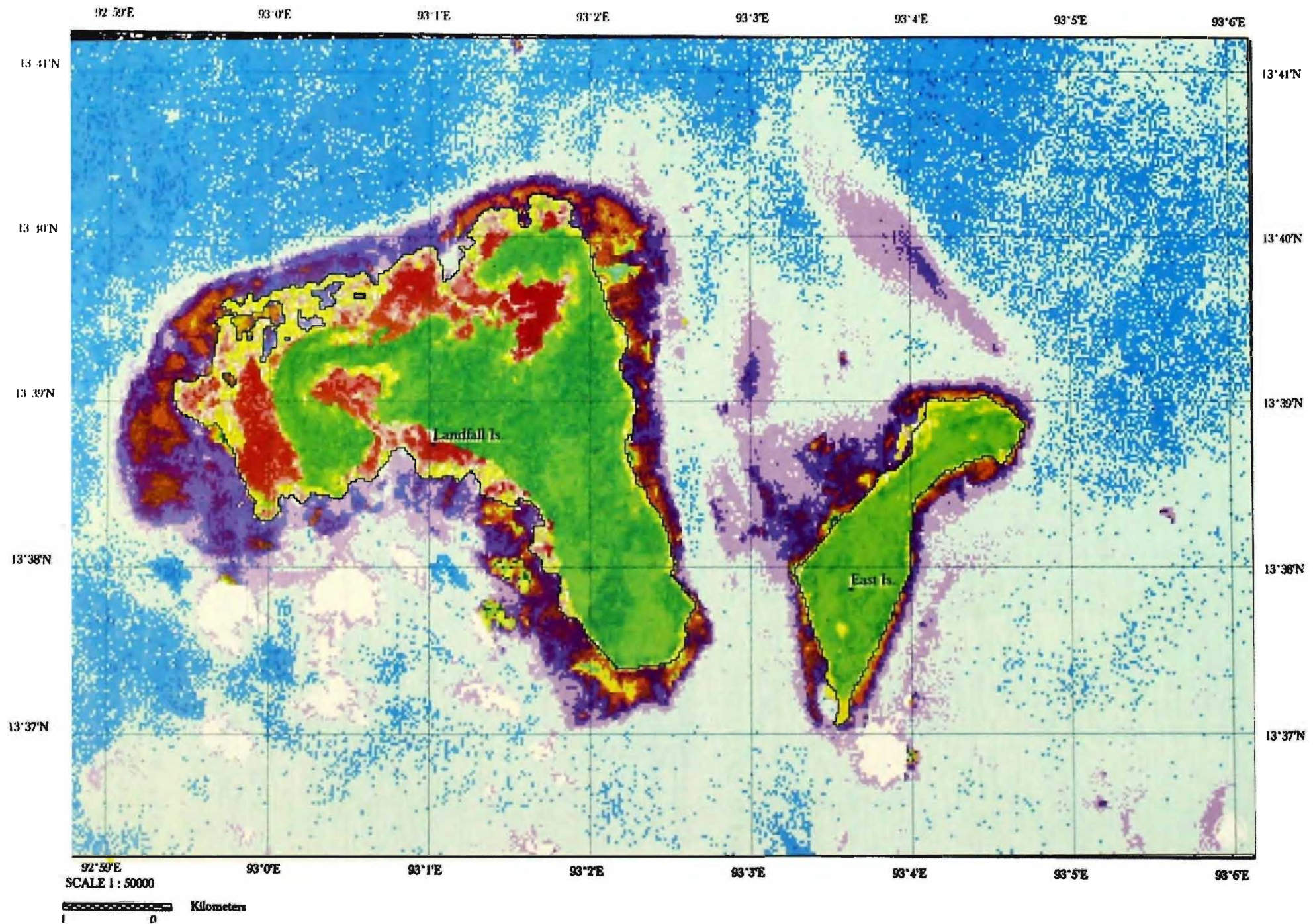


Fig. 2.6. Subsection of Terrestrial and Marine Biotope map for Landfall and East Islands created using a unsupervised classification of Landsat 7ETM+ (for legend please refer Fig. 2.7).

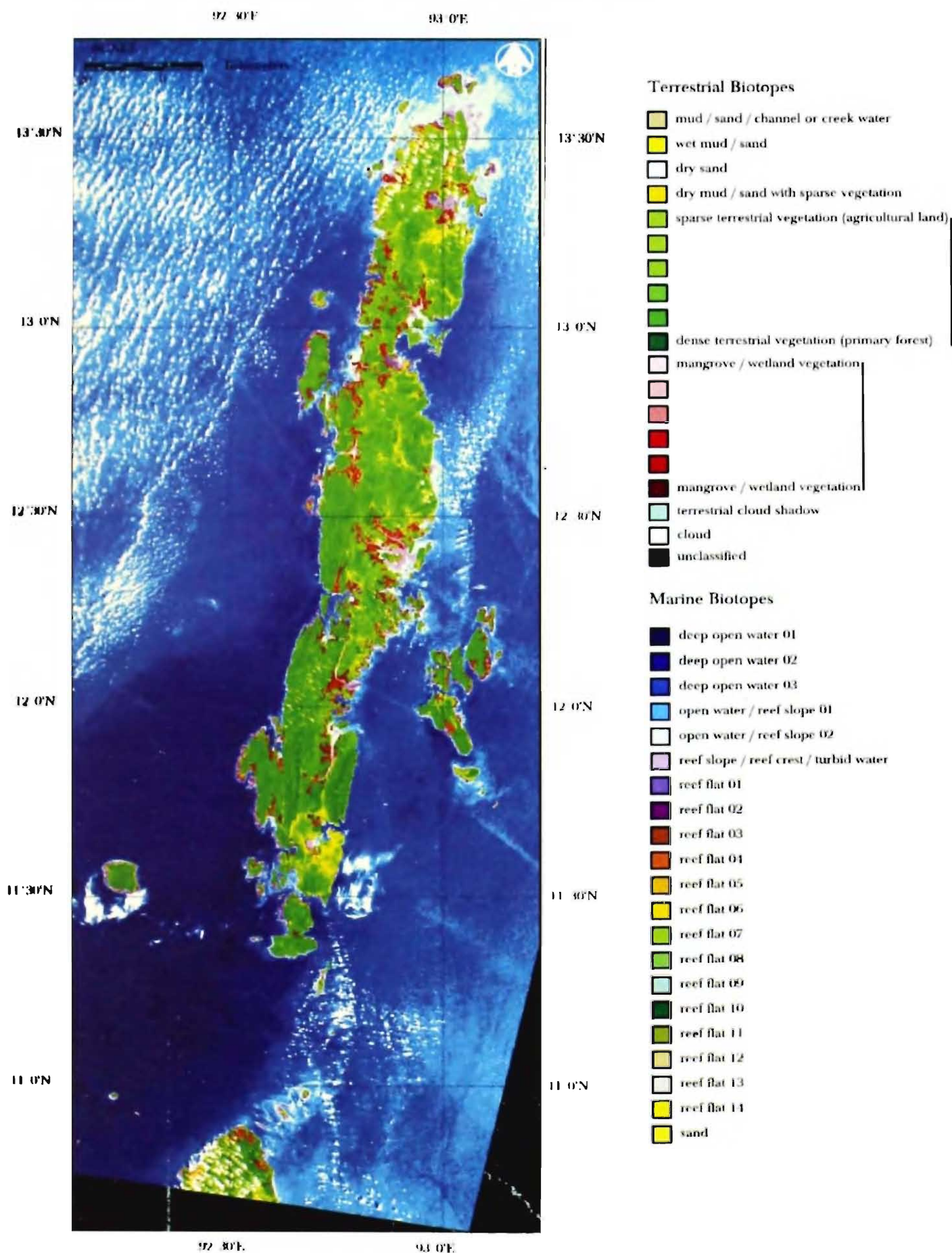


Fig. 2.7. Overview of the Terrestrial and Marine Biotope Map for the Andaman Islands created using unsupervised classification of Landsat 7ETM+ showing legend for the classification.

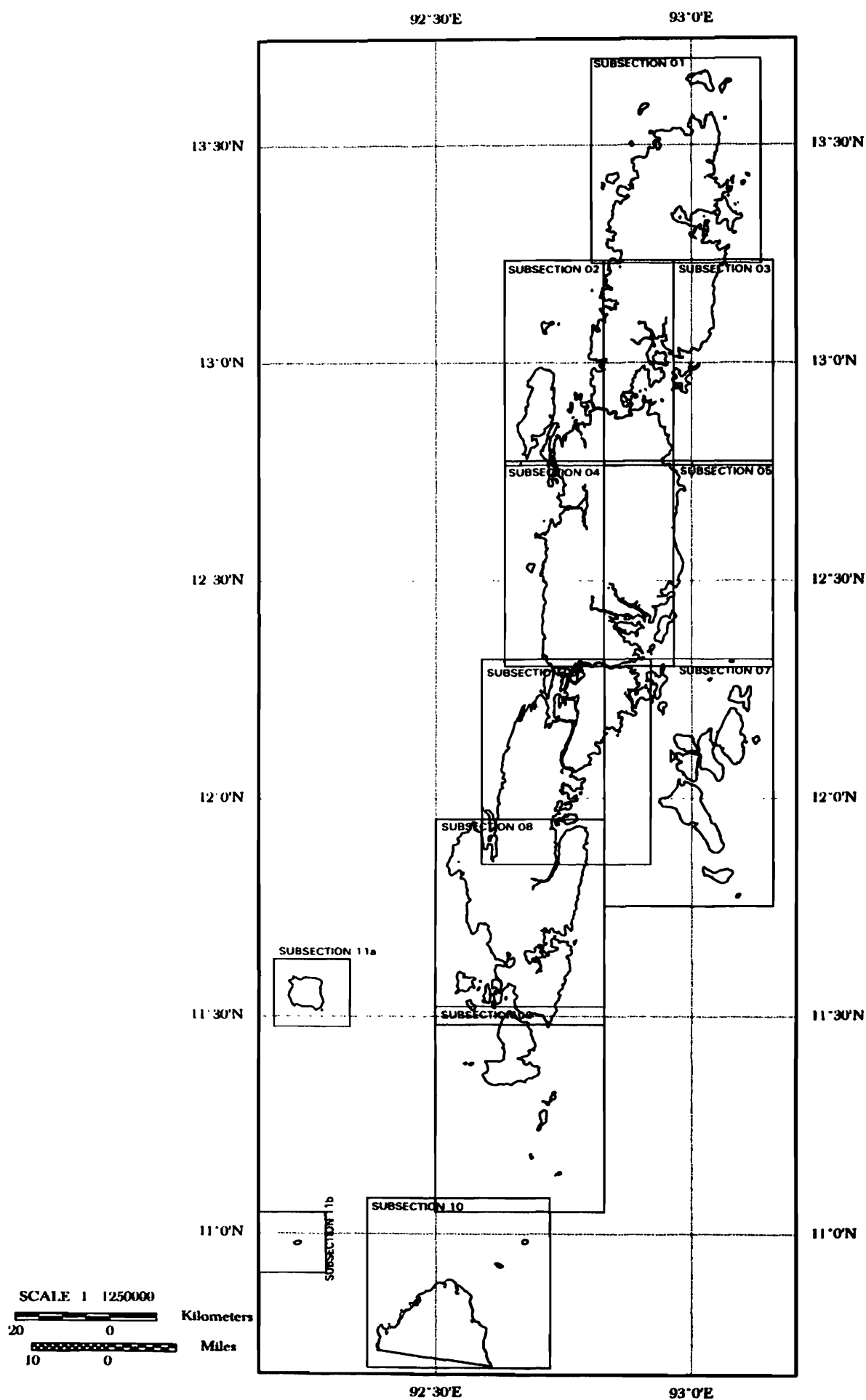


Fig. 2.8. Map illustrating the subsections created for the northern Andaman Islands at 1:200,000 scale.

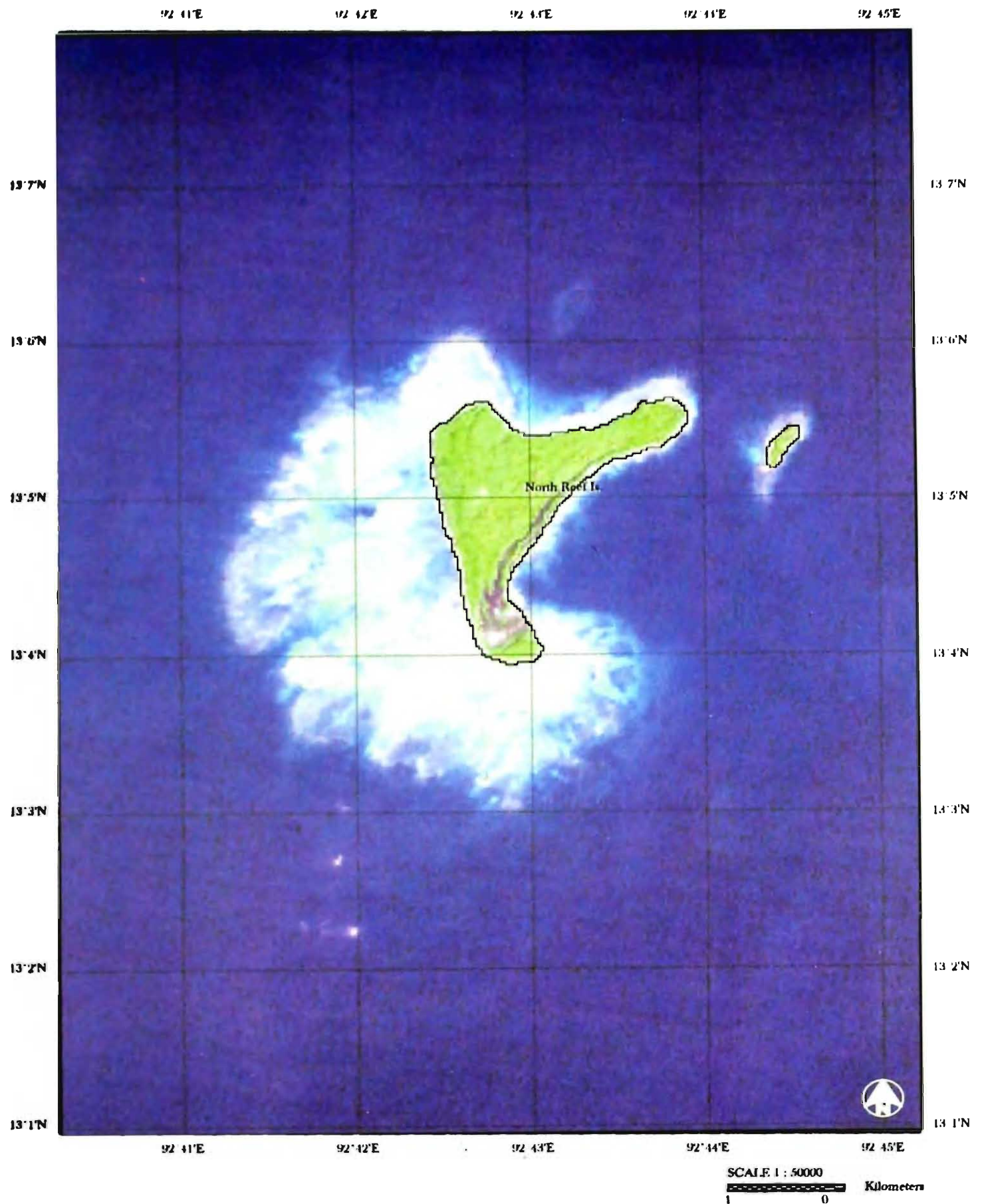


Fig. 2.9. High resolution subsection (1:50,000 scale) of the combined true colour composite of marine areas together with natural colour composite for terrestrial area for North Reef Island.

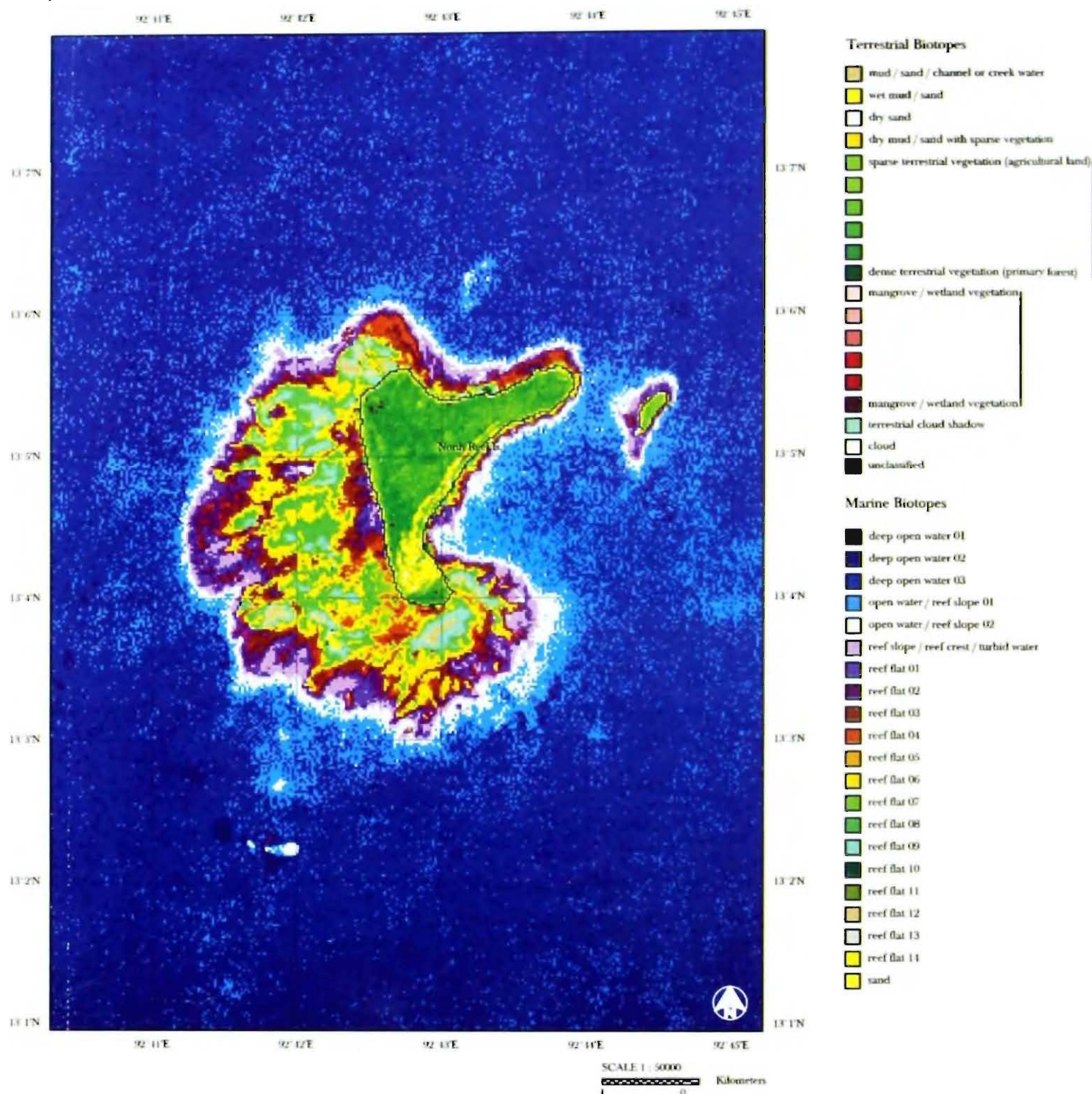


Fig. 2.10. High resolution subsection (1:50,000 scale) of the Terrestrial and Marine Biotope map for North Reef Island.

at 13 sites: Cinque Island (south of northern island) AND001; Cinque Island (north of northern island) AND002; Twin Island AND003; Wood Mason Bay AND004; Tarmugli Island AND005; Flat Island AND006; south of North Reef (slope) AND007; south of North Reef (crest) AND008; South Button Island AND009; Outram Island AND010; Henry Lawrence Island AND011; Minerva Ledges AND012; Neill Island Ledges AND013. Two teams of 3 divers or snorkelers surveyed the area for 50 minutes at each site. The surveyors traversed an area approximately 100m by 100m on flat seabed (e.g. patch reefs) or 200m x 50m

on narrow features (eg. reef fronts), depending on benthic structure and diving conditions. The surveys were normally restricted to a maximum of 18 m depth, and on reef slopes, continued to the shallowest depth possible. The visual recorders described: the state of reef development; the composition of the physical habitat; and benthic cover. Reef development was assigned scores of: 1 - reefs with extensive flats (>50 m); 2 - coral communities forming reefs with moderate flats (<50 m); 3 - coral communities with carbonate accretion but no reef flat; 4 - coral communities on non-reefal rock, sand or rubble flat. A six point index was used to estimate the percentage cover and abundance as follows: 0 = Absent: 0% cover or 0 individuals; 1 = Rare: <1% cover or 1 individual; 2 = Occasional: 1-10% or 2-10 individuals; 3 = Frequent: 11-30% or 11-20 individuals; 4 = Common: 31-50% or 21-50 individuals; 5 = Abundant: 51-75% or 50-100 individuals; and 6 = Superabundant: 76-100% or >100 individuals). The scores were applied to the following ecological attributes: Hard substrate (HS); Hard Coral (HC); Dead Standing Coral (DS); Soft Coral (SC); Turf Algae (TA); Macro Algae (MA); Bare substrate (BA); and Other (OT). The same index was applied to the composition of the substratum: Continuous Pavement (CP); large boulders >1m (LB); Small boulders <1m (SB); Unconsolidated Rubble (RB); Sand (SA); and Silt (SLT). Organisms were identified to genus or species wherever possible, and numerical abundance or per cent cover of taxa was ranked 0-6 as appropriate.

In situ identification of corals was made by examining the characteristic features. The method consisted of underwater observations, usually during 45-60 minutes dive at each site. The name of each species identified was marked on a plastic sheet on which species names were printed. A direct descent was made in most cases to the maximum depth, followed by a slow ascent along the reef in a zigzag path to the shallowest point of the reef or until further swimming was not possible. Sample areas of all habitats encountered were examined, including level bottom, sandy areas, slopes, and shallow reef.

Many corals can be identified underwater to species level with certainty, and a few must be identified alive since they cannot be identified without living tissues. Several taxonomic works were used to aid identification (Wallace, 1999; Veron, 2000). Some species require collection to confirm identification, but corals were not collected in this preliminary study. Additional references supporting identification used were: Best and Suharsono (1991); Boschma (1959); Claereboudt (1990); Dai (1989); Dai and Lin (1992); Dineson (1980); Hodgson (1985); Hodgson and Ross (1981); Hoeksema (1989); Hoeksema and Best (1991); Moll and Best (1984); Nemenzo (1986); Nishihira (1986); Ogawa and Takamashi (1993, 1995); Randall and Cheng (1984); Sheppard & Sheppard (1991); Veron (1985, 1986, 1990, 2000); Veron and Pichon (1976, 1980, 1982); Veron *et al.* (1977); Wallace (1994, 1997a); Wallace and Wolstenholme (1998).

The habitat structure of coral reefs has been photographed using a Nikonos V underwater camera equipped with 28 mm lens, TTL strobe and 200ASA Kodachrome film. Additional photographs on coral species were recorded using

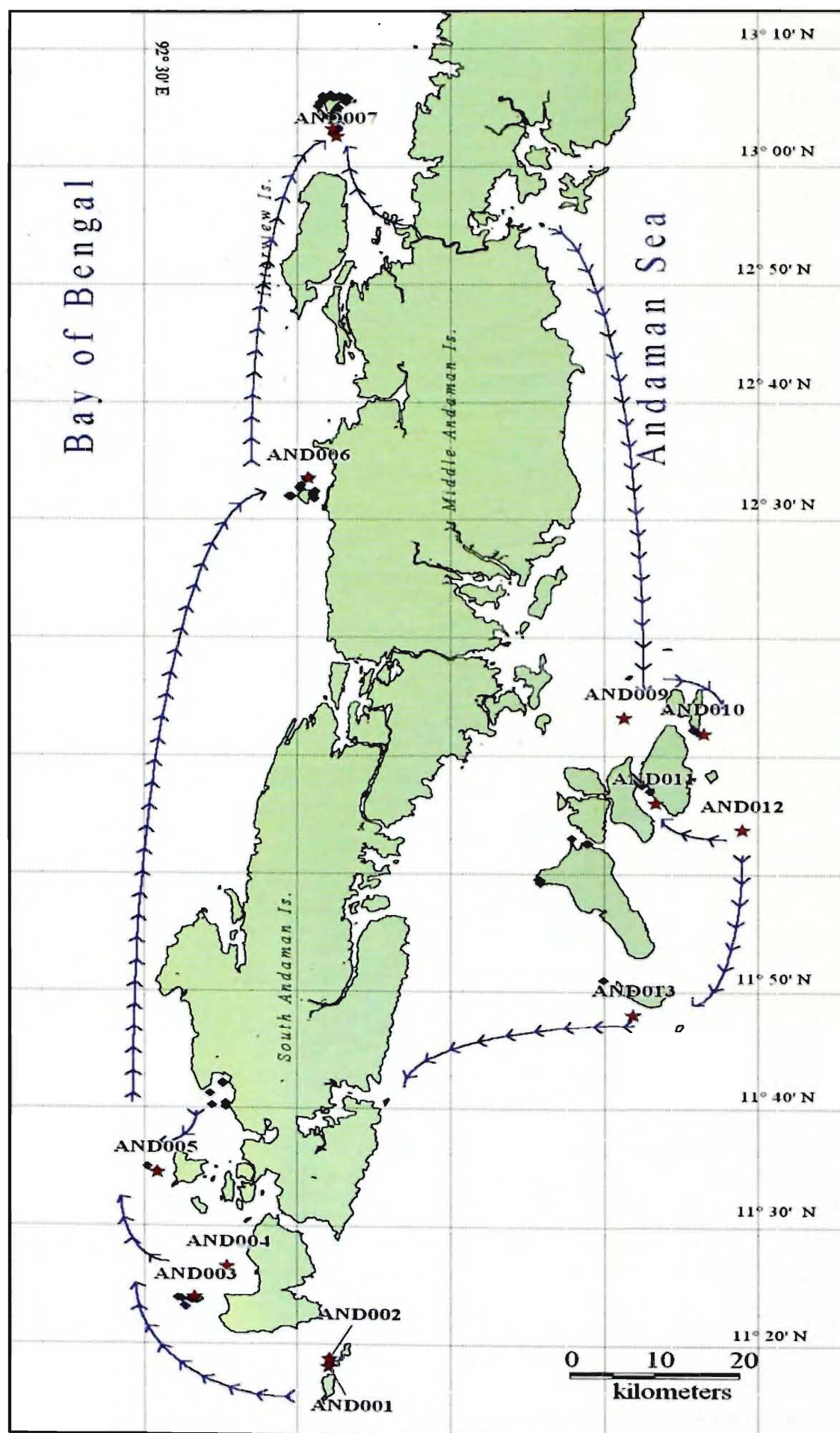


Fig. 2.11. Map showing the locations of the site surveyed (red stars) quick sites surveyed and ground control points (GCPs) and the route travelled around the Andaman Islands.

an Ocean Optics 001 close up lens. Where conditions allowed, video records were also made at 9 out of the 13 sites (except AND001, AND004, AND008 and AND013) for archive purposes and further quantitative analysis using random point count analysis. A Sony 1000 Hi8 video camera housed in Stingray housing with a wide-angle port was employed. The video technique involved swimming over the substrate with the camera 0.4 m away from the benthos, held at an angle of 45 degrees. Frequent 360 degree scans were made to record biotope structure.

2.3. DATA ANALYSIS

The visual survey data from the 13 sites was entered into a database (Access, Microsoft Corporation). 35 mm Photographic slides were scanned at 2400dpm, and written to CD-Rom. The video record was employed to validate the visual field surveys and to conduct quantitative 'Point Data Analysis' to estimate the percent cover of different benthic categories. Screen 'grabs' of video sequences were recorded at random time intervals calculated using a random number generator in MINITAB statistical software. 100 random screen grabs per site were made and for each, 10 random points were overlaid and the benthic category under each point was recorded, producing 1000 data points per site. The video point data was entered into Access and percentage cover of each benthic category was calculated.

To determine similarity between the survey sites, the data was analysed using multivariate hierarchical agglomerative clustering techniques using MINITAB statistical software and PRIMER (Plymouth Routines in Marine Environmental Research). Benthic structure and cover was analysed using Ward's linkage and Pearson's correlation distance using MINITAB statistical software. In Ward's Linkage, the distance between two clusters is the sums of squared deviations from points to centroids with the objective of minimising within-cluster sum of squares. When the distance between two clusters is larger than d (max), the maximum value in the original distance matrix, D , then the similarity is negative and there are large differences between sites. Ward's linkage was used because the results may be sensitive to outlying data, but not to measurement error (reduced in the ordinal scale used). Visual survey data was then normalised for structure and cover and the Bray Curtis linkage in PRIMER was applied to benthic structure and cover data first separately, and then combined. Coral species presence at each site was clustered using Bray Curtis (PRIMER) to identify major community types, and then combined with the video Point Count Analysis data to incorporate identifications from the archived video record. Percentage cover calculations were normalised and a final cluster analysis run for the combined data.

2.4. IMAGE PROCESSING STAGE II

The ground control points (GCPs) collected during the survey were used to geometrically correct the Landsat 7ETM+ data. The pre-survey biotope

Table 2.3. Survey Site Locations.

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon._DD	GPS	Fix Type	Location	Notes
A1	15-Apr-01	11	18.138	92	42.066	11.30230000	92.70110000	Ilala	SITE	Cinque Island	AND001
AGC1	15-Apr-01	11	18.776	92	42.112	11.31293333	92.70186667	magellan 320	GCP	Cinque Island	GCP
AGC2	15-Apr-01	11	18.76	92	42.104	11.31266667	92.70173333	magellan 320	GCP	Cinque Island	GCP
A2B	15-Apr-01	11	18.764	92	42.09	11.31273333	92.70150000	magellan 320	SITE	Cinque Islands	AND002
A3A	17-Apr-01	11	23.98	92	33.323	11.39966667	92.55538333	magellan 320	SITE	Cinque Islands	AND003
A3B	17-Apr-01	11	23.88	92	33.298	11.39800000	92.55496667	magellan 320	SITE	Twin Islands	AND003 out
WPT001	15-Apr-01	11	23.815	92	32.463	11.39691667	92.54105000	magellan 320	quick site	Twin Islands	sand
WPT002	15-Apr-01	11	23.846	92	32.19	11.39743333	92.53650000	magellan 320	quick site	Twin Islands	coral on limestone pavement
WPT003	15-Apr-01	11	23.913	92	33.294	11.39855000	92.55490000	magellan 320	quick site	Twin Islands	coral on limestone pavement
WPT004	15-Apr-01	11	23.774	92	33.282	11.39623333	92.55470000	magellan 320	quick site	Twin Islands	coral patches on sand
WPT005	16-Apr-01	11	23.773	92	33.282	11.39621667	92.55470000	magellan 320	quick site	Twin Islands	coral bommies on sand
WPT006	16-Apr-01	11	23.131	92	32.736	11.38551667	92.54560000	magellan 320	quick site	Twin Islands	acropora rubble

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon_DD	GPS	Fix Type	Location	Notes
WPT007	16-Apr-01	11	23.187	92	32.646	11.38645000	92.54410000	magellan 320	quick site	Twin Islands	dead standing tabular and branching Acropora coral (bleaching?)
WPT008	16-Apr-01	11	23.719	92	33.178	11.39531667	92.55296667	magellan 320	quick site	Twin Islands	sand 6.3m
WPT009	17-Apr-01	11	23.813	92	33.062	11.39688333	92.55103333	magellan 320	GCP	Twin Islands	south end of Twin Island
WPT010	17-Apr-01	11	23.736	92	33.077	11.39560000	92.55128333	magellan 320	GCP	Twin Island	north end of Twin Island
WPT011	17-Apr-01	11	35.012	92	30.235	11.58353333	92.50391667	magellan 320	GCP	Twin Island	south corner of Twin island
A4	16-Apr-01	11	26.623	92	35.427	11.44371667	92.59045000	paper	SITE	Twin Island	AND004
WPT012	17-Apr-01	11	34.602	92	30.831	11.57670000	92.51385000	magellan 320	SITE	Bay Island	AND005
WPT013	17-Apr-01	11	42.065	92	35.123	11.70108333	92.58538333	magellan 320	GCP	Bay Island	rocky islet
WPT014	19-Apr-01	11	42.225	92	35.154	11.70375000	92.58590000	magellan 320	GCP	Bay Island	rocky islet
WPT015	17-Apr-01	11	41.288	92	34.312	11.68813333	92.57186667	magellan 320	quick site	Bay	rock reef 2m
WPT016	17-Apr-01	11	40.288	92	34.415	11.67146667	92.57358333	magellan 320	quick site	Bay	reef slope
WPT017	17-Apr-01	11	40.124	92	35.325	11.66873333	92.58875000	magellan 320	quick site	Bay	reef crest
WPT018	17-Apr-01	11	40.426	92	35.318	11.67376667	92.58863333	magellan 320	quick site	Bay	reef crest

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon_DD	GPS	Fix Type	Location	Notes
WPT019	18-Apr-01	12	32.036	92	41.043	12.53393333	92.68405000	magellan 320	quick site	Flat Island	sand
WPT020	18-Apr-01	12	32.245	92	41.039	12.53741667	92.68398333	magellan 320	quick site	Flat Island	porites
WPT021	18-Apr-01	12	32.313	92	41.097	12.53855000	92.68495000	magellan 320	GCP	Flat Island	point off island NE
WPT022	18-Apr-01	12	32.325	92	41.116	12.53875000	92.68526667	magellan 320	quick site	Flat Island	porites
WPT023	18-Apr-01	12	32.421	92	41.163	12.54035000	92.68605000	magellan 320	quick site	Flat Island	anchorage
WPT024	18-Apr-01	12	31.781	92	41.108	12.52968333	92.68513333	magellan 320	quick site	Flat Island	limestone 2 m
WPT025	18-Apr-01	12	33.559	92	40.826	12.55931667	92.68043333	magellan 320	quick site	Flat Island	reef slope 9 m
WPT026	18-Apr-01	12	33.56	92	40.785	12.55933333	92.67975000	magellan 320	quick site	Flat Island	reef slope 16 m
WPT027	18-Apr-01	12	33.509	92	40.746	12.55848333	92.67910000	magellan	SITE	Flat Island	AND006
WPT028	18-Apr-01	12	33.381	92	40.587	12.55635000	92.67645000	magellan 320	quick site	Flat Island	reef slope 9.5 m
WPT029	18-Apr-01	12	32.911	92	40.258	12.54851667	92.67096667	magellan 320	quick site	Flat Island	reef slope smaller corals
WPT030	18-Apr-01	12	32.746	92	40.128	12.54576667	92.66880000	magellan 320	quick site	Flat Island	reef slope 12m smaller corals
WPT031	18-Apr-01	12	32.578	92	40.18	12.54296667	92.66966667	magellan 320	quick site	Flat Island	reef end island
WPT032	18-Apr-01	12	31.955	92	39.661	12.53258333	92.66101667	magellan	quick site	Flat	reef crest 2 m
WPT033	19-Apr-01	12	31.969	92	39.569	12.53281667	92.65948333	magellan 320	quick site	North Reef Island	pavement with scattered corals sand channels 6 m

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon_DD	GPS	Fix Type	Location	Notes
WPT034	19-Apr-01	12	31.974	92	39.465	12.53290000	92.65775000	magellan 320	quick site	North Reef Island	pavement with scattered corals sand channels 12 m
WPT035	19-Apr-01	12	33.459	92	40.639	12.55765000	92.67731667	magellan 320	quick site	North Reef Island	reef slope
WPT036	19-Apr-01	13	4.708	92	42.586	13.07846667	92.70976667	magellan 320	quick site	North Reef Island	sand and anchorage
WPT037	19-Apr-01	13	4.537	92	42.545	13.07561667	92.70908333	magellan 320	quick site	North Reef Island	sand
WPT038	19-Apr-01	13	4.419	92	42.494	13.07365000	92.70823333	magellan 320	quick site	North Reef Island	sand
WPT039	19-Apr-01	13	4.258	92	42.401	13.07096667	92.70668333	magellan 320	GCP	North Reef Island	SE point sand beach
WPT040	19-Apr-01	13	4.24	92	42.07	13.07066667	92.70116667	magellan 320	GCP	North Reef Island	off S. point
WPT041	19-Apr-01	13	4.262	92	41.692	13.07103333	92.69486667	magellan 320	quick site	North Reef Island	sand patch
WPT042	19-Apr-01	13	4.305	92	41.659	13.07175000	92.69431667	magellan 320	quick site	North Reef Island	seagrass on sand
WPT043	19-Apr-01	13	4.289	92	41.676	13.07148333	92.69460000	magellan 320	quick site	North Reef Island	seagrass on sand
WPT044	19-Apr-01	13	4.573	92	41.5	13.07621667	92.69166667	magellan 320	quick site	North Reef Island	seagrass on sand

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon_DD	GPS	Fix Type	Location	Notes
WPT045	19-Apr-01	13	5.163	92	41.394	13.08605000	92.68990000	magellan 320	quick site	North Reef Island	coral branching Montipora digitata up to 15 cm algae
WPT046	19-Apr-01	13	5.49	92	41.512	13.09150000	92.69186667	magellan 320	quick site	North Reef Island	seagrass on sand
WPT047	19-Apr-01	13	5.701	92	41.73	13.09501667	92.69550000	magellan 320	GCP	North Reef Island	off NW point beach
WPT048	19-Apr-01	13	5.905	92	41.7	13.09841667	92.69500000	magellan 320	quick site	North Reef Island	1.3 sand
WPT049	19-Apr-01	13	6.038	92	41.682	13.10063333	92.69470000	magellan 320	quick site	North Reef Island	reef flat acropora
WPT050	19-Apr-01	13	6.143	92	42.175	13.10238333	92.70291667	magellan 320	quick site	North Reef Island	coral 7.6
WPT051	19-Apr-01	13	6.087	92	42.217	13.10145000	92.70361667	magellan 320	quick site	North Reef Island	sand 8.3
WPT052	19-Apr-01	13	5.9	92	42.385	13.09833333	92.70641667	magellan 320	quick site	North Reef Island	sand 8.5
WPT053	19-Apr-01	13	5.996	92	42.777	13.09993333	92.71295000	magellan	quick site	North	sand 20 m
WPT054	19-Apr-01	13	5.901	92	42.94	13.09835000	92.71566667	magellan 320	GCP	North Reef Island	off NE point
WPT055	19-Apr-01	13	5.901	92	43.197	13.09835000	92.71995000	magellan 320	GCP	North Reef Island	off NE point

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon_DD	GPS	Fix Type	Location	Notes
WPT056	19-Apr-01	13	5.878	92	43.264	13.09796667	92.72106667	magellan 320	quick site	North Reef Island	sand 4.7
WPT057	19-Apr-01	13	5.843	92	43.321	13.09738333	92.72201667	magellan 320	quick site	North Reef Island	sand 20 m
WPT058	19-Apr-01	13	5.545	92	43.211	13.09241667	92.72018333	magellan 320	quick site	North Reef Island	sand 20 m
WPT059	19-Apr-01	13	5.541	92	43.175	13.09235000	92.71958333	magellan 320	quick site	North Reef Island	coral sand 14
WPT060	19-Apr-01	13	5.03	92	42.724	13.08383333	92.71206667	magellan 320	quick site	North Reef Island	coral 9.5 m
WPT061	19-Apr-01	13	3.912	92	43.075	13.06520000	92.71791667	magellan 320	quick site	North Reef Island	sand 10 m
WPT062	19-Apr-01	13	3.319	92	42.698	13.05531667	92.71163333	magellan 320	quick site	North Reef Island	coral
WPT063	19-Apr-01	13	3.128	92	42.63	13.05213333	92.71050000	magellan 320	quick site	North Reef Island	coral
WPT064	19-Apr-01	13	3.037	92	42.524	13.05061667	92.70873333	magellan 320	quick site	North Reef Island	anchorage
WPT065	19-Apr-01	13	2.617	92	42.529	13.04361667	92.70881667	magellan 320	quick site	North Reef Island	sand
WPT066	19-Apr-01	13	2.695	92	42.528	13.04491667	92.70880000	magellan 320	quick site	North Reef Island	coral 12 m

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon_DD	GPS	Fix Type	Location	Notes
WPT067	19-Apr-01	13	2.64	92	42.532	13.04400000	92.70886667	magellan 320	quick site	North Reef Island	coral 14 m
WPT068	19-Apr-01	13	2.644	92	42.557	13.04406667	92.70928333	magellan 320	SITE	North Reef Island	AND007
WPT069	19-Apr-01	13	3.298	92	42.322	13.05496667	92.70536667	magellan 320	SITE	North Reef Island	AND008
WPT070	22-Apr-01	12	12.239	93	5.777	12.20398333	93.09628333	magellan 320	quick site	Ritchies Archipelago	sand reef flat Outram
WPT071	22-Apr-01	12	12.245	93	5.832	12.20408333	93.09720000	magellan 320	quick site	Ritchies Archipelago	sand off reef 3.5 m
WPT072	22-Apr-01	12	12.017	93	6.063	12.20028333	93.10105000	magellan 320	quick site	Ritchies Archipelago	reef with flat
WPT073	22-Apr-01	12	11.964	93	6.44	12.19940000	93.10733333	magellan 320	SITE	Ritchies Archipelago	AND010
WPT074	22-Apr-01	12	7.01	93	2.942	12.11683333	93.04903333	magellan 320	quick site	Ritchies Archipelago	entrance to mangrove
WPT075	22-Apr-01	12	7.478	93	2.41	12.12463333	93.04016667	magellan 320	quick site	Ritchies Archipelago	edge of channel
WPT076	24-Apr-01	12	7.864	93	2.262	12.13106667	93.03770000	magellan 320	quick site	Ritchies Archipelago	edge of 320 channel
WPT077	24-Apr-01	12	7.552	93	2.418	12.12586667	93.04030000	magellan 320	quick site	Ritchies Archipelago	edge of channel

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon_DD	GPS	Fix Type	Location	Notes
WPT078	24-Apr-01	12	6.068	93	3.311	12.10113333	93.05518333	magellan 320	SITE	Ritchies Archipelago	AND011
WPT079	24-Apr-01	12	3.771	93	8.965	12.06285000	93.14941667	magellan 320	SITE	Ritchies Archipelago	AND012 Minerva Ledges
WPT080	24-Apr-01	12	3.798	93	8.999	12.06330000	93.14998333	magellan 320	SITE	Ritchies Archipelago	AND012
WPT081	24-Apr-01	12	2.556	92	58.877	12.04260000	92.98128333	magellan 320	GCP	Ritchies Archipelago	Off jetty at Havelock
WPT082	24-Apr-01	12	2.565	92	58.926	12.04275000	92.98210000	magellan 320	GCP	Ritchies Archipelago	North end of Havelock jetty
WPT083	24-Apr-01	12	2.575	92	58.966	12.04291667	92.98276667	magellan 320	GCP	Ritchies Archipelago	South end of Havelock jetty
WPT084	24-Apr-01	12	2.982	92	57.871	12.04970000	92.96451667	magellan 320	GCP	Ritchies Archipelago	Stowe Point right N. Havelock
WPT085	24-Apr-01	12	2.98	92	57.872	12.04966667	92.96453333	magellan 320	GCP	Ritchies Archipelago	Stowe Point right N. Havelock
WPT086	24-Apr-01	11	59.468	92	55.702	11.99113333	92.92836667	magellan 320	quick site	Ritchies Archipelago	10.5 m sand
WPT087	24-Apr-01	11	59.467	92	55.702	11.99111667	92.92836667	magellan 320	quick site	Ritchies Archipelago	10.5 m sand
WPT088	24-Apr-01	11	59.389	92	55.817	11.98981667	92.93028333	magellan 320	quick site	Ritchies Archipelago	Porites 4.7 m

Wpt.	Date	Deg.	Dmin.	Deg.	Dmin.	Lat_DD	Lon_DD	GPS	Fix Type	Location	Notes
WPT089	24-Apr-01	11	59.151	92	55.846	11.98585000	92.93076667	magellan 320	quick site	Ritchies Archipe- logo	Coral shelf
WPT090	24-Apr-01	11	50.946	92	59.96	11.84910000	92.99933333	magellan 320	SITE	Ritchies Archipe- logo	AND013 ledges off Neil Island no notes in book
WPT091	24-Apr-01	11	48.09	93	1.876	11.80150000	93.03126667	magellan 320	SITE	Ritchies Archipe- logo	AND013
WPT092	22-Apr-01	12	13.274	93	1.306	12.22123333	93.02176667	paper	SITE	Ritchies Archipe- logo	AND009

classification had been created without the use of ground truth field data, and hence a post-survey validating exercise was undertaken. Benthic types identified at accuracy assessment sites and survey sites were used to classify the imagery. Instead of simply classifying the area of a pixel (30 m x 30 m) directly under a waypoint, and to accommodate for inaccuracies in the exact position of waypoints, a vector layer was created with square polygons, each centred on a waypoint, and covering an area equivalent to 9 pixels (90 m x 90 m). The vector layer was used to extract the minimum, maximum and median value of the 9 pixels surrounding the same site from the preliminary classification and the true colour composite map (bands ETM1, ETM2 and ETM3). The median class value for each survey site was then compared against the survey site data, and the results of the cluster analysis, thus producing a supervised classification of the image. A fully supervised classification of the entire Landsat scene was not possible because only 13 sites could be surveyed in detail during the field mission. The highest concentration of accuracy assessment sites was present around North Reef Island off the east coast of Middle Andaman. Using data identifying highly reflecting carbonate sand at specific positions and depths, a depth correction was applied to this area around North Reef Island using the method of Lygenza, 1978.

3.0. RESULTS

3.1. TERRESTRIAL BIOTOPES OF THE ANDAMAN ISLANDS

3.1.1. Preliminary Mapping of Terrestrial Biotopes using Landsat 7 ETM Data : The area of land covered by the preliminary classified image was 5,352.46 km² comprising: 4,921.86 km² of terrestrial biotopes; and 430.61 km² cloud and cloud shadow areas. The total area of mangrove vegetation covered 10.51% of the land area (which as a proportion of the classified land area excluding cloud and cloud shadow, represents 517.54 km²). Non-mangrove vegetation covered 81.23% (3,998.15 km²) and bare areas of dry sand, mud and cleared land was 8.25%. It was possible to distinguish mangrove vegetation from dry or terrestrial vegetation, but no terrestrial ground truth data was collected during the field mission, and hence it was not possible to separate agricultural, primary, tropical and deciduous forest vegetation with confidence. To quantify the percentage area of bare land from agricultural land or logging, two scenarios were analysed. In the first, all vegetation classes were considered to be pristine vegetation, indicating 91% vegetation and 9% bare land, mud and sand. In the second, sparse terrestrial vegetation classes were considered to be agricultural land or logged areas with some rejuvenated vegetation and these were subtracted from the area calculation. By this means, the resulting estimate of undisturbed pristine vegetation for the northern Andaman Islands was 73.79% with cleared land, bare sand and mud at 26.21%.

Table 3.1. Area estimation from the terrestrial unsupervised classification of Landsat 7ETM+ satellite images for the northern Andaman Islands.

Terrestrial Biotopes	No. pixels	Area (km ²)	Total Area (km ²)	% Area*
Mud/sand/turbid water	30388	27.349		0.556
Wet mud/sand	116554	104.899		2.131
Dry sand	55649	50.084		1.018
Dry mud/sand/sparse vegetation	190465	171.419		3.483
Total terrestrial un-vegetated			353.750	7.187
Sparse terrestrial vegetation 01	157127	141.414		2.873
Sparse terrestrial vegetation 02	260896	234.806		4.771
Sparse terrestrial vegetation 03	700632	630.569		12.812
Terrestrial vegetation 04	1328535	1195.682		24.293
Dense terrestrial vegetation 01	1354914	1219.423		24.776
Dense terrestrial vegetation 02	588046	529.241		10.753
Dense terrestrial vegetation 03	52234	47.011		0.955
Total terrestrial vegetation			3998.146	81.232
Mud/sand/turbid water	36348	32.713		0.665
Wet mud/sand	16376	14.738		0.299
Dry mud/sand/sparse vegetation	5525	4.973		0.101
Total mangrove un-vegetated		52.424		1.065
Sparse mangrove/wetland vegetation 01	22639	20.375		0.414
Sparse mangrove/wetland vegetation 02	36241	32.617		0.663
Sparse mangrove/wetland vegetation 03	77880	70.092		1.424
Dense mangrove/wetland vegetation 01	178402	160.562		3.262
Dense mangrove/wetland vegetation 02	201148	181.033		3.678
Dense mangrove/wetland vegetation 03	58733	52.860		1.074
Total mangrove/wetland vegetation			517.539	10.515

*percentage area based on mapped area excluding cloud and cloud shadow areas.

3.2. MARINE BIOTOPES OF THE ANDAMAN ISLANDS

13 sites were surveyed during April 2001 on the coral reef ecosystems of the northern Andaman (AND001-AND013), together with observations for 66 accuracy assessment sites. The divisions of marine habitats evident from the descriptions of the survey and accuracy site data are shown in Table 3.2. Reefs were either of fringing or offshore type. Fringing reefs consisted of a gradual reef

slope seawards off moderate reef flats, occasionally with extensive flats such as at North Reef Island or Flat Island. The reef slopes rarely exceeded 20m depth, and levelled to a sand base colonised by massive coral colonies. Offshore reefs consisted of an elevated plateau occasionally bordered by steep slopes into deeper water. Of the 13 sites surveyed, 3 were on fringing reefs with extensive reef flats, 5 were on reefs with moderate flats, 4 were on reefs/coral communities with little accretion and no flat and 1 was a non-reefal coral community. The distribution of the reef structures and coral communities is represented in Fig. 3.1.

Table 3.2. The marine habitats/biotopes around the Andaman Islands identified during the survey and accuracy assessment site data.

Habitat	Reef Development	Structure/Zone		
Coral	Fringing reef with extensive flat	reef slope >15m		
		reef slope 10-15m		
		reef slope 5-10m		
		reef crest		
		reef flat		
	Fringing reef with moderate flat	reef slope >15m		
		reef slope 10-15m		
		reef slope 5-10m		
		reef crest		
		reef flat		
	Offshore/Platform reefs with no flat	reef slope >15m		
		reef slope 10-15m		
		reef slope 5-10m		
		coral community on sand		
		coral community on limestone rock		
Sand		dead coral		
		Rubble		
		sand >15m		
		sand 10-15m		
		sand 5-10m		
		sand 0-5m		
		seagrass		
		Other		deep channel

Multivariate statistical analysis of the survey data (visual survey data, coral species presence and video point count analysis data) was conducted to reveal similarities between the sites and to assist in the validation/identification of the classes in the pre-survey classification.

3.2.1. Visual Survey Data : Dendrograms of the visual survey data, including both the structural and cover data, for all 13 survey sites are presented in Figures 3.2a-b. A cluster analysis of the combined visual survey data (structural and cover data normalised) revealed 4 clusters at the 50% level (Figure 3.2c). SIMPER analysis of the combined structure and cover data from the visual survey highlighted the following characteristics about the 4 clusters (Table 3.3).

Cluster 1 : (AND006 and AND012) sites consisted of small blocks of live hard coral and hard substrate on silt, sand and rubble.

Cluster 2 : (AND001, AND002, AND003) sites consisted mainly of large blocks of live hard coral with some small blocks interspersed by rubble, sand and hard substrate.

Cluster 3 : (AND007, AND008, AND009, AND010) sites consisted of mixture of large and small blocks on a continuous pavement with a high % cover of live hard coral and some rubble.

Cluster 4 : (AND004, AND005, AND013) consists of sites with a flat continuous pavement with some rubble and small scattered blocks of hard coral.

Table 3.3. SIMPER analysis of dissimilarity between coral communities around the Andaman showing the average abundance of the normalised benthic visual survey data.

		Cluster 1	Cluster 2	Cluster 3	Cluster 4
		AND006, AND012	AND001, AND002, AND003	AND007, AND008, AND009, AND010	AND004, AND005, AND013
		Average %	Average %	Average %	Average %
Structure	CP	0.62	1.92	13.7	63.8
	LB	5.72	33.4	27.4	0.97
	SB	79.1	14.9	30.1	11.2
	CB	0	0	0	0
	RB	5.72	21.4	19.8	20.5
	SN	5.72	24.4	6.16	3.5
Cover	SLT	3.09	4	2.83	0
	HS	48.7	56.5	4.68	61.7
	LHC	40.2	28.3	73.7	12.7
	DSC	2.51	1.86	3.95	0.6
	MA	2.12	0.36	2.24	1.47
	CA	2.51	6.96	4.68	2.44
	TA	0.81	0.59	1.92	5.06

		Cluster 1	Cluster 2	Cluster 3	Cluster 4
		AND006, AND012	AND001, AND002, AND003	AND007, AND008, AND009, AND0010	AND004, AND005, AND013
		Average %	Average %	Average %	Average %
SC	2.36	3.99	6.86	2.98	
	SG	0	0	0	1.89
	SP	0.81	1.18	2.02	2.44
	BA	0	0.24	0	8.71

3.2.2. Coral Species Presence : 197 species of coral were recorded during the field mission within 58 genera, including 53 genera of zooxanthellate Scleractinia. The dominant genera (in terms of number of species rather than abundance of colonies) were *Acropora*, *Montipora*, *Pavona* and *Fungia* with 47, 11, 10 and 9 species respectively. The number of coral species recorded at each site during the field survey is shown in Table 3.4 and Figure 3.3. The distribution of coral species richness around the islands is illustrated in Figure 3.4 and the species list by site is in Appendix 6.

The most diverse sites were on the west coast; the most species rich site being South Button, with 89 species (AND009), followed by Twin Island (AND003) with 82 species and Flat Island (AND006) with 81 species. Species poor sites were: Wood Mason Bay (AND004) with 44 species, Cinque Island north northern island (AND002) with 49 species, and Minerva Ledges (AND012) with 45 species. The reef crest at North island (AND008) was also species poor (33 species), but this site represented only one zone of the reef and is not comparable with other sites when taken alone. Cluster analysis of coral species presence showed low similarities between sites, suggesting diverse and dissimilar communities (Figure 3.5).

A decreasing marginal return of species recorded with new sites surveyed was encountered, indicating that the mission was approaching a sufficient number of sites for those types of reef, additional similar sites would increase the likelihood that sufficient sites had been surveyed, but new sites of greater geographical range, depth, within mangroves and sea grass beds and other habitats would cause a step function in the graph, and more species would be expected.

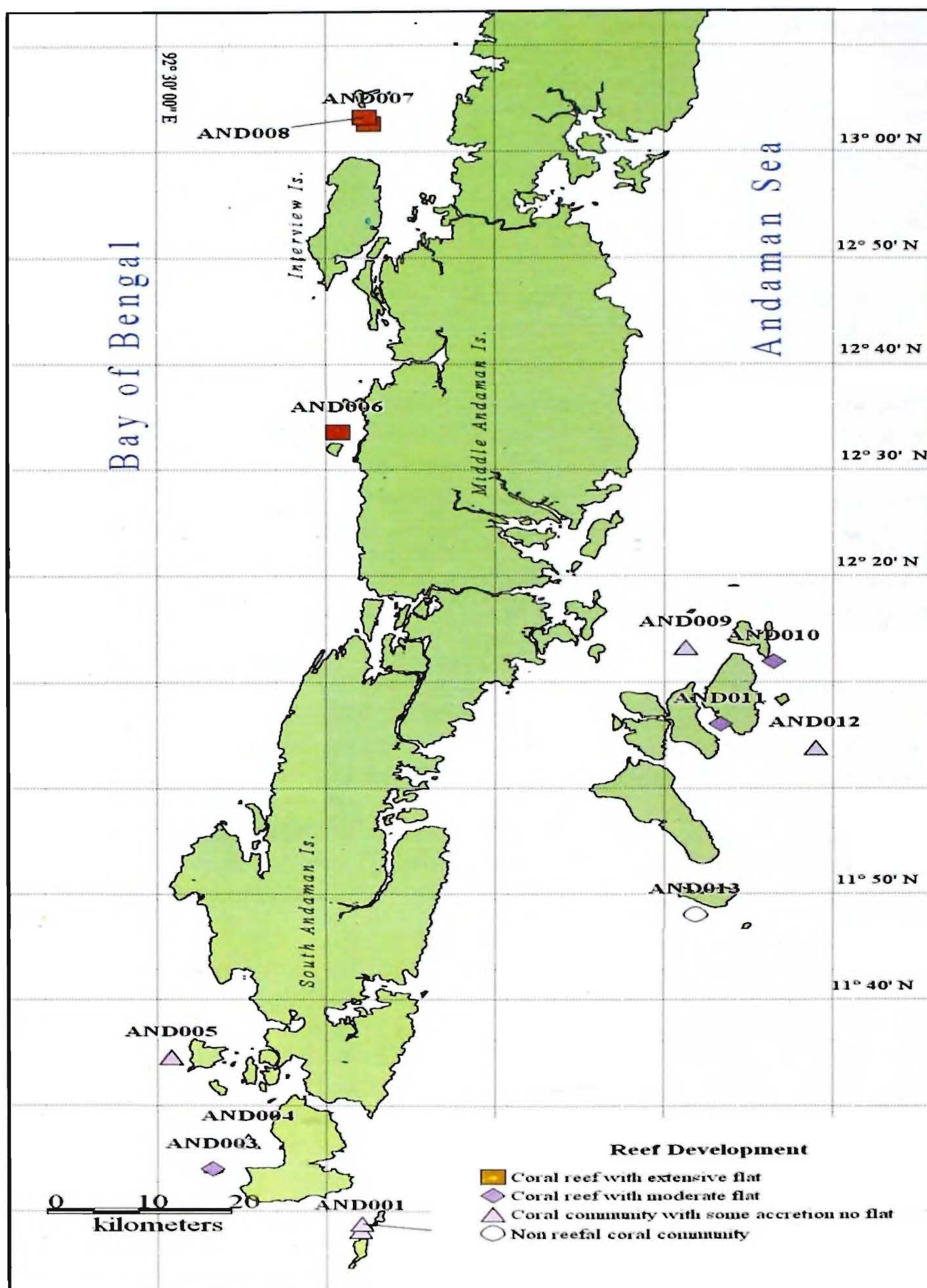


Fig. 3.1. Map showing the development of the reefs surveyed around the northern Andaman.

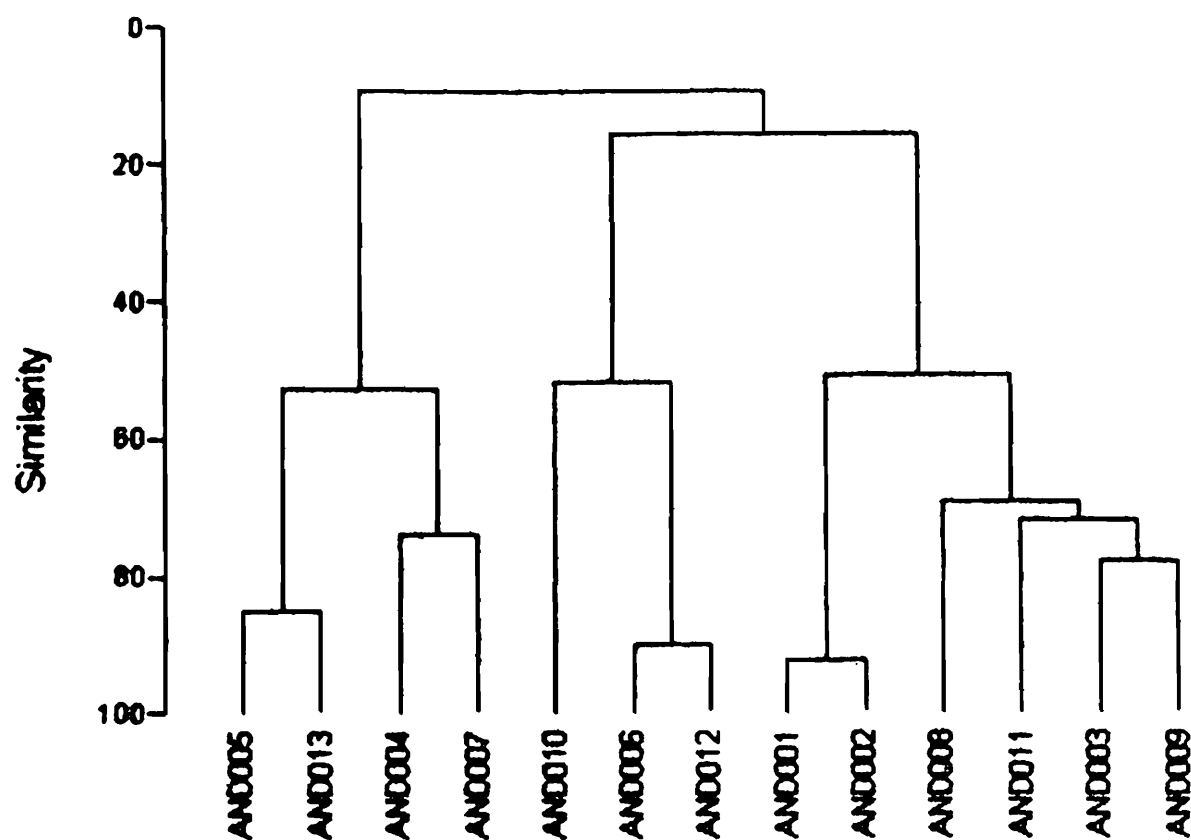


Fig. 3.2a. Cluster analysis of the visual survey structural data for all 13 survey sites.

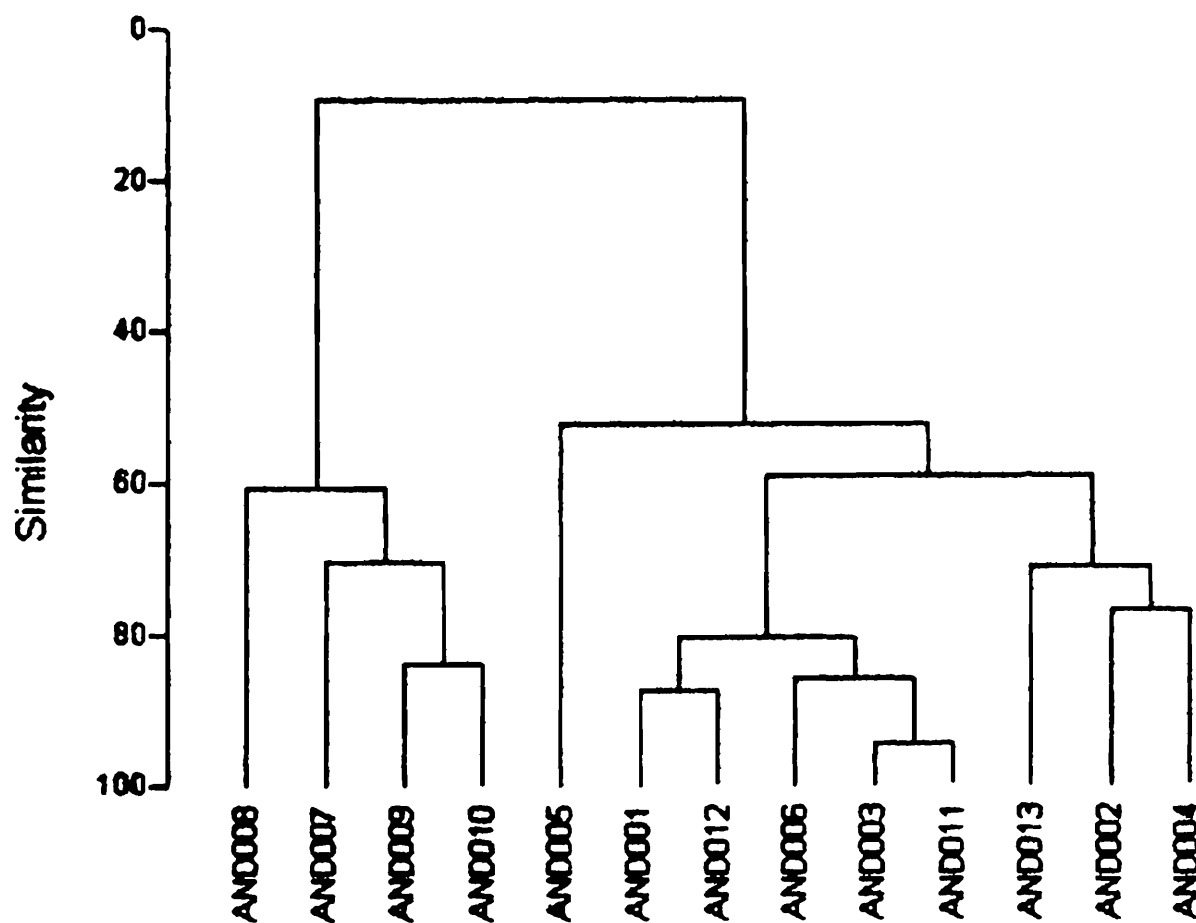


Fig. 3.2b. Cluster analysis of the visual survey cover data for all 13 survey sites.

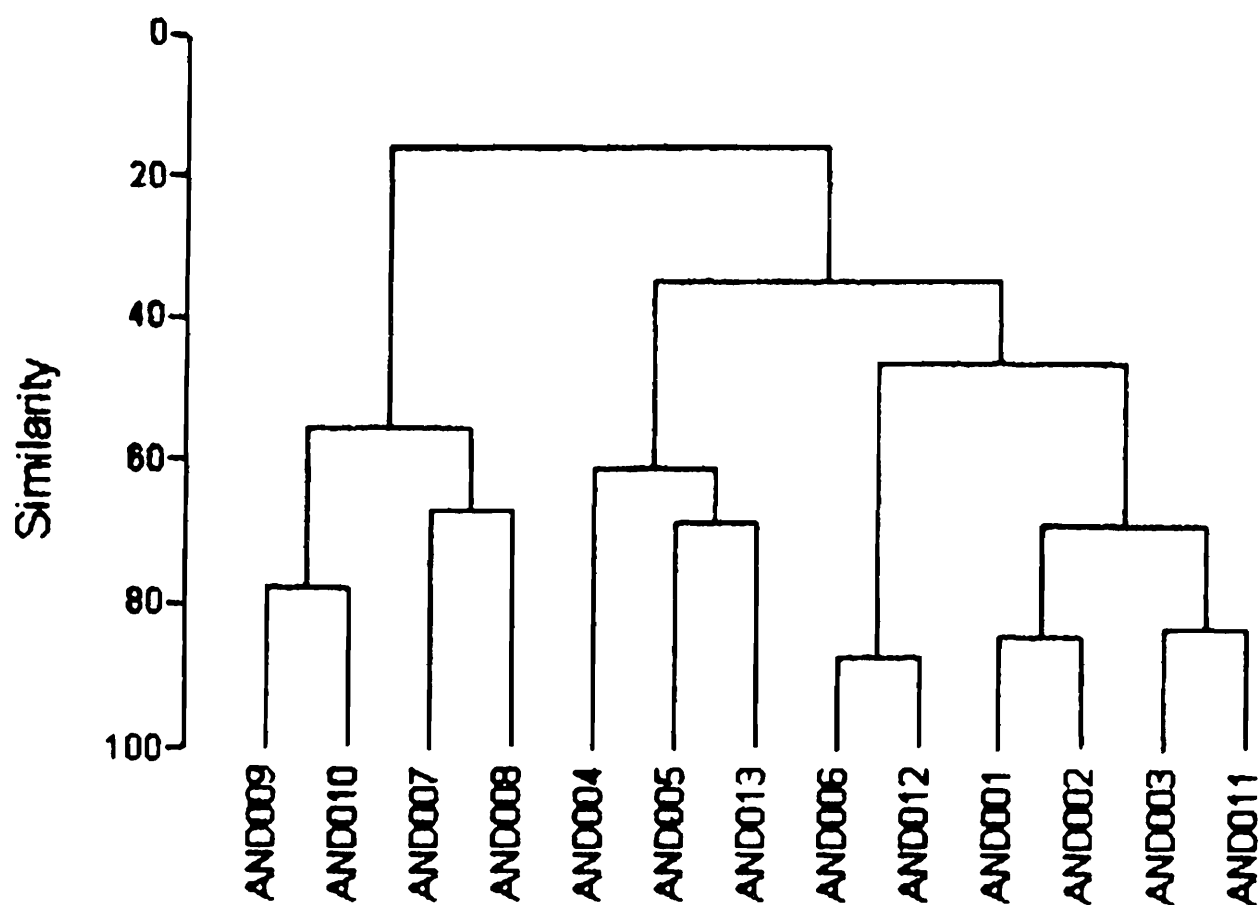


Fig. 3.2c. Cluster analysis of the visual survey structural and cover data for all 13 survey sites.

Table 3.4. Species diversity by site for the twelve sites (site 13 omitted).

Site	Species No.	Species Richness Pielou (d')	Shannon Weiner Diversity (H')	Simpson Dominance (SI)
AND001	52	12.907328	3.951244	1.923077E-02
AND002	49	12.333560	3.891820	2.040816E-02
AND003	82	18.381021	4.406719	1.219512E-02
AND004	44	11.363067	3.784189	2.272727E-02
AND005	67	15.696748	4.204692	1.492537E-02
AND006	81	18.204784	4.394449	1.234568E-02
AND007	66	15.514405	4.189655	1.515151E-02
AND008	33	9.1519894	3.496507	3.030303E-02
AND009	89	19.605063	4.488636	1.123595E-02
AND010	68	15.878629	4.219508	1.470588E-02
AND011	65	15.331591	4.174387	1.538461E-02
AND012	45	11.558682	3.806662	2.222222E-02

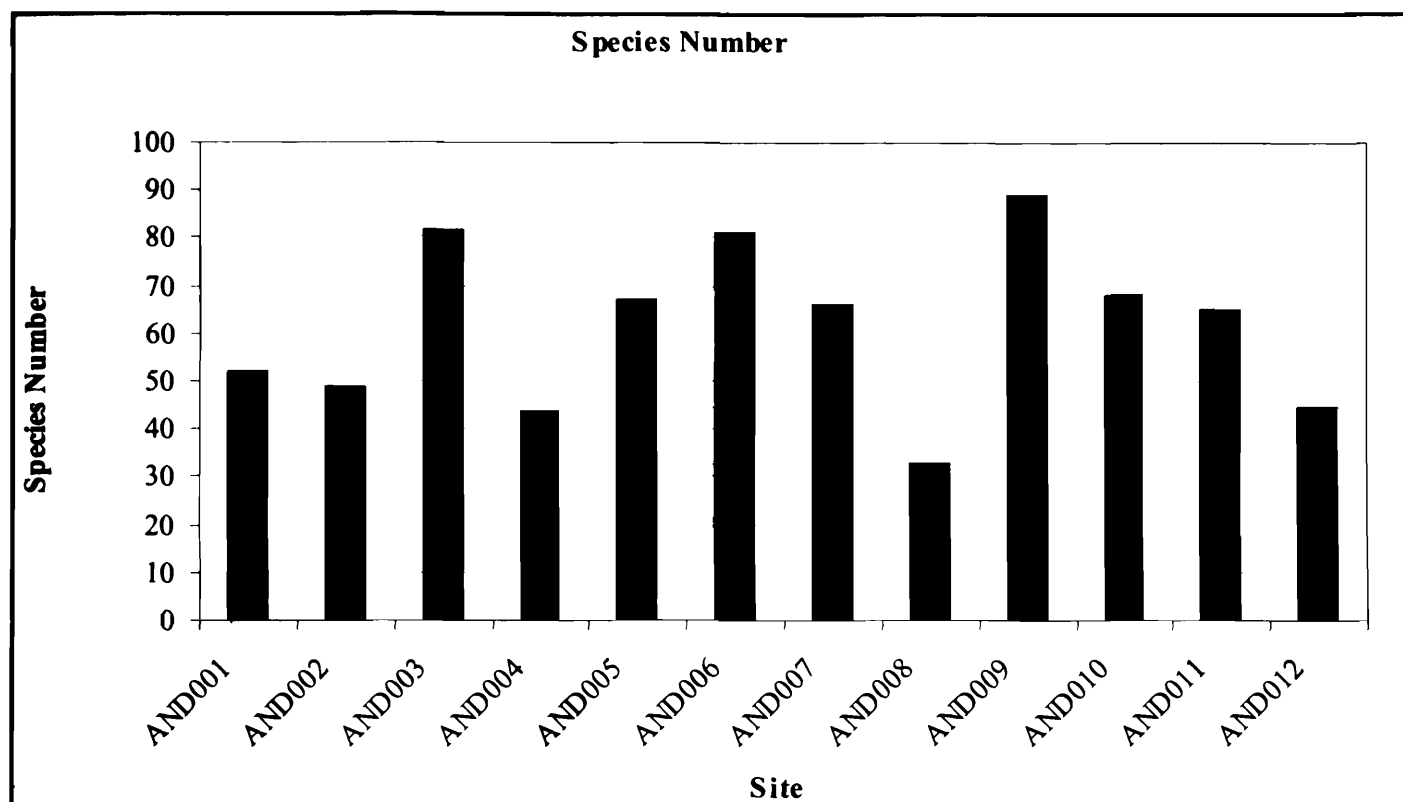


Fig. 3.3. Number of Coral Species by site.

Studies of the corals observed and collected to date has revealed one new species, and continued study of photographs and synonyms may reveal additional species. The new species is of genus *Acropora*, and consists of thick, long, radiating, digitate branches, about 2-4 cm thick at the base, and 20-40 cm long. Radial corallites are rounded oppressed. This species was found at nearly every site, and was usually brown. In addition, 4 recently described species of coral were found, described by Veron (2000) from elsewhere :

1. *Favia truncatus*
2. *Goniastrea minuta*
3. *Podabacia lanakensis*
4. *Galaxea acrhelia*

One species (*Oxypora crassispinosa*), described as common during the survey, had only previously been reported from the Philippines. In addition, 111 species were found which had not been reported from the Andaman Islands before, representing about half the coral fauna. These species are :

- | | |
|--------------------------------------|---|
| 1. <i>Acanthastrea echinata</i> | 5. <i>Acropora austera</i> |
| 2. <i>Acanthastrea hemprichi</i> | 6. <i>Acropora</i> sp. "brown digitate" |
| 3. <i>Acanthastrea ishigakiensis</i> | 7. <i>Acropora carduus</i> |
| 4. <i>Acropora aspera</i> | 8. <i>Acropora cerealis</i> |

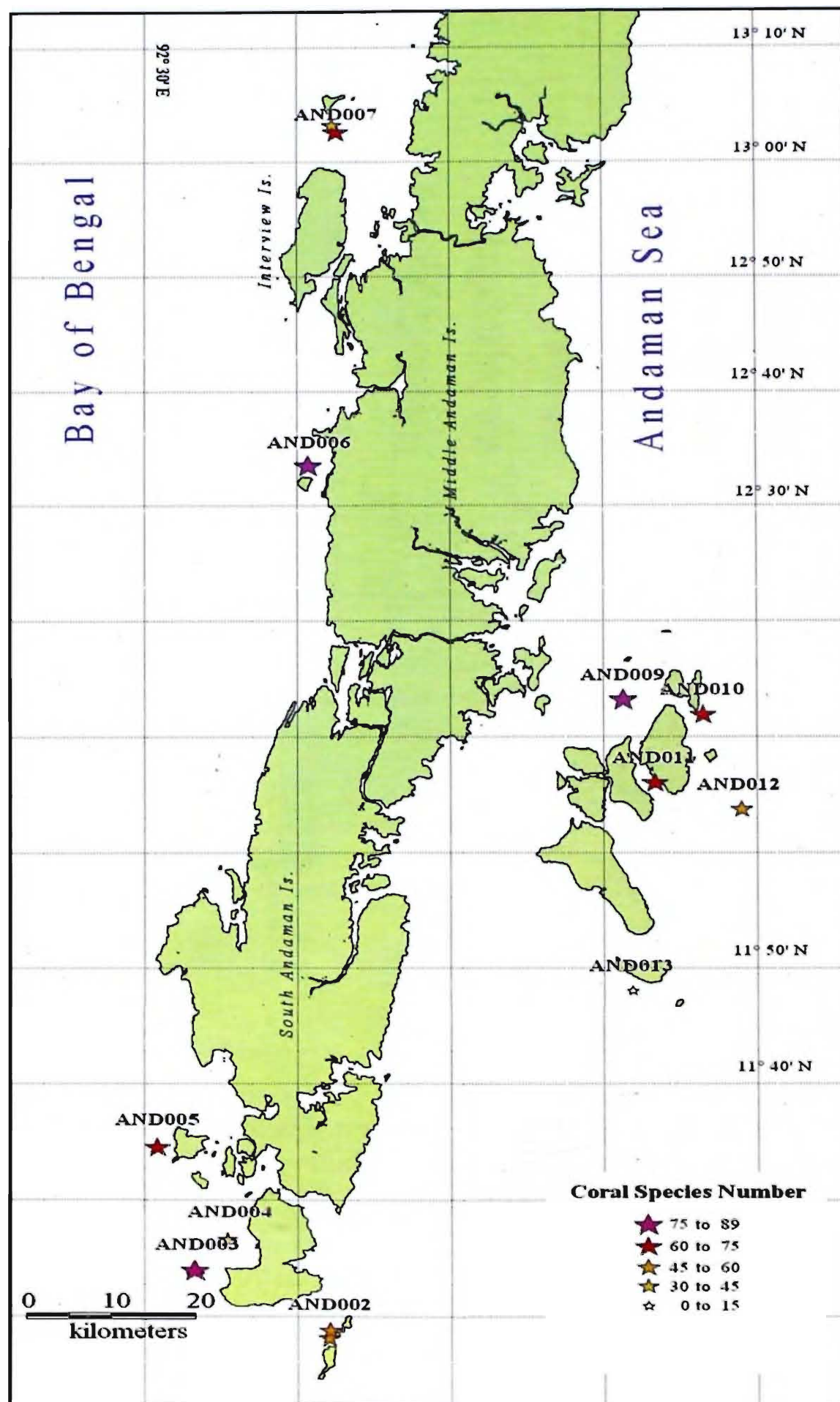


Fig. 3.4. map showing the number of coral species found at 12 survey sites in the northern Andaman Island.

9. *Acropora chesterfieldensis*
10. *Acropora clathrata*
11. *Acropora cophodactyla*
12. *Acropora* sp. "danai-like"
13. *Acropora divaricata*
14. *Acropora donei*
15. *Acropora echinata*
16. *Acropora efflorescens*
17. *Acropora gemmifera*
18. *Acropora globiceps*
19. *Acropora granulosa*
20. *Acropora* cf *hemprichi*
21. *Acropora kosurini*
22. *Acropora* cf *loisetae*
23. *Acropora longicyathus*
24. *Acropora loripes*
25. *Acropora* cf *lutkeni*
26. *Acropora paniculata*
27. *Acropora proximalis*
28. *Acropora rudis*
29. *Acropora selago*
30. *Acropora solitaryensis*
31. *Acropora* cf *spicifera* as per Veron
32. *Acropora* cf *spicifera* as per Wallace
33. *Acropora tenuis*
34. *Acropora valenciennesi*
35. *Acropora vauhani*
36. *Acropora vermiculata*
37. *Astreopora gracilis*
38. *Astreopora myriophthalma*
39. *Astreopora randalli*
40. *Astreopora suggesta*
41. *Australomussa rowleyensis*
42. *Coscinaraea collumna*
43. *Coscinaraea crassa*
44. *Cynarina lacrymalis*
45. *Distichopora violacea*
46. *Echinophyllia echinata*
47. *Echinophyllia* cf *echinoporoides*
48. *Echinopora gemmacea*
49. *Echinopora hirsutissima*
50. *Euphyllia ancora*
51. *Euphyllia divisa*
52. *Euphyllia yaeyamensis*
53. *Favia rotundata*
54. *Favia truncatus*
55. *Favites acuticollis*
56. *Favities pentagona*
57. *Fungia granulosa*
58. *Fungia klunzingeri*
59. *Fungia mollucensis*
60. *Galaxea acrhelia*
61. *Goniastrea edwardsi*
62. *Goniastrea minuta*
63. *Hydnophora pilosa*
64. *Leptoseris explanata*
65. *Leptoseris incrustans*
66. *Leptoseris mycetoseroides*
67. *Leptoseris scabra*
68. *Leptoseris yabei*

- | | |
|---|---|
| 69. <i>Lithophyllon undulatum</i> | 90. <i>Pectinia alcicornis</i> |
| 70. <i>Lobophyllia hemprichii</i> | 91. <i>Pectinia paeonea</i> |
| 71. <i>Merulina scabricula</i> | 92. <i>Platygyra acuta</i> |
| 72. <i>Millepora dichotoma</i> | 93. <i>Platygyra pini</i> |
| 73. <i>Millepora exaesa</i> | 94. <i>Platygyra</i> sp "green" |
| 74. <i>Millipora intricata</i> | 95. <i>Platygyra verweyi</i> |
| 75. <i>Millepora murrayensis</i> | 96. <i>Podabacia</i> cf <i>lanakensis</i> |
| 76. <i>Millipora platyphylla</i> | 97. <i>Porites annae</i> |
| 77. <i>Monastrea curta</i> | 98. <i>Porites cylindrica</i> |
| 78. <i>Monastrea colemani</i> | 99. <i>Porites evermanni</i> |
| 79. <i>Montipora caliculata</i> | 100. <i>Porites monticulosa</i> |
| 80. <i>Montipora capitata</i> | 101. <i>Psammocora digitata</i> |
| 81. <i>Montipora foveolata</i> | 102. <i>Psammocora explanulata</i> |
| 82. <i>Montipora meandrina</i> | 103. <i>Psammocora haimeana</i> |
| 83. <i>Montipora tuberculosa</i> | 104. <i>Psammocora superficialis</i> |
| 84. <i>Montipora</i> cf <i>vietnamensis</i> | 105. <i>Sandalolitha dentata</i> |
| 85. <i>Oulophyllia laevis</i> | 106. <i>Seriatopora caliendrum</i> |
| 86. <i>Oxypora crassispinosa</i> | 107. <i>Stylocoeniella armata</i> |
| 87. <i>Oxypora lacera</i> | 108. <i>Stylocoeniella guentheri</i> |
| 88. <i>Pavona bipartita</i> | 109. <i>Stylaster</i> sp. |
| 89. <i>Pavona venosa</i> | 110. <i>Tubipora musica</i> |
| | 111. <i>Turbinaria stellulata</i> |

3.2.3. Video Survey Data

The results from the analysis of the video survey data from 9 survey sites are presented in Figure 3.7 and Tables 3.4 and 3.5. These data were combined with the coral species presence records. Cluster analysis revealed 4 clusters, with greater than 50% similarity, which were further analysed using SIMPER (Table 3.6). The complete details on the SIMPER analysis of the video data are included in Appendix 7.

Cluster 1 : (AND002, AND003) Massive *Porites* with tabular *Acropora* on coral rock, sand and rubble.

Cluster 2 : (AND005, AND010, AND009) Massive *Porites* and/or *Millepora* corals with a branching and digitate *Acropora* on rubble and coral rock and little sand.

Cluster 3 : (AND006, AND007) Massive *Porites* and encrusting and foliose *Pachyseris* hard corals and soft corals on coral rock with little sand or rubble.

Cluster 4 : (AND011, AND012) Massive *Porites*, digitate and hispidose *Acropora*, and soft corals on coral rock with some rubble and silt.

Andaman Corals

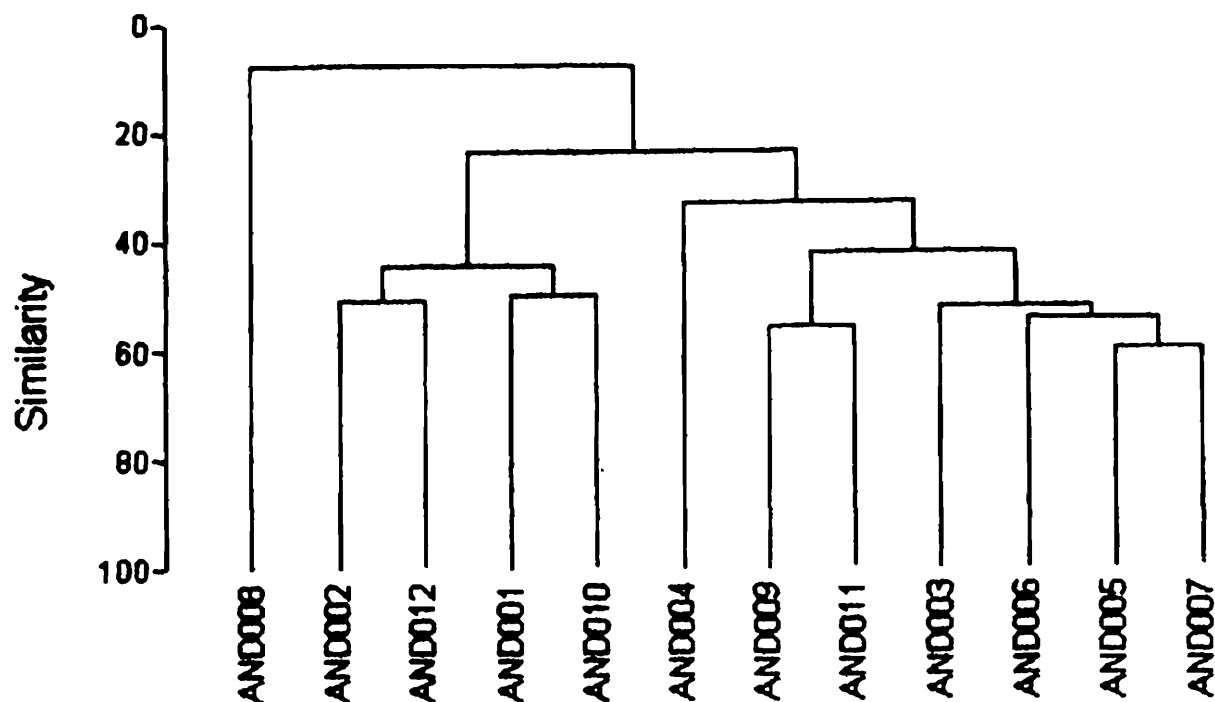


Fig. 3.5. Cluster Analysis of Coral Species Presence.

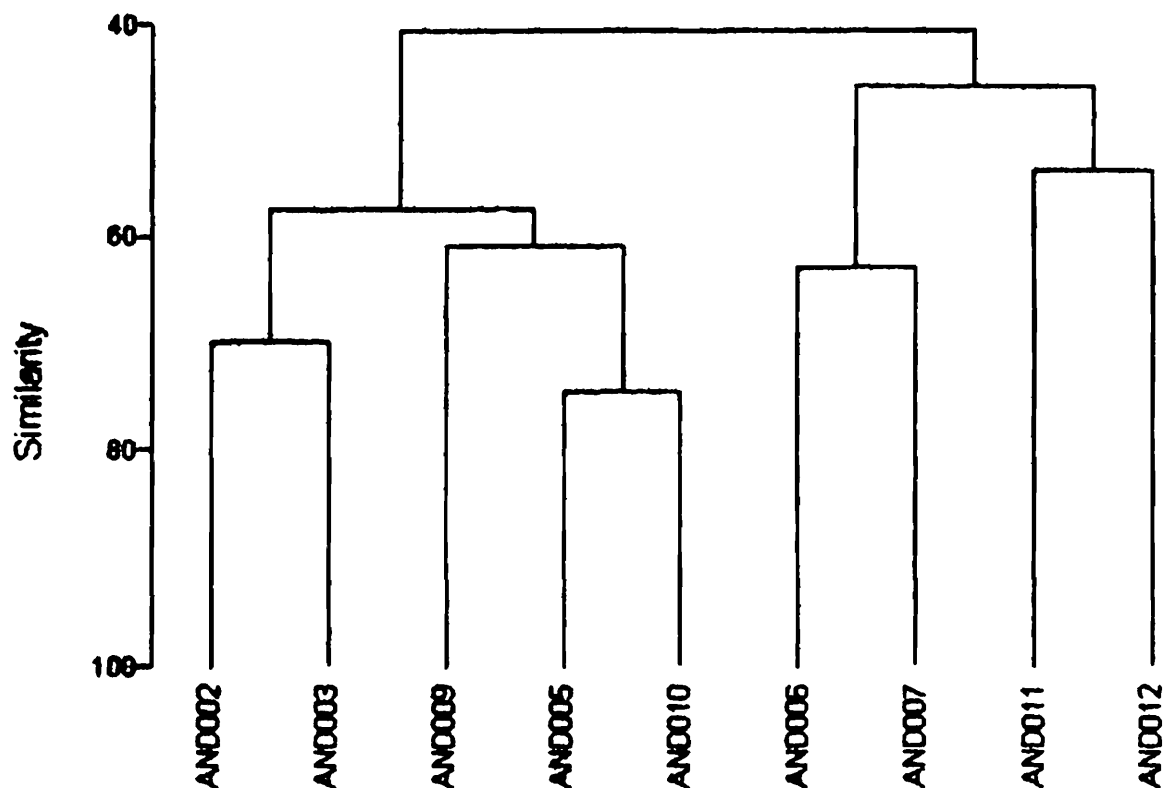


Fig. 3.6. Cluster analysis of the percentage cover data from the 9 sites with video data combined with the species presence absence data.

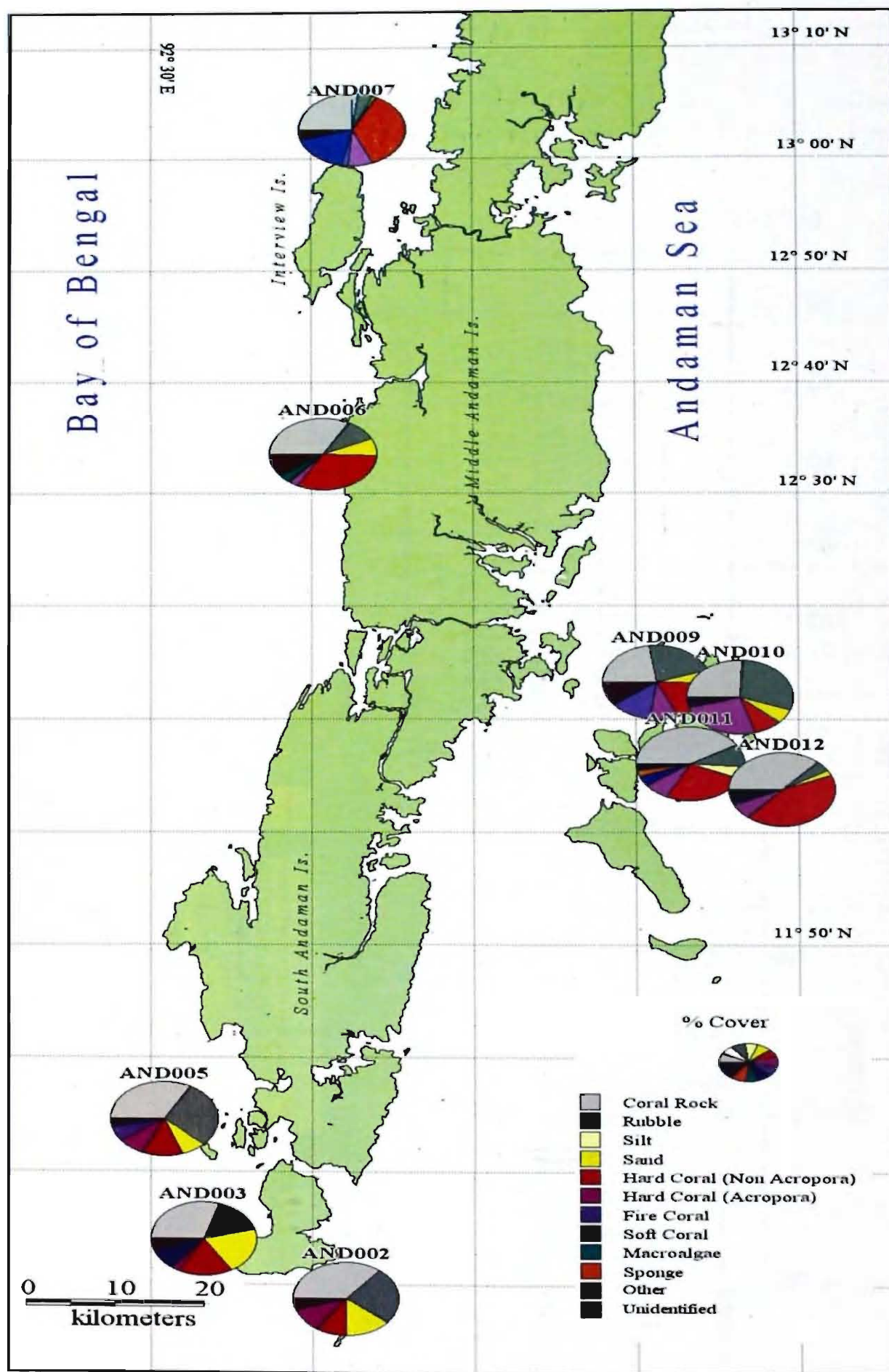


Fig. 3.7. Map showing the percentage cover as derived from point count analysis of the video survey data from 9 survey sites around northern Andaman Island.

Table 3.4. Summary percentage cover of different benthic categories for 9 of the 13 survey sites from the video data analysis.

Benthic	Code	AND002	AND003	AND005	AND006	AND007	AND009	AND010	AND011	AND012
Coral Rock	CR	35.6	30	33	33.2	26.9	22.9	25.7	41.4	36.8
Dead Coral (Bleached)	DSC	0	0	0	0	0	0	0.1	0	0
Rubble	RBL	25.2	15.7	29	9.5	4.4	22	29.8	9.7	4.8
Silt	SIL	0	0	0	0	0	0	0	5.7	0
Sand	SND	14.2	20.3	7.3	7.8	1.1	5.3	6.4	0	2.2
Acropora Branching	ACB	1.1	1.1	0.8	0.3	0.4	5.8	16.3	1.6	1
Acropora Digitate	ACD	0.4	0.1	2.3	0	1.2	1.9	5.8	0.7	3.8
Acropora Submassive	ACS	0	0	0.1	2.3	0	0.8	0	0	1.2
Acropora Tabular	ACT	9.1	1.7	4.9	0	5.6	0.1	2.5	0	0.9
Acropora Bottlebrush	ACX	0	0	0	0	0	0	0.1	5.5	0
Coral Branching	CB	0	0.2	0.2	0	0.4	2.8	0	0	0
Coral Encrusting	CE	0	0.1	2.1	4.6	4.1	1.6	0.3	7.1	0
Coral Foliose	CF	0	0	0	10	9.9	0	0.6	1	0
Coral Massive	CM	9.3	16.2	10.2	17.9	22.1	13.2	7.9	17.2	32.2
Coral	CMR	0	0	0	0	0	0.7	0	0	0
Solitary Coral	CS	0	0.1	0	0	0	0.1	0	0.1	10.2
Macroalgae	MA	0	0	0	3.7	0.2	0.4	0.3	0.4	0
Fire Coral	CME	0	0	6.4	0	1.8	12.5	0.7	0	1.2
Soft Coral	SC	0.6	8.9	1	0.5	17.9	0.2	0.1	4.1	0.2
Sponge	SP	0.7	0.6	0.4	0	0	0	0.7	2.4	0
Anemone	ANEM	0	0	0	0.7	0	2.2	0	0.3	0
Antipatharian	ANTIP	0	0	0	0.2	0	0	0	0	0
Other	OT	3.3	4.7	2	9.3	4	7.5	2.7	0.1	0
Unidentifiable	IN	0.5	0.3	0.3	0	0	0	0	2.7	5.5

Table 3.5. Summary percentage cover of benthic categories analysis for 9 of the 13 survey sites from the video data.

Benthic Categories	AND 002	AND003	AND005	AND006	AND007	AND009	AND010	AND011	AND012
Coral Rock	35.6	30	33	33.2	26.9	22.9	25.7	41.4	36.8
Dead Coral (Bleached)	0	0	0	0	0	0	0.1	0	0
Rubble	25.2	15.7	29	9.5	4.4	22	29.8	9.7	4.8
Silt	0	0	0	0	0	0	0	5.7	0
Sand	14.2	20.3	7.3	7.8	1.1	5.3	6.4	0	2.2
Hard Coral (Non Acroporid)	9.3	16.6	12.5	32.5	36.5	18.4	8.8	25.4	42.4
Hard Coral (Acroporid)	10.6	2.9	8.1	2.6	7.2	8.6	24.7	7.8	6.9
Fire Coral	0	0	6.4	0	1.8	12.5	0.7	0	1.2
Soft Coral	0.6	8.9	1	0.5	17.9	0.2	0.1	4.1	0.2
Macroalgae	0	0	0	3.7	0.2	0.4	0.3	0.4	0
Sponge	0.7	0.6	0.4	0	0	0	0.7	2.4	0
Other	3.3	4.7	2	10.2	4	9.7	2.7	0.4	0
Unidentified	0.5	0.3	0.3	0	0	0	0	2.7	5.5

Table 3.6. SIMPER analysis of dissimilarity of the video survey data for 9 sites around the Andaman Islands.

Benthic Category	Code	Cluster 1	Cluster 2	Cluster 3	Cluster 4
		Average % AND002, AND003	Average % AND005, AND010,	Average % AND006, AND007 AND009	Average % AND011, AND012
Coral Rock	CR	32.8	27.2	30.05	39.1
Dead Coral (Bleached)	DSC	0	0.03	0	0
Rubble	RBL	20.45	26.93	6.95	7.25
Silt	SIL	0	0	0	2.85
Sand	SND	17.25	6.33	4.45	1.1
<i>Acropora</i> Branching	ACB	1.1	7.63	0.35	1.3
<i>Acropora</i> Digitate	ACD	0.25	3.33	0.6	2.25

Benthic Category	Code	Cluster 1	Cluster 2	Cluster 3	Cluster 4
		Average % AND002, AND003	Average % AND005, AND010,	Average % AND006, AND007 AND009	Average % AND011, AND012
<i>Acropora</i> Submassive	ACS	0	0.3	1.15	0.6
<i>Acropora</i> Tabular	ACT	5.4	2.5	2.8	0.45
<i>Acropora</i> Bottlebrush	ACX	0	0.03	0	2.75
Coral Branching	CB	0.1	1	0.2	0
Coral Encrusting	CE	0.05	1.33	4.35	3.55
Coral Foliose	CF	0	0.2	9.95	0.5
Coral Massive	CM	12.75	10.43	20	24.7
Coral	CMR	0	0.23	0	0
Solitary Coral	CS	0.05	0.03	0	5.15
Macroalgae	MA	0	0.23	1.95	0.2
Fire Coral	CME	0	6.53	0.9	0.6
Soft Coral	SC	4.75	0.43	9.2	2.15
Sponge	SP	0.65	0.37	0	1.2
Anemone	ANEM	0	0.73	0.35	0.15
Antipatharian	ANTIP	0	0	0.1	0
Other	OT	4	4.07	6.65	0.05
Unidentifiable	IN	0.4	0.1	0	4.1

3.2.4. Mapping the Marine Biotopes using Landsat 7ETM Data

The pre-survey unsupervised marine biotope classification using the Landsat 7ETM+ satellite data included 21 classes (Figure 2.7), the areas of which are detailed in Table 3.7. The classes defined in the pre-survey classification were based only on the interpretation of the satellite data. In order to test the validity of the classes, field data was employed. The median value of 9 pixels (3 pixels by 3 pixels) surrounding each waypoint extracted from the classified satellite image and from the first three bands ETM1, ETM2 and ETM3 (Appendix 8) were compared against the accuracy assessment site survey data (Table 3.8). 12 out of the 21 mapped classes in the pre-survey classification were encountered during the ground truth survey. The most common class encountered was 'reef slope 01', followed by 'open water 03', 'reef slope 02', and 'reef slope/reef crest'

Comparison of the pre-survey classification with the field survey data identified relationships between classes and some problems with the pre-survey classification. Deep sand classes and shallow coral communities were frequently confused in the pre-survey classification from satellite data. Similarly, when compared to the ground truth data, the class '*open water 03*' represented both sand and reef slope in water > 15 m. Thus, classes were renamed to account for field survey observations where appropriate: The '*reef slope 01*' class included 9 different marine biotopes/habitats, dominated by reef slope between 5-10 m and 10-15 m depth; class '*reef slope 02*' included 8 marine biotopes/habitats, dominated by shallower reef slopes and coral communities on sand and limestone. Several classes within the reef flat category were sand at different depths. The following classes were identified: '*reef flat 01*' is reef crest; '*reef flat 02*' and '*reef flat 03*' are both reef flat; '*reef flat 08*' is seagrass; and '*reef flat 09*' and '*reef flat 12*' are both shallow sand. The total area of reef flat was estimated to be 258.56 km², and the area of shallow reef slope and reef crest was 261.62km² giving a total area of shallow reef of 520.18 km² around the northern Andaman covered by the images.

Table 3.7 : Area estimations from the marine unsupervised classification of Landsat 7ETM+ satellite images for the northern Andaman Islands.

Marine Biotopes	No. of Pixels	Area (km ²)	% Area
Open water 01*	2161170	1945.053	—
Open water 02*	5874720	5287.248	—
Open water 03*	13245880	11921.292	—
Reef slope 01*	11197936	10078.142	—
Reef slope 02*	1489690	1340.721	70.562
Reef slope/reef crest*	290692	261.623	13.769
Reef flat 01*	113331	101.998	5.368
Reef flat 02*	63696	57.326	3.017
Reef flat 03*	34790	31.311	1.648
Reef flat 04	24922	22.430	1.180
Reef flat 05	14643	13.179	0.694
Reef flat 06	13709	12.338	0.649
Reef flat 07	7278	6.550	0.345
Reef flat 08*	5377	4.839	0.255
Reef flat 09*	2365	2.129	0.112
Reef flat 10	2749	2.474	0.130
Reef flat 11	1805	1.625	0.085
Reef flat 12*	968	0.871	0.046
Reef flat 13	1080	0.972	0.051
Reef flat 14	573	0.516	0.027
Sand	43511	39.1599	2.061

*Classes that have been surveyed during the field work and renamed as a result of field verification.

Table 3.8. A contingency matrix comparing the marine habitats/biotopes identified during the accuracy assessment and survey sites with the median pixel values extracted from a group of 9 pixels surrounding each site from the preliminary unsupervised classification.

Class		deep open water 01	deep open water 02	deep open water 03	reef slope 01	reef slope 02	reef slope /reef crest	reef flat 01	reef flat 02	reef flat 03	reef flat 08	reef flat 09	reef flat 012		
Coral reef with extensive flat	Class	21	22	23	24	25	26	27	28	29	34	35	38	Total	No. of Classes
	reef slope >15m			3	1									4	2
	reef slope 10-15m			6	1	1								8	3
	reef slope 5-10m				5	1	1							7	3
	reef crest							2						2	1
	reef flat					1				1				2	2
reef with moderate flat	reef slope >15m		1											1	1
	reef slope 10-15m			1	3									4	2
	reef slope 5-10m						2							2	1
	reef crest				1	1								2	2
	reef flat				2		1		1					4	3
reef with no flat	reef slope >15m	1	1											2	2
	reef slope 10-15m				1									1	1

Class		deep open water 01	deep open water 02	deep open water 03	reef slope 01	reef slope 02	reef slope /reef crest	reef flat 01	reef flat 02	reef flat 03	reef flat 08	reef flat 09	reef flat 012		
reef with no flat	reef slope 5-10 m					1		1						Total 2	No. of Classes 2
	coral community on sand					3	2							5	2
	coral community on lime stone rock			3		2	1							6	3
	dead coral rubble				1									1	1
				1										1	1
Sand	sand >15m			3										3	1
	sand 10-15m			5									5	1	
	sand 5-10m					4	4	1						9	3
	sand 0-5 m												2	13	2
	seagrass											3	1	4	2
	deep channel			1										1	1
	TOTAL	1	2	18	20	14	11	4	1	1	3	3	1	79	
	No of Classes	1	2	7	9	8	6	3	1	1	1	2	1		

3.3. SITE DESCRIPTIONS

The results of the field survey and the validated classification are presented for each site surveyed. Since only 13 sites were surveyed in detail during the field mission, and all of these were coral dominated areas, it was not possible to complete a fully supervised classification for habitats and communities within the entire island group with confidence and >80% accuracy. The greatest concentration of accuracy assessment and survey site data was recorded for North Reef Island, and results for the depth invariant processing routine were obtained for the same area (Figure 3.8). A supervised classification of the depth corrected subsection around North Reef Island was conducted (Figure 3.9). Comparing Figure 3.9 to Figure 2.10, fewer classes remain and the image appears 'cleaner' due to the removal of depth effects. Unfortunately, to date there is no independent data with which to quantify the accuracy of this image.

Several offshore features were evident on the preliminary unsupervised classification, classed as "reef slope 01" and "reef slope 02", but the results of the preliminary classification did not reveal a 350 km barrier reef west of the Andaman (10-12° N), as reported by Sewell (1935). Some classes were identified as shallow offshore reef structures during the field survey, such as those found on east coast sites AND012: Minerva ledges and AND013: Neill ledges. Further investigation of the spectral signatures using bands ETM1, ETM2 and ETM3 of these areas known to be offshore reefs, also revealed the presence of spectral signatures representing similar patches off the west coast of Andaman. Two lines of structures are aligned parallel to the shore and these appear to be shallow offshore areas not unlike those at AND012 and AND013, which mainly consisted of rock colonised by coral communities (Figure 3.10). The position of these structures, west of the islands and away from the influence of sedimentation from terrestrial run off, may represent extensive coral communities which might be parts of a barrier reef, worthy of future investigation.

SITE – AND001 Cinque Island: Minto Bay - Lat. 11°18.138'N and Long. 92°42.066'E) – Fig. 4.1a & b

This station is situated in Cinque Island having 3 reefs with a depth ranged from 10-13.6 m. The underwater visibility during the survey was 15-20 m. A total of 52 species of corals were recorded at this site.

STRUCTURE							% COVER												
OP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR	
2	3	0	0	3	3	0	5	4	0	1	0	0	1	0	1	1	0	0	

Structure : Coral ridge extending perpendicular to the coast in a protected bay of a rocky island. The rocky ridge was mostly 1 m above the seabed and in places rising 3-4 m. Site surrounded by sand with rubble.

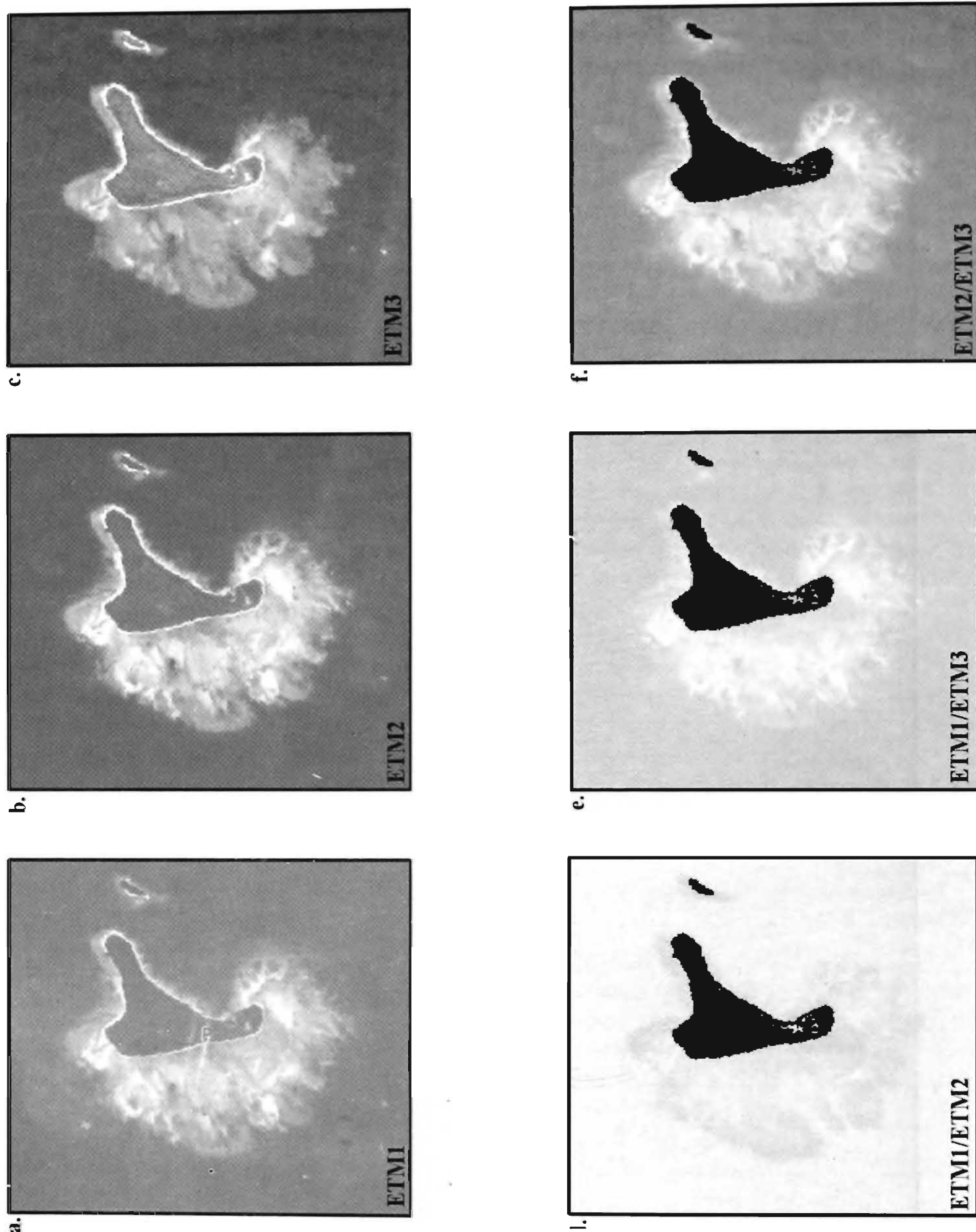


Fig. 3.8. Subsection of Landsat 7ETM image for North Reef Island showing gray scale images of the visible bands (a) ETM 1 (b) ETM 2 and (c) ETM 3 and the depth invariant bands, processed according to Lygenza (1978) (d) ETM/ETM 2 (e) ETM 1/ETM 3 and (f) ETM 2/ETM 3.

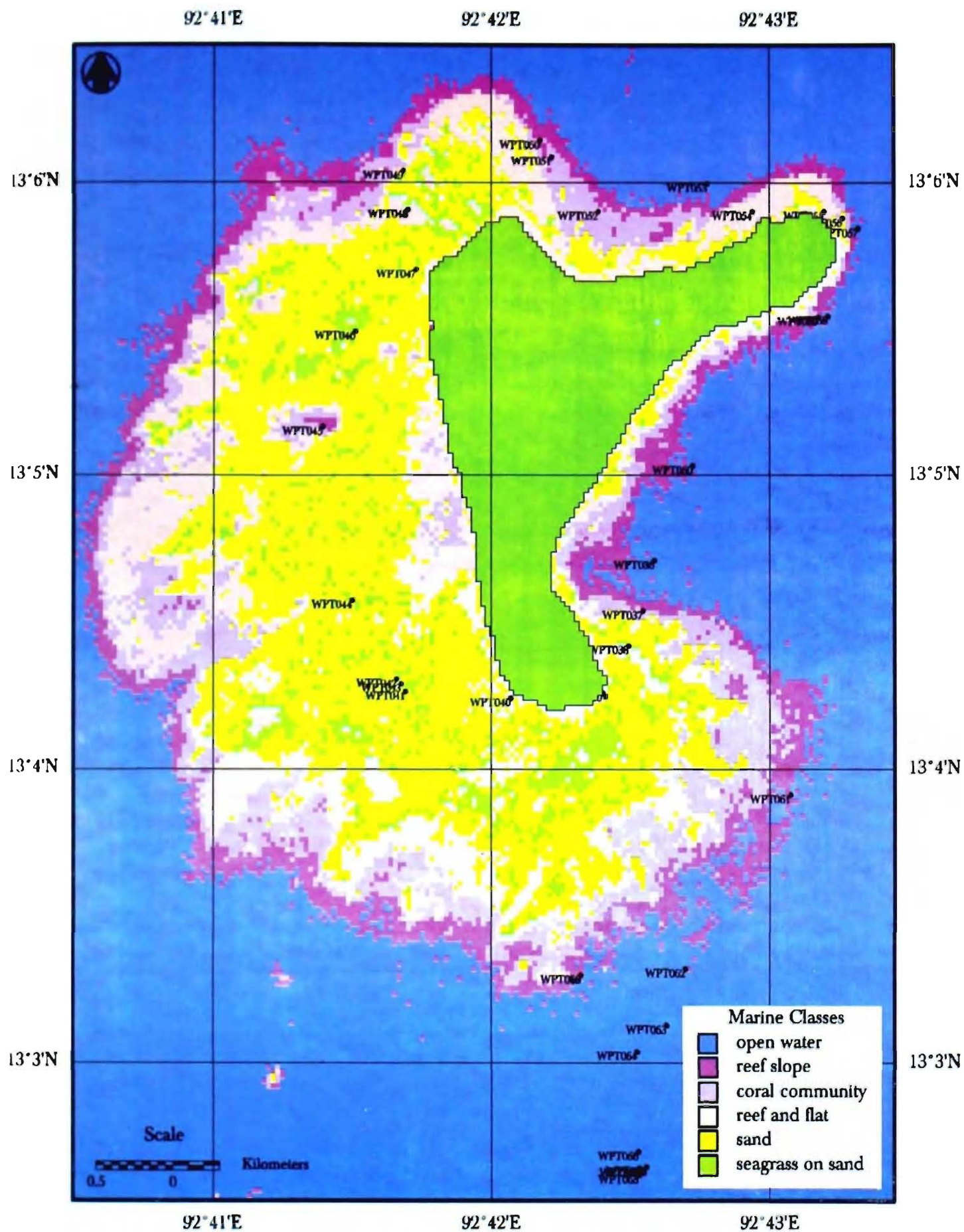


Fig. 3.9. High resolution subsection (1:50,000 scale) of the marine biotope map for North Reef Island from supervised classification of the Landsat 7ETM depth invariant band.

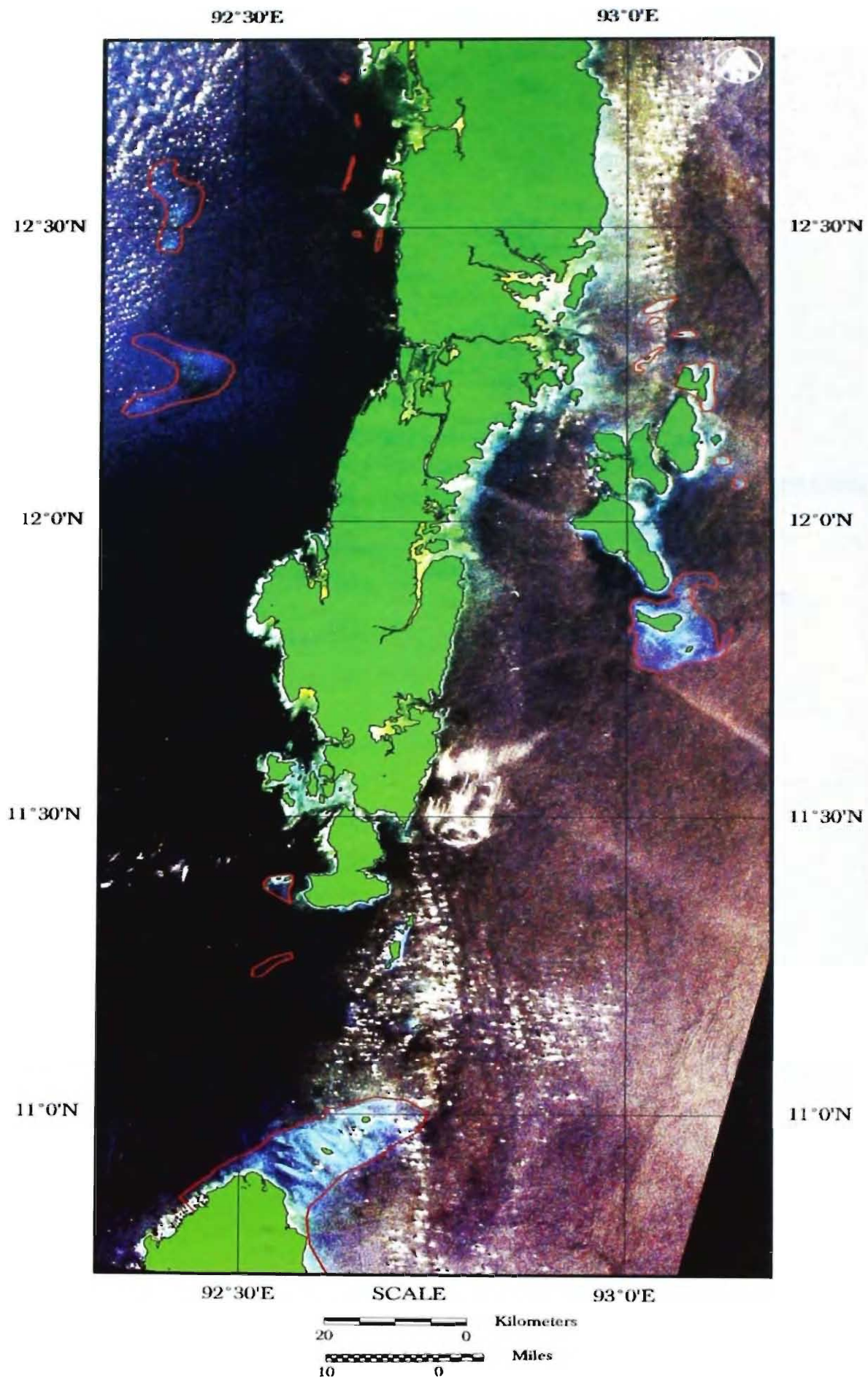


Fig. 3.10. Overview map of Landsat & ETM satellite image, (Red ETM 3; Green ETM 2; Blue ETM 1) of the northern Andaman Islands, processed to highlight areas of shallow shoaling areas of either reef or rock. Areas of interest are also outlined in red and include a potentially extensive area of offshore reef to the west of the islands.

Cover : The ridge was colonised by mixed corals on rock and dead corals surrounded by sand and rubble to either side. *Acropora* were particularly prevalent as was *Hydnophora grandis*.

Impacts : A few corals were broken or turned over, probably by storms.

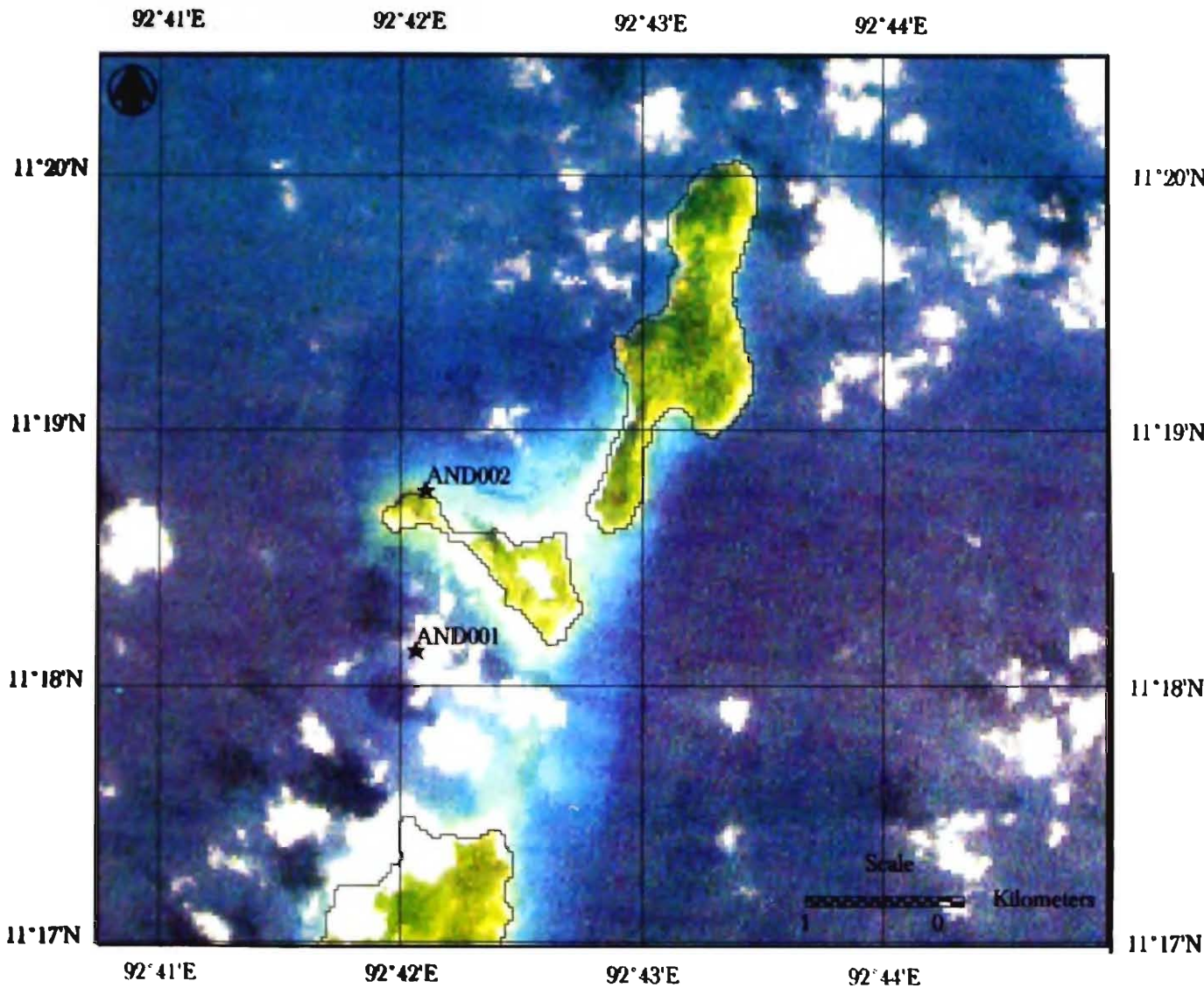


Fig. 4.1a. True colour composite (Landsat 7, R:ETM3, G:ETM2, B:ETM1) of Cinque Island showing AND001.

SITE – AND002 (Cinque Island: North Coast - Lat. 11°18.764N and Long. 92°42.106'E) – Fig. 4.1a & b, Plate 1

Two reef formations were found at this site with the depth of 5-11 meters. Underwater visibility during the course of survey was 15 m. Forty nine species of corals were recorded at this site.

STRUCTURE							% COVER											
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR
0	3	2	0	3	3	0	5	3	2	1	0	1	3	0	1	0	0	0

Structure : Shallow fringing reef extending from a rocky shore, comprised of a moderate reef flat and a shallow reef slope with very low profile spurs colonised by small mixed corals surrounded by coral rubble. In shallow water, *Acropora* tables were dominant whereas at the base of the reef slope at 11m, massive corals occupied sand.

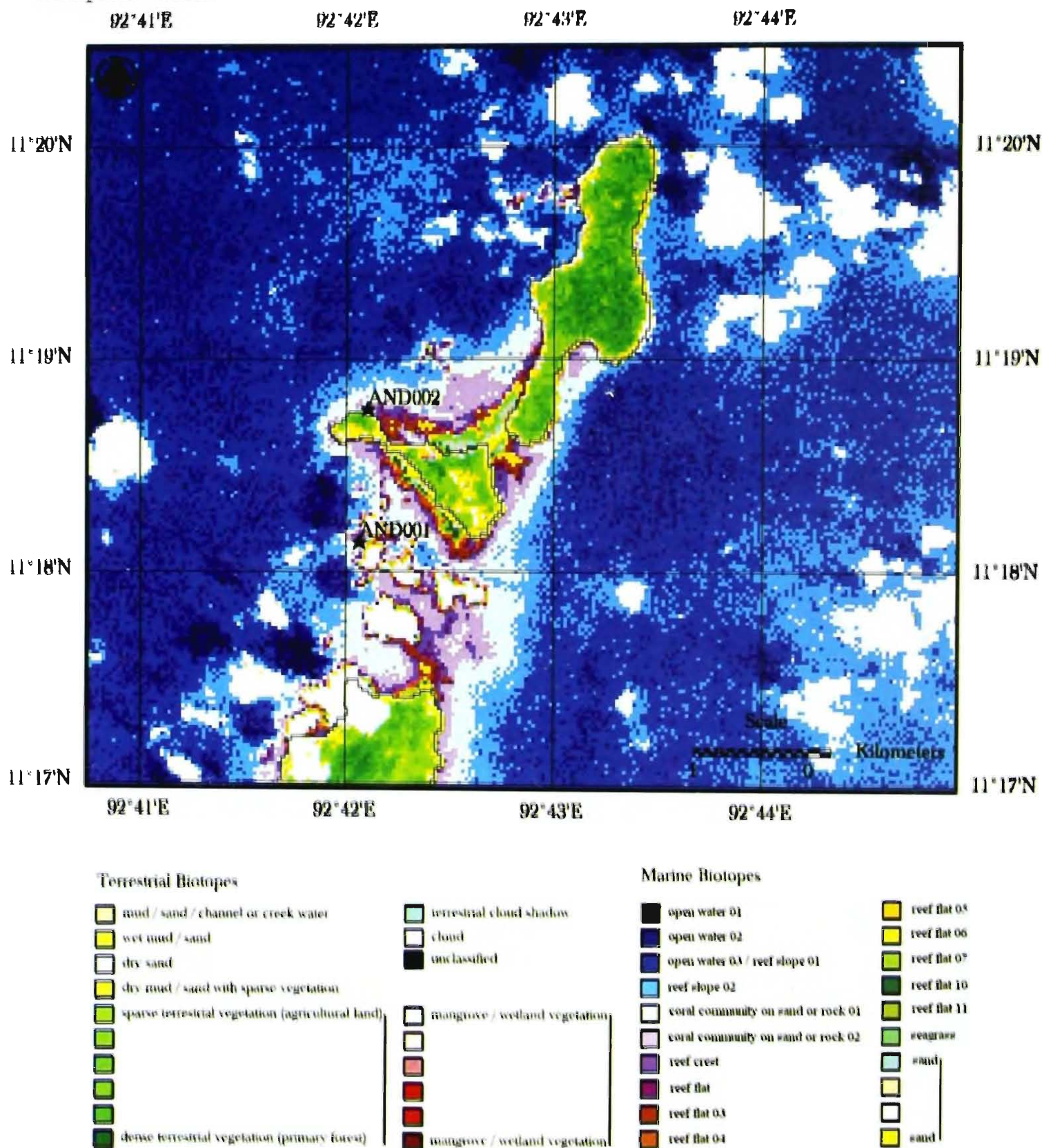


Fig. 4.1b. Terrestrial and marine biotope classification of Cinque Island showing AND001.

Cover : On the shallow reef slope were well developed large *Acropora hyacinthus* tables 3-4m in diameter. In water less than 6m surrounding the tables was *Acropora* rubble. Low profile spurs were colonised by small mixed coral colonies including *Pocillopora*, *Acropora* and *Porites*. At the base of the reef slope were massive colonies mainly *Porites* and *Diploastrea*. Many Crinoids were associated with coral colonies. Over the entire site, living hard coral cover was about 20%, dominated by tabular *Acropora* 35%, coral rock, 25% rubble 14% sand (Fig. 4.1d).

Impacts : Some broken corals, probably storm damage.

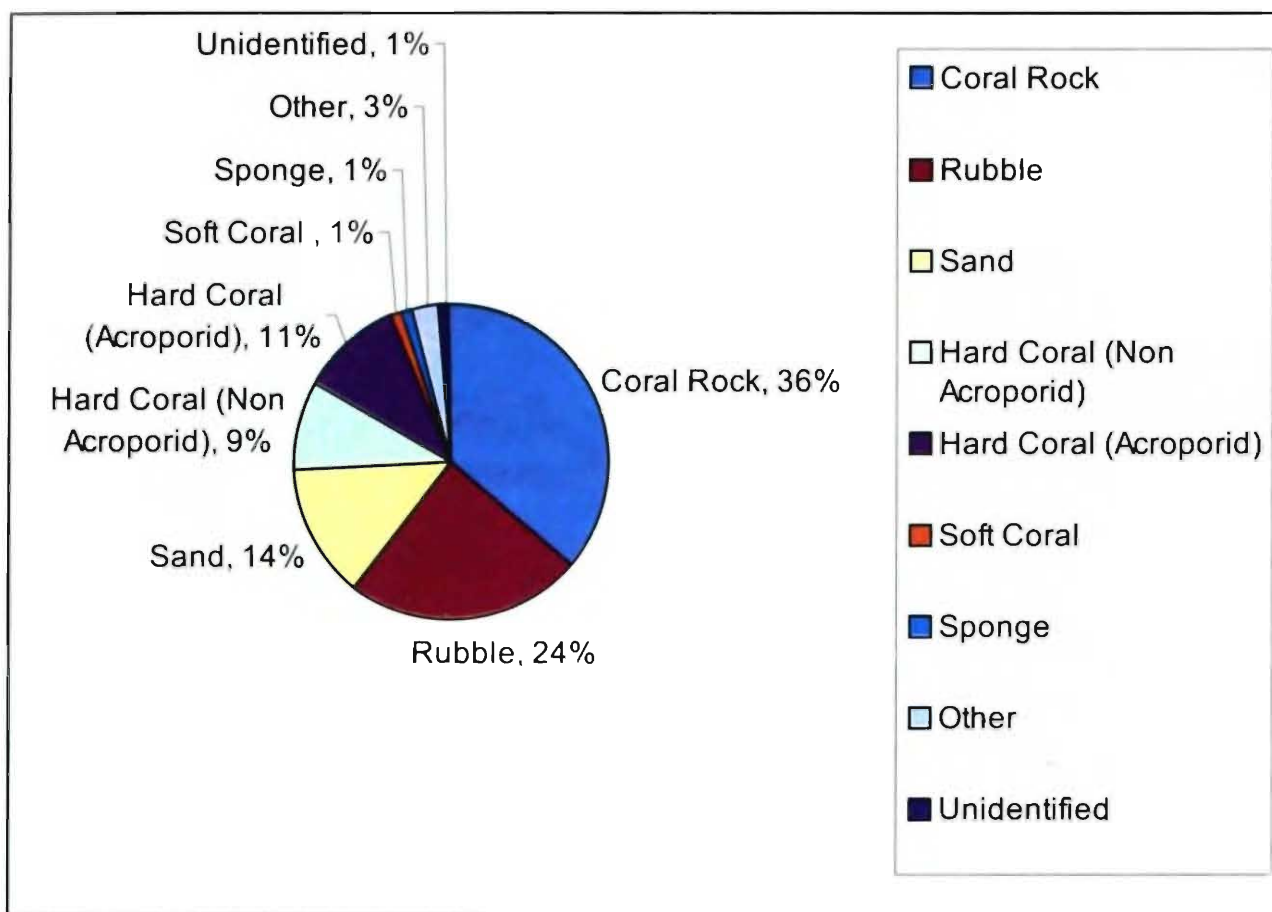


Fig. 4.1c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND002 (North Coast, Cinque Island).

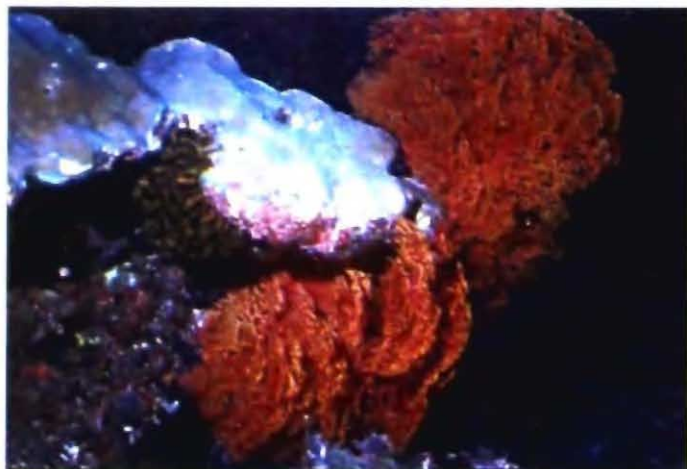


Plate 1. North coast of Cinque Island AND002. (Photo J.R. Turner)

SITE – AND003 (Twin Islands : Twin Islands Reef) – Fig. 4.2a & b, Plate 2

Two reefs in the Twin Islands were surveyed and its depth ranged from 7.3 to 11.3m. Visibility of water column during the course of study was 20m. A total of 82 species of corals were reported from this site.

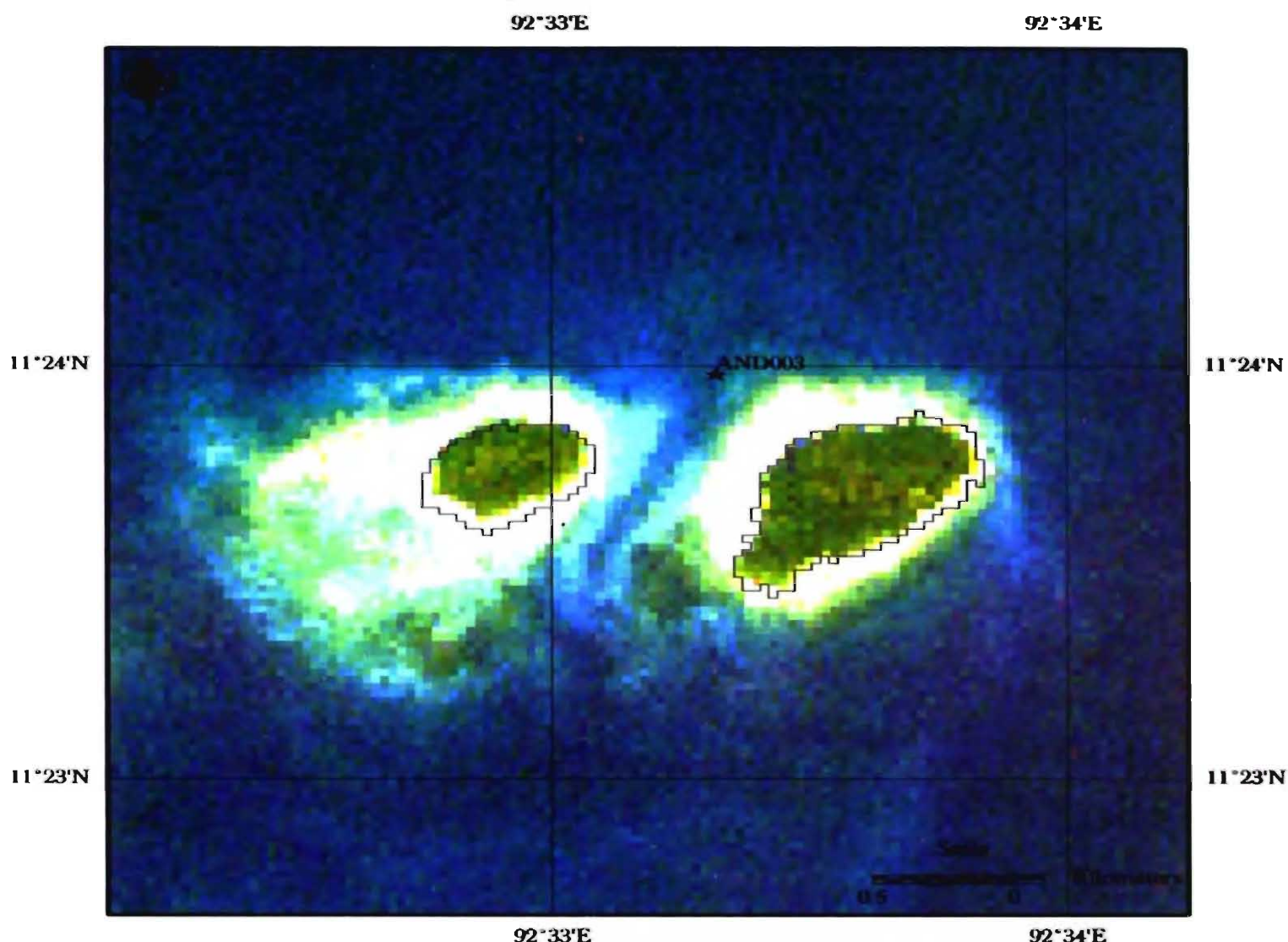


Fig. 4.2a. True colour composite (Landsat 7, R:ETM3, G:ETM3, G: ETM2, B:ETM1) of Twin Islands Reef Twin Island AND003.

STRUCTURE							% COVER												
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR	
0	4	3	0	3	3	0	4	3	1	2	0	0	2	0	1	0	0	0	

Structure : Fringing reef with a moderate to extensive flat on the outer edge of a channel between two densely vegetated low sand cay islands. Steep drop through large coral outcrops from the reef crest to 7 m followed by a gentle reef slope to 11m and sand where corals become sparse and scattered. In shallow water, *Porites* formed living dome shapes up to 7m across or tall rounded towers with living tops. This station is structurally complex site with extensive rubble at 7 m depth (Fig. 4.2c).

Cover : Coral cover was mixed, with large massive and small branching species. Soft corals and gorgonia were common between 7-10 m. *Diploastrea* was

present on sand at base of slope as were branching and tabular *Acropora*, including *Acropora clathrata*. Diversity of corals at this site was high. Many soft corals and crinoids were also noticed.

Impacts : Damage from storms had broken *Acropora* and overturned coral heads.

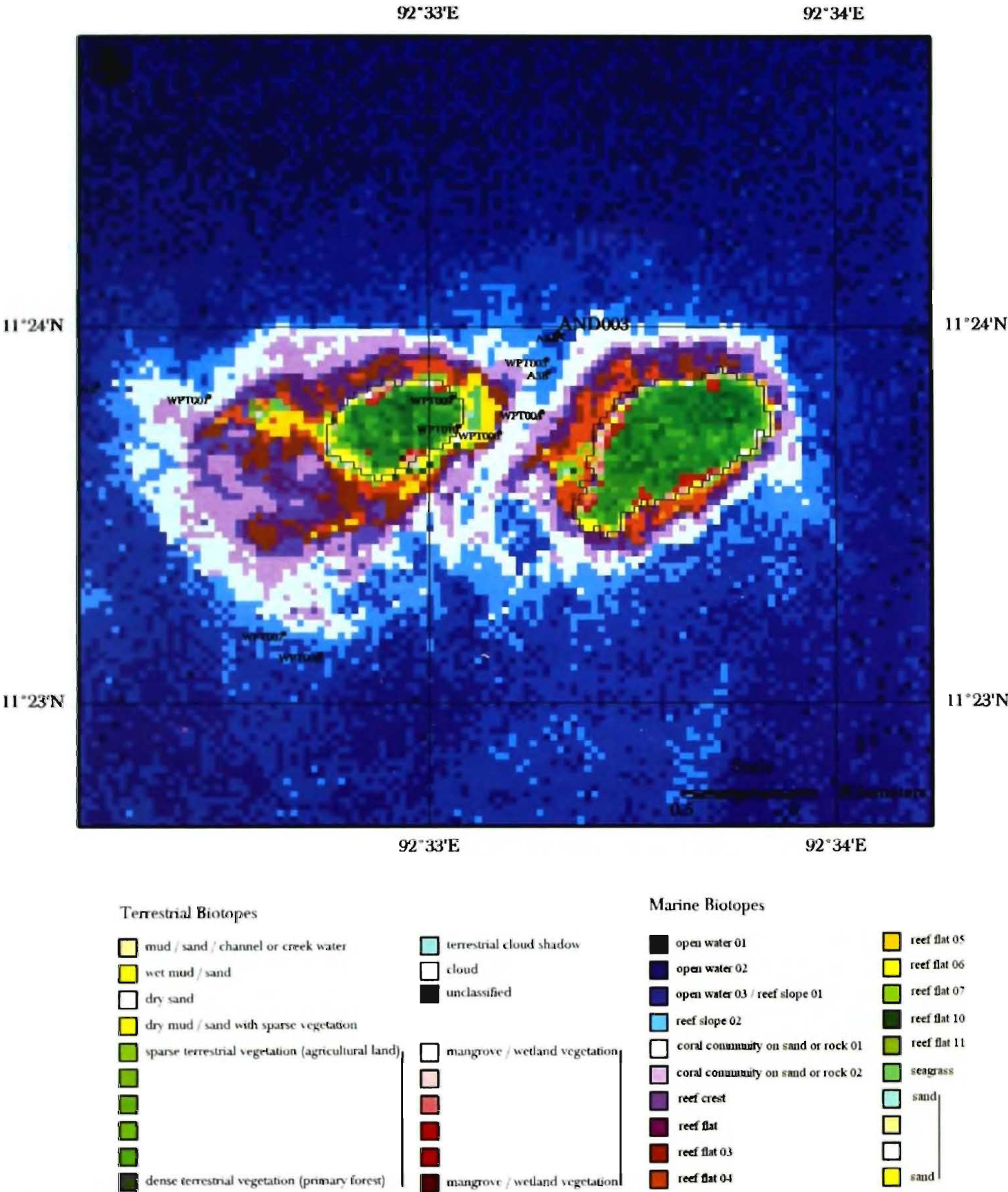


Fig. 4.2b. Terrestrial and Marine Biotope classification of Twin Island AND003.

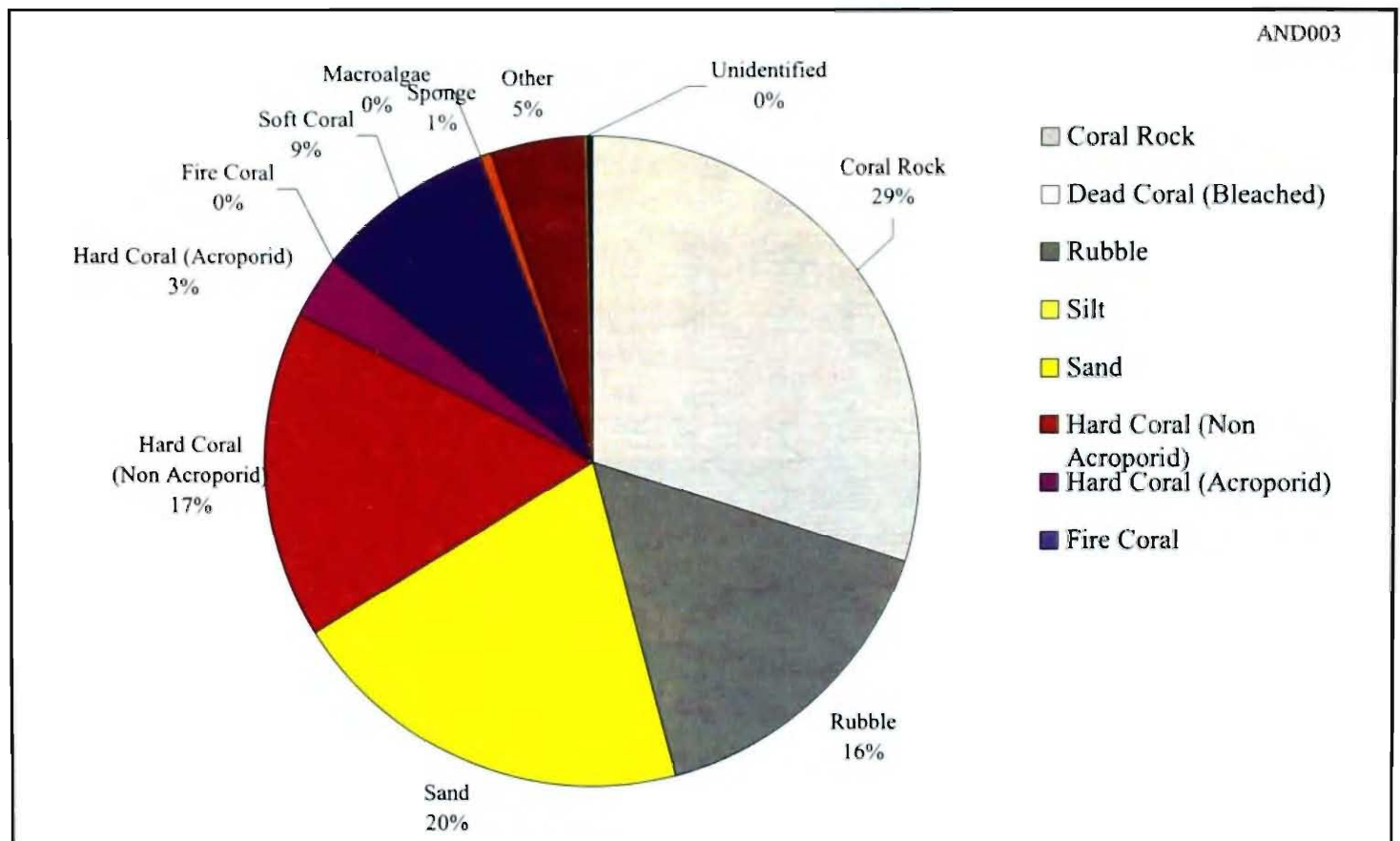


Fig. 4.2c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND003 (Twin Islands Reef).

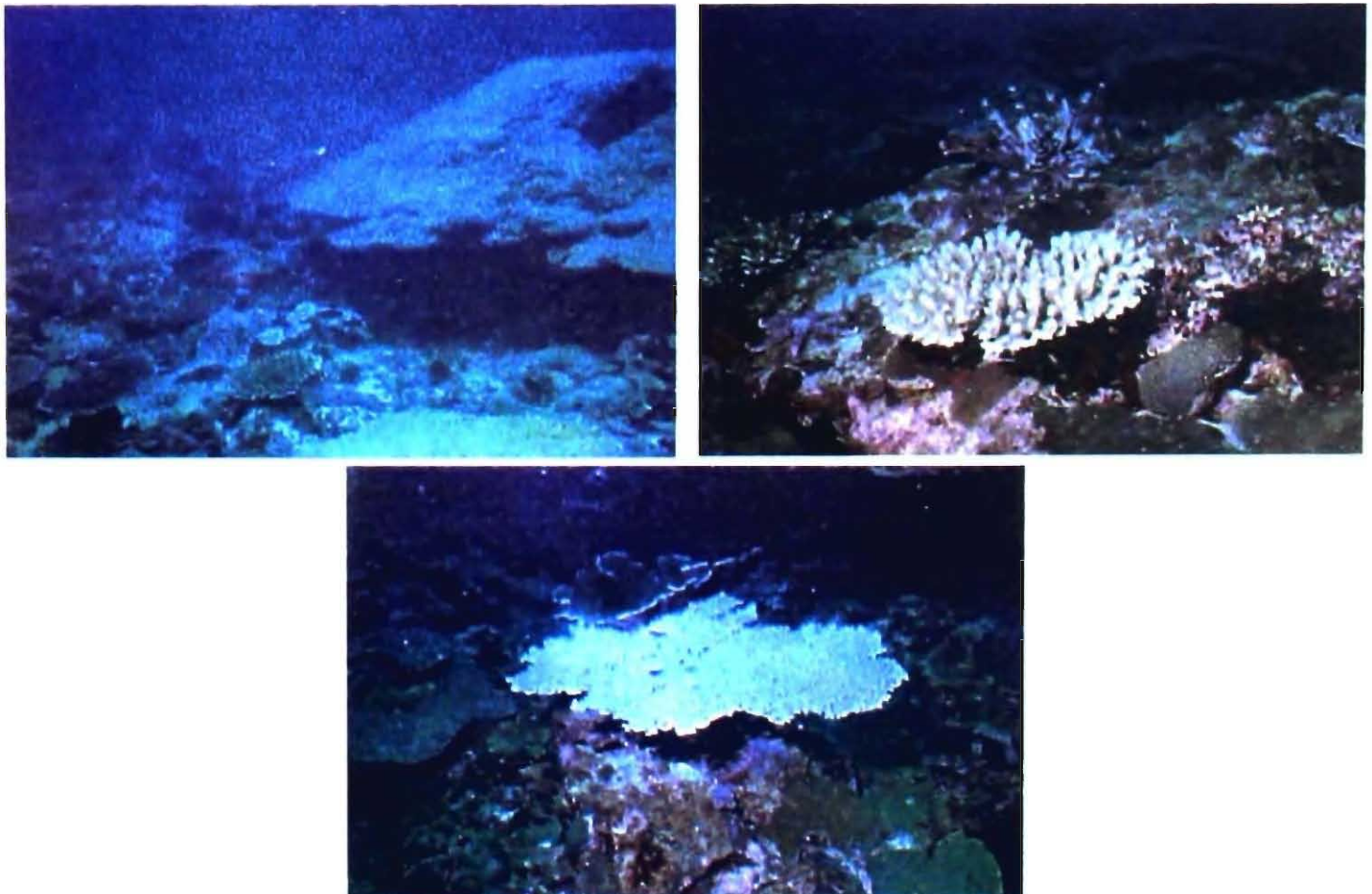


Plate 2. Twin Islands Reef, Twin Islands, AND003. (Photos J.R. Turner)

SITE – AND004 (West Rutland Island: Wood Mason Bay Dome – Lat. 11°26.623'N and Long. 92°35.427'E) – Fig. 4.3a & b, Plate 3

Rutland Island is one of the biggest islands in South Andaman. At the survey site 3 reefs were found and the depth ranged between 14 and 16 with the visibility of 10-15m. Forty four species of corals were recorded at this site.

STRUCTURE							%COVER										
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO COR
6	1	4	0	1	0	0	6	3	0	0	0	1	1	0	1	0	0

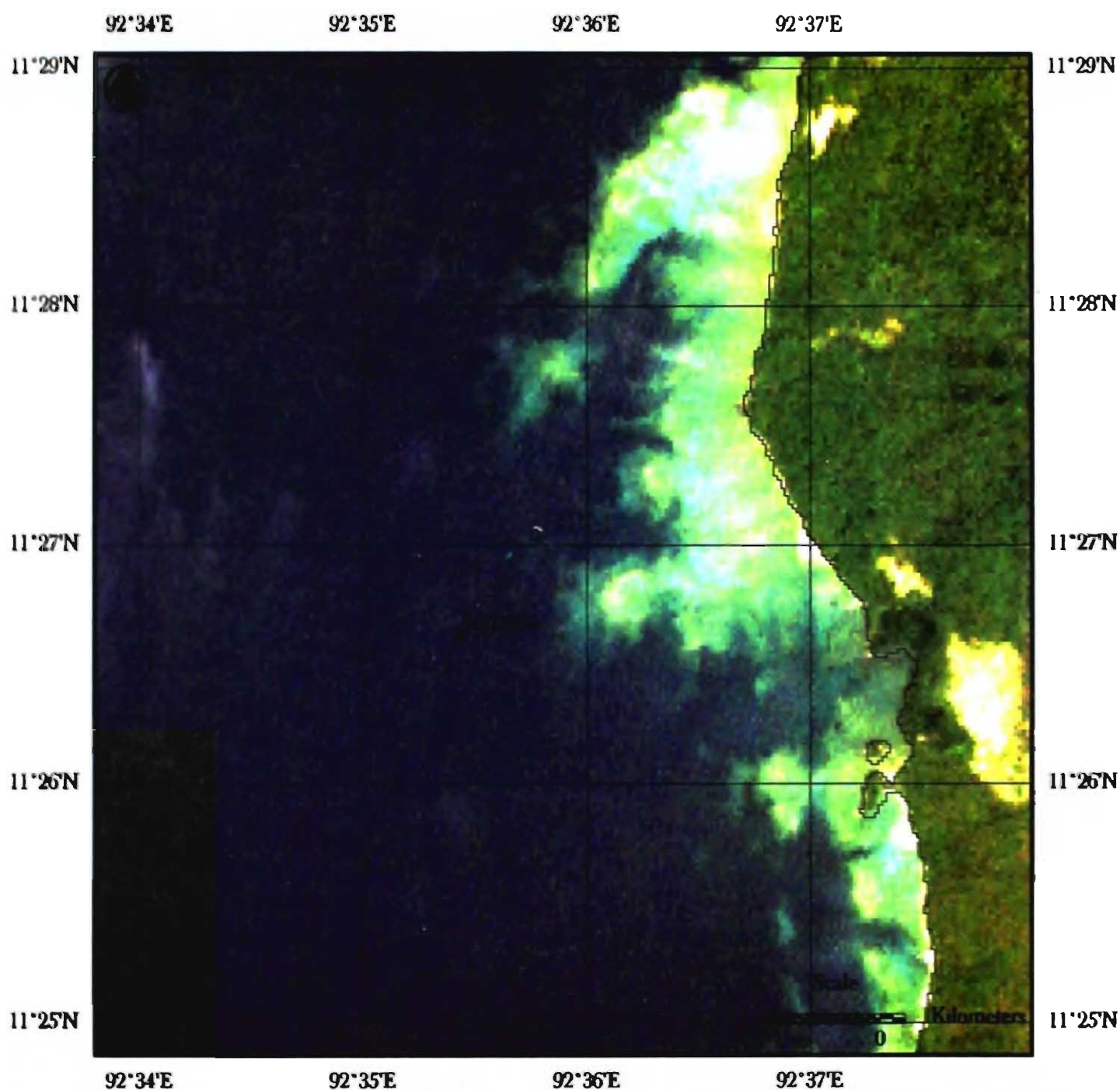


Fig. 4.3a. True colour composite (Landsat 7, R:ETM3, G:ETM2, B:ETM1) of West Rutland Island showing AND004.

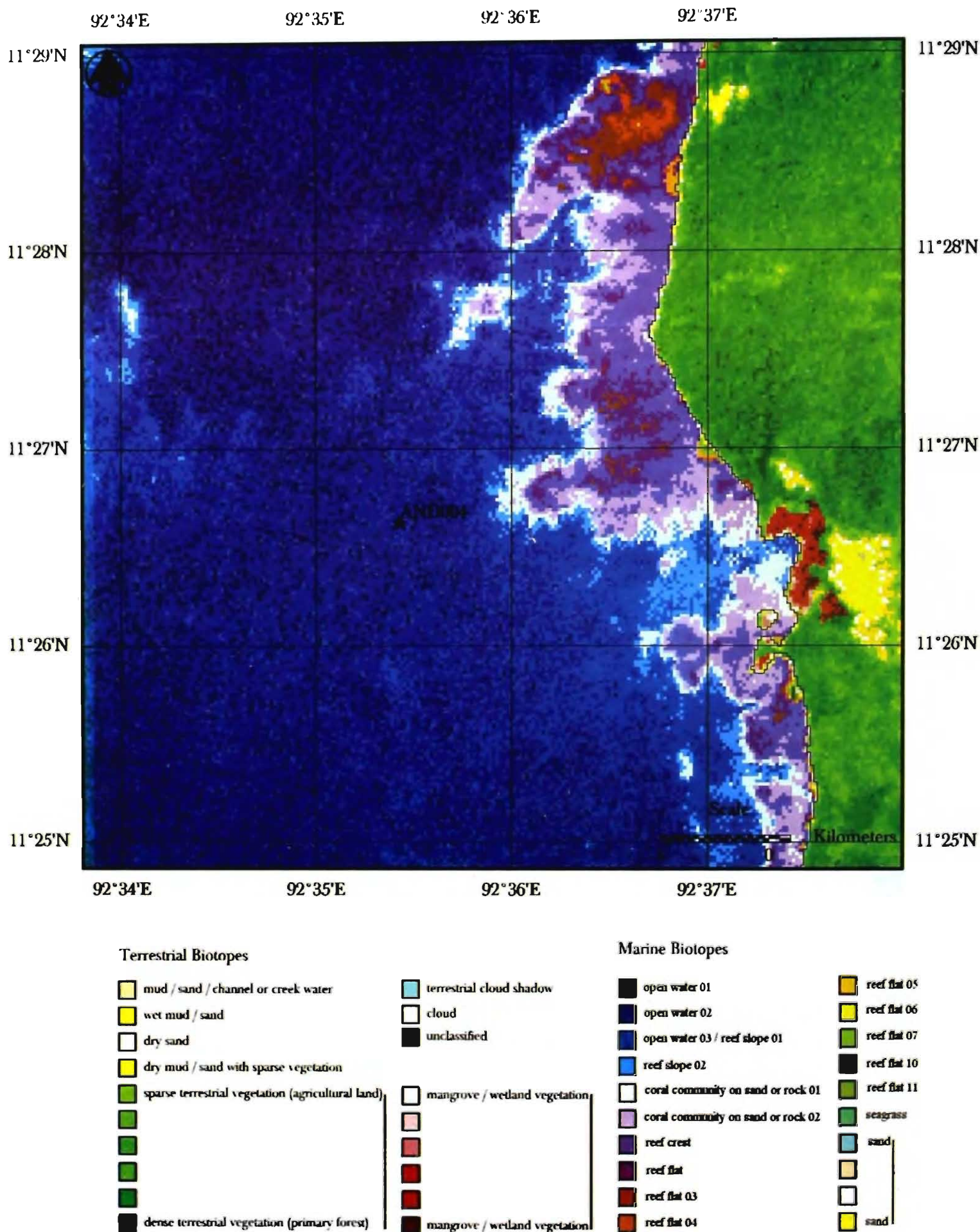


Fig. 4.3b. Terrestrial and Marine Biotope classification of West Rutland Island showing AND004.

Structure : Reef structure on a rock dome covering an area approximately 100 m x 50 m between 10m to 15 m, and may have continued to 27-30 m depth on each side. Consisted of a coral pavement hard substrate with a low profile cover of mixed small coral colonies including encrusting and massive forms with some larger tables

Cover : Living hard coral cover was approximately 20%. Generally small colonies of <50 cm of varied encrusting branching and tabular and massive forms were noticed. *Diploastrea* largest at 1-2 m colony size and most other coral colonies were small.

Impacts : Poor fish life. Site was probably very exposed but no obvious signs of damage. Juvenile recruits of most species are evident.



Plate 3. Wood Mason Bay Dome, West Rutland, AN004. (Photos J.R. Turner)

SITE – AND005 (Tarmugli Island: West Coast – Lat. 11°34.59'N and Long. 92°30.852'E) – Fig.4.4a&b, Plate 4.

Tarmugli Island is located in Mahatma Gandhi Marine National Park. Three reefs were surveyed in this Island. The depth at surveyed area ranged from 10-17 m with the visibility of 20 m. 67 species of corals were identified at this site.

STRUCTURE							% COVER												
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR	
5	1	0	0	3	2	0	5	3	1	2	2	3	1	0	1	4	0	0	

Structure : Offshore bank reef with very low profile spurs running nearly parallel to the island. The spurs were separated by sand channels, each <1 m in depth and approximately 2m across. At 10-12 m depth the spurs were 2-3 m in height rubble filled grooves at 17 m+. The reef flat, which was closer inshore, was not surveyed.

Cover : The deeper wider grooves were full of *Acropora* rubble and the spurs were covered by small mixed colonies with a few larger *Acropora* tables on the shallowest widest spurs. There were many small coral colonies on rock and

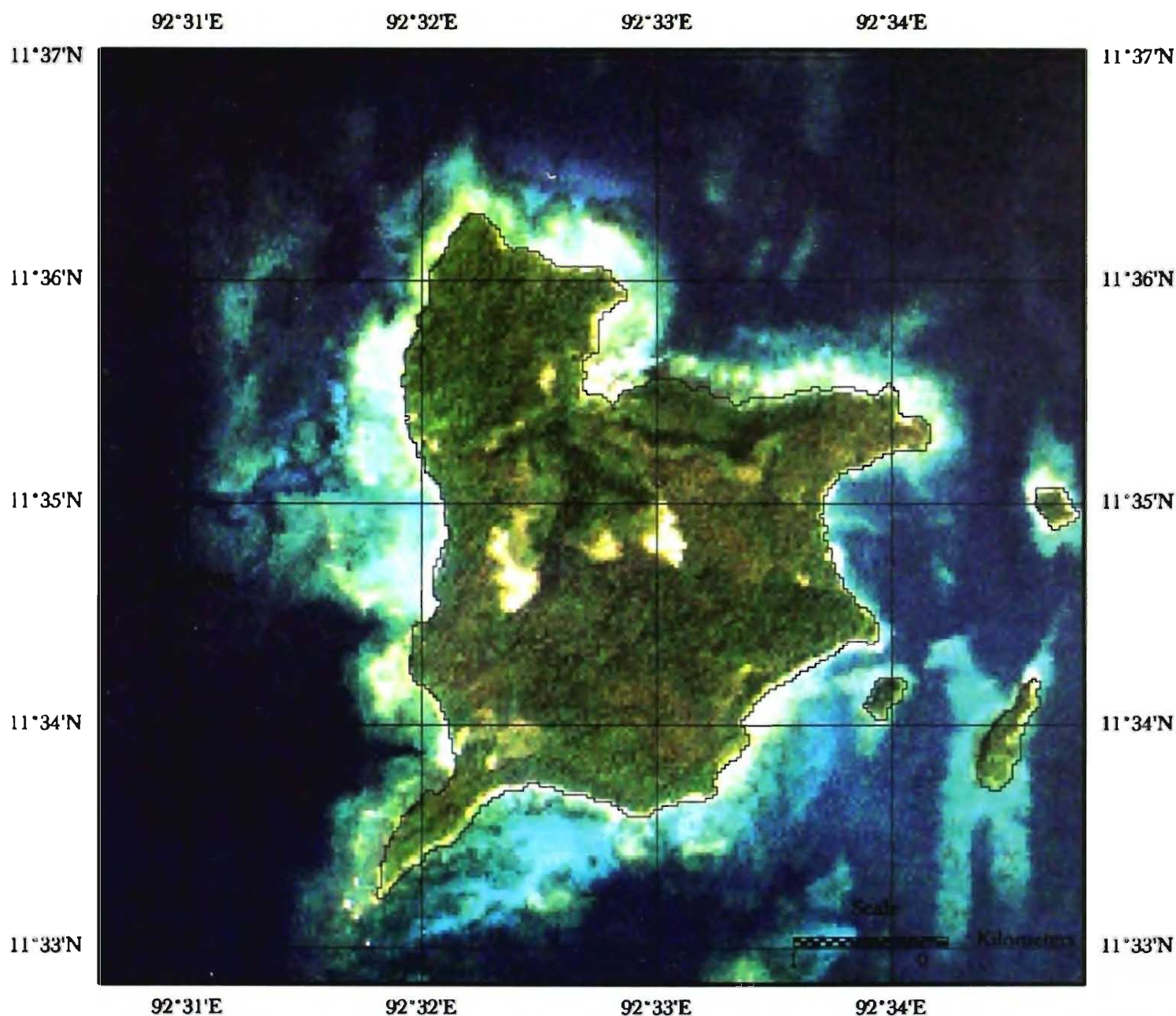


Fig. 4.4a. True colour composite (Landsat 7, R:ETM3, G:ETM2,B:ETM 1) of Tarmugli Island showing AND005.

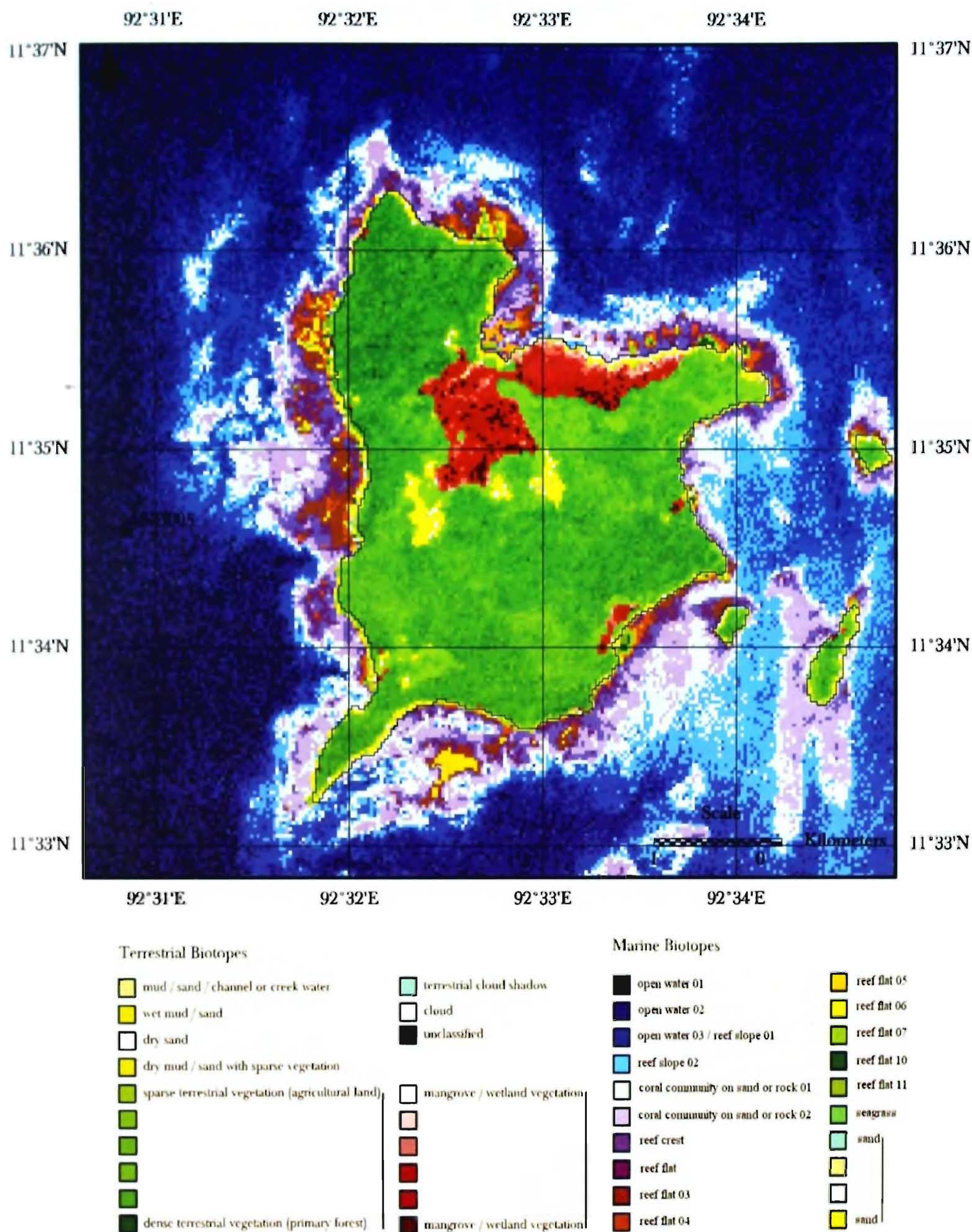


Fig. 4.4b. Terrestrial and Marine Biotope classification of Tarmugli Island showing AND005.

especially *Acropora*, *Millepora*, *Pocillopora*, *Seriatopora hystrix*, small *Turbinaria*, *Pachyseris*. Branching *Acropora danae* were common on top of tables on edges of spurs, as were small *Porites* (<50 cm) *Millepora*, *Mycedium* and *Lobophyllia*. The new species of *Acropora* "brown digitate" sp. 1 was common. Tabular coral present included *Acopora clathrata* and *A. hyacinthus*. Diversity was moderate and associated organisms moderate and included *Culcita*. Many juvenile coral colonies (<25 cm) and many colonies with 25-50 cm size have been observed (Fig. 4.4c)

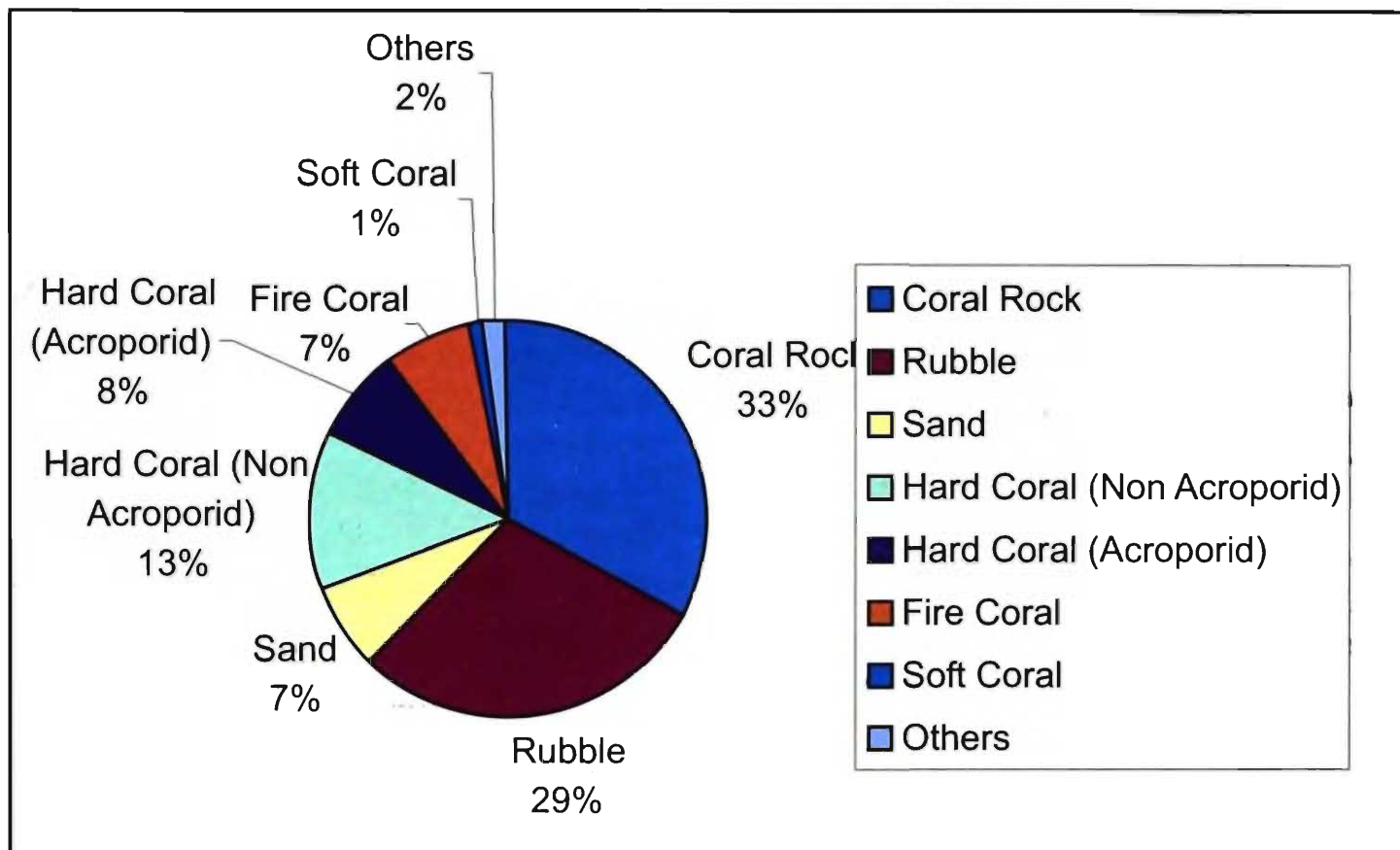


Fig. 4.4c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND005 (Tarmugli Island).

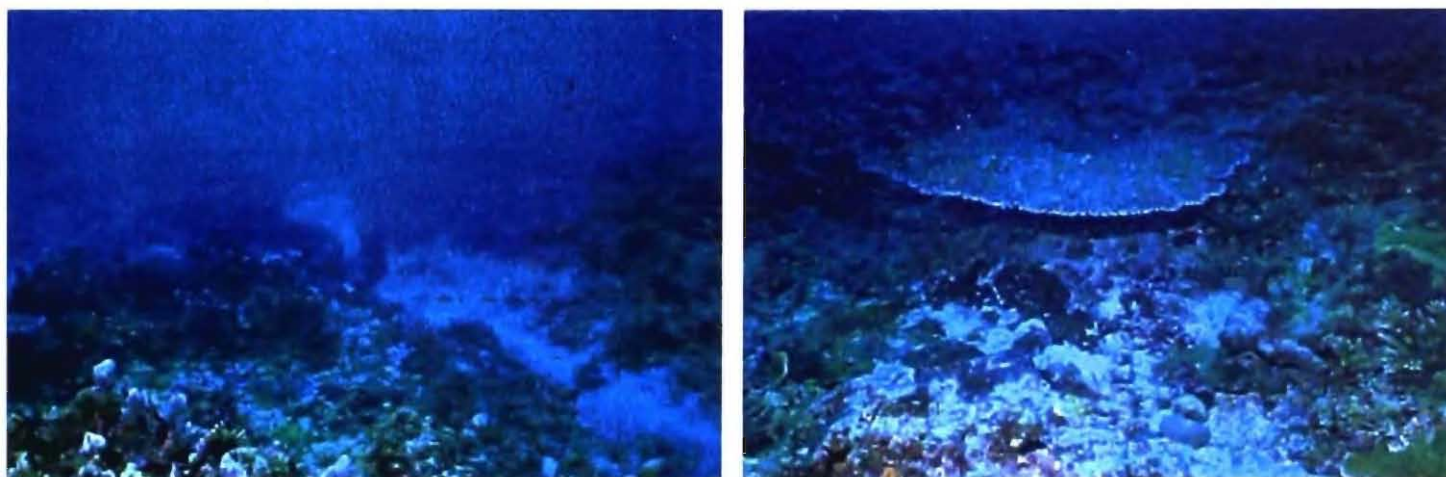


Plate 4. West coast of Tarmugli Island AND005. (Photos J.R. Tuner)

SITE – AND006 (Flat Island : North Flat Island Reef – Lat. 12°33.509'N and Long. 92°40.746'E) – Fig 4.5a & b, Plate 5

One reef in this island has been surveyed. The depth of the surveyed area was 6-18m with the visibility of 10m. A total of 81 coral species has been identified from this reef.

STRUCTURE							% COVER											
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR
1	2	5	0	2	2	2	5	4	2	1	2	1	2	0	1	0	0	0

Structure : Fringing reef with an extensive reef flat and sloping to 18m depth to sand on the northern prolongation of a vegetated island.

Cover : Hard coral cover was 36%, coral rock 82%, rubble 10% and sand 8%. The most diverse and highest coral cover was found between 12 and 15 m. The shallowest parts of the slope above 8 m were dominated by *Porites* and *Acropora* and the deeper reef slope below 12 m was dominated by foliaceous and laminar coral colonies particularly *Pachyseris speciosa* forming foliose whorls each <50 cm forming colonies up to 2 m diameter. *Acropora* and *Porites* more dominant above 8 m. Good site for associated species. Coral recruits observed at 12-15 m (Fig. 4.5c).

SITE – AND007 (North Reef Island : South Coast – Lat. 13°2.644'N and Long. 92°42.557'E) – Fig. 4.6a & b, Plate 6

North Reef Island is located in northern most part of Andaman and one reef having the depth of 10-18 m with the visibility of 15 m has been surveyed. The study encountered 66 species of corals in this area.

STRUCTURE							% COVER											
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR
6	4	4	0	2	1	0	1	6	2	3	1	2	1	0	0	0	0	0

Structure : Fringing reef slope, with an extensive reef flat to south of vegetated sand cay island. Gradual slope from 8 to 20 m with the most diverse corals between 15-18 m where there was 100% coral cover of mixed species and size classes. At about 10 m the slope began to flatten, eventually forming a reef flat at <3 m (see next site).

Cover : Cover was dominated by 46 % hard coral cover, abiotic cover was low, 27% coral rock, 4% rubble 1% sand. The most diverse corals were found between 15-18 m where there was close to 100% cover of vigorous live coral. Colonies of all sizes of mixed species *Acropora*, *Pachyseris*, *Porites*, *Montipora*. Poor cover of corals was above 10 m. Cover of massive *Porites* in shallow water was 50% cover and *Acropora hyacinthus*, *Acropora clathrata*, *Montipora*, *Seriatopora*

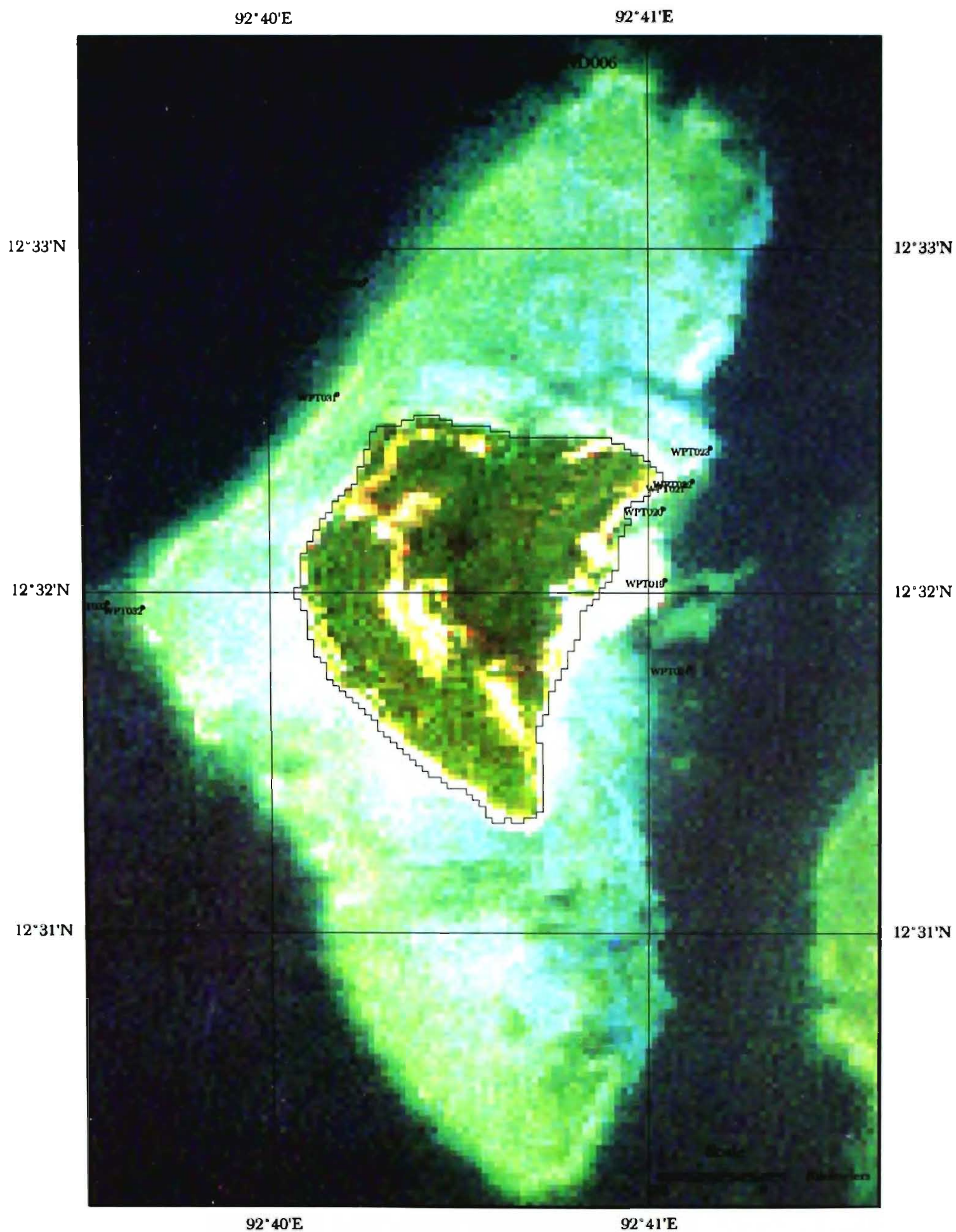


Fig. 4.5a. True colour composite (Landsat 7, R:ETM3, G:ETM 2, B:ETM 1) of Flat Island showing AND006.

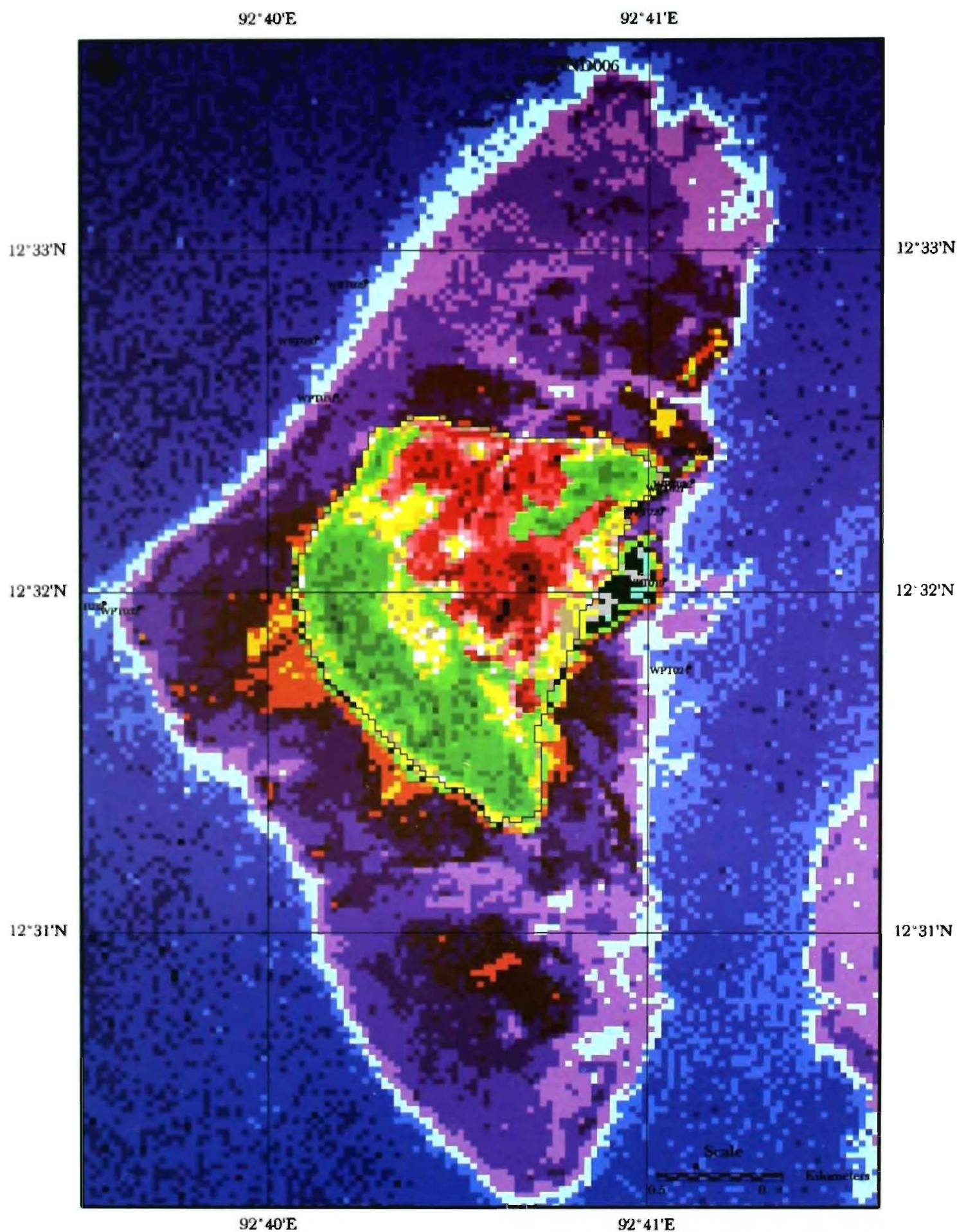


Fig. 4.5b. Terrestrial and Marine Biotope classification of Flat Island showing AND006 (refer to Fig. 4.5b for legend).

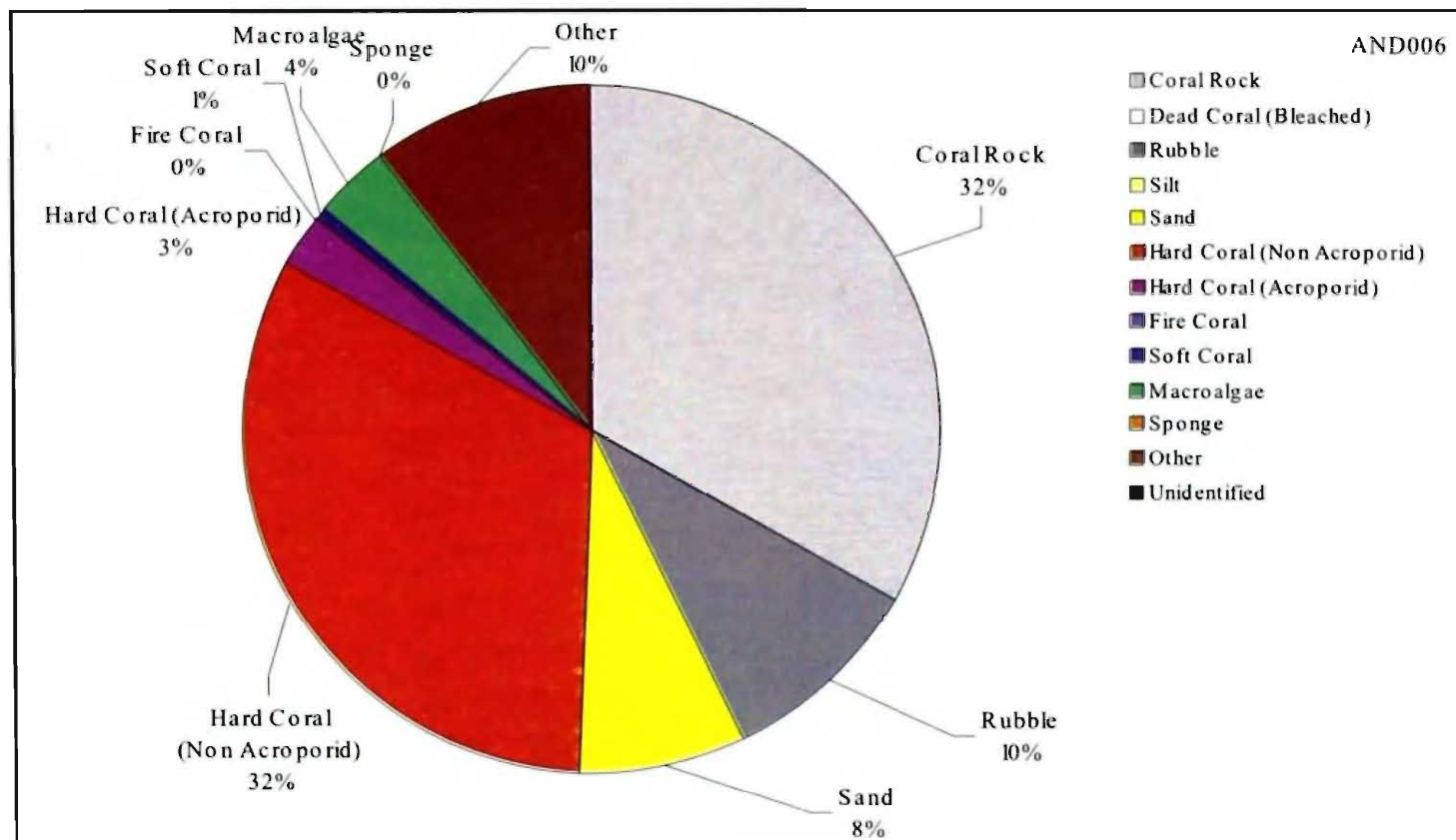


Fig. 4.5c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND006 (Flat Island).

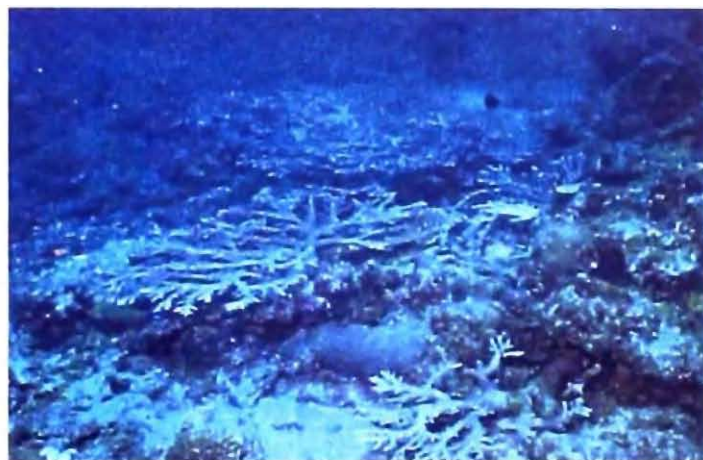


Plate 5. North coast of Flat Island AND006 (Photos J.R. Turner).

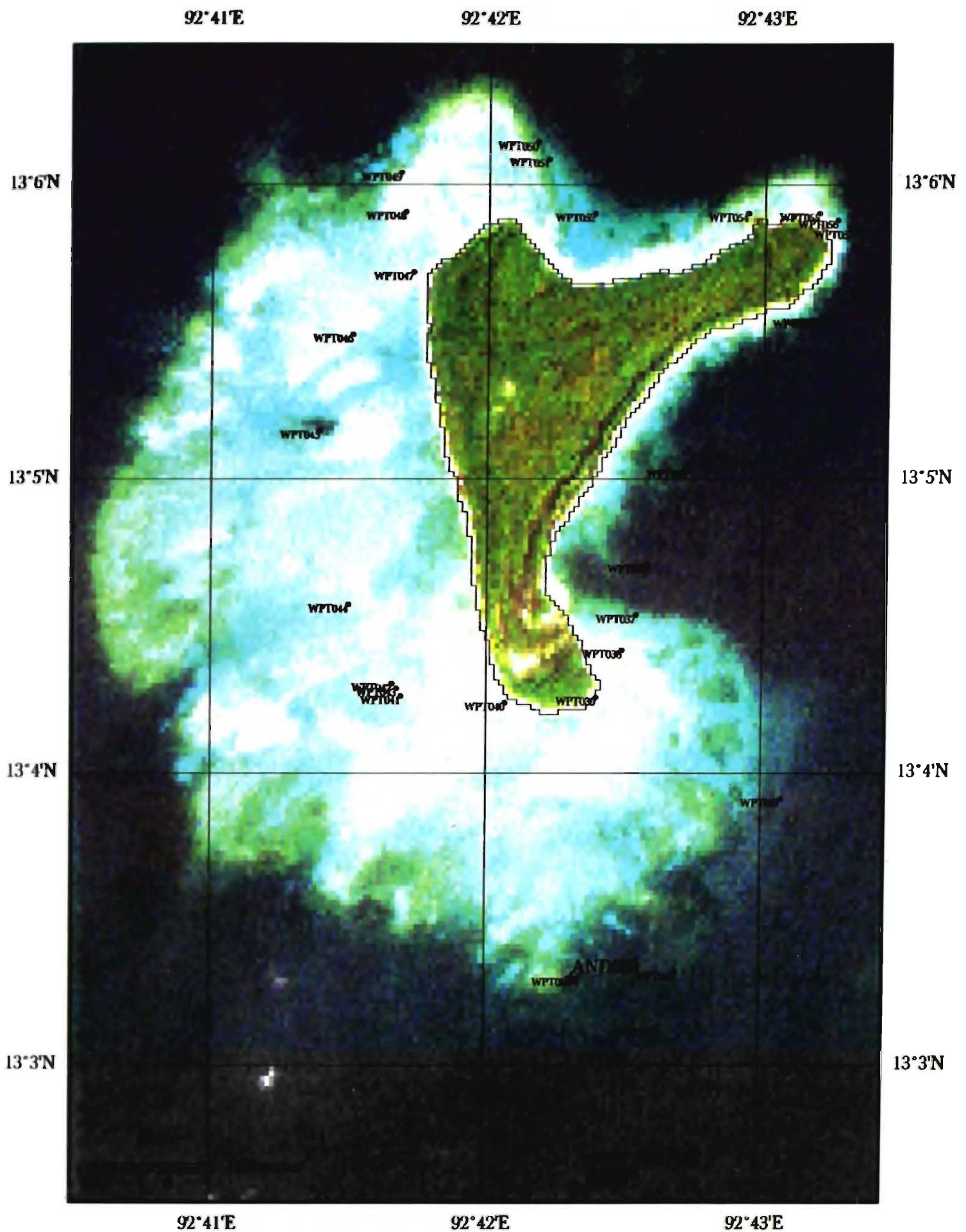


Fig. 4.6a. True colour composite (Landsat 7, R:ETM3, G:ETM2, B:ETM1) of North Reef Island showing AND007.

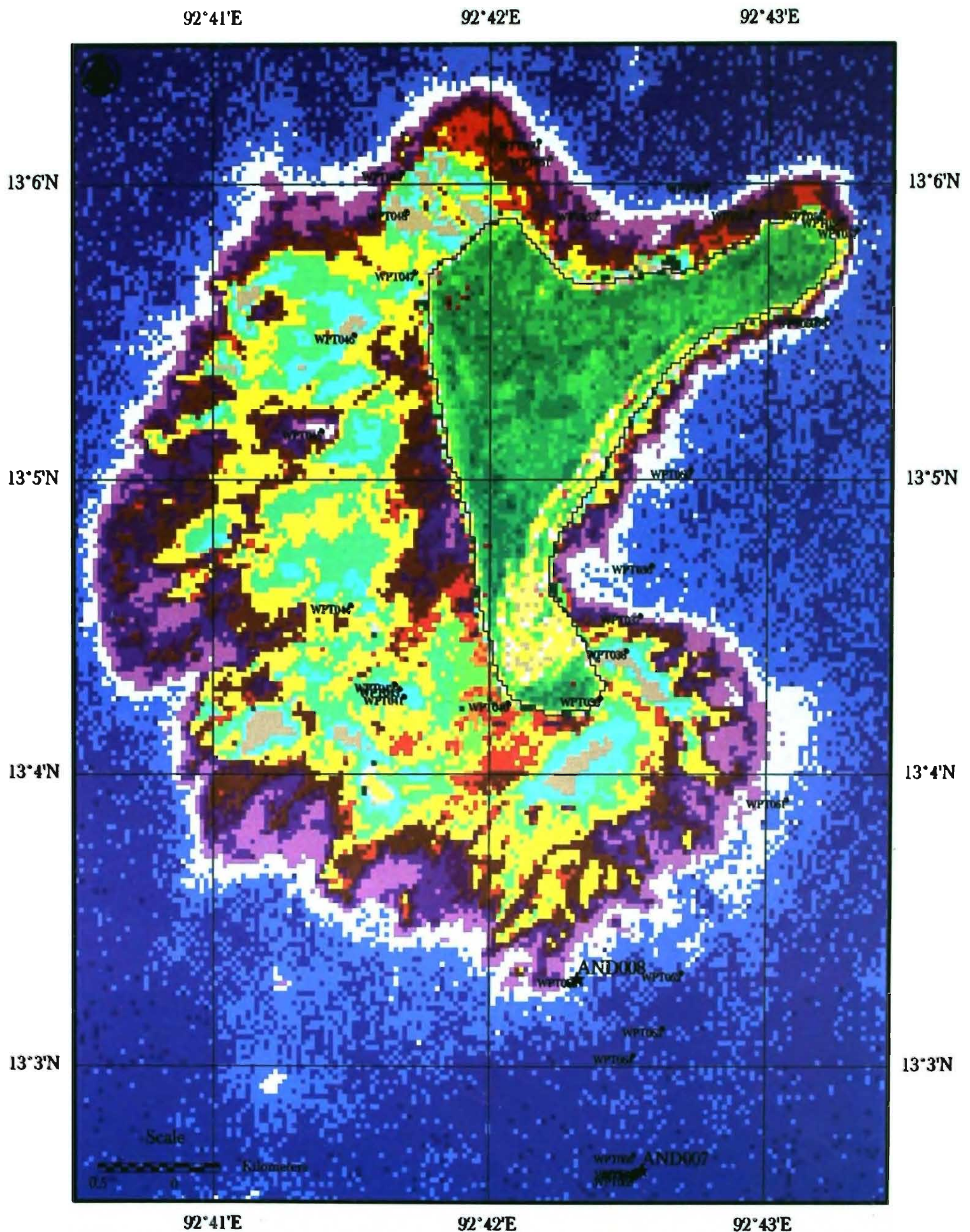


Fig. 4.6b. Terrestrial and Marine Biotope classification of North Reef Island showing AND007 (refer to Fig.4.5b for legend).

and *Pachyseris speciosa* were all high. The new brown digitate *Acropora* sp., soft coral *Sinularia* and crinoids were commonly found (Fig. 4.6c).

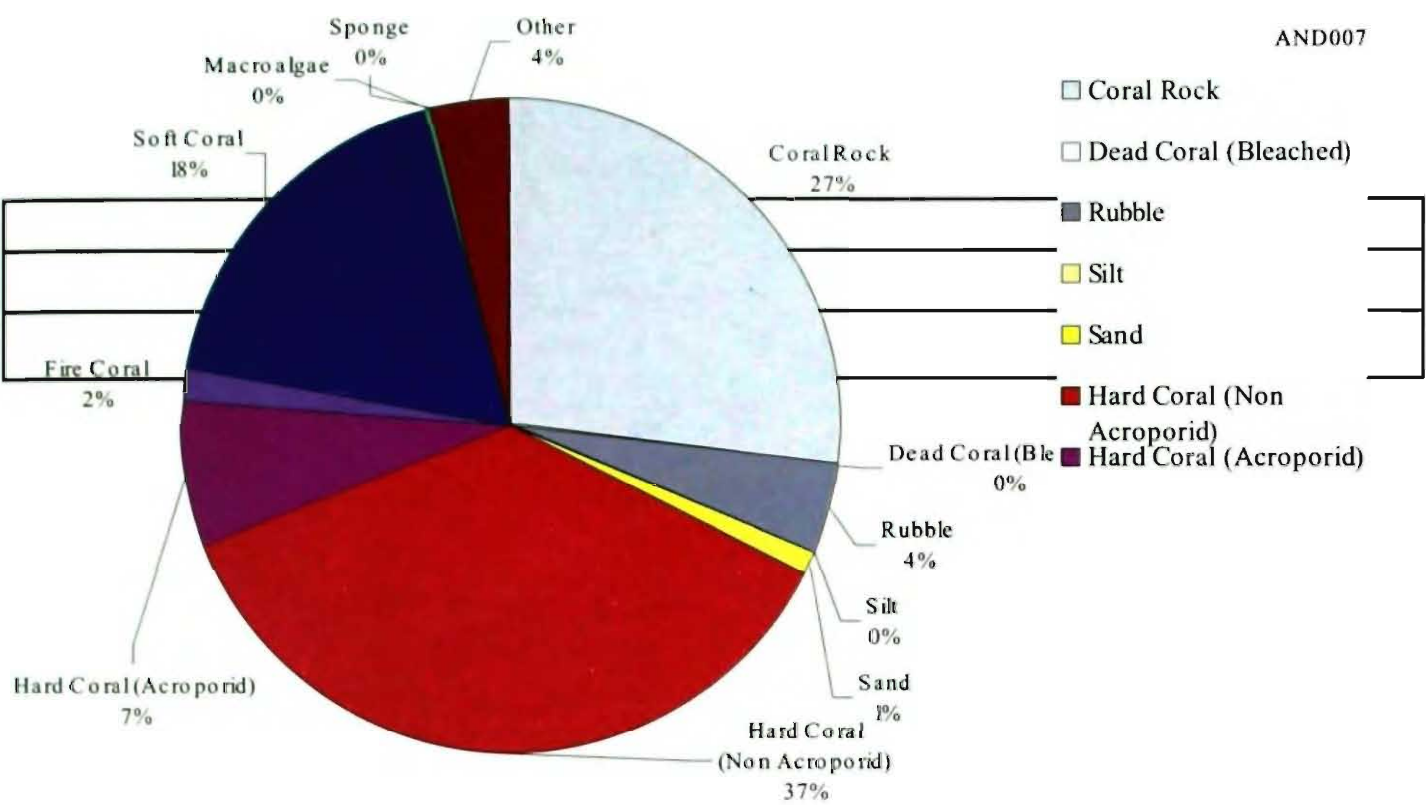


Fig. 4.6c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND007 (North Reef Island).

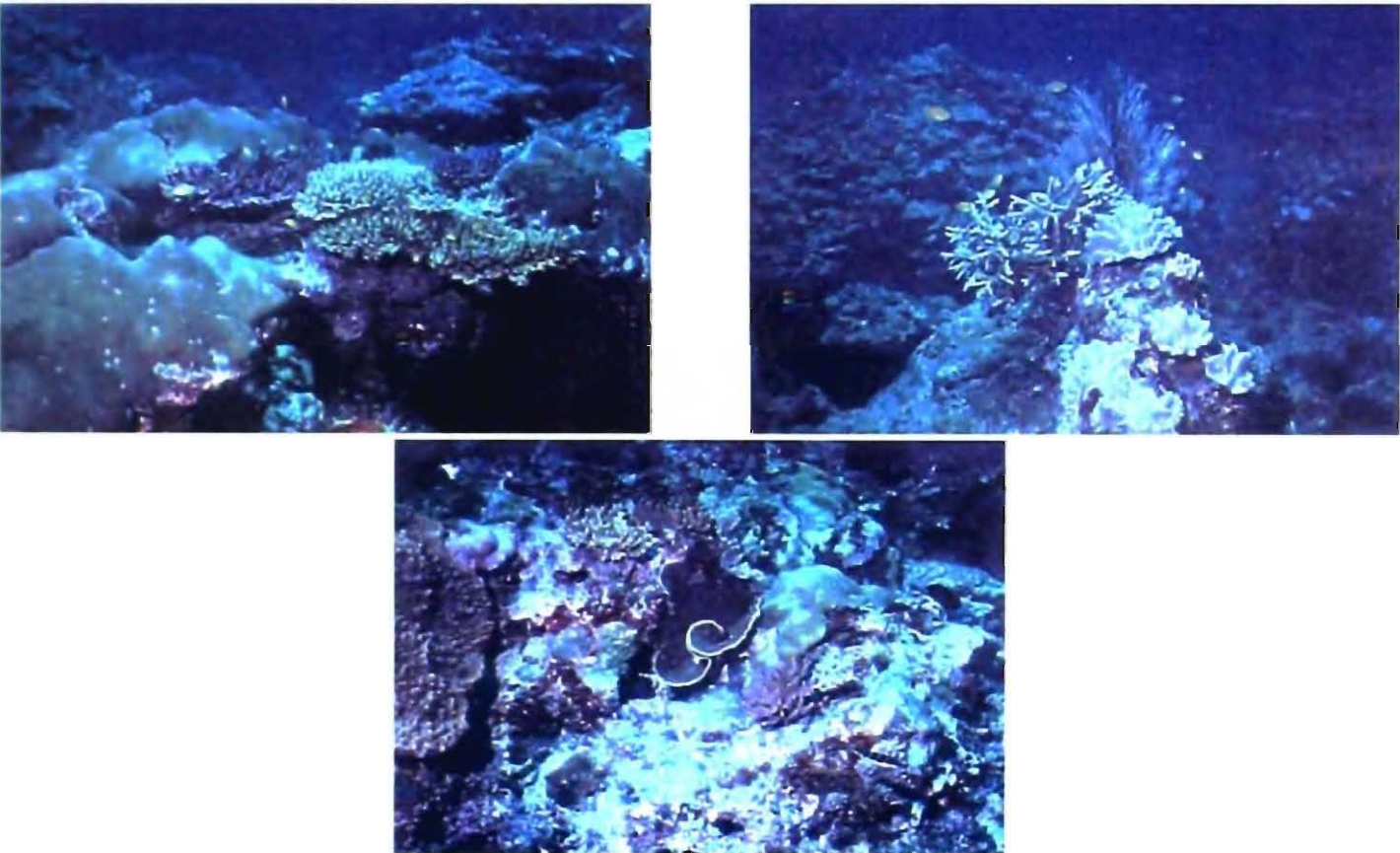


Plate 6. South Coast of North Reef Island AND007. (Photos J.R. Turner)

SITE – AND008 (North Reef Island : South West reef crest – Lat. 13°32.998'N and Long. 92°42.322'E) – Fig. 4.6a & b, Plate 7.

One reef having the depth of 4 meters with 15 m visibility has been surveyed. In this reef 33 species of corals were identified.

STRUCTURE							% COVER												
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR	
2	4	3	0	2	2	0	1	5	1	1	0	0	1	0	0	0	0	0	

Structure : Reef crest and shallow reef front of the reef surveyed in AND007. Reef with an extensive flat between 0-4 m depth.

Cover : Living hard coral cover observed as 51-75%. Coral cover dominated by *Acropora* tables. The digitate *Acropora* were common while *Acropora robusta* was dominant along with bushy *Millepora* and foliaceous whorls of *Montipora aequituberculata* also noticed.

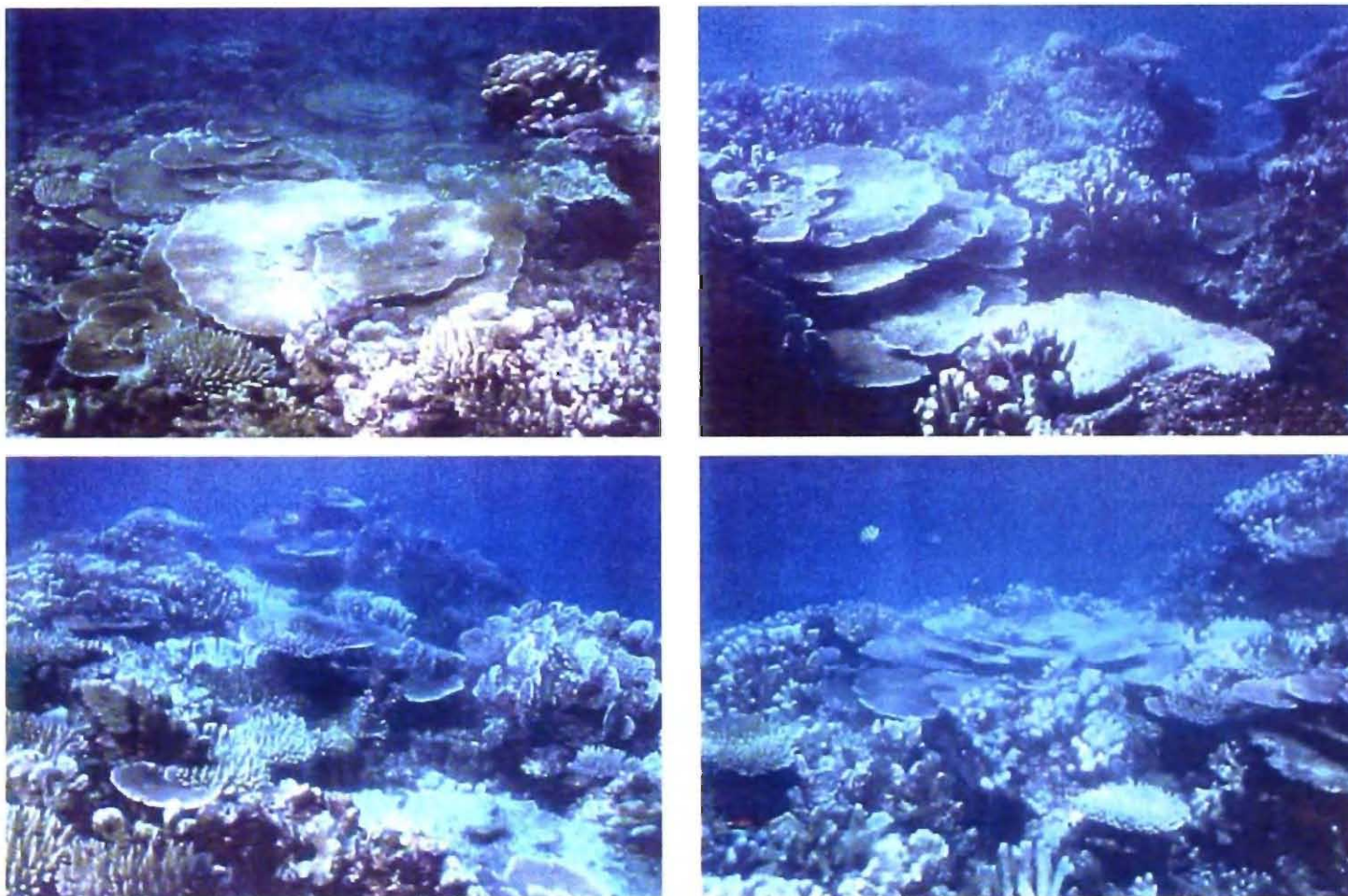


Plate 7. Reef flat, south coast of North Reef Island AND008. (Photos J.R. Turner)

SITE – AND009 (Little Button Island– Lat. 12°13.274'N and Long. 93°1.306'E)- Fig. 4.7a & b, Plate 8

Little Button Island is located in Ritche's Archipelago. Two reefs under this have been surveyed. The depth of the reef varied from 3 to 19 m with the visibility of 40 m. Altogether 89 species of corals were reported during the period of study.

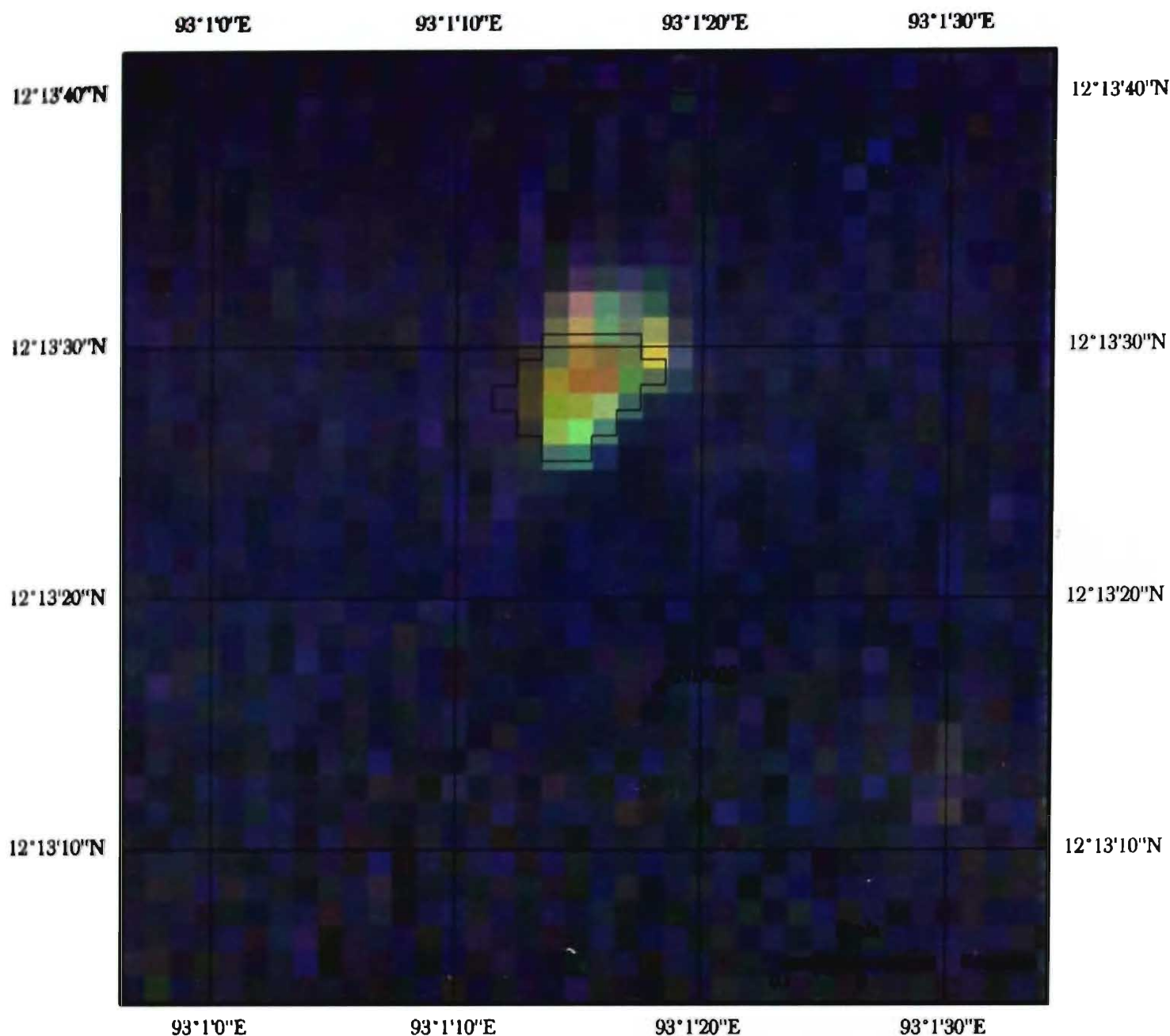


Fig. 4.7a. True colour composite (Landsat 7, R:ETM3, G:ETM2, B:ETM1) of Little Button Island showing AND009.

STRUCTURE							% COVER												
CP	LB	SB	CB	FB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR	
0	3	3	0	3	2	1	2	4	1	0	2	1	2	0	2	0	0	0	

Structure : Steep fringing reef slope, extending between 3-20 m with no reef flat, in the lee of a rocky vegetated limestone pinnacle island several hundred metres across. Reef constructed from coral outcrops protruding from slope interspersed with sand and rubble. Deeper areas 12-20m were steeper with large upright outcrops and small outcrops covered in numerous coral colonies.

Cover : A diverse corals with hard and fire coral cover at approximately 30%. Above 5 m, corals were dense and dominated mostly by small branching *Acropora* sp. Branching *Acropora* and *Millepora* were dominant to 10 m on the

shallow slope. All 5 species of *Millepora*, found around the islands with bushes, thick vertical plates and foliose forms, were present. From about 10 to 20m was a steep slope consisting of rubble on sand with coral outcrops towards the base at around 18m then a slope of sand extending further off. Species present included *Lobophyllia*, *Pachyseris*, *Acropora*, *Stylophora pistillata* the new brown digitate *Acropora*, *Acropora formosa*, massive *Porites* and *Diploastrea*. Solitary corals

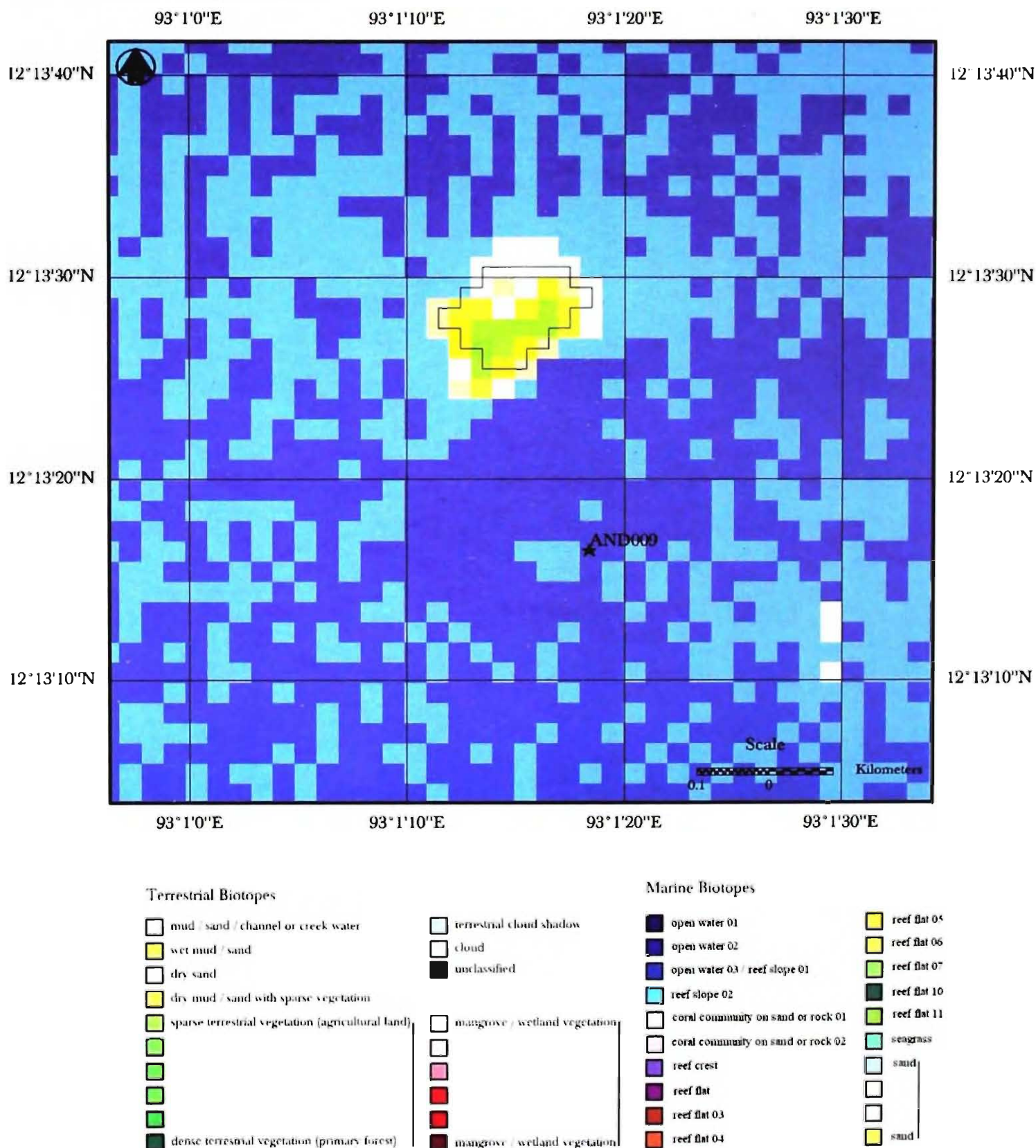


Fig. 4.7b. Terrestrial and Marine Biotope classification of Little Button Island showing AND009.

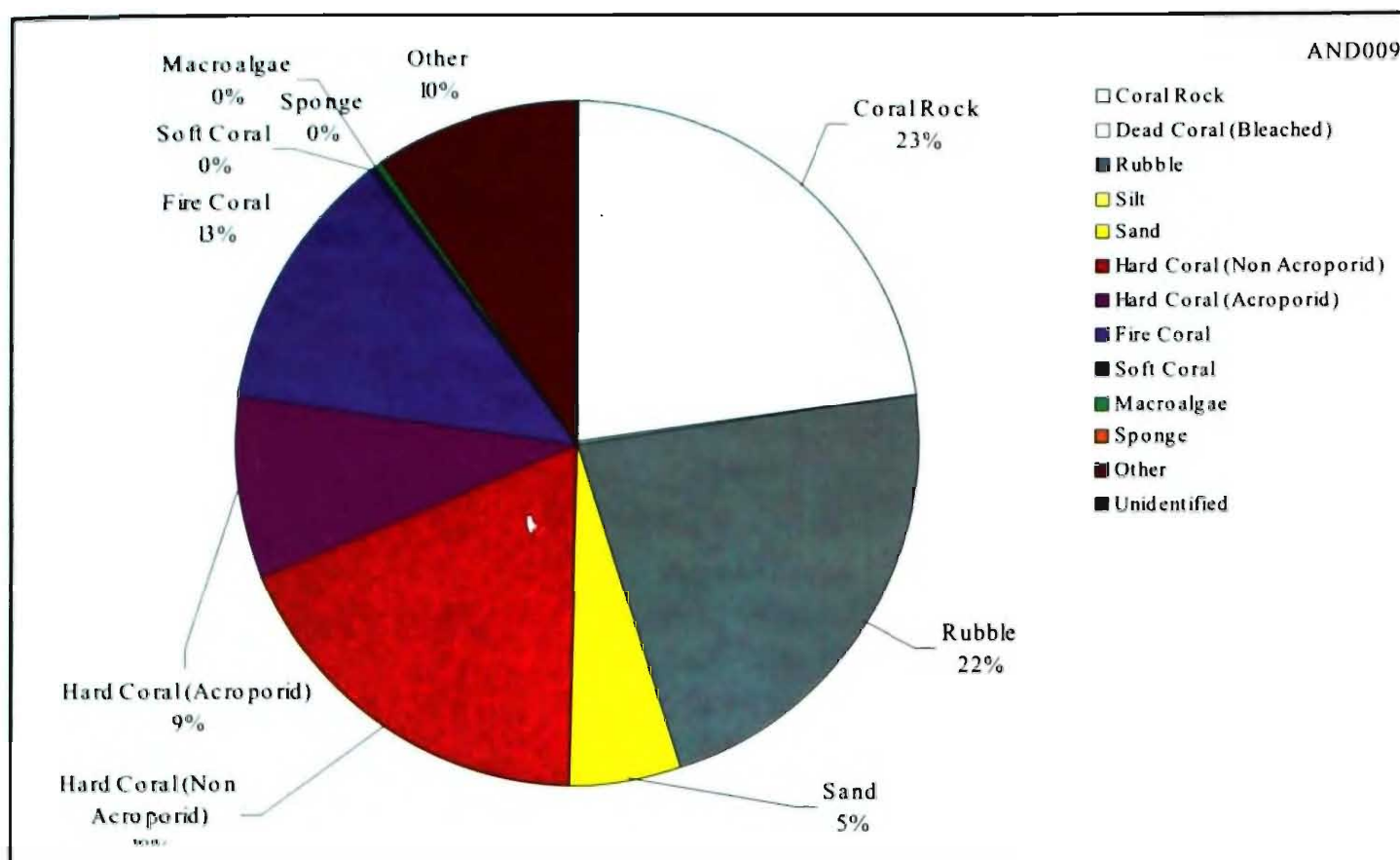


Fig. 4.7c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND009 (Little Button).

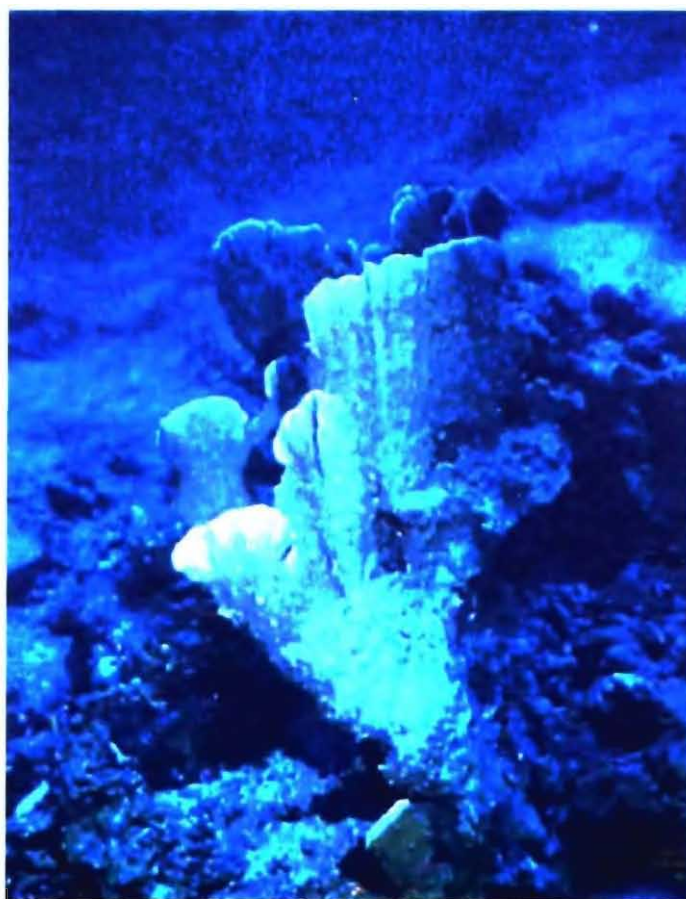


Plate 8. Little Button Reef AND009. (Photos J.R. Turner)

including *Ctneactis echinata*, and other fungiids such as *Sandolitha robusta* were abundant. Anemones and holothurians were present above 12 m (Fig. 4.7c).

Impacts : Anchor damage and storm damage evident with many broken corals

SITE – ANDo10 (Outram Island: Southwest Coast – Lat. 12°11.964'N and Long. 93°6.440'E) – Fig. 4.8a & b, Plate 9

Outram Island falls under Rani Jhansi Marine National Park. Two reefs having the depth range of 11.5 to 15 m with 10 m visibility have been surveyed. Sixty eight species of corals have been recorded during the survey.

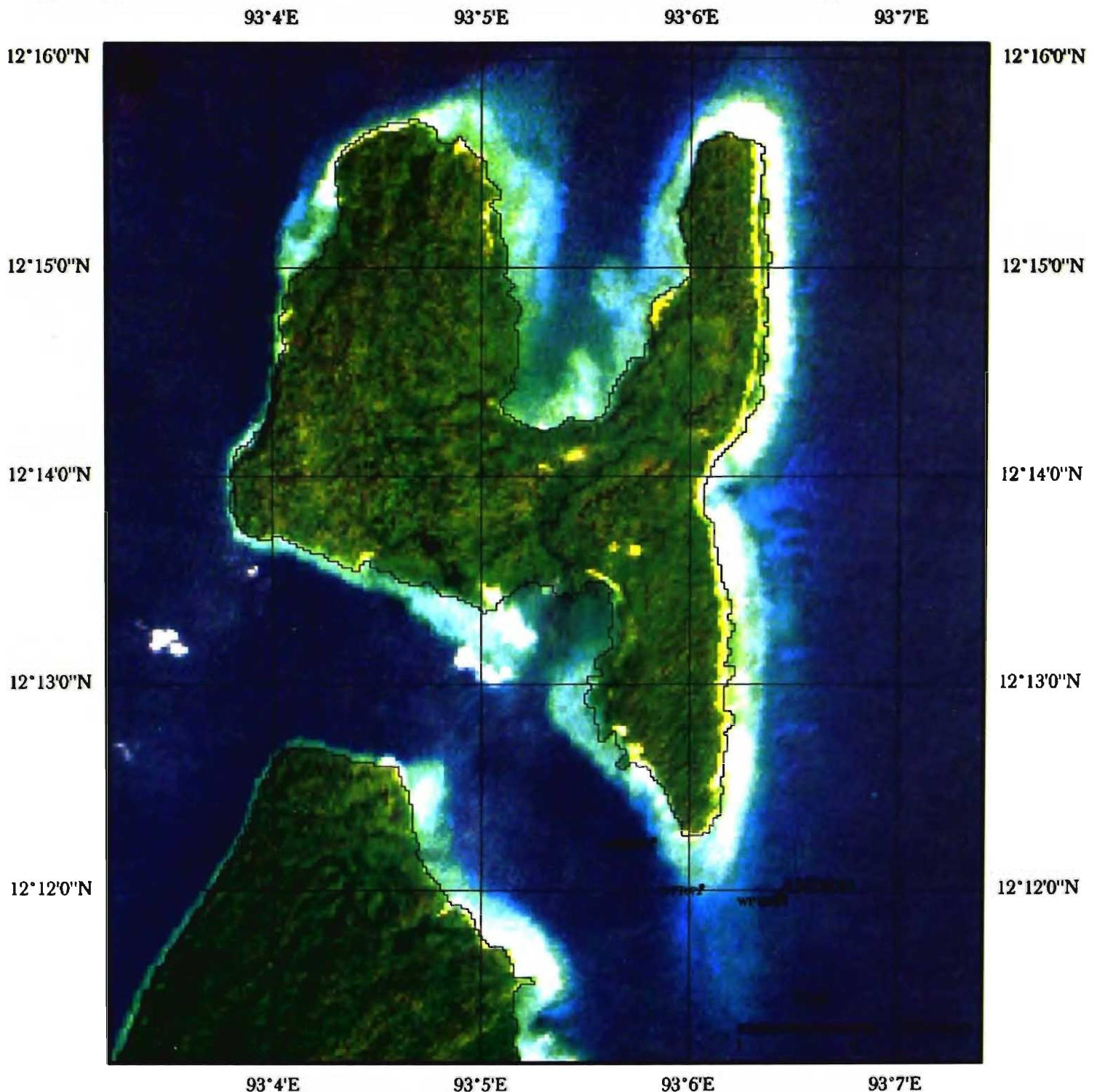


Fig. 4.8a True colour composite (Landsat 7, R:ETM3, G:ETM2, B:ETM 1) of Outram Island showing ANDo10.

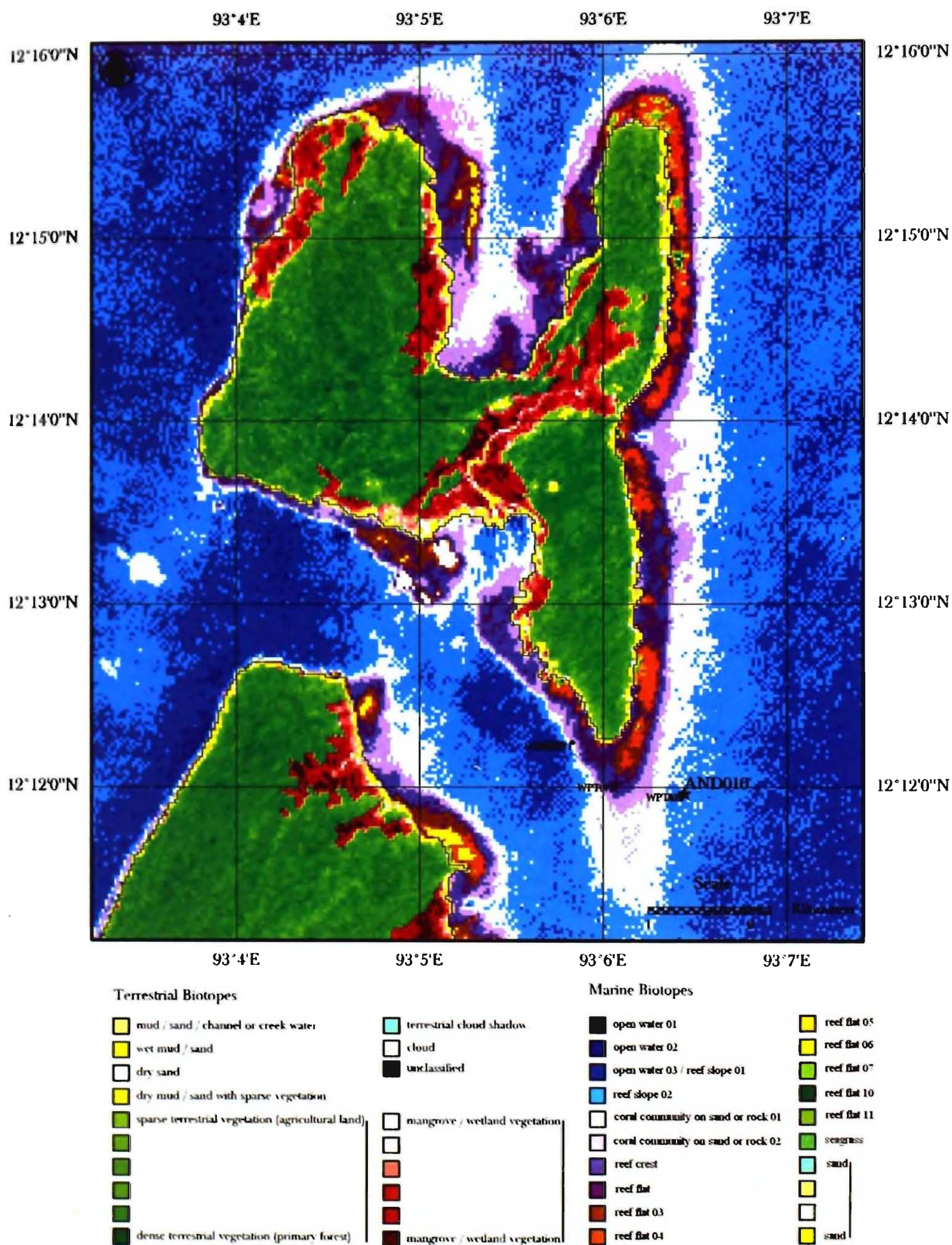


Fig. 4.8b. Terrestrial and Marine Biotope classification of Outram Island showing AND010.

STRUCTURE							% COVER											
CP	LB	SB	CB	FB	SN	SLT	HS	LH	CD	SC	MA	TA	CA	SG	SP	BA	ZOO	COR
0	1	3	0	3	2	2	2	4	2	2	0	1	2	0	0	0	0	0

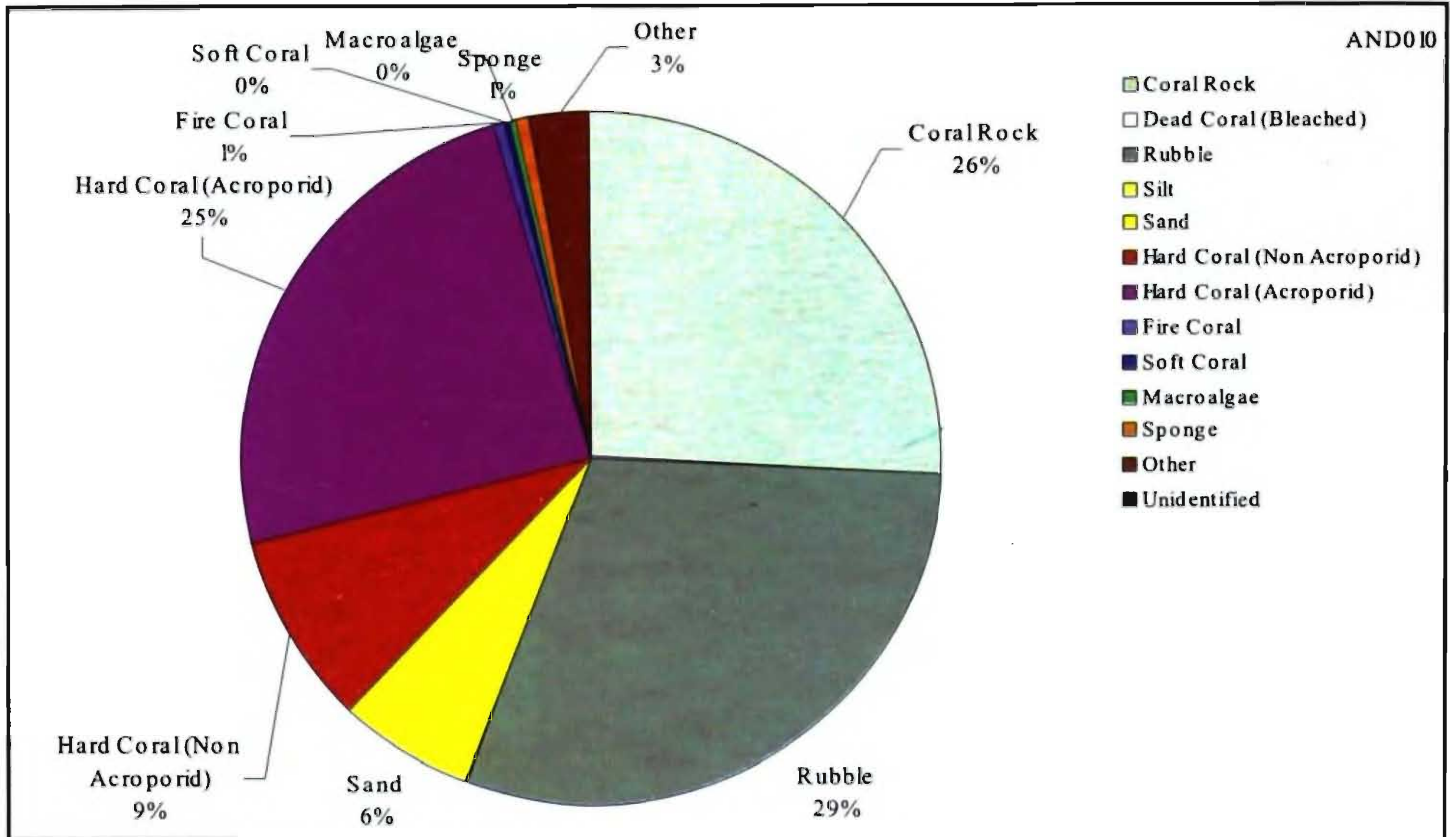


Fig. 4.8c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND010 (Outram Island).



Plate 9. South West Coast Outram Island. (Photos J.R. Turner)

Structure : Exposed bank reef with moderate flat site on exposed flat seabed at 11-15 m depth with coral colonies on sand. Poorly developed structure but very diverse and repeated topography. Some bare sand patches. Visibility was reduced and cold layer of water with suspended sediment appeared at change of tide.

Cover : Total cover consisted mainly of coral colonies on sand, 35% hard coral, 26% coral rock, 29% rubble, 6% sand. Numerous dead tables and small dead *Acropora* were found. Mixed colonies with the new undescribed brown digitate *Acropora*, small tables of *A. clathrata* and *A. cytherea*, small *Porites* mostly less than 50cm, some foliaceous *M. aequituberculata*, *Diploastrea*, *Millepora* (Fig. 4.8c).

SITE – ANDo11 (Henry Lawrence Island: East Coast – Lat. 12°6.067'N and Long. 93°3.313'E) – Fig. 4.9a & b, Plate 10.

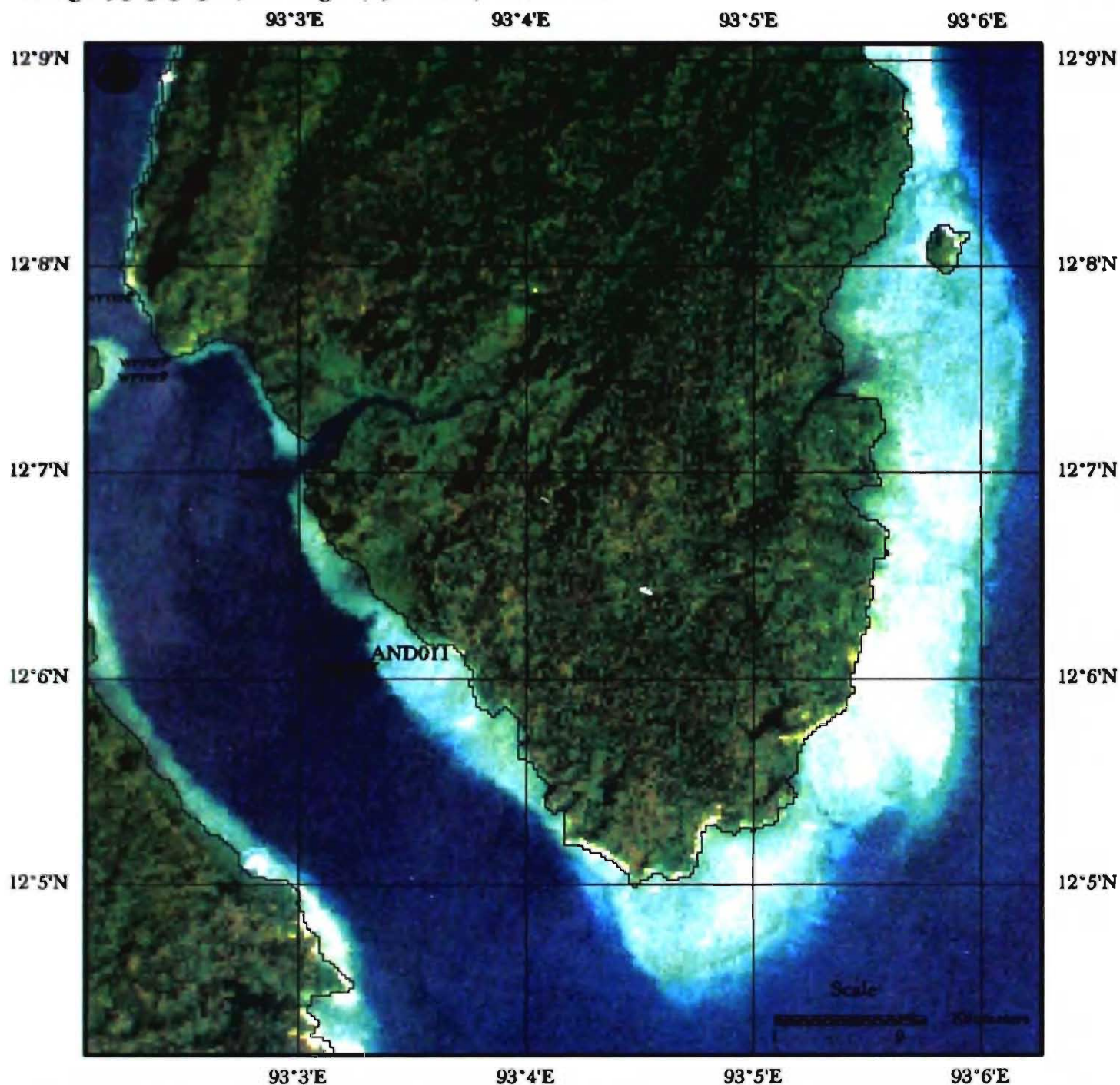
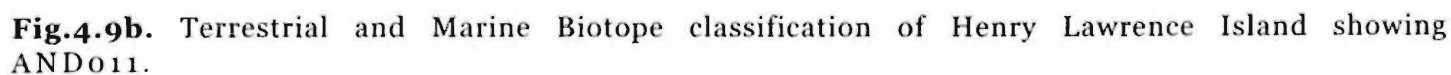


Fig. 4.9a True colour composite (Landsat 7, R:ETM3, G:ETM2, B:ETM 1) of Henry Lawrence Island showing ANDo11.



Henry Lawrence Island is also located in Rani Jhansi Marine National Park. Two reefs in this island have been surveyed. The depth of the reefs ranged from 4-18 m with the visibility of less than 10m. Sixty five species of corals were identified at this site.

STRUCTURE							% COVER												
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR	
0	4	4	0	2	3	3	4	3	1	2	1	1	1	0	1	0	0	0	

Structure : Fringing channel reef, with a steep slope and moderate flat, in a channel between islands with substantial water flow shelving to sand colonised by massive hard corals at the base. Close to an extensive mangrove system.

Cover : Total cover included hard coral 33%, coral rock 42%, rubble 10%, silt 6%. Silt from the mangrove had settled on the corals. The steeper slopes and shallows dominated by *Porites*. At the base of reef slope and in deeper water were *Goniastrea* and *Diploastrea heliopora*, *Lobophyllia hemprichii*, *Symphyllia radians* and *Favites abdita*, *Goniastrea pectinata*, *Physogyra lichensteini*, *Pleurogyra sinuosa*. Other species include the new brown digitate *Acropora*, *Acropora echinata*, encrusting *Montipora*, *Pachyseris*, and *Oxypora crassispinosa*. Other organisms such as *Gorgonids* and *Nepthea* are abundant as are anemones and sponges. Crinoids and sea fans observed as occasional to frequent (Fig. 4.9c)

Impacts : Silt from adjacent mangroves settled on corals

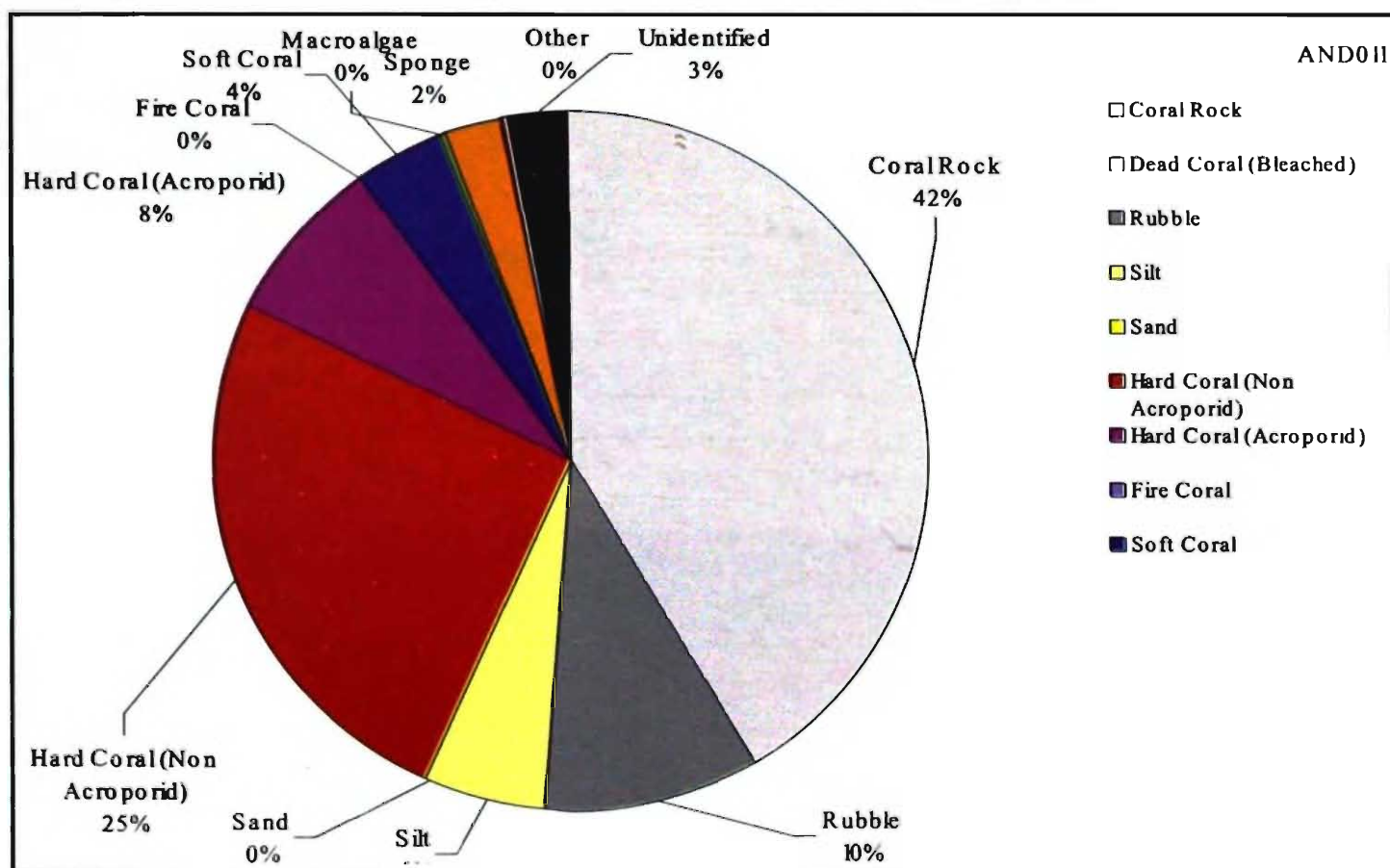


Fig. 4.9c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND011 (Henry Lawrence Island).

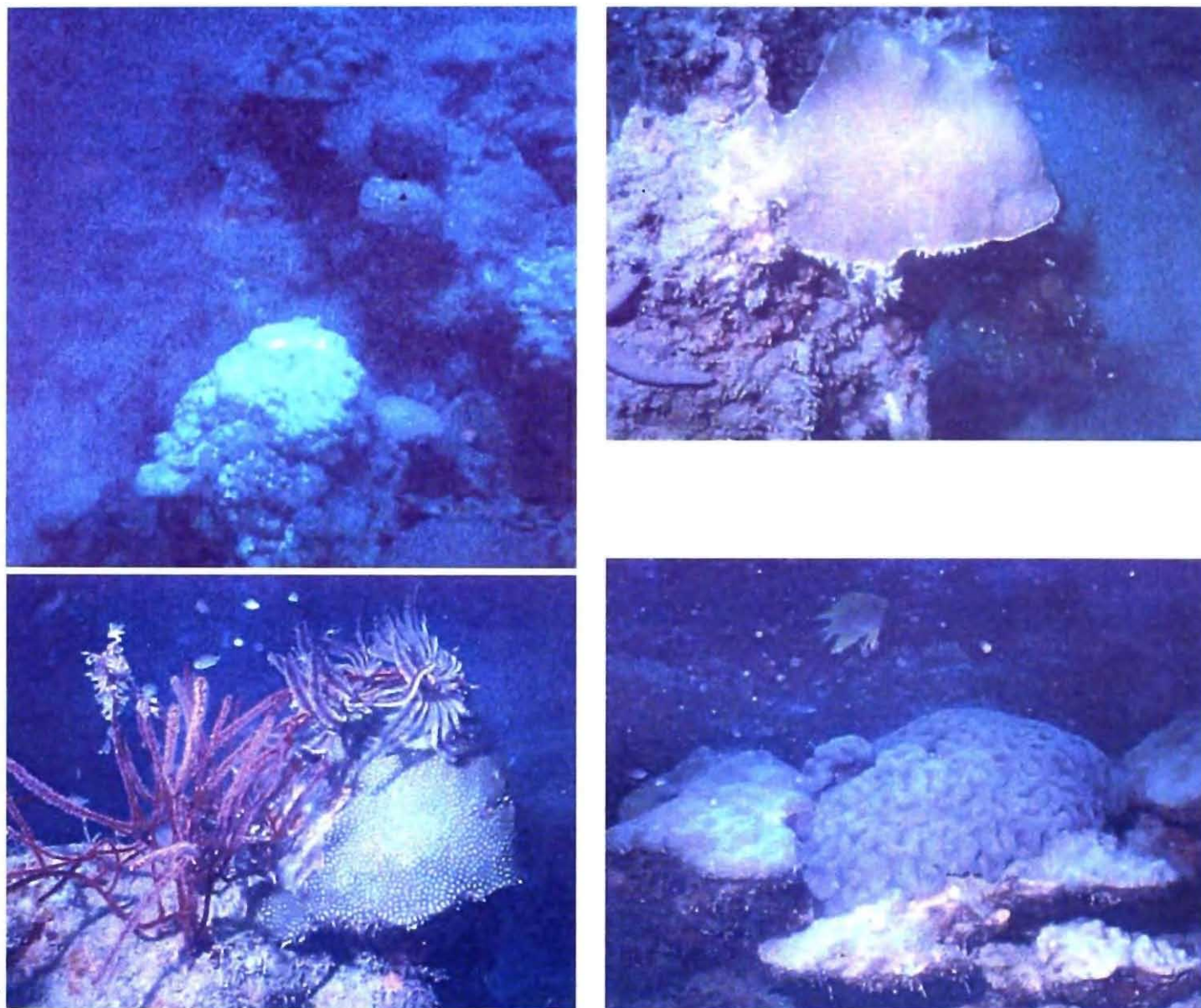


Plate 10. East coast of Henry Lawrence Island. (Photos J.R. Turnner)

SITE – ANDo12 (Minerva Ledges – Lat. 12°3.798'N and Long. 93°8.999'E)
Fig. 4.10a & b, Plate 11.

Three reefs under this site were surveyed. The depth of the reef was 9-12 m with the visibility of 20 m. Sixty five species of corals were recorded at this site.

STRUCTURE							% COVER												
CP	LB	SB	CB	RB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR	
0	2	6	0	2	2	0	5	5	1	2	0	1	1	0	1	0	0	0	

Structure : Offshore platform reef extending from 20m depth to 6 m depth east of John Lawrence Island in 14-11 m water depth. The substrate was constructed of some *Porites* pinnacles rising from 11 m 7 m depth. Surrounding these were low profile spurs of densely packed corals particularly *Acropora*. Oceanic condition exists at this site.

Cover : Coral cover is high (50% live hard coral) dominated by *Porites* and *Acropora* with the rest of the cover by coral rock (37%) and sand (2%). *Porites* pinnacles rising from 11m depth to 7 m depth. Low profile spurs of densely packed corals particularly *Acroporas* and these included the new brown digitate *Acropora*, *Acropora florida*, *A. gemmifera*, *A. hyacinthus*, *A. robusta* abundant *Pocillopora eydouxi*, *Pavona clavus*, *Symphyllia radians* and *Millepora*. Fish diversity is very abundant (Fig. 4.10c).

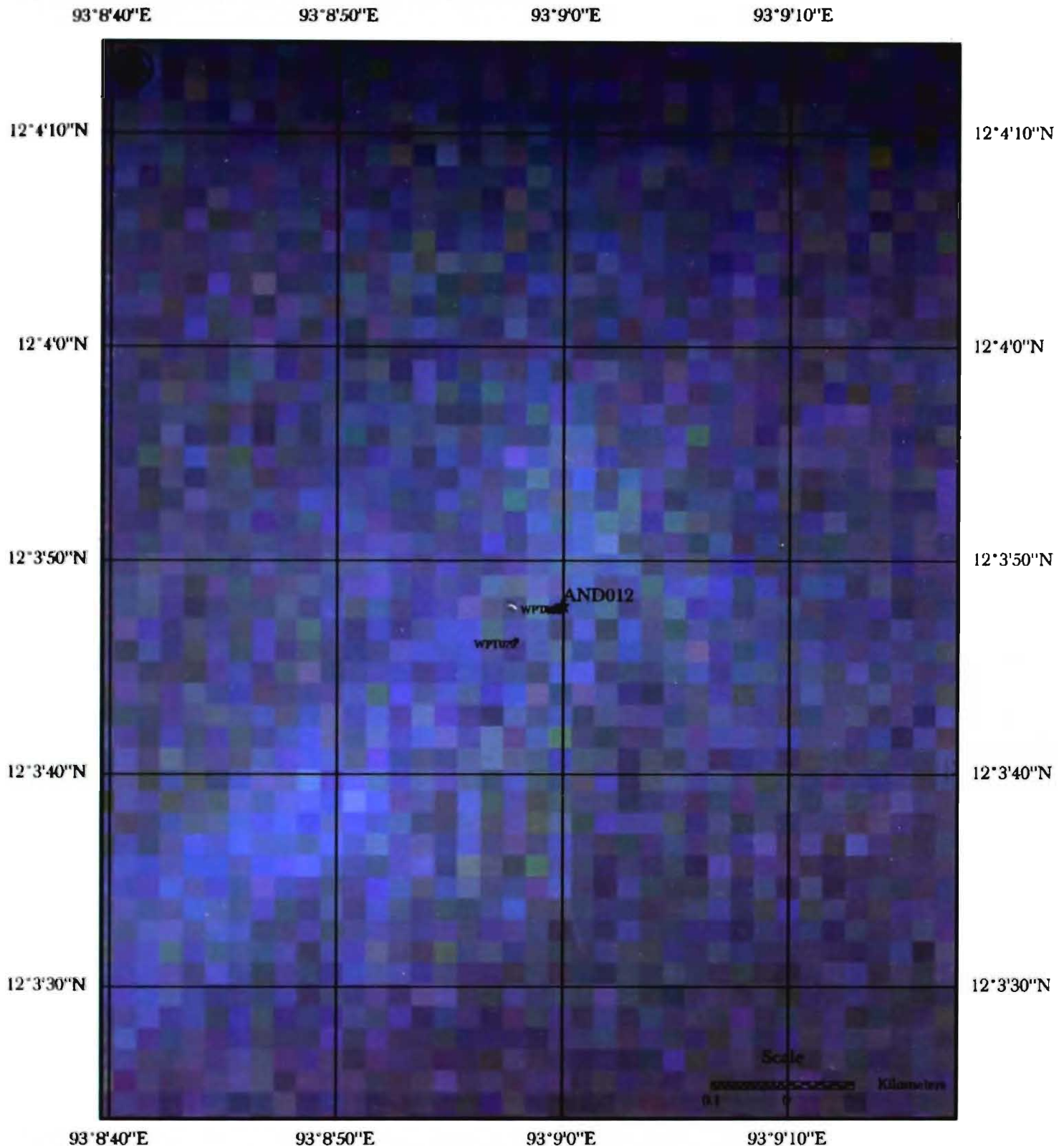


Fig. 4.10a. True colour composite (Landsat 7, R:ETM3, G:ETM2, B:ETM 1) of Minerva ledges showing AND012.

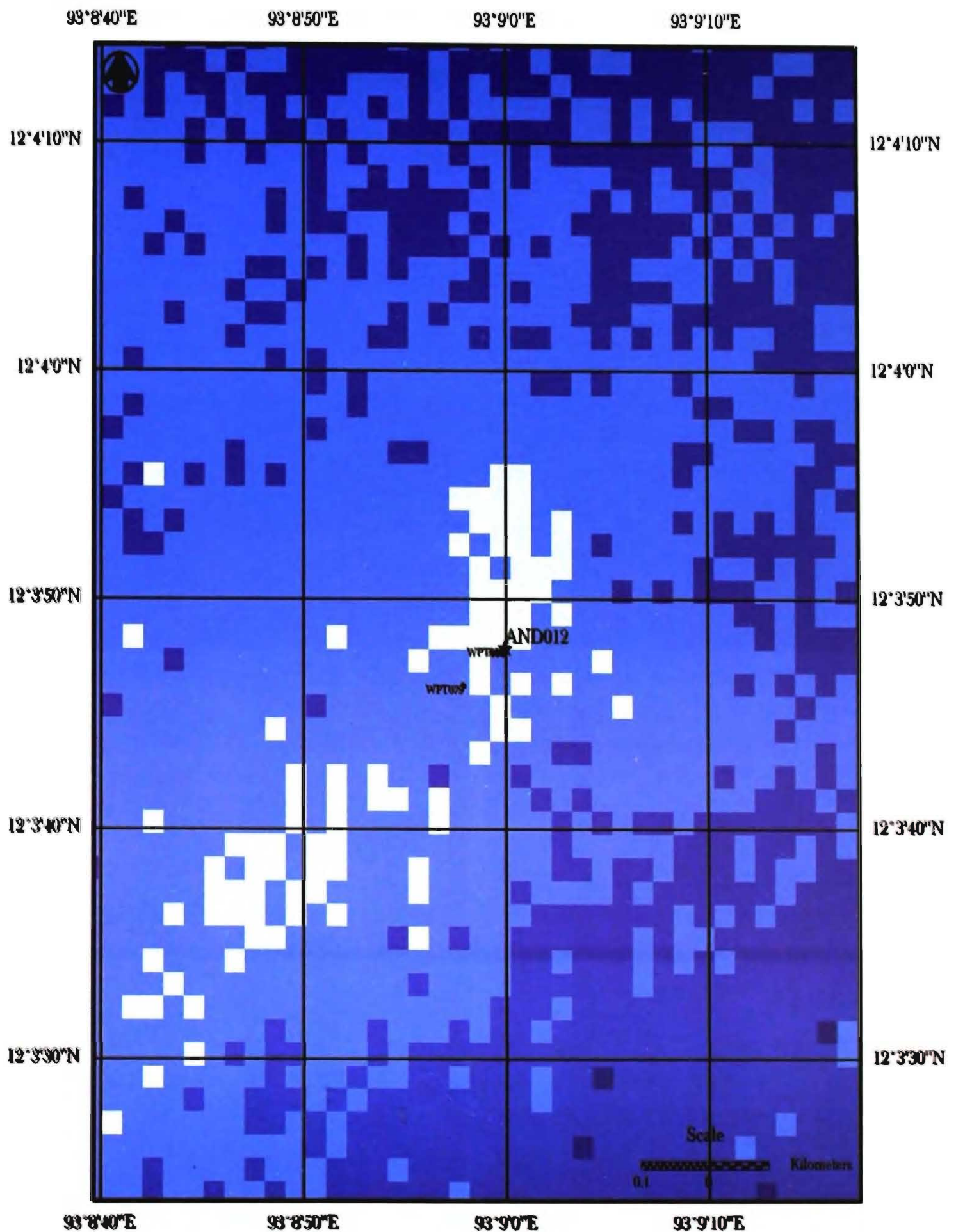


Fig. 4.10b. Terrestrial and Marine Biotope classification of Minerva Ledges showing AND012. (refer to Fig. 4.9b for legend).

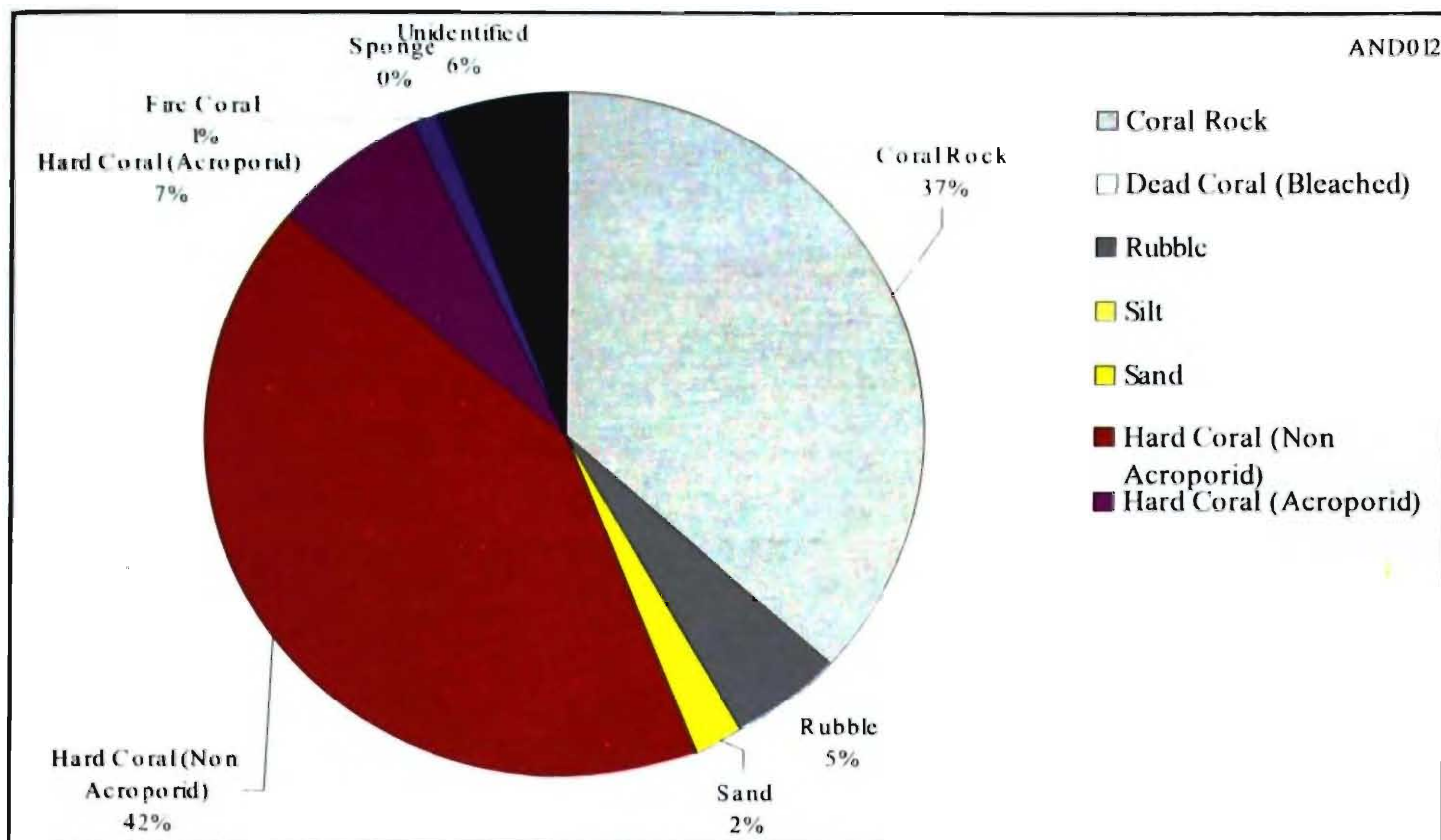


Fig. 4.10c. Percentage cover of different benthic categories as determined from the video data analysis from survey site AND012 (Minerva Ledges).

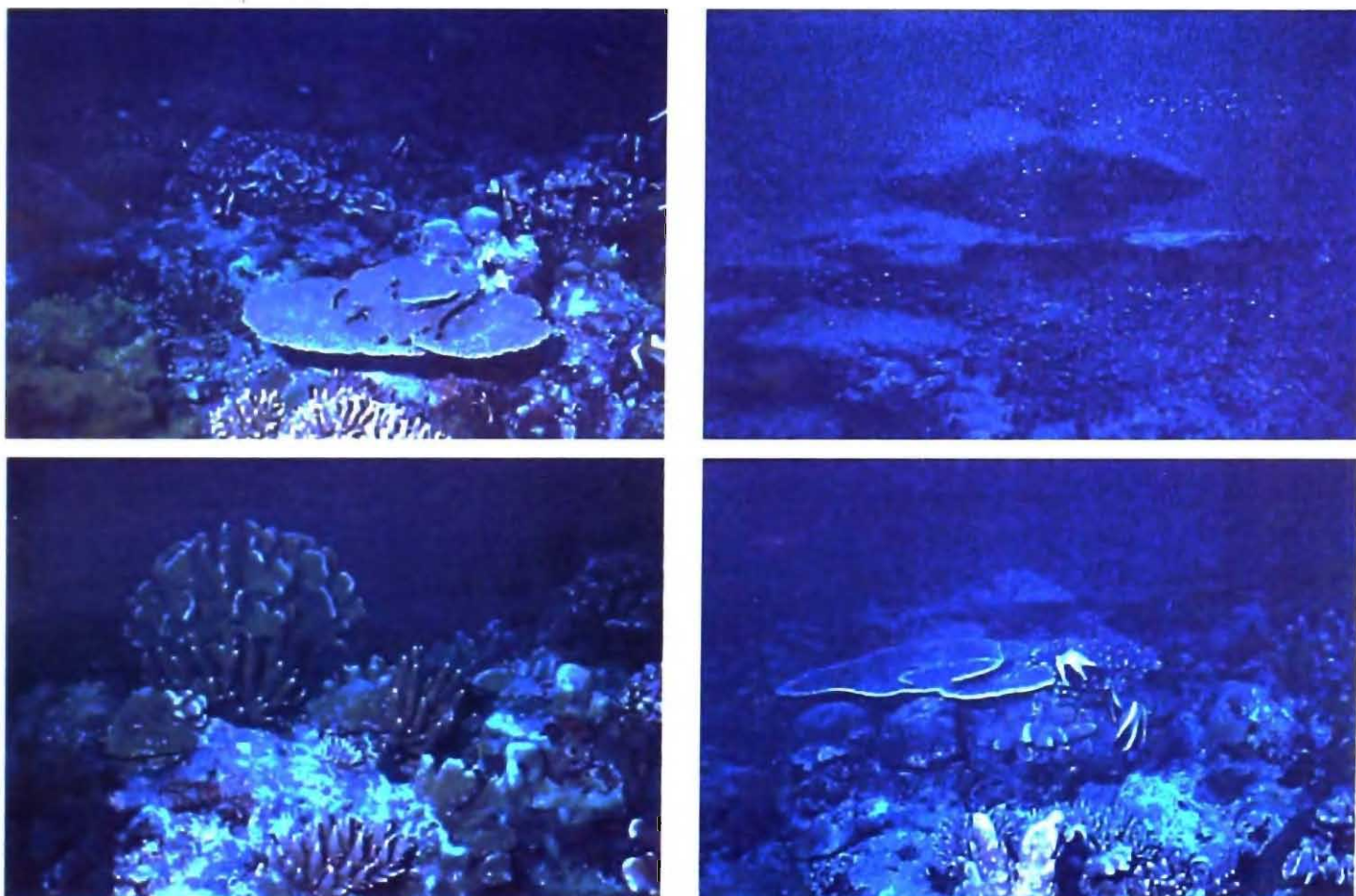


Plate 11. Minerva Ledges, Andaman. (Photos J.R. Turner)

SITE – AND013 (Neill Island: Ledges of Neill – Lat. 11°48.09'N and Long. 93°1.876'E) – Fig. 4.11a & b, Plate 12.

Four reefs in Neil Island have been surveyed. The depth of the survey area was 8-14 m with the visibility of 15 m. A total of 45 species of corals were recorded at this site.

STRUCTURE							% COVER												
CP	LB	SB	CB	FB	SN	SLT	HS	LHC	DSC	SC	MA	TA	CA	SG	SP	BA	ZOO	COR	
5	1	1	0	4	2	0	5	2	1	2	1	1	2	2	2	0	0	0	

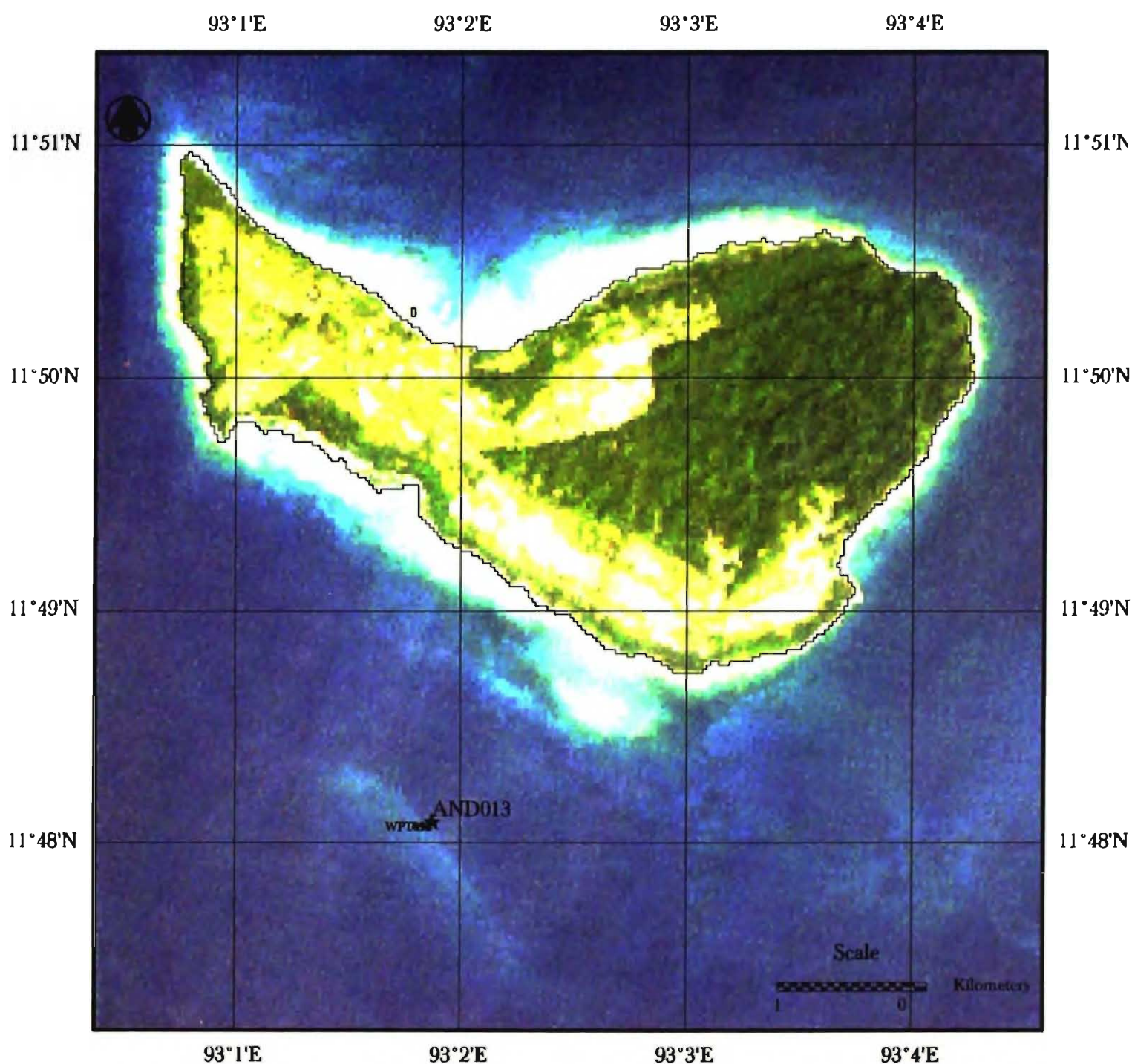


Fig. 4.11a. True colour composite (Landsat 7, R:ETM3, G:ETM2, B:ETM 1) of Neill Island showing AND013.

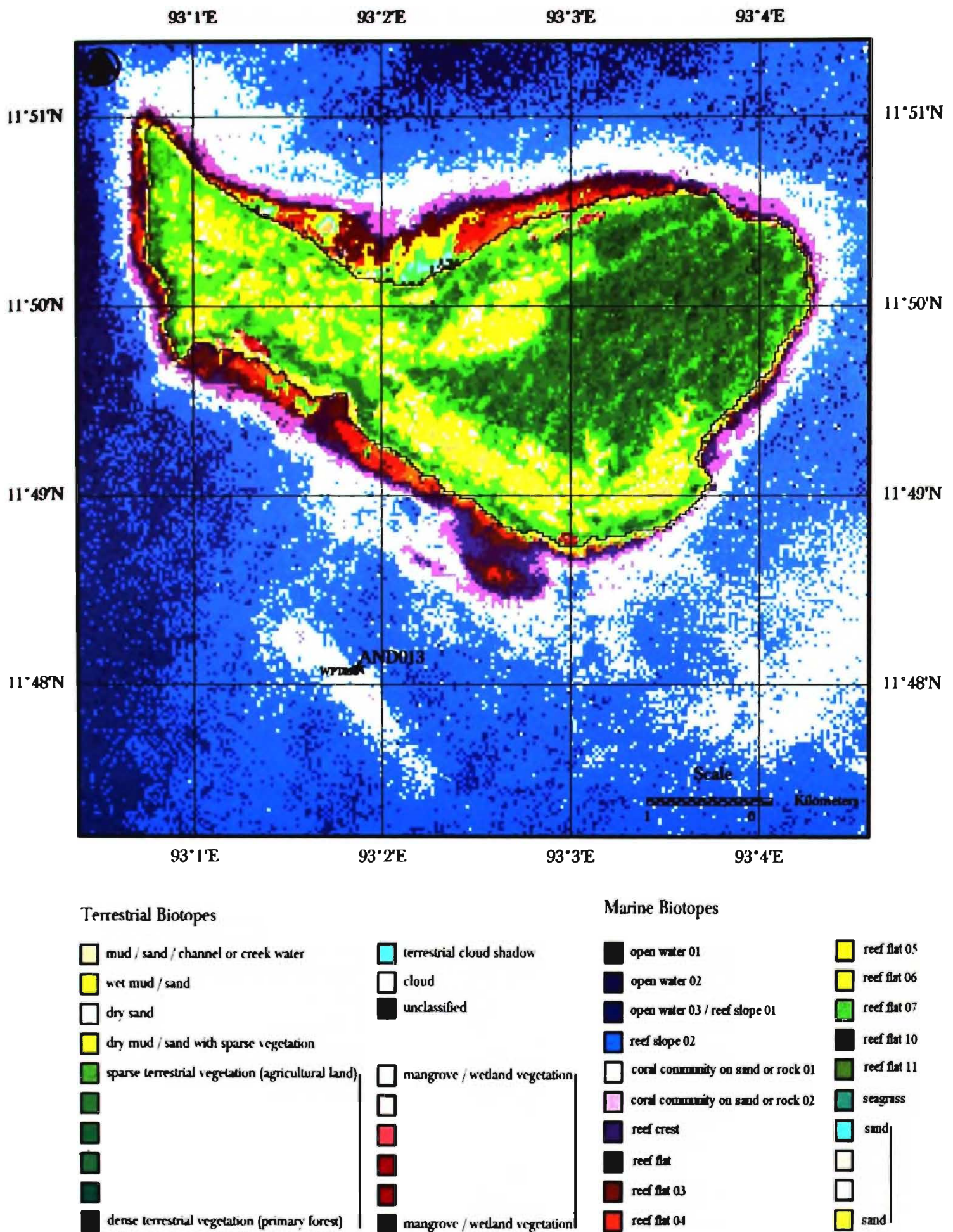


Fig. 4.11b. Terrestrial and Marine Biotope classification of Neill Island showing AND013.

Structure : Offshore rock ledges off Neill Island extending over a distance of about 400 m at depths of 8-14 m. Edges of the structure were stepped, and top surfaces inclined at a gradual angle. The ledges were exposed to strong current and waves action and colonised by small coral colonies and sponges, together with rippled sand and exposed bedrock.

Cover : Living coral cover was only 10% even though hard substrate was over 60% coral rock. Seagrass *Halophila ovata* was present at 14 m depth. There were abundant *Nephtid* soft corals. Other organisms included crinoids and sponges. Fish diversity is high at the time of survey.

The list of species recorded from different stations are presented in Table 3.9.

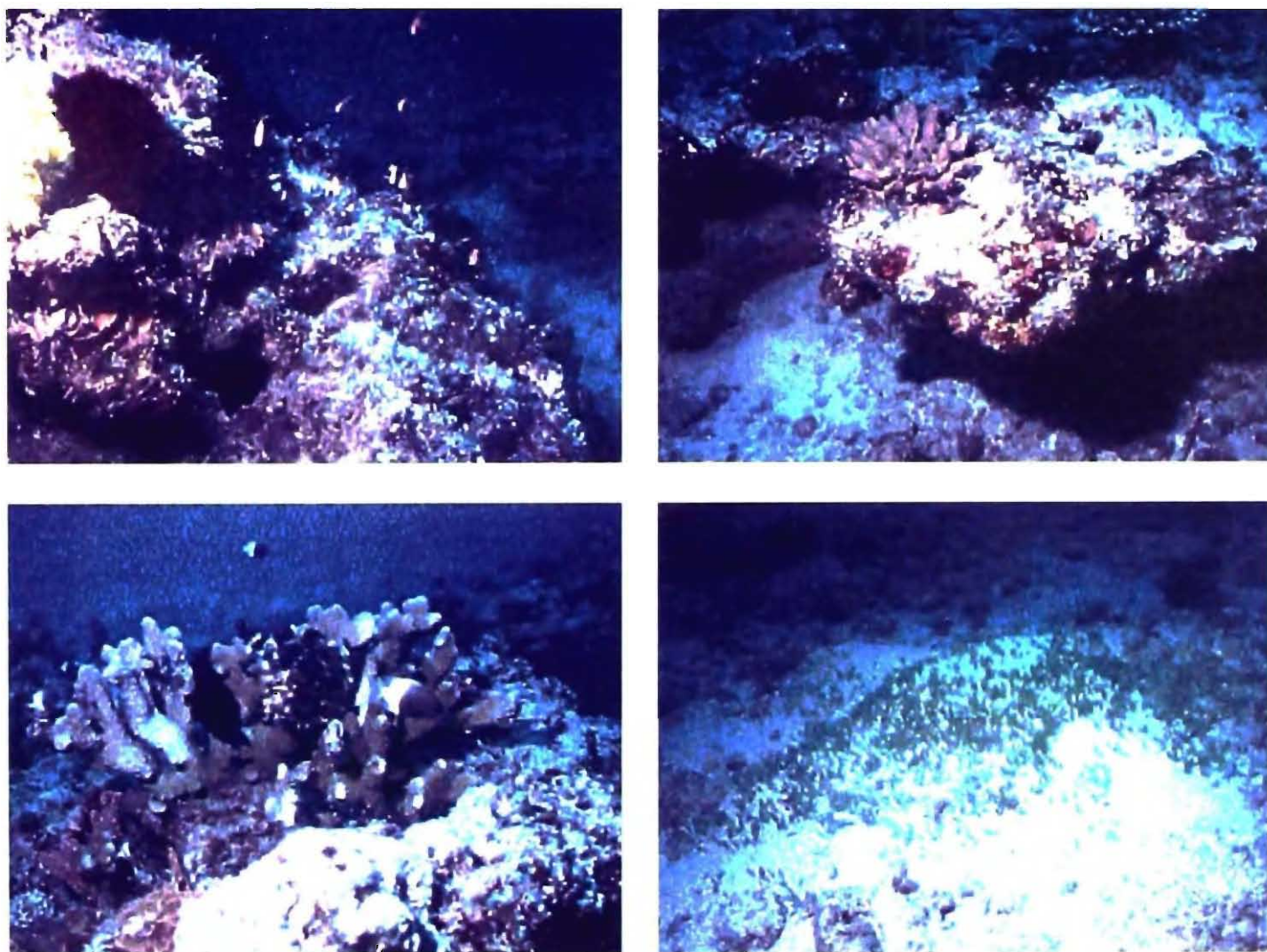


Plate 12. Ledges at Neill Island. (Photos J.R. Turner)

Table 3.9. Inventory of species recorded at the Andaman Islands, April 2001.

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
Family Astrocoeniidae												
<i>Stylocoeniella armata</i> (Ehrenberg, 1834)		+	+	+					+			
<i>Stylocoeniella guentheri</i> Bassett-Smith, 1890		+	+	+			-		+			
Family Pocilloporidae												
<i>Pocillopora damicornis</i> (Linnaeus, 1758)	+		+	+		+	+	+	+		+	
<i>Pocillopora eydouxi</i> Milne Edwards & Haime, 1860	+	+			+	+	+		+	+	+	
<i>Pocillopora meandrina</i> Dana, 1846								+	+			
<i>Pocillopora verrucosa</i> (Ellis & Solander, 1786)	+	+	+	+	+		+	+	+	+		
<i>Seriatopora caliendrum</i> Ehrenberg, 1834							+	+				
<i>Seriatopora hystrix</i> Dana, 1846	+			+			+	-	+	+		
<i>Stylophora pistillata</i>	+	+	+	+	+	+	+		+	+	+	+
Family Acroporidae												
<i>Acropora aspera</i>								+				
<i>Acropora</i> sp. 1 "brown digitate"					+	+				+	+	+
<i>Acropora austera</i> (Dana, 1846)	+	+						+		+		+
<i>Acropora brueggemanni</i> (Brook, 1893)									+	+	+	
<i>Acropora carduus</i> (Dana, 1846)										+		
<i>Acropora cerealis</i> (Dana, 1846)		+	+		+	+				+	+	+
<i>Acropora chesterfieldensis</i>									+	+	+	+

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
<i>Acropora clathrata</i> (Brook, 1891)	+			+	+	+	+					
<i>Acropora cophodactyla</i> (Brook, 1842)	+	+	+		+		+					
<i>Acropora cytherea</i> (Dana, 1846)							+					
<i>Acropora</i> sp. 1 "danai-like"		+										
<i>Acropora digitifera</i> (Dana, 1846)								?				
<i>Acropora divaricata</i> (Dana, 1846)						+						
<i>Acropora echinata</i> (Dana, 1846)											+	
<i>Acropora efflorescens</i>						+						
<i>Acropora florida</i> (Dana, 1846)	+	+	+			+			+	+	+	+
<i>Acropora formosa</i> (Dana, 1846)		+	+		+	+		+				
<i>Acropora gemmifera</i> (Brook, 1892)	+	+			+		+	+	+	+	+	+
<i>Acropora globiceps</i> (Dana, 1846)(?)			+		+							+
<i>Acropora grandis</i> (Brook, 1892)											+	
<i>Acropora granulosa</i> (Milne Edwards & Haime, 1860)	+						+		+			
<i>Acropora hemprichi</i>										+		
<i>Acropora humilis</i> (Dana, 1846)					+						+	
<i>Acropora hyacinthus</i> (Dana, 1846)	+	+				+		+	+	+		+
<i>Acropora kosurini</i> Wallace										+		
<i>Acropora loisetiae</i> Wallace, 1994										+		
<i>Acropora longicyathus</i> (Milne Edwards & Haime, 1860)											+	

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
<i>Acropora loripes</i> (Brook, 1892)	+											
<i>Acropora lutkeni</i> Crossland, 1952	+	+	+									+
<i>Acropora monticulosa</i> (Bruggemann, 1879)		+						+	+			+
<i>Acropora nasuta</i> (Dana, 1846)								+	+			
<i>Acropora nobilis</i> (Dana, 1846)								+		+		
<i>Acropora palifera</i> (Lamarck, 1816)	+	+	+			+	+	+		+	+	+
<i>Acropora palmerae</i>		+						+	+			
<i>Acropora paniculata</i> Verrill, 1902				+								
<i>Acropora proximalis</i>	+	+										
<i>Acropora pulchra</i> (Brook, 1891)								+		+		
<i>Acropora robusta</i> (Dana, 1846)		+	+			+		+	+			
<i>Acropora rudis</i>			+		+	+						
<i>Acropora samoensis</i> Brook, 1891)		+			+	+	+		+	+	+	+
<i>Acropora selago</i> (Studer, 1878)				+	+	+						
<i>Acropora solitaryensis</i> Veron & Wallace, 1984			+	+	+	+	+					
<i>Acropora spicifera</i> as in Wallace 1999						+						
<i>Acropora tenuis</i> (Dana, 1846)			+		+	+	+		+			+
<i>Acropora valenciennesi</i> (Milne Edwards & Haime, 1860)			+							+		
<i>Acropora vauhani</i> Wells, 1954			+		+		+			+		+
<i>Astreopora gracilis</i> Bernard, 1896		+	+				+					

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
<i>Astreopora listeri</i> Bernard, 1896			+									
<i>Astreopora myriophthalma</i> (Lamarck, 1816)	+	+	+		+	+	+		+	+		+
<i>Astreopora randalli</i> Lamberts, 1980						+					+	
<i>Astreopora suggesta</i> Wells, 1954						+						
<i>Montipora aequituberculata</i> Bernard, 1897								+				
<i>Montipora caliculata</i> (Dana, 1846)						+						+
<i>Montipora capitata</i> Dana, 1846						+						
<i>Montipora digitata</i>												
<i>Montipora foveolata</i> (Dana, 1846)		+	+		+					+		
<i>Montipora meandrina</i>									+		+	
<i>Montipora tuberculosa</i> Lamarck, 1816)			+									
<i>Montipora turgescens</i>			+									
<i>Montipora venosa</i> (Ehrenberg, 1834)			+							+		+
<i>Montipora verrucosa</i> (Lamarck, 1816)	+		+	+		+				+		
<i>Montipora vietnamensis</i> Veron, 2000								+				
Family Poritidae												
<i>Porites annae</i> Crossland, 1952									+		+	
<i>Porites cylindrica</i> Dana, 1846									+		+	
<i>Porites evermanni</i> Vaughan, 1907	+		+				+					+
<i>Porites monticulosa</i> Dana, 1846									+		+	

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
<i>Porites rus</i> (Forskal, 1775)	+		+					-	+		+	
<i>Porites vauhani</i> Crossland, 1952		+		+	+	+	+		+	+	+	+
Family Siderasteridae												
<i>Coscinaraea columna</i> (Dana, 1846)										+		
<i>Coscinaraea crassa</i>				+	+	+	+					
<i>Psammocora contigua</i> (Esper, 1797)			+						+		+	
<i>Psammocora digitata</i> Milne Edwards & Haime, 1851	+		+					+				+
<i>Psammocora explanulata</i> van der Horst, 1922						+						
<i>Psammocora haimeana</i> Milne Edwards & Haime, 1851						+						
<i>Psammocora profundacella</i> Gardiner, 1898	+			+			+		+		+	
<i>Psammocora superficialis</i> Gardiner, 1898	+		+									
Family Agariciidae												
<i>Coeloseris mayeri</i> Vaughan, 1918	+	+	+			+	+	+		+	+	+
<i>Gardineroseris planulata</i> Dana, 1846	+	+	+		+	+			+	+	+	
<i>Leptoseris explanata</i> Yabe & Sugiyama, 1941											+	
<i>Leptoseris hawaiiensis</i> Vaughan, 1907	+											
<i>Leptoseris incrustans</i>						+						+
<i>Leptoseris mycetoseroides</i> Wells, 1954	+	+	+	+	+							+
<i>Leptoseris scabra</i> Vaughan, 1907									+			
<i>Leptoseris yabei</i> (Pillai & Scheer, 1976)						+						

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
<i>Fungia moluccensis</i> Horst, 1919									+			
<i>Fungia paumotensis</i> Stutchbury, 1833				+	+	+	+		+		+	
<i>Fungia repanda</i> Dana, 1846					+		+					
<i>Fungia scutaria</i> Lamarck, 1816				+	+				+			
<i>Herpolitha limax</i> (Houttuyn, 1772)				+					+			
<i>Lithophyllon undulatum</i>				+		+			+		+	
<i>Podabacia lanakensis</i> Veron, 2000				+	+				+	+		
<i>Polyphyllia talpina</i> Lamarck, 1801							+		+	+		
<i>Sandalolitha dentata</i> Quelch, 1884									+			
Family Oculinidae												
<i>Galaxea acrhelia</i>											+	
<i>Galaxea astreata</i> (Lamarck, 1816)	+	+	+	+		+	+			+		+
<i>Galaxea fascicularis</i> (Linnaeus, 1767)		+	+	+	+	+	+	+		+		+
Family Pectinidae												
<i>Echinophyllia aspera</i> (Ellis & Solander, 1788)			+		+		-		+		+	
<i>Echinophyllia echinata</i> (Saville-Kent, 1871)						+						
<i>Echinophyllia echinoporoides</i> Veron & Pichon, 1979						+						
<i>Mycedium elephantotus</i> (Pallas, 1766)			+	+	+	+	+		+	+		
<i>Oxypora crassispinosa</i> Nemenzo, 1979			+	+	+	+	+		+	+	+	
<i>Oxypora lacera</i> Verrill, 1864			+	+	+	+	+		+			

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
<i>Scapophyllia cylindrica</i> Milne Edwards & Haime, 1848	+		+			+				+	+	
Family Faviidae												
<i>Diploastrea heliopora</i> (Lamarck, 1816)	+	+	+	+	+		+		+	+	+	+
<i>Echinopora gemmacea</i> Lamarck, 1816	+	+	+		+	+	+	+	+	+	+	
<i>Echinopora hirsutissima</i> Milne Edwards & Haime, 1849	+		+		+	+			+			
<i>Favia pallida</i> (Dana, 1846)												+
<i>Favia rotundata</i> Veron & Pichon, 1977			+			+	+				+	
<i>Favia stelligera</i> (Dana, 1846)		+	+		+	+	+	+	+		+	
<i>Favia truncatus</i> Veron, 2000			+			+			+	+	+	
<i>Favites abdita</i> (Ellis & Solander, 1786)	+	+	+			+		+	+		+	+
<i>Favites acuticollis</i>			+									
<i>Favites halicora</i> (Ehrenberg, 1834)			+							+		
<i>Favites pentagona</i> (Esper, 1794)					+							
<i>Goniastrea edwardsi</i> Chevalier, 1971			+					+	+	+		
<i>Goniastrea minuta</i>							+	+	+			
<i>Goniastrea pectinata</i> (Ehrenberg, 1834)		+	+			+			+		+	
<i>Goniastrea retiformis</i> (Lamarck, 1816)	+	+	+	+	+	+	+		+	+	+	+
<i>Leptastrea purpurea</i> (Dana, 1846)		+	+						+		+	
<i>Leptastrea transversa</i> Klunzinger, 1879			+	+		+	+					+

[illegible]

SPECIES	1	2	3	4	5	6	7	8	9	10	11	12
Family Dendrophylliidae												
<i>Tubastraea coccinea</i> Lesson, 1829			+						+			
<i>Tubastraea diaphana</i>		+	+									
<i>Tubastraea micranthus</i> Ehrenberg, 1834			+									
<i>Turbinaria mesenterina</i> (Lamarck, 1816)			+		+							
<i>Turbinaria stellulata</i> (Lamarck, 1816)	+		+	+		+	+				+	
Family Heliporidae												
<i>Heliopora</i> sp 1 "short"						+		+				+
Family Clavulariidae												
<i>Tubipora musica</i> Linnaeus, 1758					+							
Family Milleporidae												
<i>Millepora dichotoma</i>		+							+			
<i>Millepora exaesa</i>		+	+		+	+	+		+	+		+
<i>Millepora intricata</i>	+	+			+				+			
<i>Millepora murrayensis</i>			+					+	+	+		
<i>Millepora platyphylla</i>			+		+			+	+	+		
Family Stylasteridae												
<i>Stylaster</i> sp. 1 orange or pink			+				+					
<i>Distichopora violacea</i> (Ellis & Solander, 1788)			+			+	+	+				
Total	51	49	82	43	67	81	50	32	88	68	65	45

3.4. DIVERSITY OF CORALS

Andaman and Nicobar Islands are the richest of the Indian region in coral diversity with as many as 228 species belonging to 58 genera and 18 families (Venkataraman *et al.*, 2003). The chief contributing families are Acroporidae (74 species), Faviidae (31 species), Agariciidae (24 species), Fungiidae (16 species) and Poritidae (15 species) (Table 3.10). Of these *Coeloseris mayeri* Vaughan under Agariciidae is so far known from Andaman waters. The generic diversity of corals were highest in the family Faviidae as it contributed 13 genera followed by Fungiidae (7 genera) and Agariciidae (6 genera). The generic representation of remaining families is 1 to 5 only. The common genera contributing reef formation in these islands are *Acropora*, *Montipora*, *Pocillopora* (branching type), *Porites*, *Goniopora*, *Favia* (massive type) and *Echinopora* (folioceous type). In addition the solitary *Fungia*, hydrocoral *Milleporina*, blue coral *Heliopora* and several gorgonaceans and alcyonaceans contribute to the formation and structure of the coral reef ecosystem.

Table 3.10. Family-wise species diversity of corals recorded from Andaman and Nicobar Islands.

Sl. No.	Family	Genera	Species
1.	Astrocoeniidae	1	2
2.	Pocilloporidae	3	7
3.	Acroporidae	2	74
4.	Poritidae	2	15
5.	Siderasteridae	2	9
6.	Agariciidae	6	24
7.	Fungiidae	7	16
8.	Oculinidae	1	3
9.	Pectinidae	4	8
10.	Mussidae	5	9
11.	Merulinidae	3	8
12.	Faviidae	13	31
13.	Euphyllidae	2	6
14.	Dendrophyllidae	2	5
15.	Heliporidae	1	1
16.	Clavularidae	1	1
17.	Milleporidae	1	5
18.	Stylasteridae	2	2
	Total	58	228

3.5. PRE-TSUNAMI STATUS OF CORALS

The status of live coral cover of Andaman and Nicobar Islands was estimated by INTACH during 1988-90 and by the Zoological Survey of India (ZSI) under UNDP programme during 2000 and the data are depicted in tables 2 and 3. The study revealed that the percentage cover of live corals in Middle Andaman is up to 70.6% while in Nancowry Island 60.5% (Table 3.11). In general the reefs of these islands are one of the healthiest and least impacted of the other Indian reefs with the estimated average live coral coverage of 55% (Jeyabaskaran, 1999).

Table 3.11. Percentage of live coral cover in reef area of Andaman and Nicobar Islands.

Reef Area	Live coral cover	Status
Middle Andaman	57.0 -70.6%	Good
North Andaman	49.0 54.0%	Fair to Good
Ritchie's Archipelago	32.0 59.1%	Fair to Good
Mahatma Gandhi Marine National Park (South Andaman)	40.0 55.0%	Fair to Good
Car Nicobar	39.2 57.6%	Fair to Good
South Andaman	13.8 47.7%	Poor to Fair
Little Andaman	10.8 30.9%	Poor
Great Nicobar	16.0 31.8%	Poor
Nancowry	34.0 60.5%	Fair to Good

The live coral cover in selected Islands has also been estimated by ZSI and the data indicated that the maximum of 58.29km² observed as Little Andaman followed by 30.81 km² at Great Nicobar Island while only 27.15 km² reported from Rani Jhansi Marine National Park which comprises of three islands (Table 3.12). Nayak *et al.* (1994) estimated total live coral reef area of these Islands is about 953.3 km². The quantification of reef areas has been carried out by Space Application Centre (MWRD 2000) using Landsat TM, IRS LISS II and SPOT satellite imagery. The reef area calculated by this study comprised 795.7 km² in Andaman Islands, 30.81 km² in Great Nicobar, 15.53 km² in North Reef, 27.15 km² in Rani Jhansi Marine National Park, 6.78 km² in Cinque and 58.29 km² in Little Andaman. However the existing records shows that the total reef area of these islands is about 2000km² i.e. 6% of the total continental shelf of these islands (Saxena *et al.*, 2008).

Table 3.12. Live coral cover in selected Islands of Andaman and Nicobar Islands.

Island	Live coral cover (km ²)
North Reef Island	15.53
Rani Jhansi Marine National Park (John Lawrence, Henry Lawrence and Outram Islands)	27 15
Cinque Island	6.78
Little Andaman Island	58.29
Great Nicobar Island	30.81

3.6. POST-TSUNAMI STATUS OF CORALS

A massive earthquake cum *tsunami* struck Andaman and Nicobar Islands posed geomorphological changes which caused irreparable devastation to coral reefs of these islands. The damages were extensive in North Andaman and Nicobar group islands. In consequent upon earthquake, the land mass of North and Middle Andaman was uplifted more than 1 m and submergence of land by 1.9m in Nicobar group of islands. This leads permanent exposure of coral reefs in North and Middle Andaman resulting 30% loss of coral cover while in South Andaman loss was estimated as 20%. According to the remote sensing data carried out by Space Application Centre during 2005, it is revealed that a total loss of coral reefs in Andaman Islands was 22978ha and in Nicobar Islands, 17180 ha.

Post-*tsunami* surveys have been conducted by ZSI in the selected islands of Andaman groups and Nicobar groups during 2007-2008 in order to find out the present status of live coral cover and the results are presented in tables 4.13 and 3.14. The results of the study revealed that loss of coral reef covers in 7 islands of Mahatma Gandhi Marine National Park ranged from 27.27 to 71.43% due to the impact of *tsunami*. However, in Grub Island reverse trend has been observed as the 30% increment has been noticed in total coral cover area (Table 3.13). This might be due to the geographical location of this island which is not affected *tsunami* waves as it is enclosed by labyrinth group of islands in the marine national park.

Table 3.13. Estimated loss of live coral cover in Mahatma Gandhi Marine National Park, South Andaman.

Island (pre-tsunami)%	Live coral cover (post-tsunami)%	Live coral cover	Loss(%)
Alaxendra Island	30	15	50.00
Bellie Island	35	10	71.43
Boat Island	16	10	37.50
Chester Island	55	40	27.27
Grub Island	42	60	30.00 (gained)
Redskin Island	33	20	39.40
Snob Island	37	20	45.95

The estimated loss of live coral cover in selected islands ranged from 13% in Noncowry Island to 90% in Little Nicobar Islands. The species belonging to the genera *Acropora*, *Montipora*, *Pocillopora*, *Porites*, *Platygyra*, *Goniastrea* etc. are the mostly affected corals (Table 3.14). It is also noted that in Car Nicobar Island reefs were damaged up to the depth of 20m.

Table 3.14. Estimated loss of live coral cover in selected Nicobar group Islands.

Island	Loss of live coral cover (%)	Affected Genera/Species
Andaman group		
Landfall Island	85	<i>Acropora florida</i> , <i>A. cytheria</i> , <i>A. monticulosa</i> , <i>A. humilis</i> , <i>A. palythoa</i> , <i>A. palifera</i> and <i>A. hyacinthus</i>
East Island	70	<i>Acropora</i> , <i>Platygyra</i> , <i>Pocillipora</i> , <i>Symphyllia</i> and <i>Porites</i>
Smith & Ross Islands	82	<i>Acropora</i> , <i>Porties</i> , <i>Montipora</i> , <i>Porites</i> and <i>Favites</i>
Aves Island	19	<i>Acropora</i> and <i>Porties</i>
North Reef	77	<i>Acropora</i>
Interview Island	80	<i>Diploastrea heliopra</i>
Nicobar group		
Car Nicobar Island	70	<i>Acropora</i> , <i>Pocillopora</i> and <i>Montipora</i>
Teressa Island	37	<i>Montipora</i> , <i>Porites</i> and <i>Platygyra</i>
Camorta Island	80	<i>Montipora</i> , <i>Porites</i> and <i>Platygyra</i>
Katchal Island	49	<i>Montipora</i> , <i>Porites</i> and <i>Pocillopora</i>
Trinket Island	62	<i>Acropora</i> , <i>Porites</i> , <i>Montipora</i> and <i>Goniastrea</i>
Nancowry Island	13	<i>Pocillopora</i> , <i>Porites</i> and <i>Echinopora</i>
Little Nicobar Island	90	<i>Acropora</i> , <i>Pocillopora</i> and <i>Montipora</i>
Great Nicobar Island	70	<i>Acropora</i> , <i>Pocillopora</i> and <i>Montipora</i>

The mortality of corals in Andaman group of islands is mainly due to the exposure of reefs while in Nicobar groups the damages caused by severe wave action. Most of the massive corals are uprooted and turned upside down while branching type corals broken in wider extent. Deposition of sand, mud and detritus on reefs in Nicobar Islands has been observed as these islands are in the proximity of epicenter of the earthquake which generated heavy siltation and spread across by oceanic currents. ZSI's recent survey conducted during February 2008 in Nicobar Islands revealed out the abundant growth of soft coral *Sinularia* sp over grown on the corals especially Teresa, Trinket and Nancowry Islands.

3.7. STATUS OF NEW CORAL RECRUITS

Recruitment of new colonies was estimated in some of the *tsunami* affected islands were surveyed by LIT method (English *et al.*, 1994) during March to November 2008. The results indicated the recuperation of corals was found in most of the islands and density of coral varied from 14 to 22 colonies/10 m² area with the species diversity (H') of 1.98 - 2.85 in Rutland Island of South Andaman. However in Nicobar group it was recorded as 8–12 colonies/10m² with the species diversity of 1.73–2.18 in Great Nicobar Island. The species composition also verified through field study and it shows 103 species under 39 genera and 17 families in the Jolly Buoy Island of Mahatma Gandhi Marine National Park and 104 species of coral belonging to 24 genera and 8 families in the North Bay region of South Andaman indicated the recuperation of coral in the affected areas are underway.

4.0. DISCUSSION

Preliminary results of mapping the coral reef ecosystems of the northern Andaman Islands using two Landsat 7ETM+ satellite scenes and a rapid ground truth survey at selected sites have been presented. The approach is appropriate given the large area, isolation, and lack of supporting infrastructure to support detailed field studies at the present time.

The total area of reef flat was estimated to be 258.56 km², and the area of shallow reef slope and reef crest was 261.62 km², giving a total area of shallow reef of 520.18km² around the northern Andaman covered by the images. Previous estimations by MWRD (2000) indicated that coral reefs covered 795.7 km² around Andaman. The difference of 275.52 km² is probably due to the difference in satellite sensors, although a lower estimation would have normally be expected from SPOT used by MWRD (2000) because of the poorer depth penetration of the sensitive wavelengths when compared to Landsat 7 ETM. The area estimations from the current study indicate that when lagoon, banks, reef slope and reef flat are considered together, an area of 11,939 km² is derived, which compares with the estimation by Wafar (1986) of total reef area used in reef fisheries yield calculations as 11,000 km² for the Andaman.

The vegetation on the islands was mapped using Normalised Differential Vegetation Index and mangrove vegetation was distinguished using the classification of band ratio images. The area of mangrove present around the northern Andaman was estimated from the Landsat 7ETM satellite image as 517 km². MWRD (2000) using SPOT, estimated the area of mangrove around the Andaman to be greater at 679 km² (Table 1.1). It is not possible at present to explain the difference of 162km² of mangrove between the two studies. Mangroves were found on northward facing open shores, in sheltered areas between islands and on the inner edges of channels, often occurring within the proximity of fringing reefs. There are 27 species of mangrove on the Andaman Islands (Jagtap 1985) and 10 species on the Nicobars (Jagtap, 1991). The dominant mangrove species are *Rhizophora mucronata* and *R. stylosa* and the co-dominant is *Bruguiera gymnorhiza* while *Nypa fruticans* occurs upstream within estuaries and neritic inlets.

The percentage of undisturbed pristine forest vegetation calculated in this study ranges between 79.84% and 91% depending on the pixel values incorporated. Compared against those cited by MWRD (2000) and Jeyabaskaran (1999), where 86% of land around the Andaman and Nicobar Islands is reserve forest and 14% is agricultural land (note these figures include the Nicobar islands where exploitation of forestry resources for logging is lower than for the Andaman). Further conclusions on the extent of vegetation require ground truth data to validate the findings. Ramachandran (2000) reported forest extraction to have increased from 49,000m³ per year in the 1950s to 182,590 m³ in 1994, and agricultural land to have increased from 10,000 ha in 1940s to 48,000 ha in 1990s. Further, some 12,000 ha of mangrove have been removed for firewood.

There was insufficient data available to attempt a fully supervised classification of all habitats and communities of the islands, due to limitations in field time, and because sites surveyed during the field mission were focused on coral dominated habitats. There is little quantitative literature available from previous surveys to support classifications based background information. The survey report by Jeyabaskaran (1999) contained quantitative data but unfortunately did not include the correct geographic coordinates to be able to relocate sites on images.

The reef structures observed around the Andaman Islands confirm to those reported by Reddiah (1977) and were mainly offshore coral growth on exposed banks, shallow gradual sloping fringing reefs windward shores, reef patches in bays, and steep sloping channel reefs in sheltered narrows. Extensive and moderate reef flats were found on fringing reefs around islands, and an extensive fully enclosed lagoon was only surveyed at North Reef (satellite imagery indicated extensive lagoon around Sentinel Island). The exposure to monsoonal conditions accounts for the gradual reef slopes and incipient coral growth on offshore banks. High profile spur and groove formations are absent although some low profile growth was apparent. Reef flats were most extensive on windward outer islands, and were usually prolonged north-south, with steeper slopes and greater

development at the points. Leeward shores and sheltered channels often contained turbid water and fine sediments of terrigenous origin covered the seabed, except where water currents were strong such as through narrows.

The surveys indicated little reef zonation, although it should be noted that the surveys were not designed to specifically to investigate such patterns. Most gradual reefs sloped onto flat or sloping sand. Plates of *Pachyseris* were often observed at the base of the slope, with mixed coral colonies up to 10 m depth, where *Acropora* tables often dominated. *Porites* colonies, often forming large domes or tall pinnacles were usually present around 7 m depth, and *Millepora*, branching and tabular *Acropora* and small (around 50 cm diameter) *Porites* colonies grew in shallow water. In many areas, these shallow (3-5 m) coral growths formed narrow reef slopes adjacent to moderate reef flats close inshore. Reef crests were rarely reached by the surveyors, but appeared to lack algal ridges.

The survey mission examined inaccessible and offshore areas away from human intervention. Impacts on the reef directly caused by man were rarely observed during the survey, and in general, the condition of the reefs and shores appeared pristine. There were no indications of fishing damage such as broken corals, ghost traps or lost lines. One anchor was found at Twin Islands, but anchor damage was not apparent anywhere. Poachers were encountered at North Reef Island. There was evidence of storm damage on windward reefs where coral tables were often upturned. Such colonies usually remained alive and showed signs of regrowth in their new orientation. Leeward and channel reefs close to shore were exposed to turbidity and sedimentation from terrigenous sediments, and it is likely that impacts caused by man are greater in areas close to human habitation. The human population and number of visitors to Andaman have increased over recent years, and activities causing environmental degradation are reported to be accelerating (Ramachandan, 2000). The effects of deforestation on estuaries, mangroves and coral reefs are poorly investigated, although some attempts have been made (Soundarajan, 1989). Urbanisation activities are increasing and wastewater runoff, quarrying of sand, harbour and jetty construction, buildings and roads are all increasing as a result, often causing shoreline erosion and sedimentation. Logging and sawdust dumping probably causes localised damage. Fishing is believed to cause localised damage in nearshore waters, but offshore fisheries are underexploited. *Trochus* and *Turbo* are believed to be over collected (Ramachandan, 2000).

The field mission encountered no reefs revealing direct damage resulting from coral reef bleaching. The surveyors were familiar with observations of bleaching and post bleaching degradation, having undertaken surveys of bleaching impacts in other parts of the Indian Ocean (Turner *et al.*, 1999; Turner *et al.*, 2000a, b). A finding of no bleaching damage is surprising because Pet Soede *et al.* (2000) reported that the bleaching event of 1998 affected the coral reefs of Andaman and Nicobar the greatest in the Indian region, with up to 80% bleaching, although

post bleaching mortality had not been assessed. However, the report was based on anecdotal information, and was probably based on observations from a shallow inshore environment close to inhabited areas. There may have been localised extensive mortality in shallow areas in bays close to shore.

Echinoderms were less abundant when compared to other Indian Ocean reefs. The urchins *Toxopneustes pileolus*, *Tripneustes gratilla*, *Diadema* spp, *Echinometra mathaei*, and *Echinothrix* spp. were not seen, and only one Crown of Thorns starfish *Acanthastrea planci* was recorded during the survey. *Echinostrephus molaris* was the most regularly observed urchin, usually embedded in coralline rock, and asteroids such as *Linckia* spp. and *Leiaster coriaceus* were usually present. Crinoids were common in the south, and Holothuria such as *Holothuria nobilis*, *H. atra*, *H. leucospilota*, *Thelenota ananas* and *Stichopus hermanni* were present but not as abundant as seen on western Indian Ocean reefs. *Tridacna* were seen amongst coral usually at 5-7 m, but most other Mollusca were less conspicuous, and species such as *Trochus* were rarely observed. Lobsters were regularly seen sheltering by day under large *Porites* outcrops.

The Andaman coral fauna is rich. 197 species and 59 genera of stony corals (187 species and 56 genera of zooxanthellate Scleractinia) were recorded during this field mission. Total species is less than found by the same observer in the Coral Triangle area of highest diversity consisting of the Philippines, Indonesia, and New Guinea, using the same methodology: 303 species in the Philippines, 315 in Sulawesi, and 318 in Milne Bay, PNG, and 331 in Irian Jia, Indonesia. However, more surveys were conducted during these other studies. At a comparable number of surveys, 237 species were found in Irian Jia, suggesting that the present survey found 83% of the number of species found in Irian Jia. Diversity was similar to sites on the east coast of Peninsular Malaysia, which also had about 80% of the diversity that was found in the Coral Triangle. The total number of species found in this study exceeds by 62, those previously reported (Pillai, 1983b). 35 of the previously reported species were azooxanthellate species, most of which are found only in much deeper water than coral reefs. In addition, the present study included only 13 surveys all on shallow coral reefs and thus represents only a first step in the assessment of coral diversity in the Andaman. The 187 species of zooxanthellate corals found in this study is greater than the 100 species of zooxanthellate corals previously reported (Pillai, 1983b). It is expected that further study will reveal additional species, especially when deeper sites and other habitats are examined. If the coral diversity in the Andaman is 80% of that in the Coral Triangle, about 400 coral species may eventually be found in the Andaman. When those species already reported in the literature, but not found in this survey, are accounted for, then about 170 species remain to be found. Four newly described species, previously found elsewhere, were also found around the Andaman Islands (Table 4.2). 223 species of Scleractinia (and a total of 234 species of all stony coral) have now been reported from the Andaman Islands (Tables 4.1, 4.2), when the results of the current mission are combined

with those of previous studies, probably representing about half of the total coral fauna of the Andaman.

Table 4.1. Numbers of stony coral species reported from Andaman shallow waters in published reports and the present study. Includes zooxanthellate scleractinia, shallow water azooxanthellate scleractinia, stony octocorals and hydrocorals.

Source	Reported	New Reports	Cumulative
Pillai, 1983a*	102	102	102
Other reports		20	122
Andaman public Aquarium display	About 30	1	123
This report	197	111	234

*All earlier literature (such as Scheer and Pillai, 1974) on Indian corals was reviewed in this article. Figures are adjusted to be consistent with the taxonomy of Veron (2000).

Table 4.2. Number of zooxanthellate Scleractinia reported from the Andaman in published reports.

Source	Reported	New Reports	Cumulative
Pillai, 1983a	100	100	100
Other reports		20	120
Andaman Public Aquarium display	About 30	1	121
This report	187	102	223

The coral fauna consists mainly of Scleractinia. The genera with the largest numbers of species found were *Acropora*, *Montipora*, *Pavona*, *Fungia*, *Porites*, *Platygyra*, *Leptoseris*, *Psammocora*, *Astreopora*, *Hydnophora*, and *Millepora*. These 11 genera account for about 59 % of the total observed species (Table 4.3). Families are less stable and useful in corals than genera, and thus were not used. *Montipora* and *Porites* had fewer species than is typical of Western Pacific reefs (Table 4.4). colonies of these two genera were noticeably uncommon at most sites; *Goniopora* and *Alveopora* were also comparatively rare, but it is not evident why. *Acropora*, *Montipora*, and *Porites* are usually the three most species-rich genera. Further down the coral genus list, the more variable the order becomes, with both the number of species and the differences between genera decreasing. Most of the corals were zooxanthellate (algae-containing, reef-building) Scleractinian corals, with 95% of the corals in this group. There were 3 corals that were azooxanthellate (lacking algae) Scleractinia for 1.5% of the total. And there were 9 corals that were not Scleractinia, for 4% of the total.

Table 4.3. Genera with the greatest number of species in the Andaman Islands.

Rank	Genus	Number of Species
1	<i>Acropora</i>	47
2	<i>Montipora</i>	11
3	<i>Pavona</i>	10
4	<i>Fungia</i>	9
5	<i>Porites</i>	6
6	<i>Platygyra</i>	6
7	<i>Leptoseris</i>	6
8	<i>Psammocora</i>	6
9	<i>Astreopora</i>	5
10	<i>Hydnophora</i>	5
11	<i>Millepora</i>	5

Table 4.4 Genera with the greatest number of species from West Pacific sites, East & West Australia, Philippines & Japan from Veron (1993). Calam. = Calamian Is., Philippines, Sulawesi = Indonesia, PNG = Milne Bay, Raja Ampat = Irian Jia. Data are percent of coral fauna.

Speceis	E. Aus.	W. Aus.	Philip-pines	Japan	Calam.	Sula-wesi	PNG	Raja Ampat	Andaman Island
1. <i>Acropora</i>	19	18	17	19	13	16	22	21	24
2. <i>Montipora</i>	9	10	10	9	7	5	10	9	6
3. <i>Porites</i>	5	4	6	6	3	3	6	4	3
4. <i>Favia</i>	4	4	4	4	3	2	4	2	2
5 <i>Goniopora</i>	4	4	3	4	1	1	3	1	0
6. <i>Fungia</i>	4	3	4	3	4	3	4	3	5
7. <i>Pavona</i>	2	3	3	3	4	2	3	3	5
8. <i>Leptoseris</i>	2	2	2	3	4	2	3	2	3
9. <i>Cycloseris</i>	3	2	3	2	1	1	1	2	0
10. <i>Psammocora</i>	2	3	2	2	2	2	2	2	3

Most coral species found in this area have wide distributions within the Indo-Pacific. Most corals have a pelagic larval stage, with a minimum of a few days pelagic development for broadcast spawners, and larval settling competency lasting for a few weeks. A minority of species release brooded larvae that may be capable of anything from immediate settlement to a long pelagic dispersal period. Most have broad distributions that extend beyond the Andaman Islands to both the west and east; 90% have ranges that extend both west and east of the Andaman Islands. 9% have ranges that extend from the Andaman Islands only to the east, and just 1% have ranges that extend only to the west. Among those species that extend both east and west from the Andaman Island, a few have ranges that end in Sri Lanka, southern India, the Lakshweep Islands, or the Maldives. Thus, a large majority of the corals found in the Andaman Islands extend far to the west and east of the Andaman Islands, while a minority of species have ranges that extend to the east but for which the Andamans represent the western limit of their range. Very few species have the Andaman Islands as the eastern limit to their range. This is consistent with the fact that only a relatively small expanse of ocean separates the Andaman from other reef-bearing islands to the east and southeast, while a much larger gap separates the Andamans from the next coral reefs to the west in Sri Lanka and southern India.

It is recommended that future surveys in and around the Andaman and Nicobar Islands continue to use Landsat 7ETM data to map the shallow tropical marine habitats and biotopes on the basis that it is a cost effective and an efficient tool for mapping and monitoring large areas. The spectral and spatial resolution of Landsat 7ETM data are appropriate for shallow water mapping and the global coverage of Landsat satellites facilitates the comparability of satellite data between and within different regions. The temporal coverage of Landsat 7ETM data is lower than with previous satellites in the Landsat series, however this reduction in the number of scenes is compensated for by the reduction in cost per scene. When the Landsat 7 satellite was launched in April 1999, a Long Term Acquisition Plan (LTAP) was implemented which, instead of providing 16-day repeat coverage as in previous missions, specifies target scenes on specific dates. The reduction in the number of scenes acquired due to the LTAP contributed to a decrease in the cost of data handling and storage, which together with other factors resulted in a considerable cost reduction for each individual scene. Each scene now costs approximately \$600 compared to the previous cost of \$2500 per scene. Landsat 7ETM data is now a cost efficient tool for mapping and monitoring large areas of shallow marine habitats. Table 6.1 compares the cost of mapping the Andaman Nicobar Islands to other similar visible multispectral remote sensing data such as the Indian Remote Sensing (IRS) satellite data and SPOT.

Over one hundred corals were found for the first time in 13 surveys and approaching half of all the coral species are now known from the Andaman Islands. It is predicted that many more species of corals will be found in the Andaman when further studies are undertaken over a wider geographical range

encompassing a greater diversity of habitats. Further work should examine all coral samples previously collected from the Andaman and held in museums in Port Blair, Chennai, Delhi and other locations outside of India. Coral species should be photographed and all species not already represented in museum collections need to be collected and studied to verify the tentative species identifications based on observation only. The goal should be to publish a review of the Andaman coral species, similar to those published by Veron and Hodgson (1989) for the Philippines or Wallace and Wolstenholme (1998) for Indonesia. In addition, the Nicobar Islands have not been studied since Sheer and Pillai (1974), which was based on limited surveys. The Nicobar Islands remain a rich potential source of additional coral species, and should be included in future studies.

THREATS TO CORAL REEFS OF ANDAMAN AND NICOBAR ISLANDS

Reefs world over are threatened by natural and anthropogenic factors in large-scale as well as regional level. Climatic changes including bleaching of corals due to rise in sea surface temperature, hurricanes, cyclones, earthquakes and diseases are natural threats. The manmade threats are mostly limited and it includes pollution, dredging, sedimentation, anchorage, ship grounding and tourism. The potential threats for the coral reefs of Andaman and Nicobar Islands are as follows.

Bleaching : It occurs when the symbiotic algae that live in the endoderm tissue of the corals are expelled due to stress. Mass bleaching of corals observed in the reef of the Indo-Pacific coinciding with El Nino event in 1997-98. Western part of India lost much of their coral cover, whereas those on some part of the east coast of Sri Lanka and most of the Andaman Islands were not seriously affected (Wilkinson, 2000). Reports of leaching from Andaman Islands noted that the Little Andaman Island reef was severely affected and in Dugong creek the live coral coverage was only 12.0% (Jeyabaskaran, 1999).

Sedimentation : The problem of sedimentation in the reefs is both natural and anthropogenic. The natural causes observed commonly are river and ground runoff. While these natural causes may be little impact and the actual damage is caused when this is associated with land based human activities such as agricultural farming, dredging of channel and sand mining results the chronic sedimentation. This leads to reduction in the availability of light for photosynthesis in corals and clogging of polyps, smothering of mucus laden coenosarcs thereby affecting the tentacular feeding. Almost all the reefs fringing mainland India and Andaman and Nicobar Islands are affected by sedimentation due to developmental activities along the coast as well as natural causes. Freshwater runoff damages have been observed in the semi-enclosed area in a channel near Mahatma Gandhi Marine National Park and also farming practices have been cited as reason for siltation in Hut Bay area of Little Andaman Island (Venkataraman, 2003)

Pollution : Coral reefs are highly susceptible to pollution. Mainly caused by indirect activities such as industrial development, increased urbanization, sewage runoff, oil spills etc. The fringing reefs of the Andaman and Nicobar Islands experienced eutrophication through untreated sewage disposal and runoff from farm lands. Coral mortalities have also been observed in and around Port Blair (Venkataraman, 2003) which may be associated with these pollution. Increasing vessel traffic in these islands is also posing considerable threat for oil pollution.

Tidal/Tsunami waves : The tidal/tsunami waves are becoming the potential threat as it damages the coral frame work especially branching corals, clogging of reef area with garbage wastes and deposition of sand and mud on the reef surface which leads to mass mortality.

Crown-of-Thorns starfish : The crown-of-thorn starfish *Acanthaster planci* is a coral predator. The outbreaks of this species lead to extreme feeding upon coral polyp resulting mass mortality of corals. Repeated outbreaks can lead to the degradation of the entire reef. The causes of outbreak have not been clearly understood. In Andaman Islands, the outbreak has been noticed in Outram Island of Rani Jhansi Marine National Park (Jeyabaskaran, 1999).

Tourism : Tourism creates large amount of solid wastes. Inappropriate disposal of solid waste and leaching of toxic substances leads to coral destruction. Construction of tourism infrastructure causes increased sedimentation. Boat anchoring, snorkeling and diving activities are also incurring damages to breakage of branching corals and causing lesions on the massive corals.

MANAGEMENT STRATEGIES

There is an urgent necessity for reef structure mapping and assessments of its associated biota and other ecological variables in Indian reefs as baseline data acquisition. The baseline assessments so far available are restricted to certain reef and shallower depths in Andaman and Nicobar Islands. Mikkelsen and Cracroft (2001) pointed out the need for systematic inventories for reef areas on more cryptic species other than mapping just the cnidarians, fishes, larger sponges and macroalgae.

Periodic monitoring of coral reefs is a prerequisite by setting up a permanent monitoring station at each reef site which will provide the useful information about the health, morphological changes, bleaching, disease outbreak of the reef and its associated organisms. Organized monitoring of water quality parameters and primary and secondary productivities will give the health of ambient environment for monitoring corals in better perspectives. It is also noticed that the survey of corals conducted in Andaman and Nicobar Islands restricted to

selected reefs as well as nearshore regions only. As per the estimates about 55% **of the** reef area of these islands is yet to be explored. Combing survey on the **entire** reef areas and the offshore regions may bring out several new records and **new species** of corals to Indian subcontinent.

5.0. SUMMARY

The objective of the mission was to conduct a rapid assessment of reefs around **the** Andaman Islands to identify the level of importance of the reef systems to **global** biodiversity, and to assess the status of the reefs with respect to their **general** condition. The stepped approach adopted involved: (1) reviewing **relevant** literature; (2) processing satellite imagery of the region; (3) field surveys to 'ground truth' imagery and record coral diversity at selected reef sites; and (4) **production** of satellite image classification maps for future survey and **management**.

There is relatively little information on the coral reef ecosystems around the **Andaman and Nicobar Islands**, when compared to many other island groups in **the Indian Ocean**.

The reef corals of the Andaman Islands belong to the Indo-west Pacific faunal **province**. The Andaman Islands are just northwest of the central area of greatest **marine biodiversity**, referred to as the *Coral Triangle*.

Pillai (1983a) listed 135 coral species from the region, including 31 genera with **82 species** found in the Andaman Islands.

Previous mapping projects to quantify marine habitats using remote sensing **have been undertaken** in the Andamans. Wafar (1986) calculated the reef area around the Andamans to be 11,000km² (taken as all lagoon and submerged banks together).

In the current study, two Landsat 7 ETM+ scenes were corrected for **radiometric and atmospheric variation** using the 6S atmospheric model in ERDAS Imagine. The scenes were mosaiced and georeferenced to Latitude Longitude WGS84 using GIS vector data.

The vegetation of the northern Andamans was mapped using a Normalised Differential Vegetation Index (NDVI). The NDVI image was classified into 10 **classes**, which represent different levels of 'greenness' or vegetation cover.

The preliminary marine biotope classification used 21 classes based on **experience of using similar satellite data**, since prior to the field survey, no **suitable georeferenced data** was available to define classes. One of the intended **objectives** of the field survey was to collect data to use in validating the **preliminary classification** to conduct a new classification based on field data.

The Terrestrial and Marine Biotope maps were combined and sectioned into 11 regions at a scale of 1:200,000. The true colour composite of marine areas combined with a natural colour composite of terrestrial areas was used to create a second set of maps covering the same subsections. 34 higher resolution subsections, at 1:50,000 or 1:60,000 were produced to cover particular features in the reefs and lagoons for use in the field survey.

A rapid site assessment of reef sites around the northern Andaman islands was conducted between 14th and 24th April 2001 from the SY '*Ilala*'. Surveys were conducted at representative and accessible reef sites in the south, west, north and east of the northern Andaman Island group, selected using the satellite imagery.

The survey technique assessed benthic physical structure and biological composition over an area of approximately one hectare at 13 sites: Cinque Island (south of northern island); Cinque Island (north of northern island); Twin Island; Wood Mason Bay; Tarmugli Island; Flat Island; south of North Reef (slope); south of North Reef (crest); South Button Island; Outram Island; Henry Lawrence Island; Minerva Ledges; and Neill Island Ledges. Two teams of 3 divers or snorkellers surveyed reefs for 50 minutes at each site. The surveyors traversed an area approximately 100m by 100m on flat seabeds (eg patch reefs) or 200m x 50m on narrow features (eg reef fronts), depending on benthic structure and diving conditions. The surveys were normally restricted to a maximum of 18 m depth, and on reef slopes, continued to the shallowest depth possible. The visual recorders described the state of reef development; the composition of the physical habitat; and benthic cover.

One visual surveyor concentrated on identifying and recording coral species by examination of characteristic features *in situ*.

Another surveyor photographed habitat structure and where conditions allowed, video records were made at 9 out of the 13 sites for archive purposes and further quantitative analysis using random point count analysis.

The visual survey data from the 13 sites was entered into a database and photographic slides were scanned at 2400 dpm, and written to CD-Rom. The video record was employed to validate the visual field surveys and to conduct quantitative 'Point Data Analysis' to estimate the percent cover of benthic categories.

Field and video data was analysed using multivariate hierarchical agglomerative clustering techniques using MINITAB statistical software and PRIMER (Plymouth Routines in Marine Environmental Research).

The ground control points collected during the survey were used to geometrically correct the Landsat 7ETM+ data. The presurvey biotope classification had been created without the use of ground truthed field data, and hence a postsurvey validating exercise was undertaken. Benthic types identified at accuracy assessment sites and survey sites were used to classify the imagery.

12 out of the 21 mapped classes in the pre-survey classification were encountered during the ground truth survey. There was insufficient data available to attempt a fully supervised classification of all habitats and communities of the islands, due to limitations in field time, and because sites surveyed during the field mission were focused on coral dominated habitats.

The greatest concentration of accuracy assessment and survey site data was recorded for North Reef Island, and results for the depth invariant processing routine were obtained for the same area. Therefore, a supervised classification of the depth corrected subsection around North Reef Island was conducted.

Some classes were identified as shallow offshore reef structures during the field survey, such as those found on east coast at Minerva ledges and Neill ledges. Further investigation of the spectral signatures of these areas known to be offshore reefs, also revealed the presence of spectral signatures representing similar patches off the west coast of Andaman. The position of these structures west of the islands and away from the influence of sedimentation from terrestrial run off, may represent extensive coral communities which may be parts of the previously reported barrier reef. These observations are worthy of future investigation.

The area estimations from the current study indicate that when lagoons, banks, reef slope and reef flat are considered together, an area of 11,939 km² is derived, which compares with the estimation by Wafar (1986) of total reef area used in reef fisheries yield calculations as 11,000 km² for the Andamans.

The total area of reef flat was estimated to be 259 km², and the area of shallow reef slope and reef crest was 262 km², providing a total area of shallow reef of 520 km² around the northern Andamans covered by the images. Previous estimations by MWRD (2000) indicated that coral reefs covered 796 km² around Andaman. The difference of 276 km² is probably due to the difference in satellite sensors, although a lower estimation would have normally be expected from SPOT used by MWRD (2000) because of reduced water depth penetration of the sensitive wavelengths, when compared to Landsat 7 ETM.

The area of land covered by the preliminary terrestrial biotopes was 4,922 km², with mangrove vegetation covering 518 km² (around 10%). MWRD (2000) using SPOT, estimated the area of mangrove around the Andaman to be greater at 679 km². It is not possible at present to explain the difference of 161 km² of mangrove between the two studies. Mangroves were found on northward facing open shores, in sheltered areas between islands and on the inner edges of channels, often occurring within the proximity of fringing reefs.

Non-mangrove vegetation covered 81% (3,998 km²) and dry sand, mud and cleared land was 8.25%. Pristine vegetation for the northern Andamans was estimated as 74%. For comparison, MDRW (2000) and Jeyabaskaran (1999) recorded 86% reserve forest land around the Andaman and Nicobar Islands and

14% agricultural land (Note these figures include the Nicobar islands where exploitation of forestry resources for logging is lower than for the Andamans).

The reef structures observed around the Andaman Islands conform to those reported by Reddiah (1977) and were mainly offshore coral growth on exposed banks, shallow gradual sloping fringing reefs on windward shores, reef patches in bays, and steep sloping channel reefs in sheltered narrows. Fringing reefs consisted of a gradual reef slope seawards off moderate reef flats, occasionally with extensive flats such as at North Reef Island or Flat Island. The reef slopes rarely exceeded 20 m depth, and levelled to a sand base colonised by massive coral colonies. Offshore reefs consisted of an elevated plateau occasionally bordered by steep slopes into deeper water.

197 species of coral were recorded within 58 genera, including 53 genera of zooxanthellate Scleractinia. The genera with the largest numbers of species found were *Acropora*, *Montipora*, *Pavona*, *Fungia*, *Porites*, *Platygyra*, *Leptoseris*, *Psammocora*, *Astreopora*, *Hydnophora*, and *Millepora*. These 11 genera account for about 59 % of the total observed species, with *Acropora*, *Montipora*, *Pavona* and *Fungia* with 47, 11, 10 and 9 species respectively

The most diverse sites were on the west coast; the most species rich site being South Button, with 89 species, followed by Twin Island with 82 species and Flat Island with 81 species. Species poor sites were : Wood Mason Bay with 44 species, Cinque Island (north of northern island) with 49 species, and Neill Island Ledges with 45 species.

Studies of the corals revealed one new species, and continued study of photographs and synonyms may reveal additional species. The new species is of genus *Acropora*, and consists of thick, long, radiating, digitate branches, about 2-4 cm thick at the base, and 20-40 cm long, with rounded and appressed radial corallites. In addition, 4 recently described (from elsewhere) species of coral were found around the Andamans : *Favia truncates*, *Goniastrea minuta*, *Podabacia lanakensis*, *Galaxea acrhelia*. One species (*Oxypora crassispinosa*), described as common during the survey, had previously only been reported from the Philippines. 111 species were found which had not been reported from the Andaman Islands before, representing about half the coral fauna.

The total number of species found in this study exceeds by 62, those previously reported (Pillai, 1983). 35 of the previously reported species were azooxanthellate species, most of which are found only in much deeper water than coral reefs. In addition, the present study included only 13 surveys all on shallow coral reefs and thus represents only a first step in the assessment of coral diversity in the Andamans. The 187 species of zooxanthellate corals found in this study is greater than the 100 species of zooxanthellate corals previously reported (Pillai, 1983). It is expected that further study will reveal additional species, especially when deeper sites and other habitats are examined. If the coral diversity in the Andamans is 80% of that in the 'Coral Triangle', about 400 coral

species may eventually be found in the Andaman. When those species already reported in the literature, but not found in this survey are accounted for, then this suggests that about 170 species remain to be found. 223 species of *Scleractinia* (and a total of 234 species of all stony corals) have now been reported from the Andaman Islands when the results of the current mission are combined with those of previous studies, probably representing about half of the total coral fauna of the Andaman.

Most of the corals found in the Andaman Islands extend far to the west and east of the Andaman, while a minority of species have ranges that extend to the east but for which the Andaman represent the western limit of their range. Very few species have the Andaman as the eastern limit to their range. This is consistent with the fact that only a small expanse of ocean separates the Andaman from other reef-bearing islands to the east and southeast, while a much larger gap separates the Andaman from the next coral reefs to the west in Sri Lanka and southern India.

The survey mission examined inaccessible and offshore areas away from human intervention. Impacts on the reef directly caused by man were rarely observed during the survey, and in general, the condition of the reefs and shores appeared nearly pristine.

The field mission encountered no reefs exhibiting damage resulting from coral reef bleaching. A finding of no bleaching damage is surprising, for Pet Soede *et al.*, (2000) reported that the bleaching event of 1998 affected the coral reefs of Andaman and Nicobar to the greatest extent in the Indian region, with up to 80% bleaching. However post bleaching mortality had not been assessed, and the reports were anecdotal.

It is recommended that future surveys in and around the Andaman and Nicobar Islands continue to use Landsat 7ETM data to map the shallow tropical marine habitats and biotopes on the basis that it is a cost effective and an efficient tool for mapping and monitoring large areas.

It is predicted that many more species of corals will be found in the Andaman when further studies are undertaken over a wider geographical range encompassing a greater diversity of habitats. Further work should examine all coral samples previously collected from the Andaman and held in museums in Port Blair, Chennai, Delhi and other locations outside of India.

In addition, the Nicobar Islands have not been studied since Sheer and Pillai (1974); a study based on limited surveys. The Nicobar Islands remain a rich potential source of additional coral species, and should be included in future studies.

A massive earthquake cum *tsunami* struck Andaman and Nicobar Islands posed geomorphological changes which caused irreparable devastation to coral reefs of these islands. The damages were extensive in North Andaman and Nicobar

group islands. In consequent upon earthquake, the land mass of North and Middle Andaman was uplifted more than 1 m and submergence of land by 1.9 m in Nicobar group of islands.

Post-*tsunami* surveys have been conducted by ZSI in the selected islands of Andaman groups and Nicobar groups during 2007-2008 in order to find out the present status of live coral cover and the results are presented in tables 4.13 and 3.14. The results of the study revealed that loss of coral reef covers in 7 islands of Mahatma Gandhi Marine National Park ranged from 27.27 to 71.43% due to the impact of *tsunami*. However, in Grub Island reverse trend has been observed as the 30% increment has been noticed in total coral cover area.

Recruitment of new colonies was estimated in some of the *tsunami* affected islands and the results indicated the recuperation of corals was found in most of the islands and density of coral varied from 14 to 22 colonies/10 m² area with the species diversity (H') of 1.98 - 2.85 in Rutland Island of South Andaman. However in Nicobar group it was recorded as 8-12 colonies/10m² with the species diversity of 1.73-2.18 in Great Nicobar Island

6.o. ACKNOWLEDGEMENTS

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