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CHARACTERIZATION OF MODERN REEFS USING THE ATLANTIC AND GULF RAPID REEF ASSESSMENT (AGRRA) PROTOCOL AND DIGITIZED AERIAL PHOTOGRAPHS, TOBAGO CAYS MARINE PARK, ST. VINCENT & THE GRENADINES.

by

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ABSTRACT

This research provides valuable information on the composition and distribution of the shallow marine habitats in the Tobago Cays as well as an indication of the current health condition of the Horseshoe Reef. The Horseshoe Reef has an average coral cover of 35% and is represented by a total 16 coral species dominated by *Montastraea annularis, Porites asteroides and Porites porites.* The *Acropora palmata,* which once flourished on the shallow high energy shallow reefs areas in the Tobago Cays, has virtually disappeared as a reef builder. The near disappearance of *A. palmata* is indicative of a past disturbance events since last survey by Lewis (1975) and is most likely explained by the white-band diseases that killed most of the *Acropora* in the Caribbean during the mid 1980s. The size distribution of the major reef building coral species is dominated by smaller colonies, indicative of healthy reefs with sufficient juvenile replenishment. The presence of a low rate of recent mortality (2%), minor disease occurrences (3%) and relatively low bleaching (7%) indicates that the Horseshoe Reef has not suffered from any major recent disturbance events and has recovered (if affected) from the major Caribbean wide bleaching event of the summer/fall of 1998. Algal communities at the Horseshoe Reef are dominated by crustose coralline algae (45% cover), followed by macro algae (32%) and turf algae (23%). Dominance of macro algae (mainly *Halimeda*) on the Horseshoe Reef may be explained by a combination of reduced herbivory and possible nutrient enrichment. The long spine black sea urchin *Diadema* is relatively uncommon on the fore reef areas of the Horseshoe Reef. A total of 81 species of fish are present on the Horseshoe Reef, the fish assemblage is dominated by herbivorous fishes from the Scaridae and Acanthuridae families. The fish assemblage is showing signs of over fishing with very low densities and the small size of commercially valuable species. Based on the AGRRA indicators it is possible to conclude that the Horseshoe reef is in good condition but is showing some signs of both recent and past disturbances.

A digital thematic map of the shallow marine habitats surrounding the Tobago Cays and the Horseshoe Reef was created using a low cost remote sensing methodology. Colour aerial photographs were selected because of their high spatial resolution and availability. The aerial photographs were scanned, georeferenced, rectified (ground control points and a second order polynomial) and mosaicked to cover the entire study area. Benthic classes were derived and described objectively using agglomerative hierarchical classification of field data. Supervised classification of the Tobago Cays was obtained using this field derived classification. The final thematic map comprises 8 classes (mixed live coral community, dead coral substratum with mixed algae, seagrass dominated, macro algae dominated, sand dominated, rubble dominated, deep water and beach sands) with an overall accuracy of 87% and a Kappa and Tau coefficients of 85%. Producer and user accuracies of individual classes range between 53% and 100%. The deep water class is most commonly confused with the mixed coral community, this is mainly due to variations in water depth. The mixed coral community, the coral substratum with mixed algae, the macro algae dominated, and the seagrass dominated classes are occasionally confused due to the presence of photosynthetic pigments and similarity in spectral signatures. The thematic map provides valuable information on the composition and distribution of the shallow marine communities of the Tobago Cays Marine Park, with sufficient accuracy to be used as a baseline information for long term monitoring.

RÉSUMÉ

Ce projet de recherche procure de l'information essentielle sur la composition et la distribution des habitats marins entourant les Tobago Cays ainsi qu'un aperçu de l'état de santé et la condition actuelle du Horseshoe Reef. Le Horseshoe Reef possède une couverture corallienne moyenne de 35%, l'assemblage corallien comprend 16 espèces et principalement dominé par *Montastreas annularis*, *Porites asteroides*, et *Porites porites*. Les *Acropora palmata* qui étaient l'un des principaux constructeurs de récifs en eaux peu profondes sont maintenant rares dans la région d'étude. Le déclin de cette espèce depuis l'étude de Lewis (1975) indique qu'il y a eu une perturbation relativement récente (>30 ans). Celle-ci peut être expliquée par la maladie de la bande blanche qui a les *Acropora* dans la région des Caraïbes dans les années 1980. Les coraux sont principalement dominés par des colonies de petit diamètre (58 cm) ce qui indique un apport adéquat de coraux juvéniles. Le faible taux de mortalité récente (2%), de maladies (3%) et de blanchiment (7%) des coraux indique que le Horseshoe Reef n'a pas souffert de perturbations récentes et semble avoir bien récupéré de l'événement de blanchiment qui a affecté les Caraïbes à l'été/automne 1998. La communauté d'algues du Horseshoe Reef est dominée par les algues rouges encroûtantes qui constituent 45% de la couverture d'algues, suivi des macro-algues (32%) et des algues "turf" (23%). La dominance des macro-algues (principalement du genre *Halimeda*) dans l'avant récif profond peut s'expliquer par une diminution de la densité d'herbivores et/ou une sur abondance de nutriments. L'oursin noir *Diadema* est présent en faible densité dans l'avant récif et rare aux sites profonds. Un total de 81 espèces de poissons a été inventorié sur le Horseshoe Reef, les espèces les plus abondantes sont les herbivores de la famille des

Scaridae et Acanthuridae. La faible densité et la petite taille des poissons de grande valeur commerciale sont des indications de sur-pêche. En se basant sur les indicateurs établis par la méthode AGRRA il est possible de conclure que le Horseshoe Reef est généralement en bonne condition mais montre quelques signes de perturbations récentes et anciennes.

Une carte thématique des habitats marins peu profonds entourant les Tobago Cays et le Horseshoe Reef a été établie à l'aide des techniques de traitement d'images traditionnelles et peu coûteuses héritées de la télédétection spatiale. Les photographies aériennes ont été sélectionnées pour leur haute résolution spatiale ainsi que leur disponibilité. Les photographies furent numérisées, géoréférencées, rectifiées (à l'aide de points de contrôle au sol et un polynôme de deuxième ordre), et assemblées afin d'obtenir une mosaïque couvrant entièrement la région d'étude. Une classification des habitats benthiques a été réalisée utilisant les données de terrain et une méthode de classification hiérarchique agglomérative. La région d'étude a été entièrement classifiée utilisant une classification supervisée basée sur la classification de terrain. La classification thématique finale comprend 8 classes (communautés de coraux, substrat de coraux morts avec algues, herbier de Phanérogames, macro algues, sables coralliens nus, cailloux, eau profondes, et sables de plage) avec une précision globale de 87% et un coefficient Kappa et Tau de 85%. La classe d'eau profonde est fréquemment confuse avec la classe de communautés de coraux ce qui est due à la variation de la bathymétrie. Les classes de coraux, de substrat de coraux morts avec algues, de macro algues et des herbiers a Phanérogrames sont parfois confuses entre elles due à la présence de pigment photosynthétique et à la similarité de leurs signatures spectrales. La carte thématique procure de l'information essentielle sur la composition et la distribution des communautés marines benthiques du parc marin des Tobago Cays avec une précision suffisant pour servir d'inventaire de base et poursuive un monitoring à long terme de cette région.

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CHAPTER 1: Introduction

Coral reefs are among the most productive ecosystems on the earth supporting a great diversity of organisms. They also support life on land in several ways; i) by forming and maintaining the physical foundation for thousands of islands, ii) by building walls along the coast which serve as a barrier against oceanic waves, iii) and by sustaining the fisheries and diving tourist industries that help maintain the economies of many countries in the Caribbean and Pacific (Brown and Ogden, 1993). In addition to various natural disasters, the reefs around the world are seriously threatened by human activities such as over exploitation, coastal development, fishing, reef mining, tourism, nutrients and land-based pollution (Bryant *et al.*, 1998). The deterioration of the reef ecosystems is an issue of economic and ecologic concerns to tropical countries around the world. Most of the reefs in the Caribbean are under high potential threats with virtually all of the reefs of the Lesser Antilles being at high risk (Bryant *et al.*, 1998). The risk scale is evaluated according to potential threats to reefs such as i) coastal development, ii) overexploitation and destructive fishing practices, iii) the impact of inland pollution and erosion, and iv) marine pollution. There is a pressing need to monitor and assess the spatial and temporal scales of damages occurring in reef environment and trying to understand the underlying mechanisms involved (Hughes, 1994).

1.1 Study Objectives

The reefs of the Tobago Cays Marine Park (TCMP) are ideal candidates for reef assessment and mapping because of the lack of existing information on these reefs, the well developed reef zonations, their importance in the local economy and the lack of direct anthropogenic stress except for fishing, diving and snorkelling. The present study is divided in two sub-projects each being the subject of a specific article (see Chapters 2 and 3). This thesis is thus written in an article format to facilitate the future publication of the study as two distinct documents. The first section focuses on the reef crest and the fore reef zones of the bank barrier Horseshoe Reef. The main objectives of this section are:

1. To characterise the present condition of the Horseshoe Reef using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol, a low cost, rapid and standard methodology.
2. To contribute to the Caribbean wide AGRRA database which aims at establishing a regional baseline of coral condition in the Western Atlantic and Gulf of Mexico. This will allow us to compare results obtained from the Horseshoe Reef with other locations in the Caribbean.
3. To qualitatively compare these observations with those of Lewis collected in the Tobago Cays in 1975.

The second section focuses on the backreef area and shallow marine habitats surrounding the Tobago Cays, including the Horseshoe Reef. The main objectives of this section are:

1. To develop a rapid and cost effective field methodology for surveying the shallow marine of the Tobago Cays. The ground survey results will provide quantitative results from which a classification scheme of the main benthic assemblages and bottom types of the TCMP can be developed.

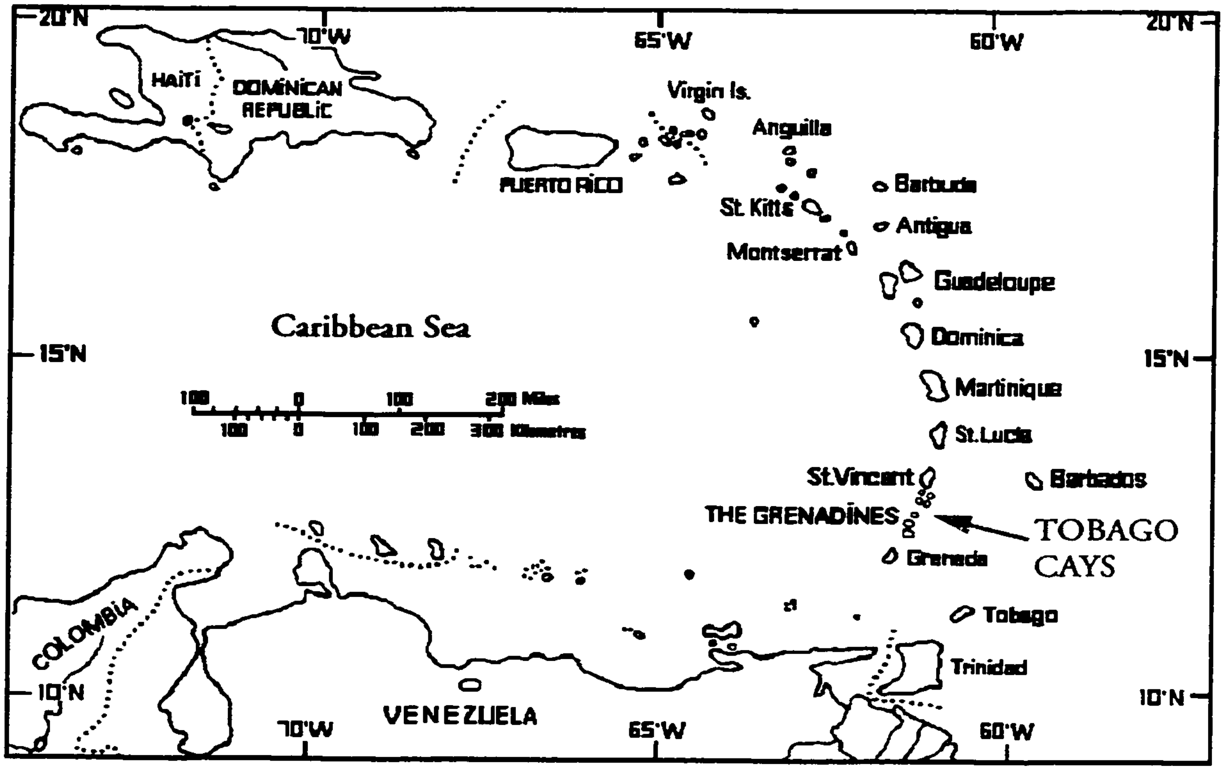
2. To produce a digital thematic map of the shallow marine habitats of the Tobago Cays, with a known accuracy, using a low cost remote sensing methodology. This will provide a visual and digital inventory of the major habitats that can be easily upgraded for long term monitoring purposes.
3. To qualitatively compare results with those obtained by Lewis (1975).

The data collected in this project are especially important since the area has recently obtained a marine park status. Very little information is available on the reefs of the Tobago Cays. The data gathered for this project can be used as baseline information for various management applications and future studies. The AGRRA survey results, being the first quantitative assessment, should serve as a baseline study to evaluate future changes in the coral reef condition and management effectiveness.

1.2 Study Area

This study focuses on the Tobago Cays located in the Lesser Antilles, West Indies (Fig.1). The Tobago Cays are composed of four small islands protected by a semi-circular bank barrier reef, the Horseshoe Reef. The Horseshoe Reef is a well-developed Holocene bank-barrier reef offshore located on the windward side of the Cays. The total length of the Horseshoe Reef is about 4 km making it one of the longest reefs of the southern Grenadine Islands (Dey, 1985; Dey and Smith, 1989). The fore reef zone is a steep slope extending eastward to depths of about 20 meters. The Cays are inhabited but are frequently

Figure 1-1: Location map of the study site.


20°N
70°W
65°W
60°W
20°N
HAITI
DOMINICAN REPUBLIC
Virgin Is.
Anguilla
PUERTO RICO
Barbuda
St. Kitts
Antigua
Montserrat
Guadeloupe
Caribbean Sea
Dominica
15°N
15°N
Martinique
St. Lucia
St.Vincent
Barbados
THE GRENADINES
TOBAGO CAYS
Grenada
COLOMBIA
Tobago
Trinidad
10°N
70°W
VENEZUELA
65°W
60°W
10°N

visited by fishermen for conch and lobster and are now increasingly used by tourists for sailing, snorkelling and diving activities. The Tobago Cays are located at 3 km from the Grenadine Island of Mayreau, the closest inhabited island with a population of approximately 250. Union Island is the closest major centre of population, with a population of approximately 3500, located at about 5 km from Tobago Cays.

Over the past 15 years a number of informal reports have indicated that the conditions of the reefs in Tobago Cays have deteriorated due to various factors including storm damage, white band diseases, physical damage, and local sewage pollution from visiting yacht (Smith *et al.* 1996; Wells, 1988). The Tobago Cays Marine Park (TCMP) has now been established for over a year and is slowly developing. Since the summer of 1999, the TCMP legislation protected only the land areas of the park, including the 5 backreef Cays and Petit Tabac Cay (park manager, pers.com.). The Tobago Cays reefs have so far received little attention in the literature; thus limited documentation is available on these reefs. Except for the preliminary descriptions by Lewis (1975), these reefs have not been the subject of any scientific research. The existing literature consists of a report from Wells (1988) containing a brief description of the reefs based on Lewis's study and more recently, of a paragraph in a report on the Status of Western Atlantic Coral Reefs in the Lesser Antilles by Smith *et al.* (1996).

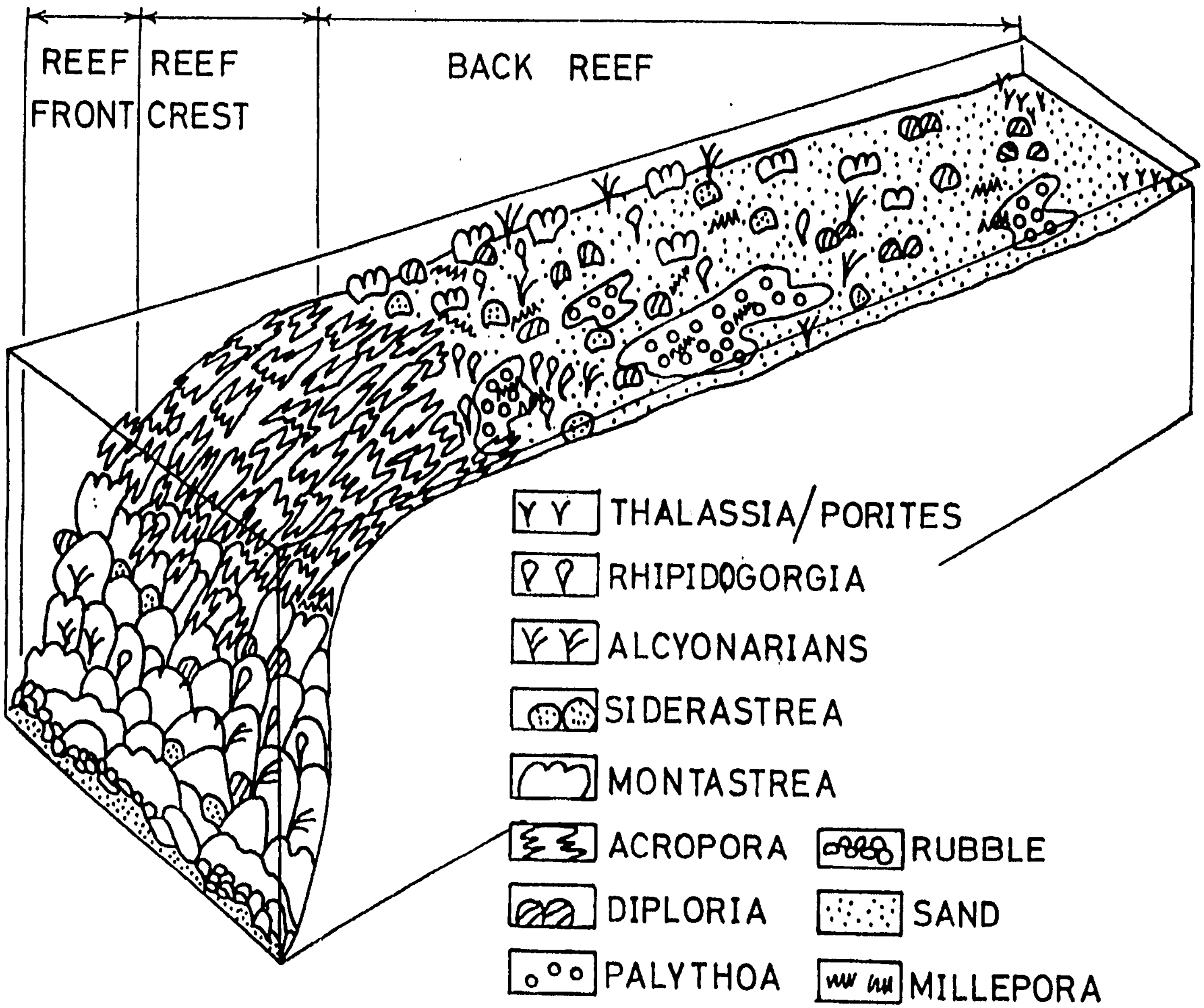
1.3 Regional Setting

The Tobago Cays are part of a string of small islands called the Grenadines located between St.Vincent and Grenada in the Lesser Antilles (Fig.1). The Grenadines are eroded remnant peaks and ridges of older volcanic islands, partially or completely drowned during the post-Pleistocene sea level rise, rising from a submarine bank called the Grenada Bank. The Grenadine Bank runs NE-SW for about 180 km between St.Vincent and Grenada, the bank has a width of 15 to 20 km with depths of 20-30 meters and locally shallow areas of 3-6 meters (Dey, 1985; Dey and Smith, 1989). The rocks exposed on the Tobago Cays are mainly composed of metamorphosed, stratified agglomerated tuff with limestone and cherty bands (Tomblin, 1970). Modern sedimentary environments around the Grenadines have a complex distribution due in part to the great sea-bottom variations provided by these submerged volcanic islands and the onshore lithologies, wave and current variations (Dey, 1985; Dey, and Smith, 1989). Most of the volcanic material is restricted to beaches because of the absence of rivers on these small islands prevents the terrigenous sediments from being carried offshore and permits reef growth (Dey, 1985).

The Grenadines Bank lies within the Trade Wind belt where strong north-east winds are developed during late autumn and winter, and easterly winds during spring, summer and early autumn (Clack, 1976). The wind driven Equatorial current flows (south-west in winter and west at other time of the year) steadily throughout the year at speeds ranging from 0.3 to 1.5 knots (Clack, 1976). The Equatorial Current moves over the Grenadines Bank, passes through the channels and reefs, and is diverted around the islands which gives considerable local variation in current flow and strength (Clack, 1976; Dey and Smith, 1989). Tides in the Grenadines are mixed with a semi-diurnal component dominating in the Tobago Cays area. The tidal range is small with a difference of 0.6 m between the mean high and the mean low water level (Clack, 1976). The westerly equatorial current accelerates the flood stream setting to the west and retards the ebb stream to the eastward (Defense Mapping Agency, 1979). The strength duration and general direction of tides among the Grenadines are influenced by local topographic variations present on the sea bottom of the shallow bank. Because of the ample water movement and the absence of coastal currents, both temperature and salinity are relatively constant over the Grenadine Bank. The variations from normal oceanic salinities are short-lived events related to intense rainfalls in very shallow water areas. The water temperature in the Grenadines reflects seasonal changes in the temperature (24-28°C) of oceanic water masses that move into the bank (Dey, 1985; NOAA, 2000). The Grenadine Bank is south of the region usually affected by hurricanes. The most violent recent hurricanes to strike the Grenadine islands were Hurricane Janet in 1955 and Hurricane Allen in 1980 (Dey and Smith, 1989). No other hurricanes in the last 50 years have seriously affected the reef conditions in the Tobago Cays (TCMP park manager, pers. com.).

The Horseshoe Reef can be divided into three major reef habitats or zones based on the geomorphology, depth and wave exposure; the shallow and deeper fore reef, the reef crest, and the reef flat. The backreef area and the lagoon patch reef system are also associated with the Horseshoe Reef. The first part of this project, which uses the AGRRA methodology, focuses on the fore reef (shallow and deeper fore reef) area of the Horseshoe Reef. The second part of this project, which uses scanned aerial photographs, focuses on the shallow marine habitats (<10 m) surrounding the Cays and the Horseshoe Reef. Lewis (1975) described the reefs of Tobago Cays as being representative of many Caribbean reefs. According to Lewis's study, the Horseshoe Reef shows three major zones from the crest to the fore-reef: a shallow branching coral zone, a mixed coral head zone and a deeper

Figure 1-2: Three dimensional sketch of a generalized transect across the Horseshoe Reef showing zonation. Depth15-20meters, horizontal distance approximately 100m. Taken from Lewis (1975).


REEF FRONT
REEF CREST
BACK REEF
THALASSIA/PORITES
RHIPIDOGORGIA
ALCYONARIANS
SIDERASTREA
MONTASTREA
ACROPORA
DIPLORIA
PALYTHOA
RUBBLE
SAND
MILLEPORA

foliaceous zone (Fig.2). The reef crest of the Horseshoe Reef was dominated by dense growths of the branching *Acropora palmata*, and a bare rock substrate encrusted with *Millepora* or *Palythoa* and scattered colonies of *Porites astreoides* and *Favia fragum*. The shallow fore-reef zone was composed of clumps of *Acropora palmata* and low mounds of *Montastraea annularis* with scattered colonies of *Porites porites*, *P. astreoides* and the encrusting zooanthid *Palythoa*. The reef slope was dominated by large massive mounds of *Montastrea annularis* from depths of 5 m to 15 m and forming tall pillar-like clumps and changing to shingle shaped colonies toward the bottom of the slope. Mixed with *Montastreas* numerous colonies of *Porites porites*, *P.astreoides*, *P.furcata*, *Agaricia fragilis*, *A. Agaricites*, *Dendrogyra cylindrus*, *Colpophylia natans*, *C. Amaranthus*, *Isophylllastreaa Rigida*, *Diploria clivosa*, and *D. Strigosa* were present. The backreef area was covered with mixed coral heads (*Diploria-Montastrea-Porites*) passing gradually shoreward to scattered patch reefs on a sandy bottom. Narrow tidal channels of a few meters wide were observed at frequent intervals along the reef crest but spur and groove systems were absent (Lewis, 1975). The back reef region is a shallow water zone with a patchwork distribution of corals and alcyonarians (Lewis, 1975). The shallow backreef was characterised by the presence of *Millepora* and the colonial zooanthids *Palythoa*. The distribution of shallow water communities around the Cays is related to coastline configuration and current velocity but Lewis (1975) described them as being very similar in each of the four Cays. In areas where the current is strong, patches of coral and dense stands of *Rhipidogorgia* and other alcyonarians flourished. The *Thalassia-Porites* associations are restricted to the areas with less current.

1.4 Coral Reefs

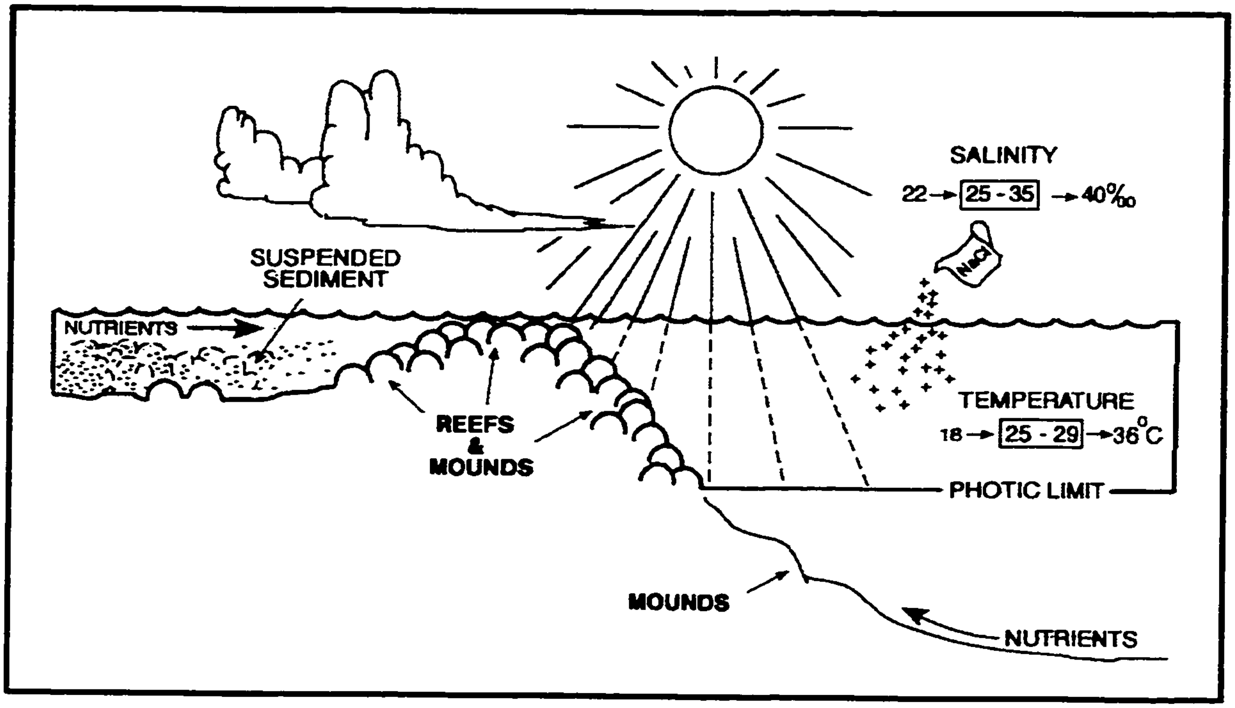
1.4.1 Modern Reef Communities

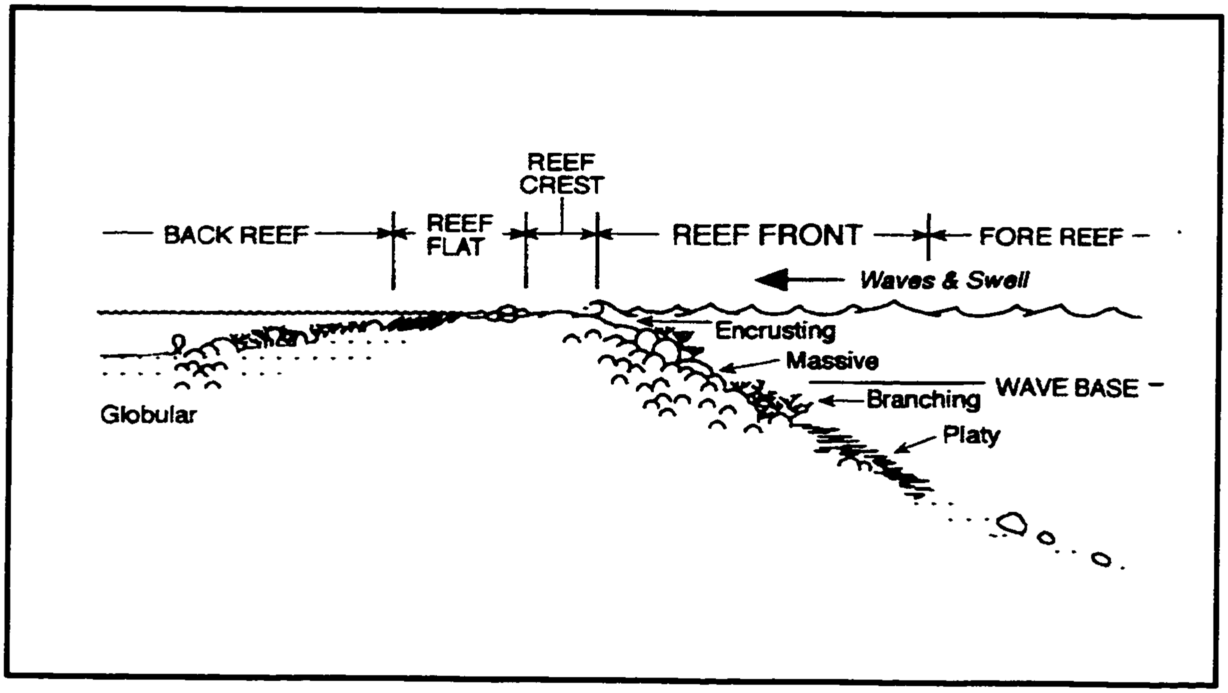
Coral reefs are highly complex marine ecosystems made up of a discontinuous biotic cover over a non-biotic substrate composed of sediments and older reef rock. Modern reef building architects are Scleractinian (stony) hermatypic corals, together with coralline red algae forming wave-resistant structures that dominate shallow tropical seas (Tucker, 1990). Coralline algae contribute to the reef building process by filling voids and cementing the coral head framework together. Hydrocorals, alcyonarians, and other calcareous algae are locally important but are not considered as major reef builders. Reef development is controlled by processes operating at various scales (Hubbard, 1996). Microscale processes are those that affect organisms at the reef level such as light, nutrients and sediments (Fig.3). Mesoscale processes are generally physical-oceanographic in nature and operate within individual oceans or basins over a variety of time periods and include factors such as temperature, salinity and wave energy (Fig.3). Macroscale processes exert control either globally or over very large areas and over long periods of time, it includes worldwide changes in sea level and large scale movements of the earth's crust (tectonics).

Coral reefs flourish in high energy and oligotrophic oceanic regions. Yet, these nutrient poor environments support highly productive and diverse reef ecosystems. The reef communities are builders of large and complex wave resistant structures, which create optimal environmental conditions for effective nutrient retention and recycling necessary for their success (James and Bourque, 1992). The corals feed on planktonic organisms but also obtain a large proportion (up to 63%) of their nutritional needs from their photosynthetic

Figure 1-3: Sketch of the environmental window for modern coral reef growth. Numbers for temperature and salinity define the growth limits of corals, boxes enclose optimum values. Taken from James and Bourque (1992).

Figure 1-4: Cross section through a typical and well-zoned marginal coral reef. Taken from James and Bourque (1992).


SALINITY
22 → 25 - 35 → 40‰
SUSPENDED
SEDIMENT
NUTRIENTS
NaCl
TEMPERATURE
18 → 25 - 29 → 36°C
REEFS
&
MOUNDS
PHOTIC LIMIT
MOUNDS
NUTRIENTS


REEF
CREST
BACK REEF
REEF
FLAT
REEF FRONT
FORE REEF
Waves & Swell
Encrusting
Massive
WAVE BASE
Branching
Platy
Globular

symbionts (Glynn, 1991). Their ability to thrive and be highly productive in less than favourable conditions is attributed to their mutualistic relationship with symbiotic photosynthetic dinoflagelate algae, zooxanthellae. The zooxanthellae (*Symbiodium sp.*) are unicellular eucaryotic algae. There is between one and two million algae cells per square centimetre of coral tissue (Brown and Ogden, 1993). Zooxanthellae contain the following major photosynthetic pigments, chlorophyll a, c2, peridinin, but others have chlorophyll a, c1, c2 and furoxanthin or some other pigment combinations (Rowan, 1998). During photosynthesis the pigments absorb light, which is converted into chemical energy (ATP, NADP) and used to synthesise organic compounds from carbon dioxide. Usable light for photosynthesis is in the 0.400-0.700 • m range of the electromagnetic spectrum (photosynthetically active radiation- PAR). The symbiotic association between coral and algae is very efficient at capturing and recycling nutrients from the water column and the waste product of the host (James and Bourque, 1992). The zooxanthellae recycle the metabolic wastes of the coral by absorbing the carbon dioxide as well as the phosphate and nitrate containing by-products, which provides continuous intracellular decontamination of the coral (Kuhlmann, 1989). The zooxanthellae supply the host with organic compounds (amino acids and sugars) and oxygen from photosynthesis. This symbiosis is important in accelerating the process of skeleton building in hermatypic corals; the removal of carbon dioxide and phosphate by the zooxanthellae accelerates the crystallisation of calcium carbonate (Goreau, 1961). The rate at which calcium carbonate is formed is about ten times higher than it is in algae free or ahermatypic corals (Kuhlmann, 1989). The symbiotic association, however, limits hermatypic corals to the photic zone where sufficient light penetrates to allow photosynthesis (25-30 meters). The relation between depth and intensity of light penetration affects the photosynthetic capacity of the zooxanthellae contained in the coral tissues. In clear water, light intensity decreases exponentially with water depth and the light spectrum shifts rapidly toward the blue (Hubbard, 1996). As a result, photosynthesis and $CaCO_3$ production drop rapidly.

Shallow water bottom communities can be predicted by temperature and nutrient supply (Hallock *et al.*, 1993). Coral reefs are generally restricted to water between 18°C and 36°C, with an optimal range of 26-28°C, and are expressed by latitudinal patterns of coral reef distribution and diversity (Hubbard, 1996). The primary carbonate sediment producers of the coral reef community (i.e. hermatypic corals) are highly adapted to nutrient deficient environments. Input of nitrates and phosphates stimulates growth of plankton, fleshy algae and ahermatypic suspension-feeding animals in the benthos (Hallock and Schlager, 1986). Increased nutrient supply will consequently enable these organisms to thrive and lead to modified or even arrested reef growth because many are fast growing competitors and bioeroders that actively destroy the reef structure (James and Bourque, 1992).

There are considerably fewer species of reef building coral species in the Caribbean (±50) comparatively to the Indo-Pacific (±700) (Stoddart, 1969). Even if the coral species diversity is lower, numerous growth forms are possible for most species. The Caribbean region is characterised by six scleractinian genera (*Acropora, Monstrastraea, Porites, Diploria, Siderastrea and Agaracia*) and one hydrozoan genera (*Millepora*), these contribute to as much as 90% of the coral biomass (Milliman, 1975). Modern and ancient reefs both exhibit zonation with depth. Coral zonation within a reef is characterised by a change in species assemblage as well as a gradual morphological modification of individual coral species. Prevailing wave exposure and light intensity have been shown to exert a primary control on the character of the shallow-water reef crest and the benthic zonation along the front of Caribbean reefs (Adey and Burke, 1976; Geister, 1977). A general trend in the growth forms from shallow water to deep water is as follows; encrusting to branching forms in shallow waters, domal, massive and columnar colonies in intermediate water depth, which are gradually replaced by follacious shapes in the deeper waters (Fig.4). Five main species zones generally characterise Caribbean reefs. With increasing depth they are as follows; the algal ridge zone, the *Millepora* zone, the *Acropora palmata* zone, the *Acropora cervicornis* zone and the *Montastraea* zone (Milliman, 1975). These are ecological zones rarely composed of a single species, but often composed of a characteristic assemblage of organisms adapted to particular environmental conditions. Diversity of species found in a zone is at its maximum when the combination of environmental stresses is at a minimum.

Most present day established coral reefs began growing 5,000 to 10,000 years ago (Hinrichsen, 1996). Modern reefs are characterised by two major events: the last interglacial episode 120,000 years ago and the initiation of modern reef structures less than 9,000 years ago (Hallock, 1996). During the last interglacial, sea level was at least 6 m higher than today, forming the limestone that make up many islands associated with present reef tracts. During the last glacial episode, which lasted more than 80 000 years, sea level fell to 130 m below the present level (Macintyre, 1988). Continental shelves were dry lands and reef growth was limited to steep island or continental slopes. Associated with the rising seas of the Holocene transgression, the Western Atlantic reef development was controlled by wave-energy conditions and the relationship between changing sea levels and local shelf topography (Macintyre, 1988). The flooding of adjacent shelves during this postglacial transgression introduced stress conditions (i.e. turbidity and nutrients) that terminated the growth of the pre-Holocene reefs. About 7,000 years ago, shelf water conditions improved, scattered deeper water coral communities re-established themselves on these stranded shelf-edge reefs, and fringing and bank-barrier reefs began to flourish in shallow coastal areas (Macintyre, 1988). The Holocene sea level curve is one of early rapid rise, late slowing and final stability (James and Bourque, 1992). The rate of sea-level rise during deglaciation relative to maximum potential growth rate of framework is also important for reef growth structure (Neumann and Macintyre, 1985).

1.4.2 Changes in the Caribbean Coral Reef Ecosystems

Human activities have been affecting coral reefs and tropical coastal ecosystems far more than has been generally recognised (Birkeland, 1977). Coral reefs are deteriorating worldwide, with some of the most serious losses occurring in the western Atlantic Ocean and the Caribbean Sea (Hallock *et al.*, 1993, Connell, 1997). Although coral reefs have encountered natural disturbances and recovered in the past, changes in the community structure and shift in balance of coral reef processes have increased in scale and frequency in recent decades. Recovery is delayed more often and situations that used to be acute are now often chronic (Glynn, 1993; Hughes, 1994). These declines have been attributed to such factors as coral diseases (Edmunds 1991, Aronson and Precht 1997), mortality of the sea urchin *Diadema antillarum* (Lessios *et al.* 1984), hurricanes (Woodley *et al.* 1981, Rogers, 1990), coral bleaching (Gleason and Wellington 1993), and nutrient excess (Hallock and

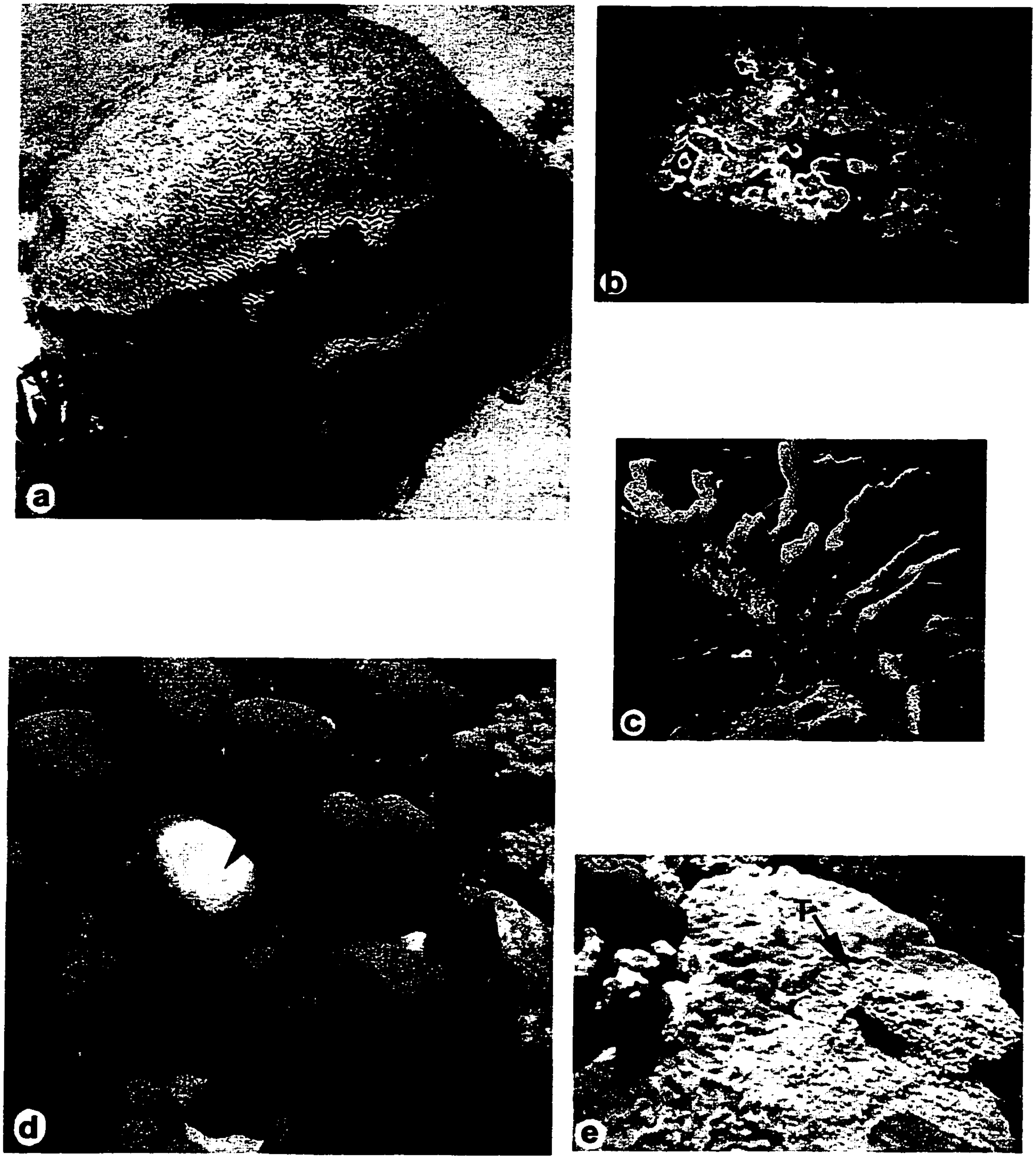
Schlager, 1986). Some major changes have affected the Caribbean coral reefs in the last 30 years, these will be discussed briefly (see cited references for more detail). Only the changes pertinent to our area of study are introduced here and will be discussed in more detail in Chapter 2.

Large-scale population outbreaks, mass mortalities, and community disturbances have been occurring on a regional scale in coral-reef ecosystems during recent decades (Birkeland, 1997). In 1983-84 an epizootic pathogen (e.g. bacteria, protozoan) resulted in a mass mortality of the long spine sea urchin (*Diadema antillarum*) in the tropical Western Atlantic (Lessios *et al.*, 1984), first noted in Panama in 1983 and then spreading around the rest of the Caribbean by January 1984. No causative agent has been isolated but a water-borne pathogen has been suggested; this epidemic being the most widespread ever reported for a marine invertebrate (Lessios *et al.*, 1984). Before the 1982-83 die-off, urchin populations were abnormally high in many areas, possibly as a consequence of increased fishing of herbivorous and predator fishes that competed with or preyed upon urchins (Hay, 1984; Ogden *et al.*, 1973). An average reduction in *Diadema* population density of 98% occurred (Lessios, 1988). This massive reduction in the abundance of *Diadema antillarum* (Lessios *et al.*, 1983; Bak and Nieuwland, 1995) combined with reduction in fish grazers due to over fishing are frequently cited as causes of fleshy algae dominance in coral reefs (Hughes, 1994; Hay, 1984; Done, 1992). The recovery of *Diadema* populations throughout the Caribbean is still uncertain but reports from Barbados show signs of slow recovery (Lessios, 1988).

A major cause of coral death is competitive overgrowth by other organisms, such as sponges, algae, ascidians or other corals. The overgrowths have accelerated in many sites around the Caribbean in recent years (Goreau *et al.*, 1998). The encrusting compound ascidian, *Trididemnun solidum* (Fig. 1-5e), is regarded as an efficient competitor for space on Caribbean reefs (Bak *et al.*, 1981). *T.solidum* is very common in Curacao as well as in other parts of the Caribbean, such as Carrie Bow Cay, Belize and in the San Blas Islands, Panama (Bak *et al.*, 1981). The ascidian colonies grow as thin sheets over turf covered rock (13 cm/ 4 week) and scleractinian corals (2.8 cm/ 4 week), with a much slower growth rate when in spatial competition (Bak *et al.*, 1981). They are commonly found in water depth ranging from 1.5 m to 34 m because they host unicellular endosymbiotic algae that limit their distribution to the photic zone (Bak *et al.*, 1981). Competitive overgrowth by organisms such as *T. solidum* may be influenced by environmental perturbations that reduce the efficiency of affected organisms to defend themselves. Bak *et al.* (1996) hypothesised that an increase in abundance of this species in Curacao may be related to eutrophication. An increased level of nutrients in coastal zones favours the growth of benthic algae, and promotes an increase in phytoplankton and zooplankton; the latter being food supplies for the ascidians. Possibilities of dispersal of *T. solidum* are low, but in a sufficiently dense population, maintenance potential is high because of the relatively high mobility of the colonies over the substratum (division, budding, fusion and rapid growth), effective competition for space, low predation pressure and high regeneration capacity and long life-span of colonies (Bak *et al.*, 1981). The occurrence of *T.solidum* has been reported frequently throughout the Caribbean and seams to be more frequent than previously noted, including the TCMP (Fig. 1-5e).

Figure 1-5: Underwater field photographs illustrating common coral diseases, bleaching and tunicate overgrowth observed in the Tobago Cays.

a) Black Band Disease (BBD) on a colony of *Diploria spp.* at Petit Bateau Cay.
b) Yellow Band Disease (YBD) on *Montastraea faveolata* (photo taken from McCarty and Peters, 2000)
c) White Band Disease (WBD) on a live colony of *Acropora palmata* (photo taken from McCarty and Peters, 2000)
d) Colony of *Montastraea annularis* showing sign of partial bleaching (B) in the fore reef area of the Horseshoe Reef.
e) Encrusting compound ascidian, *Trididemnun solidum* (T), overgrowing a colony of *Porites porites* in the fore reef area of the Horseshoe Reef.


a
b
c
d
T
e

Bleaching is recognised as a stress response to a variety of environmental perturbations such as extreme light, temperature, prolonged aerial exposure, freshwater dilution, high sedimentation and various pollutants (Glynn, 1991). Bleaching leads to the loss of zooxanthellae and/or a decrease in the photosynthetic pigment concentration within the zooxanthellae (Fig. 1-5d). The mechanism of alga release is not fully understood but a good review is provided by Brown (1997). With low concentration of plant pigments the coral tissues become translucent and the white calcium carbonate skeleton is visible, giving the coral a bleached appearance (Glynn, 1991). Most reef-building corals normally contain around $1\text{-}5x10^6$ zooxanthellae/cm^2 of live surface tissue and 2-10 pg of chlorophyll *a* per zooxanthellae (Glynn, 1996). The sudden loss of zooxanthellae greatly affects the coral host since these photosynthetic symbionts supply up to 63% of the coral nutrients and facilitate calcification (Glynn, 1991). If the stress causing bleaching is not too severe the affected corals can regain their symbiotic algae within several weeks or a few months (Glynn, 1996). Prolonged bleaching of reef corals is associated with reduction in soft tissue biomass, sexual reproduction, skeletal growth, ability to shed sediment, resistance to invading/competing species and diseases (Lang *et al.*, 1992; Glynn, 1996). Severe and prolonged bleaching can cause partial to total colony death resulting in diminished reef growth, the transformation of reef building communities to alternate non-reef building community types, bioerosion and ultimately the disappearance of reef structures (Glynn, 1996).

Local discoloration of reef cnidarians has been reported throughout the past century, yet "mass" bleaching events distributed over large geographic areas have been noted only within the last two decades (Lang *et al.*, 1992). Small scale bleaching events can often be correlated with specific disturbances whereas large scale mass bleaching occurs over hundreds to thousands of km^2 and is more difficult to explain (Glynn, 1996). Present evidence suggests that the leading factors responsible for large-scale coral reef bleaching are elevated sea temperatures and high solar irradiance (Glynn, 1996). Coral bleaching in the past two decades has been especially prominent during large scale atmospheric and oceanographic disturbances called El Nino -Southern Oscillation (ENSO), which bring in warm waters of about 3°C above normal water temperature (Glynn, 1996). Since zooxanthellae bearing corals generally live close to their physiological upper temperature tolerance limit, a relatively small positive anomaly of 1-2°C for 5-10 weeks during the summer months will usually induce bleaching (Goreau and Hayes, 1994). Extensive and widespread episodes of coral bleaching have been observed since the 1980s in all tropical oceans, the latest being in late summer of 1998 (Brown and Ogden, 1993; Goreau and Hayes, 1994; NOAA, 2000). El Nino warming events can partially explain this global pattern but extensive bleaching also occurred in non El Nino years (Goreau and Hayes, 1994).

Since the early seventies a variety of coral reef diseases has been discovered. Although coral diseases have been reported from around the world, they have been documented most widely in the tropical western Atlantic. However, the etiology of many coral diseases remains poorly understood. Full description and updated information on coral diseases are available at McCarty and Peters (2000). The three most common coral diseases will be briefly reviewed here. The black-band and white-band diseases which have been reported most frequently in the tropical western Atlantic first observed in the early 1970s while the yellow-blotch disease first noted in the lower Florida Keys in 1994 (Figs. 1-5a,b,c) (Santavy and Peters, 1997).

Black band disease (BBD) is characterised by a crescent–shape band of darkly pigmented filaments that separates white denuded skeleton from living coral tissue (Fig. 1-5a) (Bruckner *et al.*, 1997). BBD is an infection caused by the cyanobacterium *Phormidium corallyticum* (Rutzler *et al.*, 1983). The band appears dark because of the red pigments (phycoerythin) in the cyanobacteria. It has been observed on massive Faviid corals throughout the Caribbean (Rutzler *et al.*, 1983) as well as in the Indo-Pacific and the Red Sea. In the tropical western Atlantic susceptible species include the massive brain corals (*Diploria* spp., *Colpophyllia* spp.) and star corals (*Montastraea* spp.), which are the most commonly affected members of the family Faviidae (Edmunds, 1991). BBD has also been reported on milleporinids (fire corals) and gorgonians (Rutzler *et al.* 1983). The coral is killed by anoxia and sulfides produced by the microorganisms (Santavy and Peters, 1997). Healthy corals can become infected with the black band disease by contact but injured or stressed colonies are most susceptible to the disease (Rutzler *et al.*, 1983). The limited quantitative data on the BBD abundance show that less than 2% of Caribbean corals are infected with BBD (Edmunds, 1991). Most studies have found that the incidence of the disease in the Caribbean is low but increases when reefs are stressed by sedimentation, nutrients, toxic chemicals and warmer than normal temperatures (Edmunds, 1991). Infection rates increase during warm water conditions, with disease activity optimal at/or above water temperatures of 25°C but almost disappear during the winter (Rutzler *et al.* 1983)

The white band disease (WBD) is characterised by tissue peeling off colonies of Acroporid, both the Elkhorn (*Acropora palmata)* and Staghorn (*Acropora cervicornis*) corals (Fig.1-5c). The sloughing tissues start at the base of the branches and move toward the branch tip leaving a band of white denuded skeleton several cm wide next to apparently healthy tissues (Santavy and Peters, 1997). No consistent assemblage of microorganisms could be found at the junction of the sloughing tissue and the bare skeleton and the etiology of the white band disease remains unknown (Peters and McCarthy, 1996; Santavy and Peters, 1997). The disease appears to be a bacterial infection mainly affecting Acroporids, but cannot be attributed to any particular human or natural factors (Antonius, 1981). *A. palmata* was a major reef builder in much of the shallow (1-5 m) windward reefs of the western Atlantic reef systems (Macintyre, 1988; Adey and Burke, 1976; Adey, 1978). WBD has killed most of the *A. palmata* throughout much of the Caribbean region in the early 1980s, from the Florida Keys, Puerto Rico and the Virgin Islands, Antigua, St. Martin, Curacao, Nicaragua, Panama, Bahamas, Tobago, and Bermuda (Santavy and Peters, 1997). No detailed observations were made at the time of its spread. The WBD is now epizootic across the Caribbean and while there has been some new recruitment of Acropora, they are often rapidly re-infected by WBD, therefore limiting the amount of these species to no more than a few percent of former prevalence (Goreau *et al.*, 1998).

The yellow-blotch disease (YBD) is a condition that affects massive heads of *Montastraea faveolata* and less commonly of *Montastraea annularis* (Santavy and Peters, 1997). The YBD begins as an irregularly shaped blotch of lightened yellow coloured tissue on the surface of the coral (Fig.1-5b). As the disease progresses the tissue in the centre of the patch dies and the area fills with sediment and algae resulting in a band of yellow tissue around the enlarging sediment patch (Santavy and Peters, 1997). The ethiology of the disease is unknown but increased monitoring efforts and research are being done. YBD was first documented in the lower Florida Keys in 1994. It has now been confirmed in many Caribbean sites and is an important predecessor to mortality of the reef building, *M. annularis*, in much of the region (Goreau *et al.*, 1998).

The "baseline" condition for reef-building communities, against which human impact is assessed, is spatially patchy and temporally dynamic, and cannot be expressed simply as %coral cover or species diversity. A site that departs from what is considered normal is not necessarily in trouble, it may simply be in a low part of the natural temporal variation (Done, 1997). As monitoring of coral reefs becomes increasingly globalized, a better understanding of environmental differences between and within regions is important to allow interpretation of changes in reef communities. More investigation and comparison between regions are needed to determine if the change in species composition (e.g. loss of *A. palmata*) and the incidence of diseases are normal or abnormal.

1.5 Monitoring and Mapping the Reefs of the Tobago Cays Marine Park

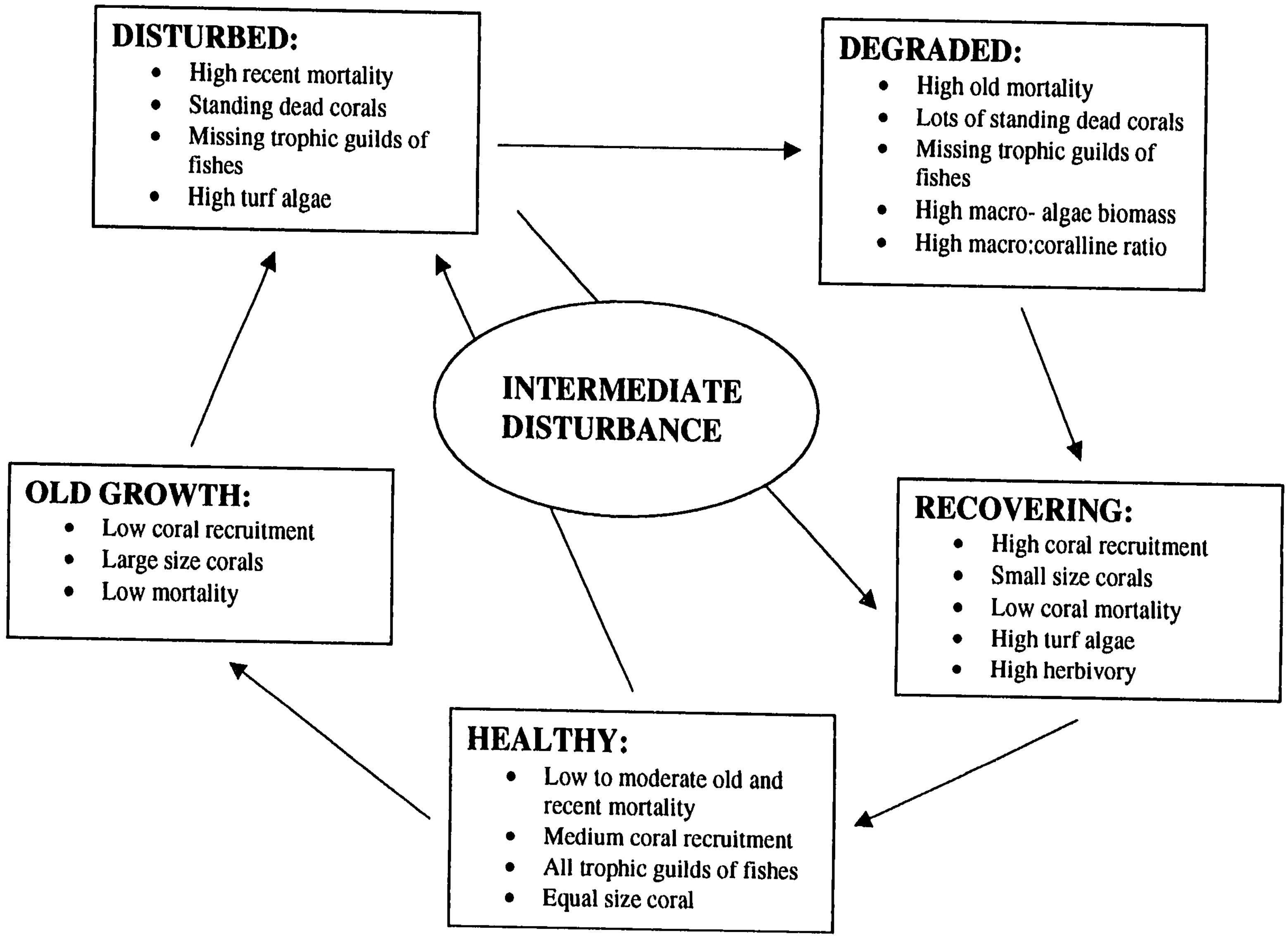
1.5.1 Baseline Monitoring of the Horseshoe Reef using the Atlantic and Gulf Rapid Reef Assessment (AGRRA).

There are serious declines in reef-building corals at a number of locations in the Western Atlantic and Gulf of Mexico. These declines have been attributed to various anthropogenic and natural causes (Edmunds 1991; Aronson and Precht 1995; Lessios *et al.* 1984; Woodley *et al.* 1981; Rogers, 1990; Gleason and Wellington 1993; Hallock and

Schlager, 1986). Unfortunately, we do not know the regional extent and severity of these declines nor do we know how much of the declines are actually due to anthropogenic causes. We especially lack knowledge on the reef condition in centres remote from of human impact. The Atlantic and Gulf Rapid Reef Assessment (AGRRA) program was developed to provide this much-needed information and a regional perspective on the extent of these declines (Ginsburg *et al.* 1996). AGRRA is the result of an international collaboration of reef scientists and their associates to assess the condition of reef-building corals and fishes throughout the Western Atlantic Ocean and Gulf of Mexico (see AGRRA, 2000). The AGRRA method is designed to obtain an overview of large areas of reefs within relatively short periods of time in order to establish a baseline of the current condition. The ultimate goal is to collect enough standardised and comparable baseline data to determine regional condition and begin to develop hypotheses on the causes of regional decline. It is necessary to emphasise that this rapid assessment protocol is not intended to replace any existing, local, regional (e.g., CARICOMP), or global (e.g., GCRMN) monitoring protocols. This rapid assessment method is presently being used throughout the western Atlantic (1999-2000) to evaluate the condition of a large number of reefs in the region. The results of this campaign will provide new information on the extent and distribution of declines; the goal of the AGRRA regional project is to provide a clearer picture of the state of the reefs by 2001. Once enough data have been collected throughout the Caribbean and the Gulf of Mexico, the data can be analysed to answer more regional questions. The first part of this project was partially funded by AGRRA and therefore contributes to the building of this Caribbean wide database on coral reef condition. Our project will provide data on the reefs in the Grenadines, West Indies.

The vitality of a reef depends on complex relationships between corals, fishes and algae. When changes occur in the community dynamics of one of these components (e.g., algae abundance), the other two components are affected as well and the whole relationship can be disrupted. Therefore, to evaluate the condition of a reef from a one-time assessment, it is critical to examine multiple indicators of the coral-alga-fish relationships. The indicators of the AGRRA protocol are i) the partial or total mortality of major reef-building corals by species and size; ii) the relative abundance of principal algal types – turf, macroalgae, and crustose corallines; and iii) the diversity of fishes and the abundance and sizes of key fish species. The results of an AGRRA survey are a quantitative indication of reef condition, which can be used to assess the state of the surveyed reefs (Fig.6). From the examination of a large number of reefs, it will be possible to develop a scale of reef conditions and allow regional comparisons. Although the approach does not attempt to distinguish between causes and effects of reef condition, the data gathered can be used to develop hypotheses on trends of reef decline, particularly across large spatial scales. The AGRRA method is focused on assessing the condition of the principal scleractinian and hydrozoan corals that contribute most to the three-dimensional structure and complexity of reefs. The vitality of these corals responsible for the construction and maintenance of reef framework is important for the long-term persistence of a coral reef (Dustan 1987; Done 1997). The AGRRA method assesses overall coral cover and for each coral, assesses the amount of partial coral mortality (both.

Figure 1-6: Hypothetical model of the status and trajectory of reef systems. Listed in the boxes are the AGRRA indicators that provide information on the state of the reefs.
(AGRRA Bonaire Workshop, written communication Dr. Philip Kramer)


DISTURBED:
High recent mortality
Standing dead corals
Missing trophic guilds of fishes
High turf algae
DEGRADED:
High old mortality
Lots of standing dead corals
Missing trophic guilds of fishes
High macro- algae biomass
High macro:coralline ratio
INTERMEDIATE DISTURBANCE
OLD GROWTH:
Low coral recruitment
Large size corals
Low mortality
RECOVERING:
High coral recruitment
Small size corals
Low coral mortality
High turf algae
High herbivory
HEALTHY:
Low to moderate old and recent mortality
Medium coral recruitment
All trophic guilds of fishes
Equal size coral

recent and old), size and height, incidence of bleaching/diseases, causes of mortality, and number of damselfish. See Chapter 2 for more information

1.5.2 Mapping the Shallow Marine Habitats of the Tobago Cays using scanned aerial photographs.

Reef research as long tried to use remote sensing techniques to map reefs areas. Historically the use of aerial photography in conjunction with field survey was one of the first remote sensing methods for reef mapping. Vertical air photos of the Great Barrier Reef have been taken as early as 1925 (Hopley, 1996). In the 1970s, the first comprehensive coverage of the Great Barrier Reef was completed using Landsat MSS and air photos. The problem back then was the limited spatial resolution. Even today with the launch of better satellites the principal obstacle is the low spatial resolution of imagery and the prevalence of clouds in tropical regions. Satellite remote sensing is not well suited for mapping reef biotic cover but is none the less an appropriate and cost effective way of mapping reef geomorphology (Mumby *et al.*, 1998c). A more complete literature review and the characteristics of potential remote sensing technology presently available for coral reef mapping are available in Appendix 2.

In the second part of this project (Chapter 3) we are proposing to take advantage of new and widely available technology such as powerful computers with large storage capacity, desktop scanners, and remote sensing software and processing techniques to produce a digital reef map from scanned aerial photographs. There is a very large stock of aerial photographs of coastal and shallow marine areas that have the potential to be used for reef mapping. Often these photos have been taken for other purposes and may be several years old. They nevertheless constitute a very important source of information, especially in areas where very few adequate (less than 20% cloud) satellite images are available. Scanned aerial photographs (archived) used in conjunction with field surveys are a low cost alternative to obtain information on reef habitats and geomorphology. The use of true colour aerial photography was selected for this project because of the presence of an important cloud cover during optimal remote sensing time in the Lesser Antilles, the small size of the study region (4 km x 4 km) and the availability of such data for a low cost (printing cost).

The high spatial resolution that can be obtained from scanned air photos makes it possible to map reef biotic communities as well as geomorphology, which should be of interest to reef managers. Traditional ground survey methods provide intensive biotic information but only over limited areas. Mumby *et al.* (1997) evaluated the capability of satellite and airborne remote sensing methods for mapping Caribbean coral reefs. They concluded that for the production of detailed habitat maps traditional photo-interpretation methods or airborne hyperspectral imagery should give better results than presently available satellite imagery. In areas where archived aerial photographs are not available and where new airborne surveys are required the acquisition of hyperspectral imagery is recommended over the commissioning of an aerial photography survey (Mumby *et al.*, 1997). It was also suggested by Catt and Hopley (1988) that digitised aerial photographs had the potential to be developed as a tool for mapping reefs at high resolution. Catt and Hopley (1988) also suggested that digitised aerial photographs had the potential to be developed as a tool for mapping reefs at high resolution. Scanned aerial photographs can be used in the same way as satellite imagery. The use of standard and semi-automatic image processing available from remote sensing software facilitates the image processing and georectification of aerial photographs. It also has the advantage of reducing observer bias in thematic map production because statistical methods are used to perform a supervised classification. Visual interpretation of aerial photographs is time consuming and requires highly experienced researchers. Some studies have used traditional aerial photography mapping methods to map seagrass and reef areas (Ferguson *et al.*, 1993; Sheppard *et al.*, 1995). Scanned aerial photographs have been used successfully for mapping small reef areas in Thailand (Thamrongnawasawat and Hopley, 1995) and the Red Sea (Manière et Jaubert, 1985), tropical coastal marine ecosystems in Martinique (Chauvaud *et al.*, 1998), seagrass beds in Martinique (Manière *et al.*, 1994) and benthic ecosystems in the Mediterranean (Pasqualini *et al.*, 1997). However, several other habitat mapping studies done before 1990 lacked quantitative results, ground data collection and accuracy assessments.

CHAPTER 2: Application of the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol to the Horseshoe Reef in the Tobago Cays Marine Park, West Indies.

Abstract

The Horseshoe Reef is one of the longest bank-barrier reefs of the St.Vincent Grenadine region. It is located away from direct anthropogenic stress with the closest inhabited island (Mayreau with a population of 250) located at 3 km. Limited information is available on the reefs of the Tobago Cays. Our study represents the first quantitative survey on these reefs. The present study is aimed at characterising and determining the present conditions of the Horseshoe Reef using the Atlantic and Gulf Rapid Reef Assessment protocol (AGRRA). Our survey reveals that 90% of the coral assemblage at the Horseshoe Reef is dominated by *Montastraea annularis* (31%), *Porites asteroides* (23%), *Porites porites* (23%), *Montastreas faveolata* (5%), *Millepora complanata* (4%), *Colpolphyllia natans* (2%) *and Siderastrea siderastrea* (2%). Standing dead colonies of *Acropora palmata* were present at only one of the shallow sites, accounting for 2% of the surveyed corals. The *A. palmata*, which once flourished on the shallow fore-reef and the reef crest of the Horseshoe Reef, has now virtually disappeared as a reef builder. Most shallow areas are now composed of a dead *A. palmata* pavement largely encrusted by crustose coralline algae and colonised by *Millepora* and *Porites*. The near disappearance of *A. palmata* is indicative of a past disturbance event since last surveyed by Lewis (1975) and is most likely explained by the white band disease that killed most of the Caribbean *Acropora* in the mid 1980s. The size frequency distributions of the three major reef building coral species are skewed toward

smaller colonies, the average diameter of these corals being 58 cm. Coral recruitment averages 2 recruits/m^2 for all the surveyed sites. The partial coral mortality at all sites is low to moderate, with recent mortality averaging 2% and old mortality averaging 25%. Relatively low incidence of coral disease is present on the Horseshoe Reef with less than 3% of colonies affected. The presence of a low rate of recent mortality, minor disease occurrences and relatively low bleaching indicates that the Horseshoe Reef has not suffered or has recovered from any major recent disturbance events.

Algal communities are dominated by crustose coralline algae (45% cover), followed by macro algae (32%), and turf algae (23%). The calcareous green alga *Halimeda* largely dominates the macro alga community. Dominance of macro algae on the Horseshoe Reef may be explained by a combination of possible nutrient enrichment and reduced herbivory. The herbivorous sea urchin, *Diadema antillarum*, is relatively uncommon on the fore reef areas of the Horseshoe Reef, with an average density of 2.4 individuals/m^2. A total of 81 species of fish was recorded on the Horseshoe Reef. The fish assemblage is largely dominated by herbivorous species from the Scaridae (parrotfish) and Acanthuridae (surgeonfish) families. Commercially valuable fish species are present in low densities ($\leq 1/m^2$) and are relatively small in size indicative of over-fishing. Using the indicators established by the AGRRA protocol, the results obtained from this survey suggest that the Horseshoe Reef is a relatively healthy reef but is also showing signs of disturbances.

2.1 Introduction

This study focuses on the Horseshoe Reef, Tobago Cays located in the West Indies (Fig.2-1). The Tobago Cays are composed of four small cays in the St.Vincent Grenadines protected by a semi-circular bank barrier reef, the Horseshoe Reef. The Horseshoe Reef is a well developed Holocene bank-barrier reef offshore on the windward side of the Tobago Cays. This research is aimed at characterising and determining the present condition of the Horseshoe Reef using the Atlantic and Gulf Rapid Reef Assessment protocol (AGRRA). The data collected will be qualitatively compared with preliminary results from other Caribbean AGRRA surveys and with Lewis (1975). The survey results, being the first quantitative assessment, should serve to evaluate future changes in the coral reef condition. This is especially important since the Horseshoe Reef has recently obtained a marine park status (Tobago Cays Marine Park, TCMP) and the collected data can also be used in various management problems. More general information on the study area is available in Chapter 1.

2.2 Research Methods

Field data collection was done over a period of two weeks in June 1999. Reef sites were selected with the help of true colour aerial photographs (scale 1:10 000, March 1991), nautical charts (Hydrographic Office of the United Kingdom, 1999), reconnaissance dives and local knowledge of experienced divers and dive operators. The site selection was limited to accessibility by boat and current conditions. Sites were selected from two depth ranges, 1-5 m and 8-15 m depth zones (sites A, C, E and sites B and D respectively), which covered areas of maximum reef development (Fig. 2-1). A site is defined as a homogeneous and

Figure 2-1: Photo mosaic of the Horseshoe Reef at Tobago Cays, St.Vincent and the Grenadines. Approximate location of the AGRRA field survey sites is indicated in red for shallow sites (B and D) and yellow for deeper sites (A, C and E). Subset map is a general location map of AGGRA field surveys for 1998-99, the Tobago Cays are indicated as number 14 and with a red arrow (from Ginsburg and Kramer, 1999).


1998-99 AGRRA Surveys
Site E
Site A
Site C
61°21'55"W
45"
61°21'40"W
35"
30"
25"
20"
15"
12°38'55"N
12°38'45"N
12°37'30"N
12°37'20"N
LONG/LAT. WGS 84 (GPS)
40"
61°21'35"W
10"
05"
00"
61°20'55"W
61°20'45"W
SCALE IN METRES
0
1000
2000

accessible area from a boat anchored or moored in one place (0.1 km scale). Corals, algae, long spined sea urchins and fishes were surveyed at each site. More details and updated information on the AGRRA regional project can be obtained on their website (AGRRA, 2000). A detailed methodology is also available in Appendix 1A.

Parameter averages for the two depth zones were obtained by pooling data from shallow sites (A, C, E) and deeper sites (B, D), while the overall parameter averages were obtained by pooling the data from all the sites. Selected parameters (%coral cover, macro algae canopy height, % recent and old mortality) were analysed to determine if there were significant differences between depth zones and to facilitate interpretations. Coral reef environments are highly variable and known for their habitat variation with depth, the goal here was not to test if all measured indicators varied with depth. Assumptions (normality, homogeneity of variance, and independence of residuals) were checked by residuals and autocorrelation plots and analysed accordingly. We either used a Nested ANOVA ($X_{ij} = \mu + \alpha_i + \beta_{j(i)} + \varepsilon$; where μ = mean, $\alpha\beta$ = perturbations due to the groups i and j, I = shallow and deeper sites, j = individual sites A,B,C,D and E, and ε = random error) with its associated F statistic or the non-parametric Mann-Whitney U test with its associated T statistic. It must be noted that the Nested Analysis of Variance was preferred to the T-test because it takes into account the variability of the sites within the depth zones, there is no non-parametric equivalent for this test except for the two sample comparison tests. The critical p-value was set at α=0.05. All statistical analyses were performed with the Systat 8.0® software.

Corals/algae- AGRRA surveys the major reef building scleractinian corals as well as one hydrozoan species. Surveyed species are as follows; *Acropora cervicornis*, *Acropora palmata*, *Agaricia agaricites*, *Agaricia tenuifolia*, *Colpophyllia natans*, *Dichocoenia stokesii*, *Diploria clivosa*, *Diploria labyrinthiformis*, *Diploria strigosa*, *Montastraea annularis*, *Montastraea annularis faveolata*, *Montastraea annularis franksi*, *Montastraea cavernosa*, *Madracis mirabilis*, *Meandrina meandrites*, *Mycetophyllia* sp., *Mussa angulosa and other sp.*, *Porites astreoides*, *Porites porites*, *Solenastrea bournoni*, and *Stephanocoenia intersepta*. Corals were surveyed by using a 10 m transect line laid at least 1m apart from one another haphazardly in a direction parallel to the long axis of the reef zones. Coral cover was approximated (nearest 10 cm) by estimating how many meters of the line overlie live coral and subtracting sandy areas. Each coral (> 25 cm diameter) under the 10 m transect line was recorded to species level and assessed for the following: maximum diameter, maximum height, percent (%) partial mortality ("recently dead" and "long dead") as seen in plan view, diseases and/or bleached tissues, sources of recent mortality that are still identifiable and contribute to "recent dead" estimate, and the number of damselfish or total area of damselfish algal gardens on each coral head. Algae were surveyed along the line using a 25 X 25 cm quadrate to estimate relative algal abundance at the 1, 3, 5, 7, 9 meter intervals. For each quadrate, we recorded the % algal abundance macro algae, turf algae, crustose coralline algae and average canopy height of the macro algae. The macro algae are the large (>1 cm) erect fleshy and calcareous algae that can be picked up with the fingers, the turf algae are the tiny filamentous algae (<1 cm), and the crustose coralline algae are the pink solid calcareous encrusting algae. Small (< 2 cm) stony coral recruits within the algal quadrates were counted and identified to genus level when possible. The long spined sea urchin, *Diadema antillarum*, was assessed using a 1 m belt along the transect line. A minimum of 50 quadrates and 100 coral colonies were compiled at each site. The list of standardised AGGRA abbreviations and benthic field data is available in Appendix 1B and 1C, respectively.

Fishes- Fish surveys were conducted using two methods, a belt transect method to obtain information on density and fish length of some target groups and a rover diver method to obtain information on fish diversity. The fish surveys were conducted at the same time as the coral transects. The belt transect uses a 30 m transect line and a T-bar pointing down at about 45 degrees to provide constant reference to help estimate the 2m width. All species from the following families were counted: grouper, snapper, grunt, parrotfish, surgeonfish, triggerfish, angelfish, and butterflyfish, except for grunts or parrotfish less than 5 cm in length. Also counted were the following five species, yellowtail damselfish (*Microspathodon chrysurus*), hogfish (*Lacholaimus maximus*), Spanish hogfish (*Bodianus rufus*), barracuda (*Sphyraena barracuda*) and bar jack (*Caranx ruber*). Fish total length was estimated according to size categories (<5 cm, 5-10, 10-20, 20-30, 30-40, >40 cm) using a 1 m T-bar with 10 cm increments for scale. The 30 m belt transects were laid haphazardly, at least 5 m laterally away from each other. A minimum of ten transects were conducted at each site. The roving diver census surveys all fish species following the methodology of REEF Environmental Education Foundation (REEF, 2000). The roving diver technique involves divers that are well trained in visual identification of tropical fishes. The diver roves around the site observing and listing as many species of fish as possible and estimates the abundance of each species using $\log_{10}$ categories; single (1), few (2-10), many (11-100), and abundant (>100). Because of the semi-quantitative nature of the roving diver data the sighting frequency and a density index can be calculated for data analysis (Schmitt and Sullivan, 1996). Percent sighting frequency (%SF) indicates the percent of all surveys in which each species was recorded and is a measure of how often the species was recorded. Observed values range from 0-100%.). Variables are defined as follows; s = single, f = few, m = many, a = abundant and n = the total number of rover diver surveys.

$$\%SF = \frac{(s + f + m + a)}{n} \qquad \text{(Equation 2.1)}$$

The density score (DEN) is a weighted average index calculated for each species based on the frequency of observations in each of the abundance categories. This index ranges from 1 to 4 and is representative of the abundance category most often recorded for a given species when it was observed (Schmitt and Sullivan, 1996). Variables are defined as follows; s = single, f = few, m = many, a = abundant and n = the number of surveys in which a particular fish species was observed.

$$DEN = \frac{(s \times 1) + (f \times 2) + (m \times 3 + (a \times 4)}{n} \qquad \text{(Equation 2.2)}$$

Abundance scores are an index that can range between 0 and 4. This measure takes into account density, frequency of occurrence, and zero observations (Schmitt and Sullivan, 1996).

$$Abundance = (DEN \times \%SF) \qquad \text{(Equation 2.3)}$$

Fish transect and rover diver field data are available in Appendices 1D and 1E, respectively.

2.3 Results

A total of 60 coral line transects with 531 coral heads, 268 algae quadrates, 10 fish rover dives and 50 fish belt transects were conducted at 5 sites on the Horseshoe Reef (Fig. 2-1 and Table 2-1). Two sites were surveyed at shallow depth ranging from 1-5 meters (sites B and D) and three sites were surveyed in the deeper water ranging from 8-15 meters (sites A, C, and E). Weather conditions were good during most survey dives with approximately 20-25m estimated horizontal visibilities.

Corals- Coral assemblage at the Horseshoe Reef is represented by 16 coral species dominated by *Montastreas annularis (31%)*, *Porites asteroids* (23%), *Porites porites (23%)*, *Montastreas faveolata* (5%), *Millepora complanata* (4%), *Colpolphyllia natans* (2%) *and Siderastrea siderastrea* (2%) which account for 90% of all corals (Figs.2-2a to d and Fig.2-3). Shallow sites are represented by only 9 coral species dominated by *Porites asteroides (32%)*, *Montastreas annularis (27%)*, *Porites porites (21%)* and *Millepora complanata* (10%), and standing dead colonies of *Acropora palmata* (9%) accounting for 95% of all the corals at shallow sites (Fig. 2-2a to c and Fig.2-3). Standing dead colonies of *Acropora palmata* are recognisable by their characteristic colony shape (Fig.2-2c) and are only present at site B. The reef crest is now characterised by dead *Acropora palmata* pavement largely encrusted by crustose coralline algae and colonised by *Millepora* and scattered colonies of *Porites* (Fig. 2-2b). Deeper sites are represented by 15 coral species dominated by *Montastreas annularis* (34%), *Porites porites* (24%), *Porites asteroides* (17%), *Montastreas faveolata* (7%), *Colpolphyllia natans* (4%) *and Siderastrea siderastrea* (4%), accounting for 90% of all the corals at deeper sites (Fig.2-2d and Fig.2-3). The Horseshoe Reef is

Figure 2-2: Underwater field photographs illustrating the characteristic coral assemblage at shallow and deep sites on the Horseshoe Reef. Photos a-c illustrate the shallow fore reef community; photo b illustrates the *Millepora* dominated reef crest and photo c illustrates standing dead colonies of *Acropora palmata*. Photo d illustrates characteristic deeper fore-reef coral assemblage dominated by *Montastraea* colonies. Photo e illustrates an encrusting tunicate on a *Porites asteroides*. Photo f illustrates a macro algae dominated quadrate from the deeper fore-reef zone. *Abbreviations represent the following; Tunicate (T), Coralline algae (C), *Dictyota* spp. (D), *Halimeda* spp. (H), *Acropora palmata* (AP), *Millepora* spp. (MI), *Montastrea annularis* (MA), *Montastrea faveolata* (MAF), *Porites porites* (PP), *Porites asteroides* (PA).

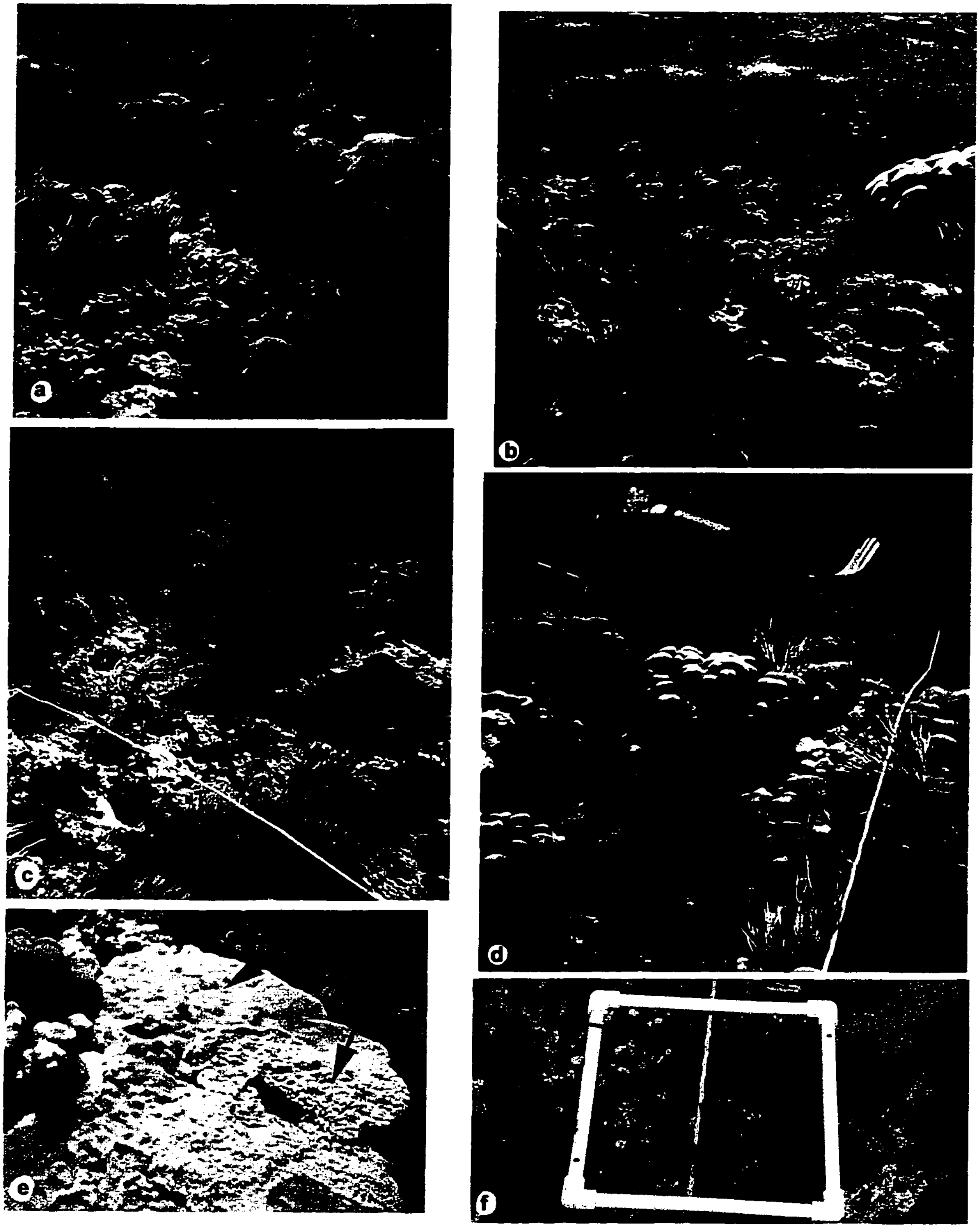

a
b
c
d
e
f

Figure 2-3: Distribution of coral species composition on shallow and deeper fore reef areas of the Horseshoe Reef.

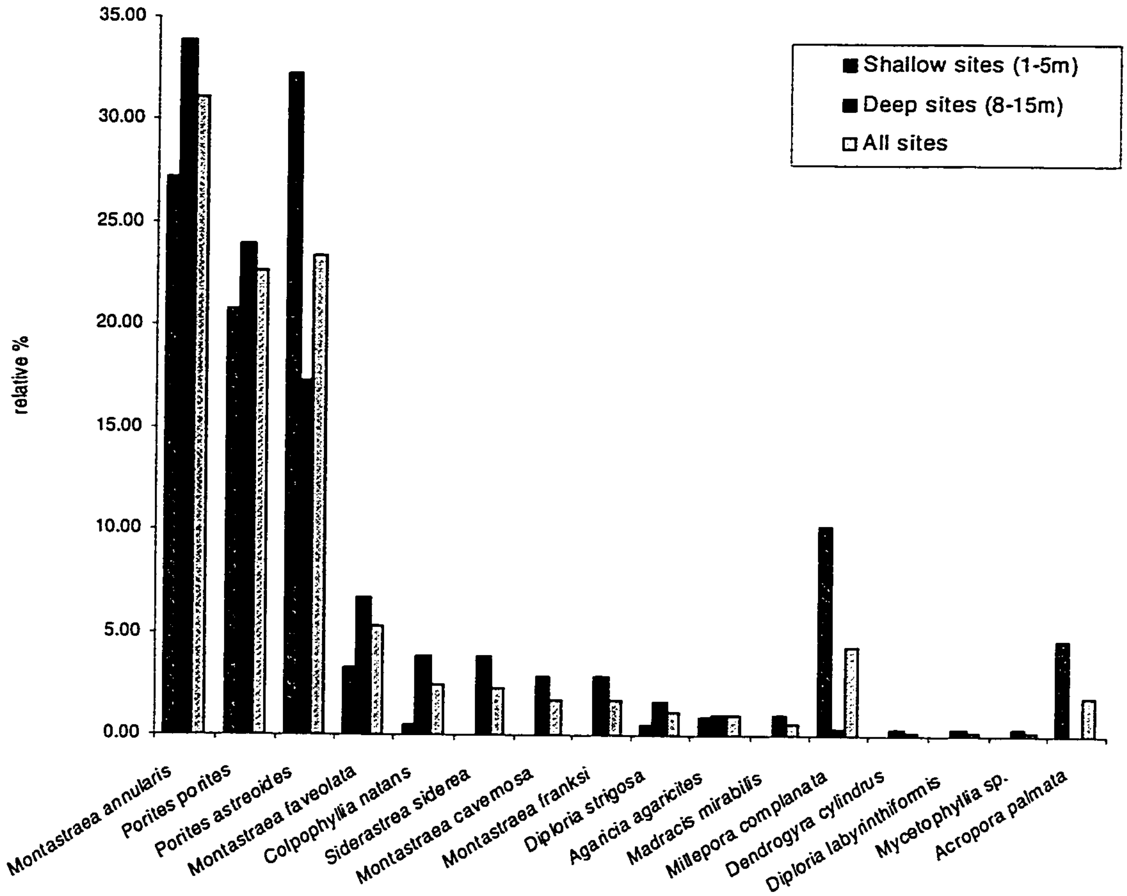

35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
relative %
Shallow sites (1-5m)
Deep sites (8-15m)
All sites
Montastraea annularis
Porites porites
Porites astreoides
Montastraea faveolata
Colpophyllia natans
Siderastrea siderea
Montastraea cavernosa
Montastraea franksi
Diploria strigosa
Agaricia agaricites
Madracis mirabilis
Millepora complanata
Dendrogyra cylindrus
Diploria labyrinthiformis
Mycetophyllia sp.
Acropora palmata

Figure 2-4: Size frequency distribution of the three major reef building coral species on the Horseshoe Reef; a) *Montastraea annularis*, b) *Porites astreoides* and c) *Porites porites*. Only corals greater than 25 cm were surveyed.

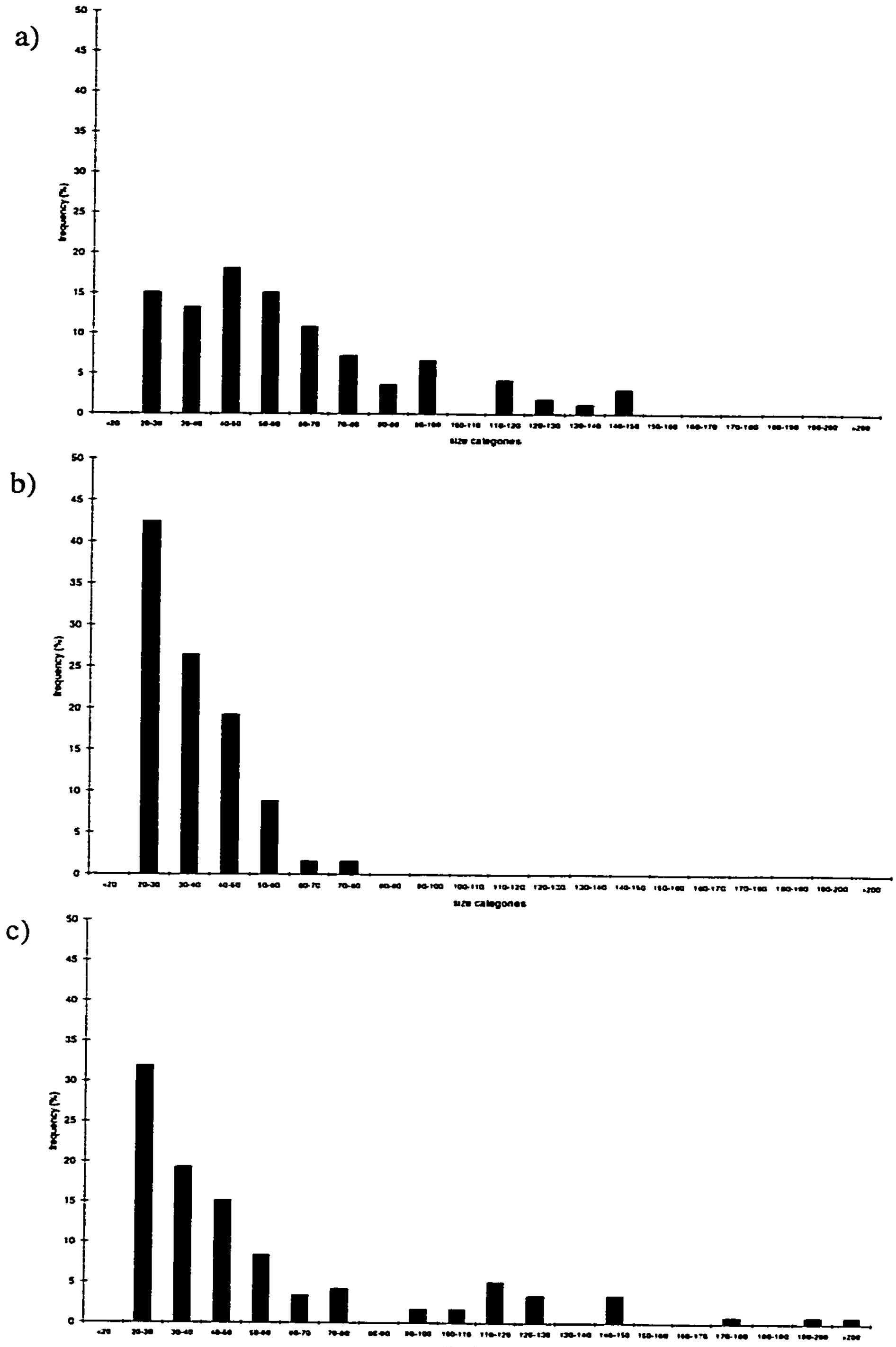

a)
b)
c)
frequency (%)
size categories

Table 2-1: Summary of the AGRRA data collection and survey site locations on the Horseshoe Reef. The average coral cover value is given with standard error on the mean in parenthesis.

Table 2-2: Summary of the AGRRA coral survey results from the Horseshoe Reef. Average values are followed by the standard error on the mean in parenthesis. The % standing dead, bleached and diseased colonies represent a count of the frequency of occurrence.

site	Lat/Long	water depth (m)	# benthic transects	# corals / transects	coral cover (%)
A	12°38'00.48"N 61°20'56.88"W	12	11	108	42 (2.6)
B	12°38'00.48"N 61°20'56.88"W	4	14	109	29 (1.6)
C	12°37'48.06"N 61°21'04.02"W	9	11	104	44 (2.3)
D	12°38'08.58"N 61°20'55.38"W	3	13	109	32 (1.4)
E	12°38'08.58"N 61°20'54.46"W	11	11	101	29 (2.6)
Shallow	-	3.5	33	313	30 (1.1)
Deep	-	11	27	218	38 (1.2)
Overall	-	8	60	531	35 (1.2)

site	# corals	coral diameter (cm)	recent mortality (%)	old mortality (%)	total mortality (%)	% standing dead colonies	% bleached colonies	% diseased colonies
A	108	55 (2.9)	1.1 (0.7)	23 (2.3)	29 (2.6)	0	14.8	4.6
B	109	54 (2.9)	1.2 (0.7)	27 (3.0)	32 (3.2)	9	2.8	0.9
C	104	64 (4.2)	2.3 (0.5)	26 (2.5)	29 (2.5)	1	6.7	1.0
D	109	65 (3.4)	2.8 (0.8)	24 (2.1)	30 (2.2)	0	1.8	1.8
E	101	50 (3.0)	2.0 (0.7)	32 (2.7)	32 (2.7)	0	9.9	5.9
Shallow	218	59 (2.3	1.9 (0.5)	25 (1.8)	31 (2.0)	4	2.3	1.4
Deep	313	56 (2.0)	1.8 (0.4)	25 (1.4)	30 (1.5)	0.3	10.5	3.8
Overall	531	58 (1.5)	1.9 (0.3)	25 (1.1)	30 (1.2)	2	7.2	2.8

Table 2-3: Summary of the AGRRA algae and coral recruitment and *Diadema* survey results from the Horseshoe Reef. Average values are followed by the standard error on the mean in parenthesis.

Table 2-4: Incidence of black band (BBD) and yellow band (YBD) disease infection on susceptible coral species on the Horseshoe Reef. Number of colonies infected followed by the total number of colonies in parenthesis.

site	# quadrates	% macro	% turf	% coralline	macro height (cm)	recruits (#/m^2)	*Diadema* (#/100m^2)
A	53	55 (3.2)	17 (2.1)	28 (2.8)	1.5 (0.3)	0.3	0
B	58	21 (3.3)	23 (3.3)	56 (4.1)	1.4 (0.1)	6.6	7
C	54	48 (4.0)	14 (1.6)	38 (3.4)	1.7 (0.1)	4.7	2
D	51	12 (2.8)	35 (3.4)	53 (3.8)	1.3 (0.2)	1.3	3
E	52	24 (4.0)	28 (3.8)	49 (4.0)	2.1 (0.2)	2.8	0
Shallow	109	17 (2.2)	29 (2.4)	54 (2.8)	1.8 (0.1)	5.0	5.1
Deep	159	42 (2.2)	19 (1.5)	38 (2.0)	1.4 (0.1)	0.7	0.6
Overall	268	32 (1.6)	23 (1.3)	45 (1.7)	1.6 (0.1)	2.4	2.4

		shallow sites	deep sites	all sites
Coral species usually affected by the BBD	*Montastraea annularis*	0 (59)	0 (106)	0 (165)
	Montastraea faveolata	0 (7)	0 (21)	0 (28)
	Montastraea franksi	0 (0)	2 (9)	2 (9)
	Montastraea cavernosa	0 (0)	1 (9)	1 (9)
	Siderastrea siderea	0 (0)	2 (12)	2 (12)
	Colpophyllia natans	0 (1)	0 (12)	0 (13)
	Diploria strigosa	0 (1)	0 (5)	0 (6)
	Diploria labyrinthiformis	0 (0)	0 (1)	0 (1)
	TOTAL	0 (68) =0%	5 (175) =3%	5 (243) =2%
Coral species usually affected by the YBD	*Montastraea annularis*	2 (59)	5 (106)	7 (165)
	Montastraea faveolata	1 (7)	1 (21)	2 (28)
	TOTAL	3 (136) =2%	6 (181) =3%	9 (353) =3%

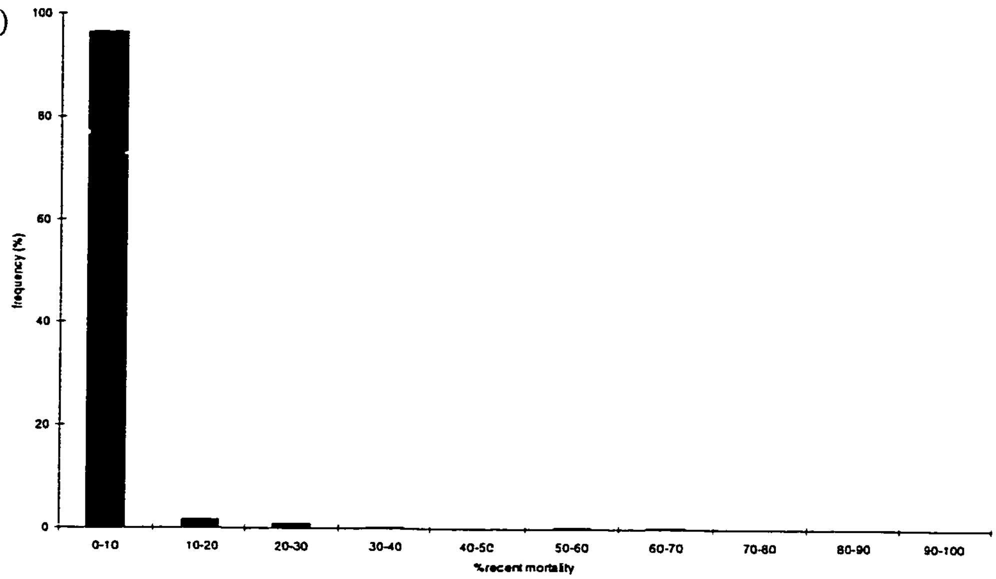
characterised by an average live coral cover of 35%, with cover ranging between 29 to 44 % for the five surveyed sites (Table 2-1). The average live coral cover is similar for both depth zones ($F = 1.7421$; $df = 1,3$; $p = 0.2786$). Coral colonies in the fore reef are dominated by small coral colonies with an average diameter of 58 cm (Table 2-2). The size frequency distribution for the three major reef building corals, *Montastraea annularis*, *Porites asteroids* and *Porites porites* are skewed toward smaller colonies (Fig. 2-4). Larger *Porites porites* banks and *Montastraea* colonies are also present, but relatively uncommon. Coral recruitment averages 2 recruits/m^2, with an average of 5/m^2 in shallow sites and less than 1 recruit/m^2 in deeper sites (Table 2-3).

Corals on the Horseshoe reef have an average of 2% recent coral mortality and an average of 25% old coral mortality (Table 2-2). The average recent and old mortalities are similar for both depth zones ($T = 34216$; $p = 0.74$ and $T = 34190$; $p = 0.92$). The frequency distribution of recent mortality shows that almost all corals have less than 10% recent mortality and is similar for both shallow and deep sites (Fig.2-5a and b). The frequency distribution of old mortality shows a wider variability of distribution for all class range, with a greater number of old mortality in the 0- 10% (Fig2-6a and b). The encrusting white tunicate (Fig. 2-2e), *Trididemnun solidum* is also present at all of the AGRRA sites. The corals partially encrusted by this organism are evaluated as part of the old mortality. This organism is mainly encrusting the *Porites, Montastraea and* occasionally *Millepora*. In total the tunicate encrusts 55 of the 532 surveyed coral colonies.

Relatively low incidence of coral disease is present on the Horseshoe Reef, with less than 3% of affected colonies (Table 2-2). Diseases encountered are the yellow band disease

Figure 2-5: Frequency distribution of the % recent mortality on the a) shallow fore reef and b) deeper fore reef sites of the Horseshoe Reef.

a)


100
80
60
40
20
0
frequency (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
%recent mortality

b)

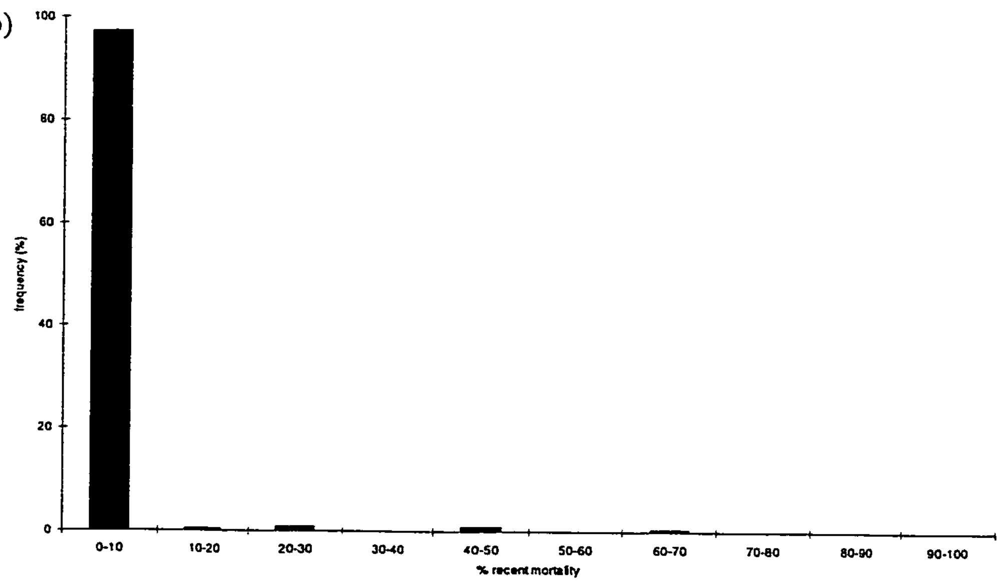
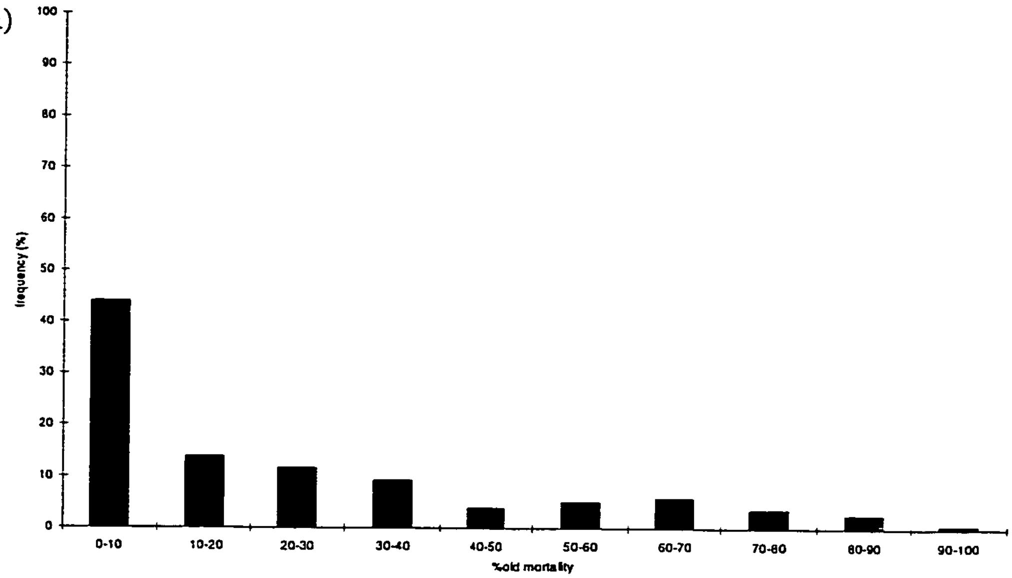
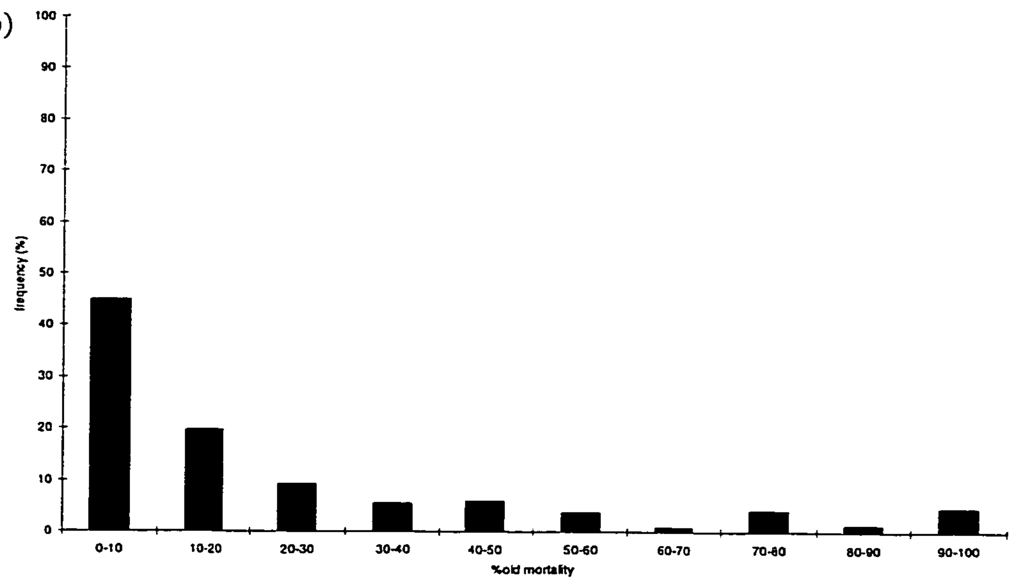

100
80
60
40
20
0
frequency (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
% recent mortality

Figure 2-6: Frequency distribution of the % old mortality on the a) shallow fore reef and b) deeper fore reef sites of the Horseshoe Reef.

a)


frequency (%)
100
90
80
70
60
50
40
30
20
10
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
%old mortality

b)


frequency (%)
100
90
80
70
60
50
40
30
20
10
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
%old mortality

affecting 4% of star corals and the black band disease affecting 2% of massive corals (Table 2-4). The black band disease is only present at site E and the yellow band disease occurs at all sites but site C. Relatively low incidence of coral bleaching is also observed with less than 3% of colonies affected (Table 2-2). No complete bleaching is observed but pale discoloured corals and partially bleached corals are present. Deeper sites account for 10% of all the bleaching while the shallow sites account for only 2% of the bleaching (Table 2-2).

Algae/Diadema- Algal communities at the Horseshoe Reef are dominated by crustose coralline algae with 45% cover, followed by macro algae at 32% and turf algae at 23% (Table 2-3). The shallow fore-reef sites are dominated by crustose coralline algae, while the deeper sites are mostly dominated by macro algae (Table 2-3, Fig. 2-2e). The presence of calcareous algae of the genus *Halimeda* largely dominates the macro alga communities. Average canopy height for macro algae on the Horseshoe Reef is 1.6 cm. The macro algae height is similar for both shallow fore-reef and deeper fore reef sites ($T = 4640$; $p = 0.63$). The sea urchin *Diadema* is relatively uncommon on the fore reef areas of the Horseshoe Reef, with an average density of 2.4 individuals/ m^2 (Table 2-3). *Diadema* are rare at the deeper sites with $0.6/100m^2$ but slightly more common with $5.1/100m^2$ at the shallow sites (Table 2-3).

Fishes- The fish assemblage on the Horseshoe Reef is dominated by herbivorous species from the Scaridae (parrotfish) and Acanthuridae (surgeonfish) families present in moderate densities of 17-59individuals/$100m^2$ and 2-14individuals/$100m^2$, respectively (Table 2-5). Commercially valuable fishes (e.g. groupers, snappers, grunts) are present in low densities of 0-1 individuals/$100m^2$ and are relatively small in size (Table 2-5). The average diameter of

Table 2-5: Composition and abundance of fish species from the roving diver survey at the Horseshoe Reef. Species are listed in order of decreasing frequency. "***" indicates the frequent species (≥70% sighting frequency), "**" indicates the common species (70%<x>20% sighting frequency), and "*" indicates the uncommon species (≤20% sighting frequency).

Fish Species	% Sighting frequency	Density	Abundance
***Yellowtail Damselfish	100	3.00	3
***Yellow Goatfish	100	2.60	2.6
***Trumpetfish	100	2.40	2.4
***Stoplight Parrotfish	100	3.00	3
***Redband Parrotfish	100	3.00	3
***Clown wrasse	100	2.00	2
***Brown Chromis	100	4.00	4
***Blue Tang	100	2.60	2.6
***Blue Chromis	100	3.60	3.6
***Yellowhead Wrass	90	2.89	2.6
***Threespot Damselfish	90	3.00	2.7
***Sharpnose Puffer	90	1.22	1.1
***Mahogany Snapper	90	2.22	2
***Longspine Squirrelfish	90	2.00	1.8
***Creole Wrasse	90	3.11	2.8
***Bluehead wrasse	90	3.22	2.9
***Bicolor Damselfish	90	3.11	2.8
***Yellowtail Hamlet	80	2.00	1.6
***RedlipBlennie	80	2.38	1.9
***Queen Parrotfish	80	2.88	2.3
***Princess Parrotfish	80	3.13	2.5
***Ocean Surgeonfish	80	2.25	1.8
***Creole-fish	80	2.25	1.8
***Striped Parrotfish	70	2.43	1.7
***Smallmouth Grunt	70	1.86	1.3
***Sergeant Major	70	2.71	1.9
***Puddingwife	70	1.57	1.1
***Masked/Glass Goby	70	2.00	1.4
***French Grunt	70	1.86	1.3
***Foureye Butterflyfish	70	1.86	1.3
***Banded Butterflyfish	70	2.14	1.5
**Greenblotch Parrotfish	50	2.60	1.3
**Graysby	50	1.60	0.8
**Bridled Goby	50	1.60	0.8
**Yellowtail Snapper	40	2.25	0.9
**Spotted Drum	40	1.00	0.4
**Glasseye Snapper	40	1.25	0.5
**Dusky Damselfish	40	1.75	0.7
**Doctorfish	40	2.25	0.9
**Smooth Trukfish	30	1.33	0.4
**Silversides	30	3.67	1.1

Fish Species	% Sighting frequency	Density	Abundance
**Queen Angelfish	30	1.00	0.3
**Orangespotted Filefish	30	1.67	0.5
**Orange filefish	30	1.67	0.5
**Harlequin Bass	30	2.00	0.6
*Spotted Moray	20	1.00	0.2
*Spanish Hogfish	20	1.00	0.2
*Slippery Dick	20	2.00	0.4
*Shy Hamlet	20	1.00	0.2
*Sand Diver	20	1.00	0.2
*Red Hind	20	1.00	0.2
*Cocoa Damselfish	20	2.00	0.4
*Bluestriped Grunt	20	2.00	0.4
*Barred Hamlet	20	1.00	0.2
*Bar Jack	20	2.50	0.5
*Yellowmouth Grouper	10	1.00	0.1
*Yellowcheek Wrasse	10	1.00	0.1
*Tobaccofish	10	1.00	0.1
*Spotted Eagle Ray	10	1.00	0.1
*Spotfin Butterflyfish	10	2.00	0.2
*Southern Stingray	10	1.00	0.1
*Slender Filefish	10	1.00	0.1
*Sharptail Eel	10	1.00	0.1
*Scrawled Filefish	10	1.00	0.1
*Schoolmaster	10	2.00	0.2
*Rock Hind	10	2.00	0.2
*Rock Beauty	10	2.00	0.2
*Redtail Parrotfish	10	2.00	0.2
*Redfin Parrotfish	10	2.00	0.2
*Rainbow Runner	10	2.00	0.2
*Majorra,Yellowfin	10	2.00	0.2
*Longjaw Squirrelfish	10	1.00	0.1
*Grey Snapper	10	1.00	0.1
*Great Barracuda	10	1.00	0.1
*Fairy Basslet	10	1.00	0.1
*Coney	10	1.00	0.1
*Cero	10	2.00	0.2
*Bucktooth Parrotfish	10	1.00	0.1
*Blackbar Soldierfish	10	2.00	0.2
*Black Durgon	10	2.00	0.2
*Beaugregory	10	2.00	0.2

Table 2-6: Density and total length of fish families from the AGRRA belt transect surveys at the Horseshoe Reef.

Family :	Surveyed species (number of observations)	length (cm)	Density (/100m^2)
Angelfish : (Pomacanthidae)	French - *Pomacanthus par (0)* Gray - *Pomacanthus arcuatus (0)* Rock Beauty - *Holocanthus tricolor (0)* Queen - *Holocanthus ciliarus (2)*	15.5 (±0.0)	0.1 (±0.04)
Butterflyfish: (Chaetodontidae)	Foureye - *Chaetodon capistratus (8)* Banded - *Chaetodon striatus (9)* Spotfin - *Chaetodon ocellatus (1)* Reef - *Chaetodon sedentarius (0)* LongSnout - *Chaetodon aculeatus (0)*	13.8 (±1.6)	0.6 (±0.18)
Grunt: (Haemulidae)	Porkfish - *Anisotremus virginicus (0)* White - *Haemulon plumieri (0)* Bluestriped - *Haemulon sciurus (1)* French - *Haemulon flavolineatu (2)* Tomtate -*Haemulon aurolineatu (0)* Smallmouth - *Haemulon chrysargyreum(5)* Caesar - *Haemulon carbonarium (0)* Spanish - *Haemulon mactostomum(0)* Sailors Choice - *Haemulon parra (0)*	18.0 (±3.4)	0.3 (±0.16)
Parrotfish: (Scaridae)	Stoplight - *Sparisoma virid (323)* Redfin - *Sparisoma rubripinne (0)* Redband - *Sparisoma aurofrenatum (177)* Princess - *Scarus taeniopterus (138)* Striped - *Scarus croicensis (114)* Queen - *Scarus vetula (156)* Redtail - *Sparisoma chrysopterum (10)* Midnight - *Scarus coelestinus (0)* Rainbow - *Scarus guacamaia (0)* Greenblotch - *Sparisoma atomarium (64)* Blue - *Scarus coelruleus (0)*	16.0 (±3.5)	32.7 (±2.00)
Seabass: (Serranidae)	Tiger - *Mycteroperca tigris (0)* Red Hind - *Epinephelus guttatus (2)* Graysby - *Epinephelus cruentatus (6)* Nassau - *Epinephelus striatus (0)* Black - *Mycteroperca bonaci (0)* Rock Hind - *Epinephelus adscensionis (0)* Coney - *Epinephelus fulvus (0)* Yellowfin - *Mycteroperca venenosa (0)* Yellowmouth - *Mycteroperca interstitialis (0)*	28.6 (±0.0)	0.3 (±0.08)
Snapper (Lutjanidae)	Schoolmaster - *Lutjanus apodus (0)* Gray - *Lutjanus griseus (0)* Mutton - *Lutjanus analis (0)* Mahogany - *Lutjanus mahogany (0)* Yellowtail - *Ocyurus chrysurus (2)* Lane - *Lutjanus synagris (0)* Cubera - *Lutjanus cyanopterus (0)*	15.5 (±0.0)	0.2 (±0.04)
Surgeonfish (Acanthuridae)	Ocean - *Acanthurus bahianus (64)* Doctorfish - *Acanthurus chirurgus (8)* Blue Tang - *Acanthurus coeruleus (107)*	15.2 (±1.8)	6.0 (±1.57)
Leatherjacket (Balistidae)	Queen Triggerfish - *Balistes vetula (0)* Black Durgon - *Melichthys niger (1)* Orangespotted Filefish - *Cantherines pullus (5)*	18.8 (±0.0)	0.2 (±0.08)
Other	Yellowtail Damselfish - *Microspathodon chrysurus (100)* Spanish Hogfish - *Bodianthus rufus (61)* Great Barracuda - *Sphyraena barracuda (1)* Bar Jack - *Caranx rubber (0)* Blue Runner - *Caranx chrysos (0)* Hogfish - *Lachnolaimus maximus(0)*	15.2 (±1.7)	5.4 (±0.41)

commercial fish families range between 16-29 cm in total length (Table 2-5). A total of 81 species of fishes was recorded during the 10 rover surveys (≈7 hours) on the Horseshoe Reef (Table 2-6). Of those species, a total of 31 are frequently observed, 14 are commonly observed and 36 are uncommon (Table 2-6).

2.4 Discussion

The use of the AGRRA methodology enables us to evaluate the present condition of the Horseshoe reef using standard and quantitative indicators of reef condition. The first section will provide an interpretation of the measured indicators of coral condition and will conclude with a brief and qualitative comparison with other AGRRA surveys conducted in the Caribbean and the Gulf of Mexico (Fig.2-1). The preliminary summary results of these Caribbean surveys are presently available on the AGRRA website (AGRRA, 2000). It must be noted that a database is presently being constructed to compile the survey data and start looking at regional trends. The second section is a discussion of the temporal changes observed on the Horseshoe Reef since the preliminary survey by Lewis (1975).

2.4.1 Interpretation of AGRRA survey results

Corals- The Caribbean reefs are mainly characterised by the presence of six scleractinian genera (*Acropora*, *Montastrea*, *Porites*, *Diploria*, *Siderastrea* and *Agaricia*) and one hydrozoan genus (*Millepora*), these contribute to as much as 90% of the coral biomass (Milliman, 1975). The coral cover in the Western Atlantic reefs typically reaches a maximum of approximately 30% (Mumby *et al.*, 1998a). The Horseshoe Reef has an average coral cover of 35% and is represented by a total 16 coral species with fewer coral species present in the shallow fore-reef. The main reef builders of the Horseshoe Reef are thus *Montastreas spp.* in the deeper fore-reef and *Porites spp.* in the shallower fore-reef. The coral assemblage and coral cover on the Horseshoe Reef are typical of high energy windward Caribbean reefs. The relatively greater coral diversity in deeper waters may be due to a more constant environment than those at shallower depths where physical and biological disturbances are more pronounced (Bak and Nieuwland, 1995).

The coral size distributions typically show many small colonies, however, numbers decrease down to zero in the largest colonies where mortality puts a limit to size (Bak and Meesters, 1998). The size distribution of corals in a population results from two processes; individual colony growth in size and population dynamic in terms of colony size (Bak and Meesters, 1998). Coral populations at degraded sites typically show negatively skewed distributions (having fewer small colonies), this implies an ageing population without juvenile replenishment (Bak and Meesters, 1998). The size frequency distributions for the three major reef building coral species on the Horseshoe Reef are skewed toward smaller diameter colonies with most of the corals being smaller than 100cm (Fig. 2-4). Fewer large colonies of *Montastraea annularis* (110-150cm) and *Porites porites* banks (110-300cm) are also present (Fig. 2-4). The positively skewed size distribution of the main reef building corals of the Horseshoe Reef is an indication of a "healthy" reef system with adequate juvenile input.

Partial mortality is a dominant process in larger corals while total mortality is more frequent on the smaller size corals (Hughes, 1989). The regeneration capacity of living coral tissues is limited with small lesions having a better chance of recovery (Meester *et al.*, 1997). A higher than average number of lesions on coral colonies may be indicative of changes in the environmental conditions and the colonisation state of these lesions may also provide an indication of the time of occurrence of certain past events (Meester *et al.* 1997). Partial old coral mortality on the shallow and deep fore reef areas of the Horseshoe Reef is moderate. Recent mortality is also low in these areas. The most common observed sources of recent mortality are damselfish algal gardens, predation by *Coralliophila abbreviata*, fish bites and spatial competition with algae. Consequently the low rate of recent mortality is here an indication that the Horseshoe Reef has not suffered from any major recent disturbance events.

Coral reef bleaching is a common stress response of corals to many anthropogenic and natural disturbances (Glynn, 1996). Bleaching occurs when the densities of zooxanthellae decline and/or the concentration of photosynthetic pigments within the zooxanthellae decrease. If the stress-causing bleaching is not too severe and decreases in time, the affected corals usually regain their symbiotic algae within several weeks or a few months (Glynn, 1996; Wilkerson *et al.* 1988). No complete bleaching of corals was observed during our survey but corals appeared to be recovering from previous low/moderate bleaching events, possibly from the 1998 Caribbean wide bleaching, as indicated by with the presence of pale discoloured and patchy bleached coral colonies. Shallow reefs often have a higher rate of bleaching than deeper corals (Glynn, 1984; Bak and Nieuwland, 1995). Although moderate on the Horseshoe Reef, bleaching was more prevalent on coral colonies located at the deeper sites (8-15 m). Greater bleaching at deeper reefs in the Bahamas was related to topographic features of the reef subjecting coral to warm downwelling currents (Lang *et al.*, 1988). Some depth-related bleaching patterns may also reflect varying sensitivities of distinctive zooxanthellae genotypes within and among host species at different depths (Rowan an Knowlton, 1995). *Montastrea annularis* has been observed to be more susceptible to bleaching than other coral species (Meesters and Bak, 1993). Higher bleaching at deeper sites of the Horseshoe Reef may be explained by the greater abundance of *Montastrea annularis* on the deeper fore reef sites or simply by the greater abundance of macro algae causing local bleaching.

The variety and frequency of diseases in coral reef organisms have increased across the Caribbean during the last 10 years (Goreau *et al.*, 1998). Black band disease (BBD) is characterised by a crescent shaped band of darkly pigmented filaments that separates white denuded skeleton from living coral tissues (Bruckner *et al.*, 1997). The BBD is an infection caused by the cyanobacterium *Phormidium corallyticum* (Rutzler *et al.*, 1983). It has been observed on massive Faviidae corals throughout the Caribbean (Rutzler *et al.*, 1983) as well as in the Indo-Pacific and the Red Sea. In the tropical western Atlantic, susceptible species include the brain corals *Diploria strigosa*, *D. labyrinthiformis*, *Colpophyllia natans*, and the star corals Montastraea *cavernosa*, *M. annularis*, *M. franksi*, and *M. Faveolata* (Edmunds, 1991). Infection rates increase during warm water conditions with disease activity optimal at/or above water temperatures of 25°C and typically disappearing during the winter (Rutzler *et al.* 1983). It has been suggested that turbulence plays an integral role in limiting disease activity by reducing the settlement of the filamentous algae and bacteria (Kuta, and Richardson, 1996). Aggregated distribution of BBD was observed on the north coast of

Jamaica (Bruckner *et al.*, 1997) and in the northern Florida Keys (Kuta and Richardson, 1996) but was random on the reefs of the US Virgin Islands (Edmunds, 1991). The few quantitative surveys on the BBD show that less than 2% of Caribbean corals are infected with BBD (Edmunds, 1991). The yellow-band disease (YBD) is a condition that affects massive heads of *Montastraea faveolata* and less commonly of *Montastraea annularis* (Santavy and Peters, 1997). The YBD begins as an irregularly shaped blotch of lightened yellow coloured tissue on the surface of the coral (Fig.1-5b). As the disease progresses the tissue in the centre of the patch dies and the area fills with sediment and algae resulting in a band of yellow tissue around the enlarging sediment patch (Santavy and Peters, 1997). The YBD has been noted in many Caribbean sites and is an important predecessor to mortality of the reef building *M. annularis* in much of the region (Goreau *et al.*, 1998). Very few susceptible corals on the Horseshoe Reef were affected with the BBD and YBD at the time of the survey. Coral colonies affected by the BBD were present at only one of the deeper sites, suggesting a clumped distribution. The shallow fore-reef area of the Horseshoe Reef is a high energy environment, which may limit the development of the black band disease to quieter sites. The low incidence of diseases is an indication that the corals on the Horseshoe Reef are in good condition.

Algae/fish - On tropical reefs, the abundance of algae is commonly maintained at a low level by grazing fishes (especially by parrotfish, surgeonfish, and damselfish) and by a host of grazing invertebrates (echinoids, snails, crabs and small crustaceans) (Lewis, 1986). Coralline algae plays an important role in reef accretion processes and stabilisation of substrates (Vine, 1974), they can typically withstand conditions of higher hydraulic and light energy than corals and have a tendency to dominate the surface of many reefs on wave-exposed windward coasts (Macintyre, 1997; Bosence, 1983). Moderate to high levels of grazing by fishes and invertebrates also favour coralline algae dominance over filamentous turf algae (Steneck 1985). Grazing by herbivorous fish typically reduces the abundance of macro alga species that have a superior overgrowth abilities and also maintains a tropical benthic assemblage dominated by algal turfs and crustose coralline algae (Lewis, 1986). The shallow sites on the Horseshoe Reef are characterised by dead coral substratum largely encrusted by crustose coralline while the deeper sites are macro algae dominate.

Until the early 1980s, *Diadema* was the primary grazers on reefs especially on reefs subject to intense fishing pressures (Lewis, 1986). *Diadema antillarum* has suffered from a Caribbean wide mass mortality in 1983-84, this die off has been attributed to a waterborne pathogen transported by ocean currents (Lessios *et al.*, 1984). Since the *Diadema* die-off fishes are now grazers of primary importance on most tropical reefs (Hay, 1984). The long spined black sea urchin *Diadema antillarum* is present in low densities in the shallow sites and commonly absent from the deeper sites of the Horseshoe Reef. *Diadema antillarum* is presently not a major contributor to the grazing on the fore-reef areas of the Horseshoe Reef but no comparative data is available from before the die-off period.

Phase shift from coral/invertebrate dominated to algae dominated communities has been well documented in Jamaica (Hughes, 1994) and elsewhere in the Caribbean (Done, 1992). Macro algae compete with sessile reef invertebrates for space, relaxing herbivorous grazing pressure can ultimately result in the demise of coral communities (Hughes, 1989; Hughes *et al.*, 1987). Macro algae can easily overgrow smaller algal turfs, crustose corallines and *Porites* colonies (Lewis, 1986). It is clear that algal community structure is greatly affected by the spectrum of grazers on an individual reef, and in turn, fishing pressure that can significantly alter the type of grazing pressure (McClanahan and Muthiga, 1998). The massive reduction in *Diadema antillarum* abundance (Lessios *et al.*, 1983; Bak and Nieuwland, 1995) combined with the reduction in fish grazers due to over fishing are frequently cited as causes of macro algae dominance (Hay, 1984 and Done, 1992). Fish grazing normally decreases with depth since deeper areas are less structurally complex and leaves herbivorous fishes more exposed to attacks by predatory fish (Hay, 1984; Lewis, 1986). Fish grazing was not measured in this survey but we observed moderate to high densities of herbivorous fishes at both the shallow and deep fore reef sites of the Horseshoe Reef. Nevertheless, fish grazing must be of some importance since the macro alga assemblage is dominated by graze resistant *Halimeda* species. The low densities of *Diadema* and the typically lower grazing by herbivorous fishes in the deeper fore-reef areas of the Horseshoe reef may explain the macro algae dominance at this depth zone.

An encrusting tunicate, *Trididemnun solidum*, was observed overgrowing many coral colonies at all of our study sites. *Trididemnun solidum* is regarded as a common competitor for space on Caribbean reefs. The tunicate colonies grow rapidly as thin sheets over turf covered rocks (13cm/4wk) and scleractinian corals (2.8cm/4wk), but with a much slower growth rate when in spatial competition (Bak *et al.*, 1981). They are commonly found in water depth ranging from 1.5 m to 34 m because they host unicellular endosymbiotic algae that limit their distribution to the photic zone (Bak *et al.*, 1981). Competitive overgrowth by organisms such as *T. solidum* may be influenced by environmental perturbations that reduce the efficiency of affected organisms to defend themselves. Possibilities of dispersal of *T. solidum* are low, but in a sufficiently dense population, maintenance potential is high because of ; relatively high mobility of the colonies over the substratum (division, budding, fusion and rapid growth), effective competition for space, low predation pressure and high regeneration capacity and long life-span of colonies (Bak *et al.*, 1981). Bak and Niewland (1995) hypothesised that an increase in abundance of this species may be related to eutrophication. An increased level of nutrients in coastal zones favours the growth of benthic algae, and promotes the development of phytoplankton and zooplankton, the latter being food supplies for the ascidians. Lewis (1975) did not note the occurrence of *T. solidum* in the Tobago Cays. An increasing abundance of this species on the Horseshoe Reef may be indicative of greater nutrient supply to the reef organisms. Nevertheless, macro algae abundance on the deep fore-reef sites of the Horseshoe Reef is relatively high but is mainly composed of graze resistant macro algae of the genus *Halimeda* with a lesser abundance of fleshy macro algae (e.g. *Dictyota spp*). Dense stands of *Halimeda* are competing for space in the deep fore-reef sites of the Horseshoe Reef and are observed overgrowing corals and even causing some local bleaching. Several eco-physiological features distinguish fleshy macro algae from calcareous macro algae. In calcareous algae, photosynthesis is coupled with the deposition of calcium carbonate skeleton (Littler, 1976), a characteristic that reduces the susceptibility to predation (Lewis, 1986). According to Delgado and Lapointe (1994), fleshy macro algae are nitrogen and phosphorus limited while calcareous macro algae are not. This suggests that nutrient enrichment would enhance the productivity of fleshy algae to a greater extent than that of calcareous algae. Along coastlines experiencing increased eutrophication it was found that the calcareous algae are often overgrown by more opportunistic fleshy forms (Delgado and Lapointe, 1994). The predominance of the calcareous macro algae over fleshy macro algae at the deeper sites and the dominance of coralline algae at the shallow sites are suggesting that the Horseshoe Reef is not suffering from significant nutrient enrichment but should be closely monitored.

There are only a few field studies on larval settlement, substrate selection and survival of young corals (see references below). These studies indicate that a period of substrate conditioning is required to let favourable algal communities get established over a suitable surface for larval settlement (Pearson, 1981). Coral larvae are unlikely to settle and survive on fleshy and filamentous algae covered substrates (Pearson, 1981). Under normal conditions of intense grazing by fish and echinoids, these unfavourable algae are replaced by grazing resistant crustose coralline algae, which appear to be a more suitable substrate for coral settlement (Pearson, 1981). Studies on artificial substrates have also indicated that herbivorous fish grazing increases coral recruitment and early survivorship (Birkland 1977, Brock, 1979). Fleshy macro algae dominance leads to the reduction of the calcification processes on reefs and may also lead to coral mortality and reduction in recruitment (Hughes *et al.*, 1987). The number of coral recruits averages 5 recruits/m^2 in the shallow sites compared to less than 1 recruit/m^2 in the deeper sites on the Horseshoe Reef. These results can probably be explained by the lack of favourable settling sites in the deeper fore reef, most likely caused by the predominance of macro algae dominated substrates.

Fishing has caused massive reductions in the density of piscivorous fishes on reefs throughout the tropics. Increased fishing pressures may also have a significant effect on the size composition of certain species since heavy fishing targets larger individuals of both carnivorous and herbivorous species (Roberts, 1995). Grazing fishes typically represent dominant components of the herbivorous guild on relatively undisturbed Caribbean reefs (Hay *et al.* 1983; Hay, 1984). The fish assemblage on the Horseshoe Reef is clearly dominated by herbivorous scarids and scanthurids. Commercially valuable fish species are present in low densities ($\leq 1/100\ m^2$) and are relatively small in size (16-26 cm). The fishing effort on the Horseshoe Reef is probably mainly targeted at the larger commercially valuable species (e.g. groupers and snappers) but not at the herbivorous fishes. The low abundance and small size of commercially valuable species is here a good indication of the effect of over fishing.

Other AGRRA surveys - During the 1998-99 AGRRA campaign, reefs were surveyed in Venezuela, Bonaire, Cayman Islands, Turks and Caicos, Cuba, Belize, Honduras, Bahamas, Mexico, Flower Gardens, Netherlands Antilles (northern) and St.Vincent (this survey). Reefs of the Flower Gardens, Los Roques, Venezuela, and Bonaire are in very good condition with all areas having high (40-50%) coral cover, large coral sizes, low macro algae (<20%), low recent mortality (<2%), and good representations of fish populations. The majority of other areas surveyed, including the Horseshoe Reef, are in good condition but are showing some signs of moderate disturbances. The abundance of herbivorous fish species is low in San Salvador, Bahamas, Cuba, and Mexico but moderate in most other regions. Low abundance and smaller size of commercial fishes were also found San Salvador, Bahamas, Cuba, and Mexico as well as in St. Vincent. Moderate to severe coral mortality was observed in portions of the Bahamas and in much of South Central Belize and Honduras associated with the 1998 bleaching event. Extensive stands of healthy living *Acropora palmata* were found on the Andros Island Reef system. In comparison to the preliminary results from other AGRRA survey the Horseshoe Reef is characterised by a higher macro alga dominance and a lower abundance and smaller size of commercially valuable fish species. Based on the AGRRA indicators it is possible to conclude that the Horseshoe Reef is in good condition and can be considered as a healthy and /or recovering reef system (see Chapter 1, Fig.1-6) showing some signs of disturbances such as overfishing and the loss of *Acropora palmata* as a shallow reef builder.

2.4.2 Temporal changes on the Horseshoe Reef

Studies on coral reefs prior to the 1970's have been primarily qualitative, although many have used quadrates and various other methods to collect the data. The Horseshoe Reef and the Tobago Cays have been studied by Lewis (1975, providing the first and only qualitative description of these reefs. The coral zonation on the Horseshoe Reef is typical of high energy windward Caribbean reefs (Milliman, 1975). The synoptic AGRRA survey of the Horseshoe Reef revealed that that most shallow sites (1-5 m) are presently composed of dead *A. palmata* pavement largely encrusted by crustose coralline algae and colonised by *Porites asteroides* and *Millepora spp.* near the crest, while *Montastreas annularis* starts to dominate the coral assemblage as we move away from the crest into slightly deeper waters (>3 m). Standing colonies of dead *A. palmata* are also present in the shallow fore reef areas but less common. The shallow reef crest area (0-1 m, exposed at low tides) was not surveyed using the AGRRA methodology because of its inaccessibility. Nevertheless some observations showed that it is mostly covered by *Millepora* and dead coral pavement encrusted by coralline algae and zooanthids. Deeper sites (8-15 m) on the reef slope are dominated by, in order of decreasing abundance: *Montastreas annularis, Porites porites, Porites asteroides*, and *Montastreas faveolata*, with scattered colonies of *Colpophyllia natans, Siderastrea siderea, Montastraea cavernosa, Montastraea franksi, Diploria strigosa, Agaricia agaricites, Madracis decactis Dendrogyra cylindris, Diploria labyrinthiformis, and Mycetophyllia sp.*. It must be noted that AGRRA only surveys the major reef building corals, therefore it is likely that some of the species mentioned by Lewis were not accounted for in our 1999 survey (ex. *Favia fragum*). Gorgonians are abundant in both the shallow and the deep fore-reef areas. The species assemblages for the reef crest, the shallow fore-reef and the reef slope are very similar those that described by Lewis (1975) apart from the absence of live *Acropora palmata* from the reef crest and shallow fore-reef zones. Thus *A. palmata*, which once flourished on the shallow fore-reef and the reef crest of the Horseshoe Reef has now virtually disappeared as a reef builder. Some juvenile *A. palmata* are present in the backreef area immediately behind the reef crest (pers. obs. A. Deschamps). Secondary coral colonisers such as *Millepora, Porites* and crustose coralline algae typically encrust the dead *A. palmata*. The *Millepora* have strong competitive advantages and are able to monopolise disturbed habitats (Loya, 1976). *Millepora* are immune to scleractinian diseases, relatively tolerant to severe physical disturbances and do not appear to be subject to the intense burrowing and bio-erosion that affect the Scleractinia (Lewis, 1989).

Acropora palmata was a major reef builder of the western Atlantic reef systems (Macintyre, 1988). Caribbean windward reefs were commonly dominated by this species at depths ranging from 1 to 5 m (Adey and Burke, 1976; Adey, 1978). A decline in the *A. palmata* populations has been attributed to successional or gradual changes as well as catastrophic events such as hurricanes or diseases (Lewis, 1984). In Barbados, *A. palmata* was abundant in the early successional stages of reef development, however, other reef-building fauna such as *Montastrea annularis*, *Millepora complanata*, and coralline algae are now dominant (Lewis, 1984). The presence of standing dead colonies of *A. palmata* in the shallow fore reef areas of the Horseshoe Reef is a good indication that they were not killed by hurricanes (Fig. 2-2c). The Grenadine Islands are situated south of Caribbean hurricane belt and have not been affected by a hurricane in the last 50 years. On the other hand the WBD has been killing the *Acropora palmata* in the entire Caribbean region since the early 1980s (Aronson and Pretch, 1997). The disease appears to be a bacterial infection that mainly affects Acropoids but it cannot be attributed to any particular human or natural factors (Antonius, 1981). Gladfelter (1982) described the changes from the loss of *A. palmata* on the reefs in the Virgin Islands as causing a decrease in structural complexity, a decrease in live coral tissue, a reduction in carbonate deposition rate and an increase in filamentous and crustose algae. Throughout much of its range *A. palmata* has been subject to the WBD, from the Florida Keys, Puerto Rico, Virgin Islands, Antigua, St. Martin, Curacao, Nicaragua, Panama, Bahamas, Tobago, and Bermuda (Santavy and Peters, 1997). The loss of *Acropora palmata* on the shallow fore-reef is most likely explained by WBD killing *Acropora* in the mid 1980s. The WBD was not observed during the 1999 survey because of the absence of *Acropora palmata* on the survey sites and therefore cannot be positively identified as the cause.

2.5 Conclusion

For the first time, the condition of the Horseshoe Reef was established using the AGRRA methodology. Using the indicators established by the AGRRA protocol, the results obtained from our survey suggest that the Horseshoe Reef is a relatively healthy reef but is also showing signs of disturbances. The specific finding and conclusions of our survey are the following:

1. The coral assemblage and moderate coral cover on the Horseshoe Reef are typical of high energy windward Caribbean reefs.
2. Coral colonies are skewed toward smaller size corals indicative of a "healthy" and/or recovering reef system.
3. Low incidence of disease, bleaching, and recent mortality of reef building corals are also an indication that the reef has not suffered from any major recent disturbance events and has recovered, if affected, from the major Caribbean wide bleaching event of the summer/fall of 1998.
4. High abundance of macro algae, low densities of *Diadema*, and moderate abundance of herbivorous fishes. The macro alga assemblage is dominated by graze resistant calcareous macro algae (*Halimeda*) with a lesser abundance of nutrient demanding fleshy algae. Dominance of macro algae on the Horseshoe Reef may be explained by a combination of possible nutrient enrichment and reduced herbivory.
5. The fish assemblage is showing signs of over fishing characterised by low densities and small size of commercially valuable species.

6. Standing dead colonies of *A. palmata* are indicative of past disturbance events since the last survey by Lewis (1975). The near disappearance of *Acropora palmata* as reef builder on the shallow fore-reef was likely related to white-band diseases killing *Acropora* in the mid 1980s.

Establishing and enforcing fishing regulations and monitoring water quality in the Tobago Cays Marine Park are critical steps to avoid future degradation of these reefs. The Horseshoe Reef is situated at 4 km from the nearest populated island and may therefore be considered a remote reef. Even if the Horseshoe Reef is relatively isolated from direct human influences, the most likely factors responsible for the degradation of these reefs are over fishing and the discharge of raw sewage by visiting yatches in the back reef area of the Tobago Cays. Because of the absence of earlier quantitative surveys on the reefs of the Tobago Cays we can only speculate on the possible causes of the observed changes and/or degradations. This AGRRA survey will serve as adequate baseline information from which to measure future changes in reef condition through time and evaluate the management efficiency of the recently established marine park.

CHAPTER 3: The Use of Colour Aerial Photography to Map Coral Reef Habitats in the Shallow Waters of the Tobago Cays Marine Park, West Indies.

Abstract

The Tobago Cays are part of a string of small islands called the Grenadines located between St.Vincent and Grenada in the Lesser Antilles. They consist of four small islands protected by a semi-circular bank barrier reef, the Horseshoe Reef. Limited information is available on the reefs of the Tobago Cays, and, this study represents the first marine habitat map created for these shallow tropical water environments. A digital thematic map of the shallow marine habitats surrounding the Tobago Cays and the Horseshoe Reef was created using archived colour aerial photographs and standard remote sensing image processing techniques. True colour aerial photographs were digitised, georeferenced and rectified using ground control points and a second order polynomial transformation. A mosaic was created to cover the entire study area using seven aerial photographs. A linear stretch of water areas was done to facilitate the identification of benthic features. Masks were created to remove unwanted areas from the classification (land, deep water ≥10 m, boats and high surf areas). Ground thruthing and testing data were collected using a standard reef assessment methodology and benthic classes were derived objectively using agglomerative hierarchical classification of field data. Supervised classification of the Tobago Cays was done using the field derived benthic classes, the final thematic map comprises of 8 classes with an overall accuracy of 87% and a Kappa and Tau coefficients (other estimates of overall accuracy) of

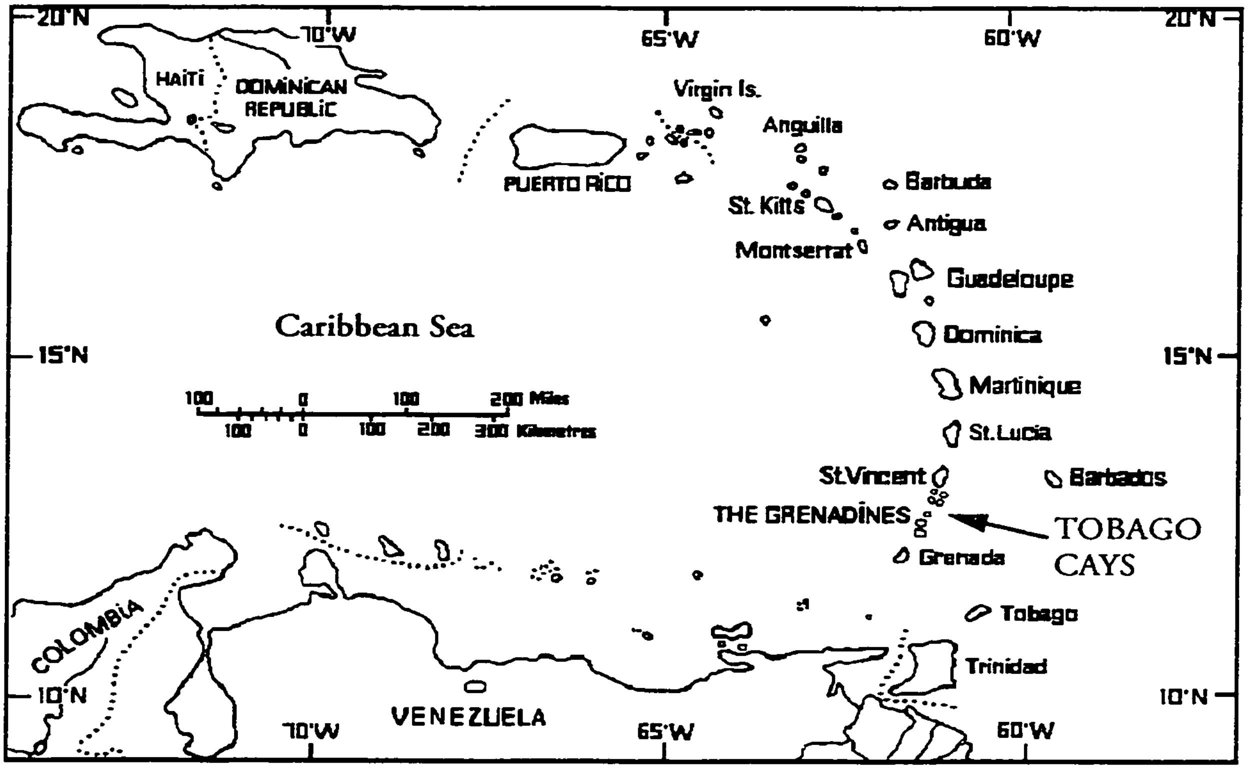
85%. Producer and user accuracies of individual classes range between 53% and 100%. The deep water class was most commonly confused with the mixed coral community at depths greater than 4 meters. This confusion was mainly attributed to the variation in water depth. The mixed coral community, the macro alga dominated, the seagrass dominated and the dead coral substratum classes were occasionally confused. This confusion may be attributed to the similarity in their spectral signatures since all of these classes have components that contain photosynthetic pigments. The main sources of errors in this study are from the discrepancy in the date of the aerial photographs survey (1991) and the field survey (1999), the non-availability of differential GPS, and the restriction to one field survey session. Our results suggest that digitised aerial photographs and supervised classification provide valuable information on the composition and distribution of the shallow marine communities of the Tobago Cays Marine Park.

3.1 Introduction

This study focuses on the shallow marine habitats of the Tobago Cays Marine Park (TCMP) located in the Grenadines, West Indies (Fig. 3-1). Over the past 15 years informal reports have indicated that the conditions of the reefs in the Tobago Cays have deteriorated due to various factors including storm damage, white band diseases, physical damage, and local sewage pollution from visiting yachts (Smith *et al.*, 1996; Wells, 1988). The TCMP has been established since 1998 and is slowly developing. The reefs of the Tobago Cays have not been the subject of any recent research; thus limited documentation is available on these reefs. Except for the preliminary descriptions by Lewis (1975), there is no recent information on the nature and the extent of the shallow marine communities in the TCMP. Obtaining an inventory of the major habitat types with their composition, distribution and location is an essential first step to protecting and managing the fragile coral reef ecosystem of the TCMP.

Reef research has long tried to use remote sensing techniques to map reefs areas. The use of aerial photography in conjunction with field surveys was one of the first remote sensing methods for reef mapping, vertical air photos of the Great Barrier Reef have been taken as early as 1925 (Hopley, 1996). The use of aerial photography has decreased over the past decade and attention has been shifted towards digital imagery from satellite and more recently airborne hyperspectral sensors. The principal obstacles in using satellite imagery in tropical regions are the low spatial resolution of imagery and the prevalence of clouds. The best spatial resolution presently available in multispectral mode is from SPOT HRV (20 m) and Landsat TM (30 m) and in panchromatic mode from SPOT PAN (10 m) and IRS (5.8 m). We are presently at the brink of a new era in remote sensing with the arrival of high-resolution commercial satellites. The first one of these high-resolution satellites, IKONOS, was launched in September 1999 with a spatial resolution of 1m in panchromatic and 3m in multispectral. Unfortunately, IKONOS images were not available in time for this study. The capability of satellite and airborne remote sensing methods for mapping Caribbean coral reefs has been reviewed by Mumby *et al.* (1997). For the production of detailed maps of marine habitats, they suggested that traditional aerial photo interpretation methods and airborne hyperspectral sensors (e.g. CASI-Compact Airborne Spectrographic Imager) should give the best results (Mumby *et al.*, 1997).

Figure 3-1: Location map of the study site.



20°N
70°W
65°W
60°W
20°N
HAITI
DOMINICAN REPUBLIC
Virgin Is.
Anguilla
PUERTO RICO
Barbuda
St. Kitts
Antigua
Montserrat
Guadeloupe
Caribbean Sea
Dominica
15°N
15°N
Martinique
100 0 100 200 Miles
100 0 100 200 300 Kilometres
St. Lucia
St.Vincent
Barbados
THE GRENADINES
TOBAGO CAYS
Grenada
Tobago
COLOMBIA
Trinidad
10°N
10°N
70°W
VENEZUELA
65°W
60°W

Previous studies have shown that aerial photographs are particularly well suited to the study of tropical coastal ecosystems because of their high resolution and simplicity of acquisition. Hopley (1977) has recommended the use of true colour photography to combine a good penetration (blue spectral band) and a good definition of themes. Traditional aerial photography mapping methods have been used successfully to map seagrass and coral reef areas (Ferguson *et al.*, 1993; Sheppard *et al.*, 1995). Digitised aerial photographs have the potential to be developed as a tool for mapping reefs at high resolution (Catt and Hopley, 1988). Scanned aerial photographs can be processed using standard remote sensing software and semi-automatic standard image processing techniques. This has the advantage of reducing observer bias by using statistical methods in the production of the final thematic maps. Scanned aerial photographs have been used for mapping small reef areas in Thailand (Thamrongnawasawat and Hopley, 1995) and the Red Sea (Manière et Jaubert, 1985), tropical coastal marine ecosystems in Martinique (Chauvaud *et al.*, 1998), seagrass beds in Martinique (Manière *et al.*, 1994) and benthic ecosystems in the Mediterranean (Pasqualini *et al.*, 1997). In general, habitat-mapping work conducted before 1990 lack quantitative results, ground data collection, and accuracy assessments of thematic maps (see references above). The use of true colour aerial photography was selected for this project because of the presence of an important cloud cover during optimal remote sensing acquisition time in the Lesser Antilles, the complex nature of the coral reef habitats, the small size of the study region (4 km x 4 km) and the availability of data for a low cost (i.e. printing cost). The specific objectives of this study are the following:

1. To develop a rapid and cost effective field methodology for surveying the shallow marine habitats surrounding the Tobago Cays and its backreef area to provide a quantitative description of the main benthic assemblages and bottom types present in the TCMP. From this, develop a classification scheme of the benthic habitats that will be used in the training process of the supervised classification.
2. To produce a digital thematic map (with a known accuracy) of the shallow marine habitats of the Tobago Cays archived colour aerial photographs and standard remote sensing techniques. This will provide a visual and digital inventory of the major habitats that can be easily upgraded for long term monitoring purposes.
3. To qualitatively compare results with those obtained by Lewis (1975).

3.2 Study area

Shallow water areas of the TCMP consist of two main ecosystems, coral reefs (patch reefs, fringing reefs, bank barrier reef) and seagrass beds. Figure 3-2 illustrates the location of the Cays and the Horseshoe Reef. The four backreef Cays are partially surrounded by a narrow fringing reef consisting mainly of low clumps or heads of coral on a sandy bottom sloping gradually down into channels or lagoon. Small patches of mangrove trees are also present on the south-east coast of Petit Rameau. Petit Tabac is an east-west elongated Cay located on the windward side of the Horseshoe Reef. It is partially surrounded by a fringing reef along the south and south-west coast and gradually passing to a bank-barrier reef to the north and north-east with a shallow backreef lagoon. The Horseshoe Reef is a bank-barrier reef that can be divided into four major reef habitats based on the geomorphology, depth and exposure to waves including; the fore reef (steeply sloping to depths of 20-30 m), the reef crest, the back reef and the lagoon patch reefs (Fig. 3-2). Narrow tidal channels of a few meters wide are present at frequent intervals along the reef crest but spur and groove systems are absent (Lewis, 1975). The fore reef area of the Horseshoe Reef was studied in detail using the AGRRA methodology (see Chapter 2 in this study). The present chapter focuses on the shallow water areas in the TCMP including the following; shallow fore-reef, reef crest, backreef and lagoon patch reefs of the Horseshoe Reef as well as the fringing reef surrounding the Cays. More information on the local and regional setting of the TCMP is available in Chapter 1, sections 1.2 and 1.3 of respectively.

3.3 Research methods

True colour aerial photographs at 1:10 000 scale (March of 1991) were available for the Tobago Cays area. Although not originally intended to study the marine environment, these photographs were perfectly exploitable for this study. The prints were available through the archives of the National Air Photo Library in Ottawa after the permission was obtained from the Office of the High Commissioner to the Countries of the Organisation of Eastern Caribbean States. The camera lens had a focal length of 152 mm and the flight altitude was calculated as being approximately 1500 meters. A nautical chart of the middle Grenadines at the scale of 1:32 500 (Hydrographic Office of the United Kingdom, 1999) was also available. The research methods are discussed below in sections including: field survey, categorisation of field data into habitat classes, image processing and extraction of thematic information and accuracy assessment (Fig. 3-3). The PCI ® software was used for image processing and SYSTAT 8.0 ® software for all statistical analyses.

3.3.1 Field Survey

A variety of sampling techniques exists for surveying coral reef environments (English *et al.*, 1997; Rogers *et al.*, 1994). Compared to most other quantitative sampling techniques, quadrates have the advantage of permitting rapid acquisition of data with moderate accuracy (Rogers *et al.*, 1994). One of the main disadvantages in using quadrates for traditional ecological assessment is that it only provides data on a two dimensional surface area, therefore underestimating coverage of features which have a predominant orientation in the vertical plane. For this project, this was in fact advantageous since vertical aerial photographs also acquire information on a two dimension surface area. The use of quadrates as a method for ground thruthing has proven very efficient in many remote sensing studies (Mumby *et al*, 1998a; Thamrongnawasawat, 1996). A quadrate method was selected to survey the wide variety of benthic components present in the back reef area and the shallow water areas surrounding the Tobago Cays. Given the high spatial resolution available with the aerial photographs we used a 1 m^2 quadrates with a grid every 20 cm permitting reasonably accurate measures of percent cover. Percent cover is estimated counting the number of squares covered by each benthic group.

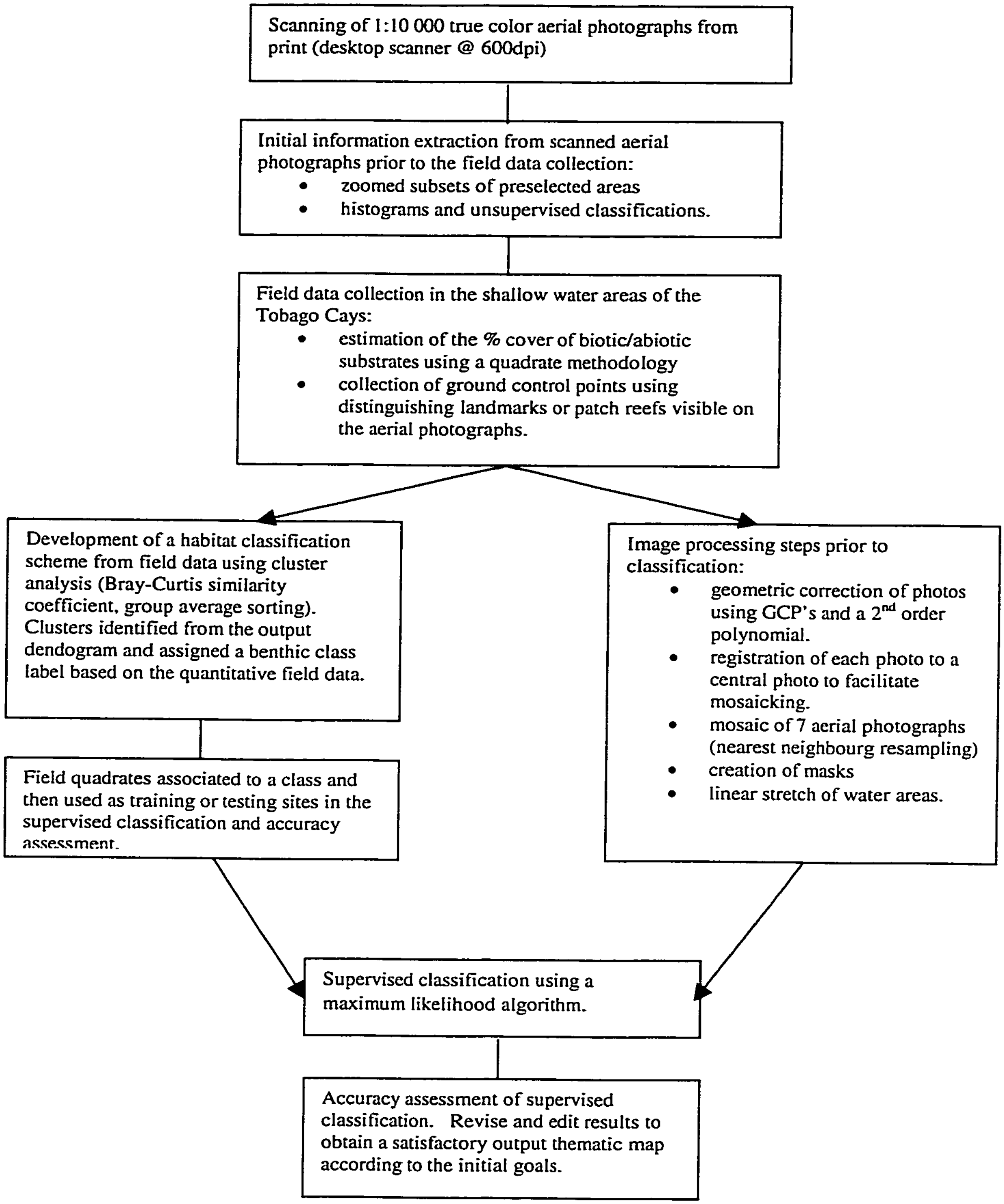
The field survey was conducted over a period of two weeks in June 1999. To maximise the diversity of habitats to be surveyed transect location was pre-selected using Lewis (1975), aerial photographs, nautical charts and preliminary results from supervised classifications of selected sites. Survey sites were limited to accessibility by boat and/or

Figure 3-2: Mosaic of the Tobago Cays created from seven colour aerial photographs (1:10 000). The mosaic was georeferenced using ground control points collected in June of 1999. The overlay identifies the Cays and indicates the location of the subsets for the following figures.

SCALE IN METRES

0 1000 2000

Figure 3-3: Schematic overview of the methodology used in the production of a shallow water habitat map of the Tobago Cays Marine Park using scanned aerial photographs.


Scanning of 1:10 000 true color aerial photographs from print (desktop scanner @ 600dpi)
Initial information extraction from scanned aerial photographs prior to the field data collection:
• zoomed subsets of preselected areas
• histograms and unsupervised classifications.
Field data collection in the shallow water areas of the Tobago Cays:
• estimation of the % cover of biotic/abiotic substrates using a quadrate methodology
• collection of ground control points using distinguishing landmarks or patch reefs visible on the aerial photographs.
Development of a habitat classification scheme from field data using cluster analysis (Bray-Curtis similarity coefficient, group average sorting). Clusters identified from the output dendogram and assigned a benthic class label based on the quantitative field data.
Field quadrates associated to a class and then used as training or testing sites in the supervised classification and accuracy assessment.
Image processing steps prior to classification:
• geometric correction of photos using GCP's and a 2nd order polynomial.
• registration of each photo to a central photo to facilitate mosaicking.
• mosaic of 7 aerial photographs (nearest neighbourg resampling)
• creation of masks
• linear stretch of water areas.
Supervised classification using a maximum likelihood algorithm.
Accuracy assessment of supervised classification. Revise and edit results to obtain a satisfactory output thematic map according to the initial goals.

land and to depths of less than 10 meters. Field data were collected to: i) build a classification based on field data, ii) provide a detailed description of the shallow marine habitats of the Tobago Cays and iii) provide training sites and testing sites for the image classification and the accuracy assessment of the thematic map. Percent cover was recorded using the following parameters: bedrock, dead coral, rubbles, sand, mud, hard corals, gorgonians, sponges, seagrass, green fleshy algae, green calcified algae, brown fleshy algae, red and brown branching algae, turf algae and coralline red algae. Hard corals and seagrass were identified to species level and algae were identified to genus level when possible. It must be noted that the percent cover of the total substrate and biotic cover may exceed 100% because of encrusting algae and canopy layers (i.e. dead coral encrusted by coralline red algae). The raw field data are available in Appendix 3A.

Quadrates were sampled every 10 m using a transect line as guideline. Transects were positioned perpendicular to the shoreline of the Cays cross-cutting most habitat zonations fringing the islands. The transect line was marked every meter and weighted at both end to measure distance from shore and to provide an estimate of water depth. The transect line was moved away from the shoreline until we reached the sand channels or water depths of 10 m. The sand channels usually occurred at depths ranging from 4 m to 8 m and anywhere from 70 m to 200 m from the shoreline. In the backreef area, transects were started at mooring buoys with recognisable starting points. Transect lines were moved toward the Horseshoe Reef up to the reef crest, wave conditions permitting. The shallow water areas surrounding the Cays were surveyed using a more qualitative approach to determine the extent of the major habitats. Particular attention was given to Petit Tabac since it was not surveyed by Lewis (1975). Field surveys near Petit Tabac were limited to the reefs north of the island and the backreef lagoon because of the high-energy more exposed environments along the south shore. Information on the shallow fore reef area was obtained from the AGRRA survey, which was done conjointly with this study (see Chapter 2). Distinguishing landmarks or patch reefs visible on the aerial photographs were chosen as the starting point and alignments of transect lines. A geographic coordinate was obtained at the beginning of each transect using a GPS unit with an accuracy of approximately 30 m. The precision of the ground control points was improved by taking a 5 minute average reading at each location (Jensen, 1996). Differential GPS was unavailable because of the absence of a base station in the study area. Ground Control Points are available in Appendix 3B.

3.3.2 Categorisation of field data into habitat classes

Classification schemes should be unambiguous, easily interpreted, objective and have a hierarchical structure to reflect the user needs (Mumby *et al.*, 1998a; Sheppard *et al.*, 1995). The habitat classification scheme for the TCMP was developed using a hierarchical cluster analysis method. This method was chosen because it provides natural grouping of sites based on the biotic assemblage and substrate measured in the field (percent cover) and provides a display of community patterns. It is most likely that remote sensing mapping would discriminate habitats on the basis of dominant benthic features rather that more cryptic species or substrates (Mumby *et al.*, 1997). Therefore, the percent cover data were not transformed so that the dominant cover features were allowed to exert an approximately large influence on the classification. Like most reefs of the Western Atlantic, the TCMP coral cover only reaches a maximum of approximately 30% (Mumby *et al.*, 1998a). Since

Caribbean reefs typically have low coral cover; thus it is very unlikely that cluster analysis will produce a coral dominated class. To obtain a valuable coral class the dataset was first separated based on coral cover. All sites containing 5% or more of live coral cover (78 sites) were analysed separately and assigned to the mixed live coral community class (class A) and further divided into subgroups by cluster analysis. Thus, we have sacrificed systematic accuracy to obtain a more logical habitat classification scheme acceptable for Caribbean reefs.

The Bray-Curtis dissimilarity measure has been shown to be a particularly robust and reliable measure of ecological distances (Faith *et al.*, 1987; Clarke, 1993). The Bray-Curtis similarity coefficient is given as:

$$S_{jk} = \left(1 - \frac{\sum_{i=1}^{p} | x_{ij} - x_{ik} |}{\sum_{i=1}^{p} | x_{ij} + x_{ik} |} \right) \qquad \text{Equation (3.1)}$$

Where x_{ij} is the abundance of the *i*th species in the *j*th sample and where there are *p* species overall. It has a number of biologically desirable properties such as ignoring joint absence of species, taking a value of 1 when two sites have no species in common, and taking a value of 0 when the abundance for all species are identical (Faith *et al.*, 1987). Ecological similarity between sites was measured using the Bray-Curtis dissimilarity coefficient (matrix); sites were clustered using an average linking method. Major clusters were identified from the output dendogram and the main features were obtained by referring to the original field data. To reduce the number of variables in the cluster analysis the clustering was performed on a reduced number of categories to highlight the dominant components. However, characteristic species have been included in each class description for adding clarity. The level at which clusters were selected was influenced by the ability to distinguish habitats from scanned aerial photographs. Cluster diagrams are available in Appendix 3C.

3.3.3 Image Processing and extraction of thematic information

Scanning- Shallow tropical reef habitats are composed of complex intermingled communities, therefore an output pixel size of less than 1m was chosen for this study. The digitisation of aerial photographs was carried out using a flatbed scanner (AFGA) at a resolution of 600 dpi giving a file size of 80 Mb with an output pixel size of approximately 42 cm. The scanning process splits the colour image into its three component colours (red, green, blue) stored in channels, each channel has spectral information corresponding to its reflectance intensity in 256 shades of grey (8 bit).

Geometric correction- Image distortion at the margins of the photographs is caused by the camera lenses and is most important when using wide-angle lenses (Ray, 1980). To reduce the radial distortion problem we eliminated these areas as much as possible from the mosaic. Ground Control Points (GCP) were collected over the entire survey area using landmarks and underwater features clearly recognisable on the aerial photographs (Appendix 3B). A correction model based on a second order polynomial was used for rectification and elimination of the geometric distortions. Geometrical rectification was applied on the central image using the best GCPs with the following distribution: Baradal (2), Petit Rameau (3), Petit Bateau (5), Jamesby (5), Petit Tabac (3) and the backreef area (6). The central image was rectified with a residual mean square error (RMS) error of 13 pixels in X and 12 pixels in Y. Each subsequent image was registered to this central image and then rectified using a 2nd order polynomial with RMS error of less than one pixel in X and Y. This step reduces the shift between adjacent photos and produces a better mosaic. Each aerial photograph was georeferenced with Lat/Long using the WGS84 ellipsoid.

Mosaic- An image file was created with the maximum coordinates to contain the entire survey area. All seven images were registered in individual channels of this file then used as a visualisation tool to trace the cutlines. The blue bands of adjacent pairs of images requiring cutlines were visualised using the following colour gun combination: image1:R, image2:G, image2:B. Cutlines were traced as vector in areas showing minimal radiometric differences between two adjacent photographs; these areas appear in shades of grey. When possible, cutlines were traced in deeper water and less visible areas to minimise the visibility of the cutlines on the final mosaic image. Radiometric correction was not performed prior to the mosaicking process since the main area of interest was completely covered by two adjacent photographs from the same flight line with similar radiometry. Problems of specular reflection predominate on the left 25% of each photograph. Since these were taken with an overlap of about 60% it is possible to discard most of these problematic regions from the area of interest in the mosaicking process. This increases the number of photographs required to build the mosaic of the TCMP from four to seven. The process of mosaicking is a balance between obtaining a visually pleasing image while minimising the number of cutlines. The mosaic was resampled to obtain a pixel size of 50 cm.

Linear contrast enhancement and masks- Contrast enhancement expand the original input brightness values to make use of the full dynamic range (e.g. 8bit=256 shades of grey). A land mask was created to remove land areas from further image analysis and increase the contrast of the water areas using a linear stretch. The goal of this process is to facilitate visual interpretation of the submerged reef biotic substrates. A deep water mask was also created to remove water areas with depths greater than 10 m from the classification. These areas were not surveyed and would likely be confused with spectrally similar classes since water depth variability is one of the most commonly cited confounding factor in remote sensing of underwater environments. It must be noted that the application of depth attenuation algorithms was not applicable to scanned aerial photographs since the wavelength information is lost (Sheppard *et al.*, 1995). The deep water mask was created using results of a preliminary classification in which deep waters formed a distinct class, boundaries were delimited using the nautical chart. It was also necessary to manually create a mask to remove the boats and the high surf areas on the reef crest since these would have been misclassified as sand or beach areas. The deep water, boats, high surf and land masks were added to a single bitmap and used to mask these areas from the classification.

Classification- A supervised classification method uses samples of known identity (training sites) to classify pixels of unknown identity to a set of predefined classes (Jensen, 1996). Field sites were located on the imagery starting with the finest habitat classification obtained from the cluster analysis. Characteristic spectral signature was obtained for each class and results were carefully evaluated and revised. Signature separability helps us determine how well each class is separate from each of the other classes, a value of 0 indicates complete overlap between the signatures of two classes and 2 indicates a complete separation between the two classes (Appendix 3E). The larger the separability values, the better the final classification results. Classes with low separability were progressively merged higher up in hierarchy since these could not be resolved adequately: A=A1+A2, B=B1+B3, E=E1+E2.

An exception to this scheme was for the macro algae dominated class (class D), which was not merged higher up in hierarchy. Class D was obtained by merging class F2 and B2 to class D, it was deemed that pixels with >50% of macro algae would classify together regardless of substrate type. Two classes were added for classification purposes only. Class G is composed of deep water ranging from 6 to 10 m with variable bottom types (mainly sand or mixed live coral), this class was added to increase the separability between various classes. Class H (beach sand) was added for completeness and was self-evident. To meet the statistical requirement for validity the training sites need to be sufficiently large to be statistically representative (>50 pixels/class) and the spectrum in each channel need to be close to a Gaussian distribution and be unimodal (Jensen, 1996). The seed function was used to increase the number of pixels belonging to a class by allowing neighbouring pixels in visibly homogenous areas to be incorporated in the signature. Once satisfying results were obtained in the training process, the spectra were used to classify the image using the maximum likelihood supervised classification algorithm (Jensen, 1996). The classification process assigns each pixel under the predefined shallow water mask to one of the eight classes. The resulting thematic map of habitats was evaluated visually and some modifications were necessary. Manual editing was done to reclassify the pixels in the sun spot area, west of the Tobago Cays since this was a known area of misclassification. The spectrum of the seagrass habitats was obviously over classified. The bias was adjusted (from 1.0 to 0.75) to reduce the probability that pixels would be assigned to this class and by constraining the size of the hyper-ellipsoid. The threshold of the hyper ellipsoid (from 3 to 1.5) was also adjusted by reducing the number of standard deviation for the decision limit.

Finally, post classification filtering was done to eliminate isolated pixels from the final classification (median filter). Based on an elementary window of 3x3 pixels, isolated pixels were identified and attributed the value of surrounding pixels.

3.3.4 Accuracy Assessment

An error matrix is a very effective way of representing accuracy of a classification (Congalton, 1991). The comparison between the supervised classification results and the actual field distribution of the themes (testing sites) provides an estimate of the accuracy for the overall classification as well as for each class and gives information on which classes are most commonly confused. Testing sites were selected from a separate dataset than the training sites to avoid an overestimation of the classification accuracy (Congalton, 1991). Where confusion between classes is high, a merge can be performed and the resultant accuracies re-examined until satisfactory results are obtained. In the present study, a total of 209 testing sites were used in the accuracy assessment. These were obtained from both the field quadrates (about 50 sites) or from a more qualitative surveys of the Cays. The error matrix was constructed with interpreted classes (classified) as rows and ground-thruthed classes (reference) as columns. The error of omission, the error of commission, the Kappa coefficient and the Tau coefficient were calculated according to Story and Congalton (1986) and Congalton (1991) and briefly explained below:

Producer's accuracy- This is the probability that a reference being correctly classified and is a measure of omission errors (Congalton, 1991). It gives the producer of the map an idea of how well a certain area can be classified and is particularly useful for assessing the accuracy of individual habitat classes. The total number of correct pixels in a category is divided by the total number of pixels of that category as derived from the reference data (column total).

User's accuracy- This is the probability that a pixel classified on the map actually represents that category on the ground and is a measure of commission errors (Congalton, 1991). It is also used to assess the accuracy of individual habitat classes. The total number of correct pixels in a category is divided by the total number of pixels that were classified in that category (row total).

Overall accuracy- This is the simplest descriptive statistic which is computed by dividing the total correct (sum of major diagonal) by the total number of test sites. It is a reasonable way to describe the overall accuracy of a map, but does not account for the accuracy component resulting from chance alone. A chance accuracy component exists because even a random assignment of pixels to habitat classes would include some correct assignments.

Kappa (K) Coefficient- The result of performing a Kappa analysis is a KHAT statistic. It determines if the agreement between remotely sensed classification and the reference data is significantly greater than 0 (random classification). This is a discrete multivariate technique to measure accuracy. This measure incorporates the off-diagonal elements as a product of the row and column marginals.

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})} \qquad \text{Equation (3.2)}$$

r=number of rows in the matrix, x_{ii}=the number of observations in row i and column i, x_{i+} and x_{+i} are the marginal totals for row i and column i, respectively, and N is the total number of observations. The overall accuracy only incorporates the major diagonal and excludes the omission and commission errors. Therefore, depending on the amount of error included in the matrix, these two measures may not agree (Congalton, 1991).

Tau coefficient (T)- This statistical parameter is readily interpretable, permits hypothesis testing, and accounts for chance agreement within the matrix. A T of 0.8 indicates that 80% more pixels were classified correctly than would be expected by chance alone. Tau is calculated from:

$$T = \frac{P_0 - P_r}{1 - P_r}, \quad \text{where} \quad P_r = \frac{1}{N^2}\sum_{i=1}^{M} n_i \times x_i \qquad \text{Equation (3.3)}$$

P_0=overall accuracy, M=number of habitats, i= ith habitat, N= total number of sites, n_i=row total for habitat I, and x_i=diagonal value for habitat i (number of correct assignments for habitat i).

The reliability of the resulting map was also assessed using on a more qualitative but global method as determined by Pasqualini *et al.* (1997). This method assigns scores based on a scale of reliability to a variety of factors, which influences the quality of image processing using scanned aerial photographs. This method gives us a better insight on the sources of errors that can influence the reliability at any levels of the classification process.

3.4 Results

3.4.1 Supervised classification results and accuracy

The hierarchical cluster analysis describes the field data at two levels of inter-habitat similarity, a coarse level (Table 3-1) with a Bray-Curtis similarity of 25-60% and a medium level (Table 3-2) and with a Bray-Curtis similarity of 65-80% (Appendix C). The coarser level consists of six habitat classes that were readily identifiable from the aerial photographs and retained for the supervised classification (Table 3-2). It must be noted that classes G (deep water) and H (beach sand) were added to the coarse level classification scheme for completeness and clarity, these will be explained below. The finer level classification consists of subdivisions of some of the main clusters and comprises eleven sub-clusters (Table 3-1). These sub-cluster classes could not be resolved using a supervised classification analysis and aerial photograph interpretation. The mosaicking process was very successful (Fig. 3-2) causing only minor misclassification errors along some of the seams; these will be addressed in the discussion. The classification results using the coarse level clusters resulted in an overall accuracy of 87%, a Kappa coefficient of 85% and a Tau coefficient of 85% (Table 3-3). User and producer accuracies for individual class ranged between 53%-100% and 74-100% respectively. Using a more global index developed by Pasqualini *et al.* (1997), the reliability of the resulting map was estimated at 69% (Table 3-4). The following section will provide a general description, overall distribution and the accuracy for each individual class. Figure 3-4 and 3-5 illustrate the main benthic assemblage for most classes and the proportion of the image classified in each class respectively. Figure 3-6 to 3-12 illustrate the classification results for the entire survey area as well as for each individual Cay and specific sections of the Horseshoe Reef.

Class A: Mixed live coral community – This class is represented by a mixed live coral community (Table 3-2). As mentioned in the introduction, this class is not necessarily dominated by hard corals in terms of percent cover. Very few coral reefs in the Caribbean

Table 3-1a: Summary and description of the main clusters and subdivisions of the field data based on the Bray-Curtis hierarchical cluster analysis with group average linkage method (n=209 sites).

Table 3-1b: Summary of the average percent (%) cover of the biotic components and the substrate contributing the main clusters and subdivisions of the field data based on the Bray-Curtis hierarchical cluster analysis with group average linkage method.

a)

Main clusters	% of sites	Cluster name	Sub-clusters	% of sites	Distinguishing features
A	35	**MIXED LIVE CORAL COMMUNITY:**	A1	24	▶ This benthic sub-cluster is characterized by sparse to dense live corals. Gorgonians and zooxanthids are also present in low percentage but are characteristic of this class. The substratum is dominated by dead coral pavement encrusted by red coralline algae, turf algae, mixed macro algae.
			A2	11	▶ This benthic sub-cluster is characterized by sparse to dense live corals. Gorgonians and zooxanthids are also present in low percentage but are characteristic of this class. The substratum is dominated sand parches and dead coral pavement encrusted with turf algae and mixed macro algae. Note: The following coral species are common to both subgroups: *Porites asteroides*, *P. porites*, *Montastraea annularis*, *Millepora spp.*, *Diploria spp.*and *Sidrastrea spp.*
B	18	**DEAD CORAL SUBSTRATUM WITH MIXED ALGAES:**	B1	8	▶ This benthic sub-cluster is dominated by dead coral substratum mixed with sand patches. The substratum is encrusted a mixed cover algae.
			B2	5	▶ This benthic sub-cluster is dominated by dead coral substratum with an important macro algae cover.
			B3	5	▶ This benthic sub-cluster is dominated by dead coral substratum. The substratum is encrusted by an important cover of coralline red algae.
C	8	**SEAGRASS ON SAND:**	-	-	This benthic class is dominated by seagrass from the genera *Thalassia* and to a lesser extent *Syringodium*. Fleshy algae and calcareous green algae are also likely to be present. Corals such as *Siderastrea* spp. and *Porites* spp. may also be present but in low cover. The substratum is dominated by sand.
D	8	**MACRO ALGAE ON SAND:**	-	-	Visually dominated by macro-algae on a sand substrate. The macro algae are mostly dominated by fleshy green, calcareous green, and fleshy brown algae.
E	22	**SAND DOMINATED:**	E1	18	▶ This benthic sub-cluster is dominated by bare sand.
			E2	4	▶ This benthic sub-cluster is dominated by sand with minor rubbles. Sparse algae, particularly green calcareous and brown branching algae, are also present.
F	9	**RUBBLE DOMINATED:**	F1	5	▶ This benthic sub-cluster is dominated by rubbles. The rubbles are commonly encrusted by coralline algae.
			F2	4	▶ This benthic sub-cluster is dominated by rubbles mixed with a lesser cover of and sand. The macro algae cover is also important in this class.

b)

Substrate (%cover) / Class	Dead Coral	Rubble	Sand	Hard coral	Gorgonian	Zooanthid	Sponge	Seagrass	Macro algae	Coralline algae	Turf algae
A1	55.8	1.3	2	23.2	3.8	2.6	0.2	0.5	18.4	24.0	22.2
A2	21.3	9.3	39	14.9	3.3	1.6	-	0.3	20.0	3.0	19.3
B1	54.7	4.9	22.9	1.4	2.5	3.6	-	-	23.7	7.1	36.6
B2	74.4	1.6	9.6	0.8	2.6	0.6	0.4	0.4	72.1	10.5	2.0
B3	86.5	-	1.8	2.5	7.3	2.9	-	-	19.3	50.9	20.7
C	-	4.6	38.8	1.1	-	-	-	42.6	10.1	-	3.8
D	2.4	4	34.5	0.7	1.2	-	0.2	1.2	55.9	0.6	1.2
E1	0.2	1.8	92.9	0.2	0.4	0.2	-	0.1	3.7	0.6	1.4
E2	9.0	21	65.8	2.0	1.3	0.5	-	-	3.0	1.0	13
F1	0.8	84.0	8.0	0.4	-	-	-	0.8	5.6	13.6	42.8
F2	0.4	64.0	15.6	3	0.6	-	0.4	-	55.6	5.3	16.0

Table 3-2a: Summary and description of the main clusters after merging of clusters which were not identifiable on the scanned aerial photographs (n=213 sites). After visual inspection and pre-classification statistical separability analysis, the following classes were merged: A=A1+A2, D=F2+D +B2, B=B1+B3, E=E1+E2.

Table 3-2b: Summary of the average percent cover (%) of the biotic components and the substrate contributing to the main clusters after merging of clusters which were not identifiable on the scanned aerial photographs. After visual inspection and pre-classification statistical separability analysis, the following classes were merged: A=A1+A2, D=F2+D +B2, B=B1+B3, E=E1+E2.

a)

Main clusters	% of sites	Cluster name	Description
A	35	**MIXED LIVE CORAL COMMUNITY:**	Characterized by sparse to dense live corals. The most common coral species are *Porites asteroides*, *P. porites*, *Montastraea annularis*, *Millepora spp.*, *Diploria spp.*and *Sidrastrea spp.* Gorgonians and zooxanthids are also present in low percentage but are characteristic of this class. Encrusting red coralline algae, turf algae, fleshy brown algae, green calcified algae, red branching and brown branching algae and are abundant. The substratum is dominated by dead coral pavement with scattered sand patches with minor rubbles. Note: This class is similar to class B, the main diagnostic feature of the latter is the lower live hard corals cover
B	13	**DEAD CORAL SUBSTRATUM WITH MIXED ALGAES:**	This class is dominated by dead coral substrate/pavement. This substrate is commonly encrusted by turf, coralline algae and low cover of mixed macro algae. Live corals may also be present but in much lower cover (<5%) than in class A. Gorgonians and zooxanthids are also present in low percentage but are characteristic of this class. The substratum is also co-dominated by scattered sand patches with minor rubbles.
C	8	**SEAGRASS DOMINATED:**	This benthic class is dominated by seagrass from the genera *Thalassia* and to a lesser extent *Syringodium*. Fleshy algae and calcareous green algae are also likely to be present. Corals such as *Siderastrea* spp. and *Porites* spp. may also be present but in low cover. The substratum is dominated by sand.
D	17	**MACRO ALGAE DOMINTED:**	This benthic class is dominated by macro-algae. The macro algae are mostly dominated by fleshy green, calcareous green and fleshy brown algae. The substratum can be dominated by sand, rubbles and dead coral pavement.
E	22	**SAND WITH SPARSE ALGAE:**	This benthic class is dominated by sand. There is usually some sparse algae, particularly green calcareous and brown branching algae.
F	5	**RUBBLE DOMINATED:**	The substratum in this class is dominated by rubbles with minor sand. The rubbles are commonly encrusted by turf and red coralline algae.

b)

Substrate (%cover) / Class	Dead Coral	Rubble	Sand	Hard coral	Gorgonian	Zooanthid	Sponge	Seagrass	Macro algae	Coralline algae	Turf algae
A	44.8	3.9	13.9	20.5	3.7	2.3	0.2	0.5	18.9	17.3	21.3
B	66.8	3.0	14.9	1.9	4.3	3.3	-	0.0	22.0	23.7	30.6
C	0.0	4.6	38.8	1.1	-	-	0.0	42.6	10.1	-	3.8
D	21.9	18.3	22.8	1.3	1.4	0.2	0.3	0.7	60.3	4.5	5.1
E	1.7	5.2	88.2	0.5	0.6	0.2	-	-	3.6	0.7	3.4
F	0.8	84.0	8.0	0.4	-	-	-	0.8	5.6	13.6	42.8

Table 3-3: Error matrix for the benthic habitats showing the classified data versus ground thruthed reference data (number of sites). The User's accuracy, Producer's accuracy, overall accuracy, Kappa coefficient and the Tau coefficient are also included in the table.

Classified Data	Reference Data A	B	C	D	E	F	G	H	ROW TOTAL
A	17	1	0	3	0	0	0	0	21
B	1	17	3	1	0	1	0	0	23
C	1	1	17	1	0	0	0	0	20
D	2	0	0	20	0	0	0	0	22
E	1	1	1	0	29	0	0	0	32
F	0	0	0	0	0	24	0	0	24
G	10	0	0	0	0	0	28	0	38
H	0	0	0	0	0	0	0	29	29
COLUMN TOTAL	32	20	21	25	29	25	28	29	209
Producer's accuracy (%)	53	85	81	80	100	96	100	100	**Overall accuracy = 87%** **Kappa coefficient = 85%** **Tau coefficient = 85%**
User's accuracy (%)	81	74	85	91	91	100	74	100	

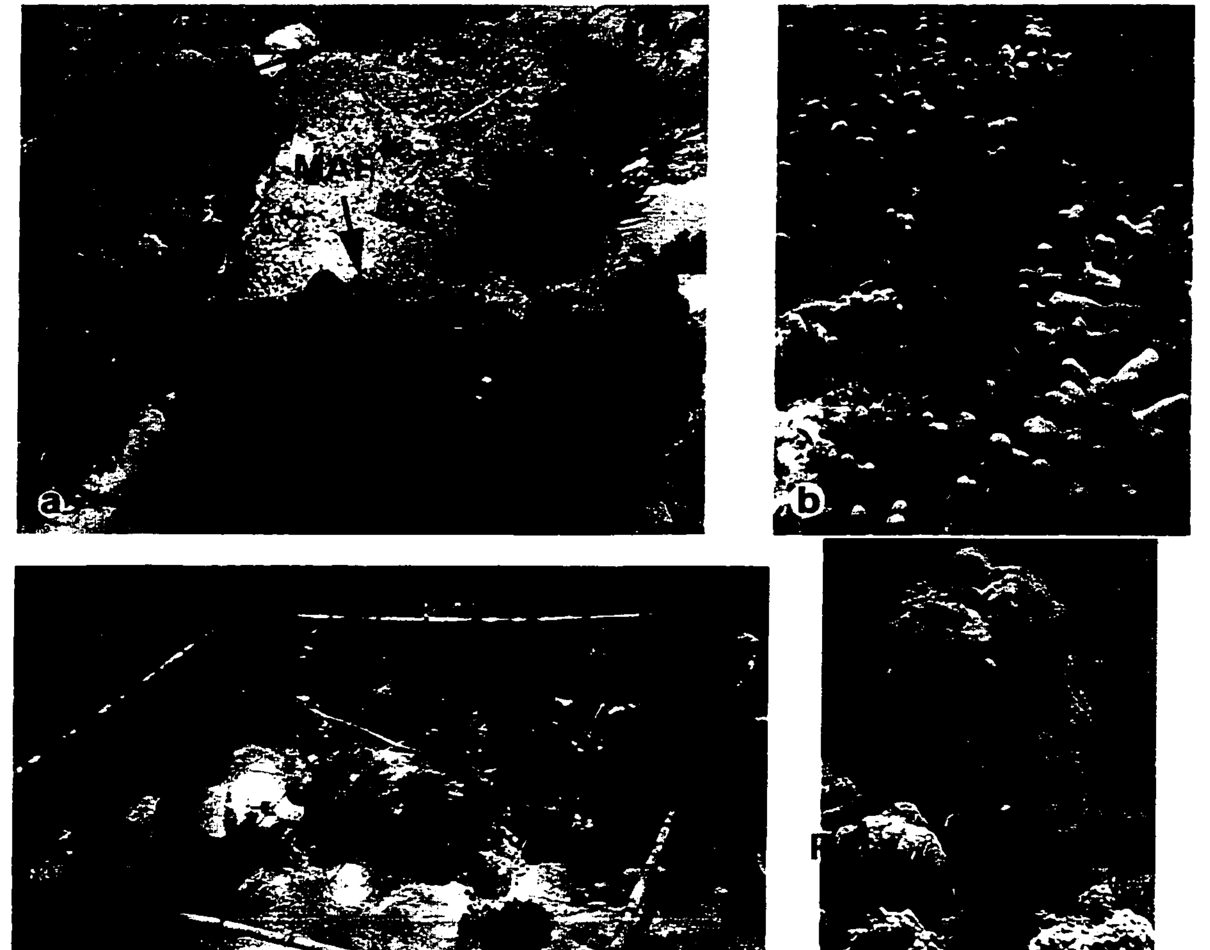
Table 3-4: List of the main factors influencing the quality of image processing of scanned aerial photographs and associated scale of reliability (adapted from Pasqualini *et al.*, 1996). This scale was used to assess the classification results obtained for the TCMP.

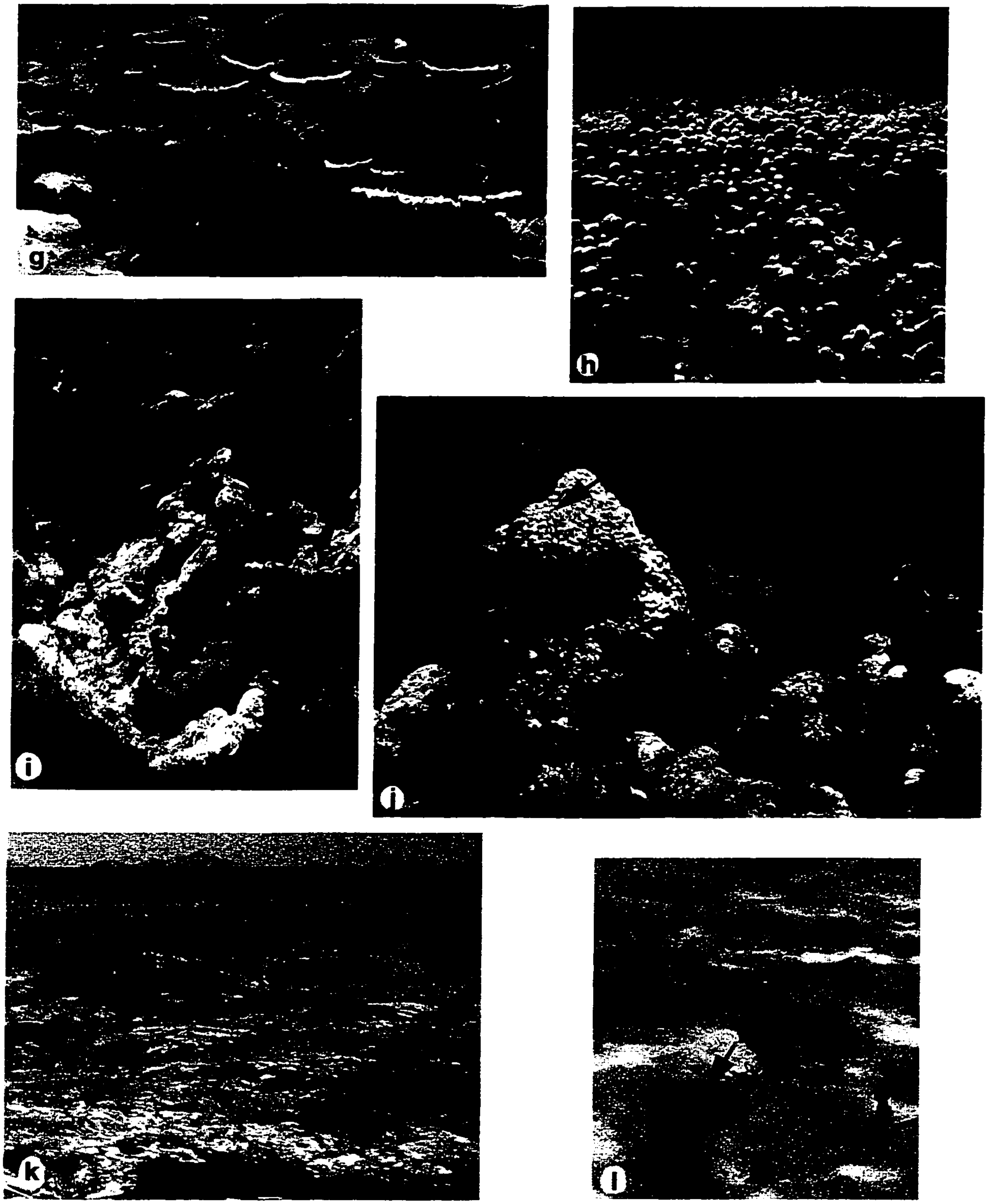
Factors	Scale of reliability				Reliability of the TCMP classification
	3 points	2 points	1 point	0 points	
Survey site:					
▶ Topography, slope	Slight and even	Strong and even	Slight and uneven	Strong and uneven	2
▶ Bathymetry range	0-5m	0-10m	0-20m	0- below 20m	2
▶ Visibility in water column (turbidity)	100% or range clear	75% of range clear	50% of rang clear	<50% of range clear	3
▶ Nature of assemblage and bottom type	Very different	Different	Similar	Very similar	2
Aerial photography:					
▶ Quality	Very good	Good	Fair	Bad	3
▶ Surface effect (ex: specular reflection)	No surface effect	Surface effect at a distance from site	Surface effect close to site	Surface effect at site	1
Scanning:					
▶ Pixel Size	Pixels ≤2m	2m< Pixel ≤5m	5m< Pixel ≤10m	Pixel >10m	3
▶ Quality	Very Good	Good	Fair	Bad	1
Geometrical rectification:					
▶ Number of reference points	Number ≥20	20> Number ≥10	10> Number ≥4	Number <4	3
▶ Distribution of reference points	Covers all area of image	Covers ¾ of image	Covers ½ of image	Covers ¼ of image	2
Field data:					
▶ Area of study site covered by field data	Area ≥ 10% of study site	10%> Area ≥5% of study site	5%> Area ≥1% of study site	Area <1% of study site	1
Classification:					
▶ Number of polygon per class	Number >30	30≥ Number >15	15≥ Number >5	Number <5	2
					▶ 25/36 = 69%

are truly dominated by hard corals. The key diagnostic features for this class is a hard coral cover greater than 4%. The hard coral assemblage is variable throughout the study area, with an average hard coral cover of 21%. The coral dominated areas commonly have a diverse assemblage of gorgonians (sea rods, sea whips and sea fans) but their percent cover varies widely with an average cover of 4%. Zooxanthids are also present but are restricted to high-energy areas such as the reef crest or backreef areas where they have an average cover of 2%. Encrusting red coralline algae, turf algae, and fleshy macro algae are omnipresent in this class; average covers being of 17%, 21%, and 19% respectively. The macro algae are mostly composed of *Dictyota* spp., *Halimeda* spp., *Amphiroa* spp. and minor *Laurencia* spp. The encrusting red algae are represented by various algae of the Corallinaceae family. The dead corals are the most abundant substratum but rubbles and sand are both likely to be present. Figure 3-4 (a-d) illustrates the characteristic assemblage of the mixed coral community.

The most common coral species in the Tobago Cays are *Montastrea annularis*, *Porites asteroides*, *P. porites*, *Siderastrea* spp., *Diploria* spp. and *Millepora* spp. The shallow fore reef is dominated by *Porites asteroides*, *Montastrea annularis*, *Porites porites* and *Millepora complanata* (Fig. 3-4e). The northern part of the reef is characterised by large banks of *Porites porites*. As the water depth in the fore reef gradually increases, the coral community becomes more diverse and shifts towards a dominance by *Montastrea annularis* and *Montastrea faveolata* (Fig. 3-4e). The reef crest and reef flat are predominantly composed of dead *Acropora palmata* pavement covered by crustose coralline algae and encrusting zooanthids *Palythoa*, it may also be colonised by scattered colonies of *Millepora* spp. and *Porites asteroides* (Figs. 3-4f). The reef flat merges lagoonward into a calmer area

Figure 3-4: Field photographs illustrating the characteristic assemblage of classes obtained from the supervised classification. Photos a-h illustrate the live coral community assemblage of class A; photos i-k illustrate the dead coral substratum with mixed algae class B; photo l-n illustrates the macro algae dominated class D; photo o illustrates the sand dominated class E and; photos p-q illustrate the rubble dominated class F. See text for more detailed information on individual photograph.
*Abbreviations represent the following; Beachrock (B), Gorgonian (G), Seagrass (S), *Amphipora* spp. (A), Coralline algae (C), *Dictyota* spp. (D), *Halimeda* spp. (H), *Acropora palmata* (AP), *Millepora* spp. (MI), *Montastrea annularis* (MA), *Montastrea faveolata* (MAF), *Porites porites* (PP), and *Porites asteroides* (PA).


a
b
c
d
e
f


g
h
i
j
k
l

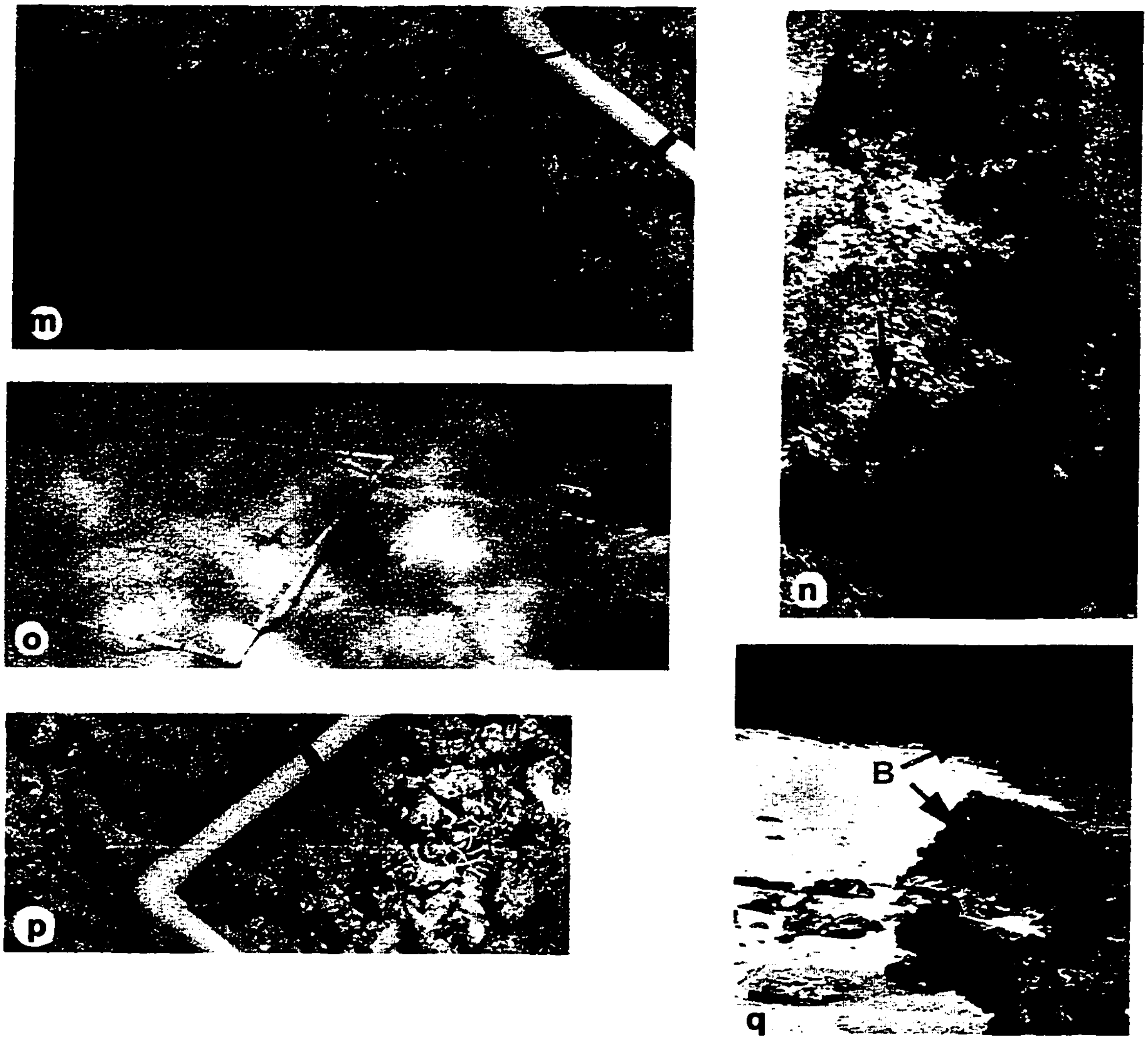
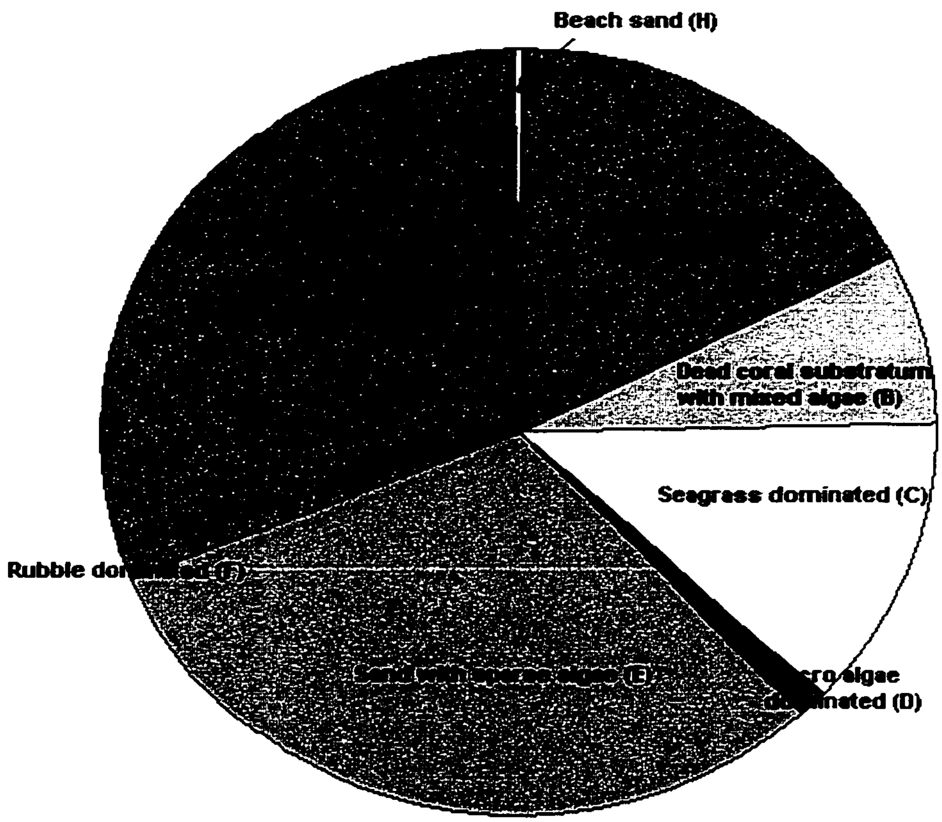

m
n
o
p
B
q

Figure 3-5: Chart showing the proportion of sublittoral substrate classes. Data is for all areas included in the supervised classification only (i.e. excluding masked areas).


Beach sand (H)
Dead coral substratum
with mixed algae (B)
Seagrass dominated (C)

where the coral pavement is gradually colonised by *Millepora* spp, *Porites asteroides* and *Palythoa*. Extensive growths of *Millepora complanata* and *Millepora squarrosa* are present in the high surge area between the reef crest and the backreef area. The backreef area is a relatively shallow without much slope and with water depth ranging between 1 and 2 meters. The patch reefs proximal to the crest are mainly dominated by large cluster *Montastrea annularis* with a gradual transition toward a more scattered patch reef systems on a sandy bottom (Fig. 3-4f). Mixed with the patch reefs are also large colonies of *Siderastrea* spp., *Diploria* spp, *Porites asteroides* and an occasional live colony of *Acropora palmata* (Fig. 3-4g). The coral community of the fore-reef and reef crest of the Petit Tabac bank-barrier reef is similar to that of the Horseshoe Reef, except for the backreef area. The patch reef system in the shallow backreef lagoon is entirely composed of medium to large banks of *Porites porites* with lesser *P. furcata* and *P. asteroides* (Fig. 3-4h).

The mixed coral community class represents 17% of the classified pixels (Fig. 3-5). This class is common around all five of the Cays as a fringing reef, the Horseshoe reef and Petit Tabac as a bank-barrier reef and the backreef and lagoon areas as patch reefs (Figs.3-6 to 3-12). The mixed coral community forms a discontinuous band partially surrounding the five Cays. This class is best developed along the windward side and in areas where the current is strongest such as the northern and southern tips of the Cays and along the western side of Jamesby Cay. At Petit Rameau, it surrounds the entire Cay while at Jamesby it is only present on the leeward side of the cay. The shallow fore reef areas up to the reef crest of the Horseshoe Reef are assigned to this class. Mixed coral communities are also identified by the classification as small patches in deeper (6-10m) sand channels with high current energy. These areas were not surveyed by the authors and therefore we cannot positively certify their presence.

The mixed coral community class has a user accuracy of 81% (19% commission error) and a producer accuracy of 53% (47% omission error) (Table 3-3). This means that only 53% of the mixed coral community areas has been correctly identified as class A but that 81% of the areas classified as A are actually a mixed coral community. A more careful look at the error matrix reveals that there is some confusion in discriminating mixed coral communities from the macro algae dominated substrate (D) and the dead coral substratum with mixed algae (B) (Table 3-3).

Class B: Dead coral substratum with mixed algae – This class is represented by dead coral substratum with an average cover of 67% (Table 3-2). This substrate is commonly encrusted by coralline algae, turf and low cover of mixed macro algae; their average covers are 24%, 31% and 22% respectively. Macro algae are mostly composed of *Dictyota* spp., *Halimeda* spp., *Amphiroa* spp. and minor *Laurencia* spp. The majority of dead coral substratum areas have a diverse assemblage of gorgonians with a variable but low average cover of 4%. Zooxanthids are also present but are restricted to the high-energy crest and backreef areas, where they have an average cover of 3%. Corals such as *Porites asteroides* and *Millepora* spp. may also be present but in low percent cover never exceeding 4%; this lower coral cover is the main feature distinguishing this class from class A. The substratum is co-dominated by scattered sand patches having an average cover of 15%. Figs. 3-4 (i-k) illustrate the characteristic assemblage of the dead coral substratum with mixed algae class.

The dead coral dominated class represents 7% of the classified pixels (Fig. 3-5). This class is common around all five of the Cays and in the backreef and reef flat areas of the Horseshoe Reef (Figs. 3-6 to 3-12). Immediately behind the reef crest is a wide zone of dead coral pavement and rubbles, this high-energy surf zone area is known as the reef flat (Figs. 3-7ab). The Elkhorn coral, *Acropora palmata*, which once flourished in the high-energy shallow areas of the Tobago Cays, has now virtually disappeared as a reef builder. The dead corals surrounding Petit Bateau, Petit Rameau, Petit Tabac and the wide zone in the Horseshoe Reef flat area are mainly composed of standing dead colonies and remnants of *Acropora palmata* (Fig. 3-4i). The dead *Acropora palmata* zones fringing Petit Tabac are readily visible from the surface of the water (Fig. 3-4k). The patch reefs in the backreef lagoon of the Horseshoe Reef are mainly composed of areas of dead ***Montastrea annularis*** (Fig. 3-4j) while the patch reefs of Petit Tabac lagoon are composed of dead ***Porites porites***.

The dead coral substrate with mixed algae community has a user accuracy of 74% (26% commission error) and a producer accuracy of 85% (15% omission error) (Table 3-3). This means that 85% of the dead coral substrate with mixed algae community areas has been correctly identified as class B but that 74% of the areas classified as class B are actually a dead coral substrate with mixed algae community. A more careful look at the error matrix reveals that there is some confusion in discriminating dead coral substrate mainly from the seagrass dominated class (C) but also occasionally from the macro algae dominated class (D), the mixed coral community class (A) and the rubble dominated class (F) (Table 3-3).

Class C: Seagrass dominated –This class is dominated by seagrass, with an average cover of 43% (Table 3-2). The seagrass is composed of two species, mainly *Thalassia testudinum* with a lesser abundance of *Syringodium filiforme*. Fleshy green algae and green calcareous algae (*Halimeda* spp.) are also likely to be present in this assemblage with an average cover of 10%. Corals such as *Siderastrea* spp. and *Porites porites* may also be present but in low cover (<4%). The substratum is mainly composed of mixed sand and rubbles with an average cover of 39% and 5% respectively.

The seagrass dominated class represents 12% of the classified pixels (Fig. 3-5). The seagrass community is most commonly present in quiet protected areas with little current. This class is well distributed in the shallow backreef lagoon of the Horseshoe Reef and around the backreef Cays (Figs. 3-6 to 3-12). It is omnipresent around Baradal but is absent from Petit Tabac. This class was also identified in the northern region of the Horseshoe Reef but its presence cannot be confirmed because of the lack of field sites in that area.

The seagrass dominated community has a user accuracy of 85% (15% commission error) and a producer accuracy of 81% (19% omission error) (Table 3-3). This means that 85% of the seagrass dominated community has been correctly identified as class C but that 81% of the areas classified as class C are actually a seagrass dominated community. A more careful look at the error matrix reveals that there is some confusion in discriminating seagrass communities from the mixed coral community class (A), the dead coral substratum class (B) and the macro algae dominated class (D) (Table 3-3).

Class D: Macro algae dominated – This class is dominated by macro algae, with an average cover of 60% (Table 3-2). The macro algae class is composed of a mixture of fleshy green (*Chaetomorpha linum*), calcareous green (*Halimeda* spp.) and fleshy red-brown algae (*Dictyota* spp., *Amphiroa* spp. and minor *Laurencia* spp.). After an initial supervised classification, sub-clusters dominated by macro algae (Table 3-1; classes F2, B2 and D) were grouped in class D regardless of the substrate composition. Either sand, rubbles or dead coral can dominate the substratum with an average cover of 23%, 18% and 22% respectively (Table 3-2). Figures 3-4 (l-n) illustrate the characteristic assemblage of the macro algae dominated class.

The macro algae dominated class represents only 1% of the classified pixels (Fig. 3-5). This class is present as small and scattered patches around Petit Rameau, Petit Bateau, Jamesby Cays and in some areas of the backreef but is omnipresent around Baradal Cay (Figs. 3-6 to 3-12). This class is not identified on Petit Tabac (Fig. 3-8).

The macro algae dominated community has a user accuracy of 91% (9% commission error) and a producer accuracy of 80% (20% omission error) (Table 3-3). This means that 80% of the macro algae dominated community areas have been correctly identified as class D but that 91% of the areas classified as class D are actually a macro algae dominated community. A more careful look at the error matrix reveals that there is some confusion in discriminating macro algae dominated communities from the mixed coral community (A) (Table 3-3).

Class E: Sand dominated - This class is dominated by bare sand, with an average cover of 88% (Table 3-2). Sparse macro and turf algae may be also present in low average cover (4% and 3% respectively). Species or macro algae are mainly represented by *Halimeda* spp. and *Dictyota spp*. The substratum may also have a minor rubble component with an average percent cover of 5%. Figure 3-4 (p) illustrates the characteristic assemblage of the sand dominated class.

The sand dominated class represents 31% of the classified pixels (Fig. 3-5). This class covers most of the shallow areas (<6 m) of the backreef lagoon seafloor behind the Horseshoe Reef as well as the Petit Tabac lagoon (Figs. 3-6 to 3-12). It also forms sand bars in some areas. The sediments in the Tobago Cays are composed of calcareous sand mainly derived from the calcareous green algae of the genus *Halimeda*.

The sand dominated community has a user accuracy of 91% (9% commission error) and a producer accuracy of 100% (0% omission error) (Table 3-3). This means that 100% of the sand dominated areas have been correctly identified as class E but that 91% of the areas classified as class E are actually sand dominated communities. A more careful look at the error matrix reveals that there is some confusion in discriminating sand dominated communities from the mixed coral community (A), dead coral substratum (B) and seagrass dominated community (C) (Table 3-3).

Class F: Rubble dominated – This class is dominated by rubbles, with an average cover of 84% (Table 3-2). The rubbles are commonly encrusted by turf, coralline red algae and macro algae with an average cover of 43%, 14% and 6% respectively (Table 3-2). Macro algae are mainly composed of *Halimeda* spp. and *Amphiroa* spp. Sand can also be present with an average cover of 8%.

The rubble dominated class represents 1% of the classified pixels (Fig. 3-5). This class forms a discontinuous band along the shoreline of the five Cays, it is also present in the very shallow reef flat pavement in the southern portion of the Horseshoe Reef (Figs. 3-6 to 3-12). In the quiet water environments such as Baradal or Jamesby Cays, the coral rubbles are mainly composed of disarticulated *Porites porites*. In higher energy environments such as

Petit Tabac, Petit Rameau and Petit Bateau Cays and the backreef area, the coral rubbles are mainly composed of large broken branches of dead *Acropora palmata*. The rubble zone proximal to the shore on Petit Tabac comprises extensive areas of turf encrusted beachrocks which are also classified as rubble dominated (Figs. 3-8, 3-4q). Figure 3-4 (p) illustrates the characteristic assemblage of the rubble dominated class in calm water environments.

The rubble dominated community has a user accuracy of 100% (0% commission error) and a producer accuracy of 96% (4% omission error) (Table 3-3). This means that 96% of the rubble dominated community areas have been correctly identified as class F and that 100% of the areas classified as class F are actually a rubble dominated community. Based on the testing sites, there was no confusion of this class with any of the other classes (Table 3-3).

Class G: Deep water (6-10m) – Class G was added to reduce the confusion between deep water areas and other classes. This class was assigned to areas with water depths ranging between 6 and 10m, regardless of substrate. The deep water sand dominated class represents 30% of the classified pixels (Fig. 3-5). Class G is distributed in the fore reef areas of the bank-barrier reefs and west of the Cays as well as in the high current sandy channels surrounding the Cays. On the fore reef slope this class is mainly a mixed coral community (class A), scattered patches of sand are commonly present at the bottom of the fore reef slope but this usually occurs between depths of 10-20 meters. In the backreef areas and surrounding the five Cays, the deep water class is mainly sand dominated with low algae cover (similar to class E).

The deep water class has a user accuracy of 74% (26% commission error) and a producer accuracy of 100% (0% omission error). This means that 100% of the deep water sand dominated community areas have been correctly identified as class G but that 74% of the areas classified as class G are actually deep water sand dominated community. A more careful look at the error matrix reveals that there is a significant confusion in discriminating deep water sand dominated areas from mixed coral communities (Table 3-3).

Class H: Beach sand – This class is composed of 100% beach sand. This class was simply added for the purpose of classification. This class is self evident and is only present on the Cays in areas not covered by the land mask representing less than 1% of the classified pixels (Fig. 5). The beach sand class has a user accuracy of 100% (0% commission error) and a producer accuracy of 100% (0% omission error) (Table 3-3).

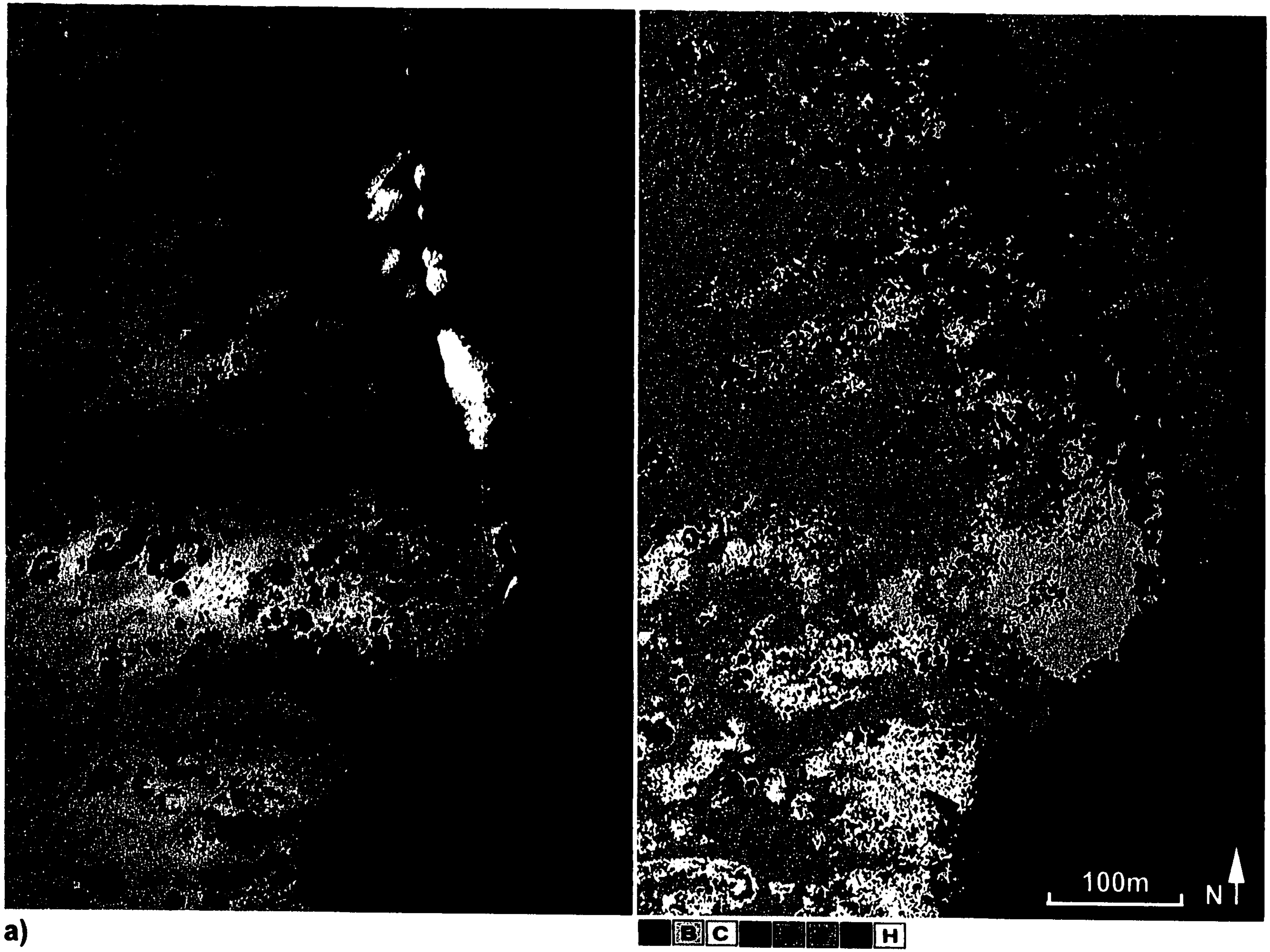
Figure 3-6: Thematic map of the main shallow marine benthic assemblages of the shallow water areas of the Tobago Cays. Areas excluded from the supervised classification (deep water >10 m, land, boats and waves) are unclassified and visible as the original aerial photographs. The overlay identifies the Cays and indicates the location of the subsets for the following figures.

LEGEND

Class A: Mixed live coral Community	**Class E: Sand dominated with sparse algae**
Class B: Dead coral substratum with mixed algae	**Class F: Rubble dominated**
Class C: Seagrass dominated	**Class G: Deep water (depth >9m)**
Class D: Macro algae dominated	**Class H: Beach sand**


61°21'55"W 45" 61°21'40"W 35" 30" 25" 20" 15" 10" 05" 00" 61°20'55"W 61°20'45"W
12°38'55"N
12°38'45"N
12°37'30"N
12°37'20"N
40" 61°21'35"W 30" 25" 20" 15" 10" 05" 00" 61°20'55"W 61°20'45"W
LONG/LAT, WGS 84 (GPS)
SCALE IN METRES
0
1000
2000

Figure 3-7: Subset of the thematic map showing the main shallow marine benthic assemblages of the northern (a) and southern (b) regions of the Horseshoe Reef. Black pixels are areas that were removed from the classification process using a mask. The black arrows indicate areas of obvious misclassifications. In a) the top arrow show medium surf areas classified as sand area (E), bottom arrow indicates an over-classification of the seagrass class. In b) both arrows indicate an over-classification of the seagrass class (C). *Refer to Table 3-2 for a complete description of classes and Figure 3-6 for legend symbols.*



a)

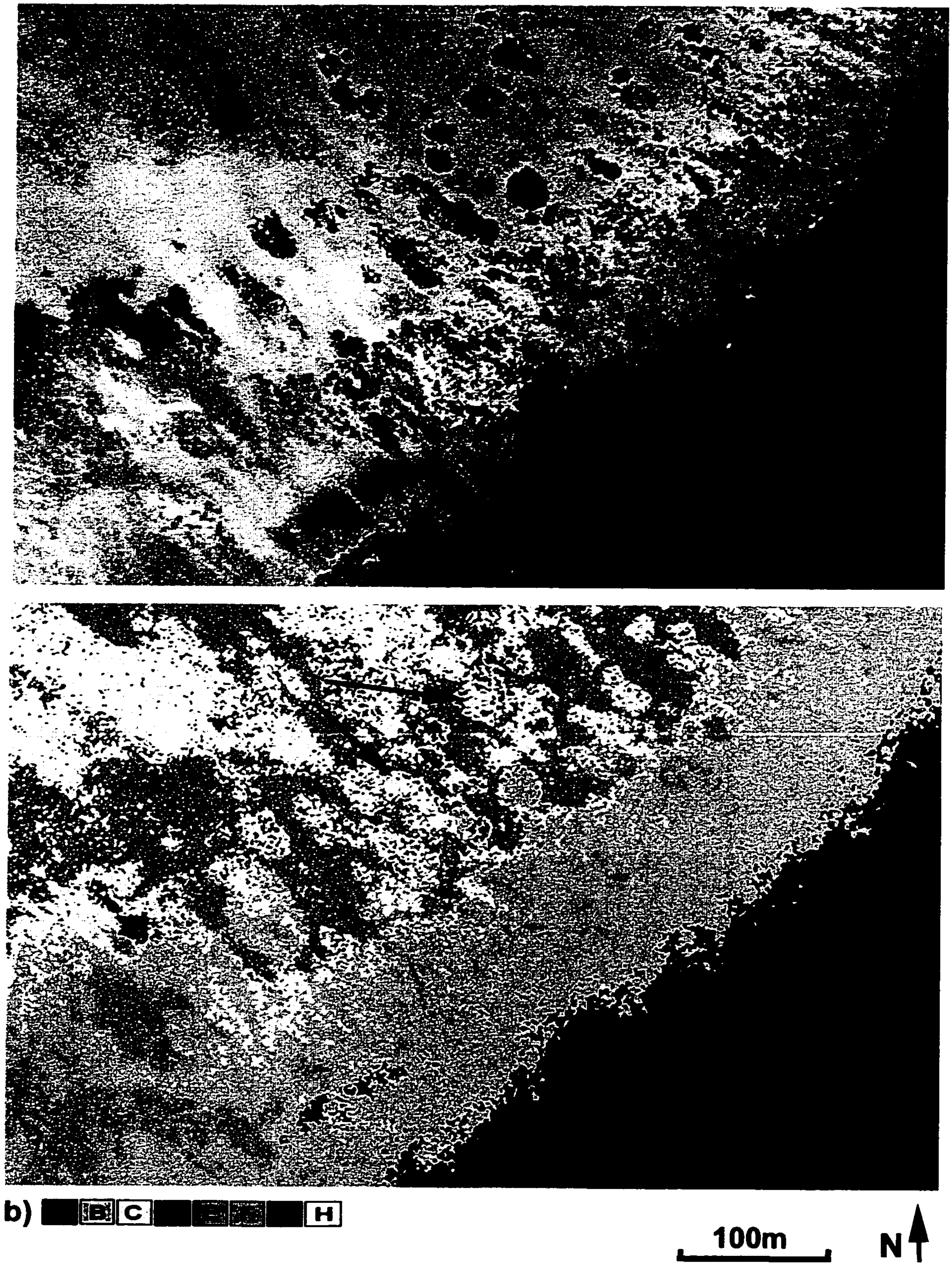

b)
B
C
H
100m
N

Figure 3-8: Subset of the thematic map showing the main shallow marine benthic assemblages surrounding Petit Tabac Cay. Black pixels are areas that were removed from the classification process using a mask. The black arrows indicate areas of obvious misclassifications. Both arrows indicate mixed coral communities (A) misclassified as deep water (G). *Refer to Table 3-2 for a complete description of classes and Figure 3-6 for legend symbols.*

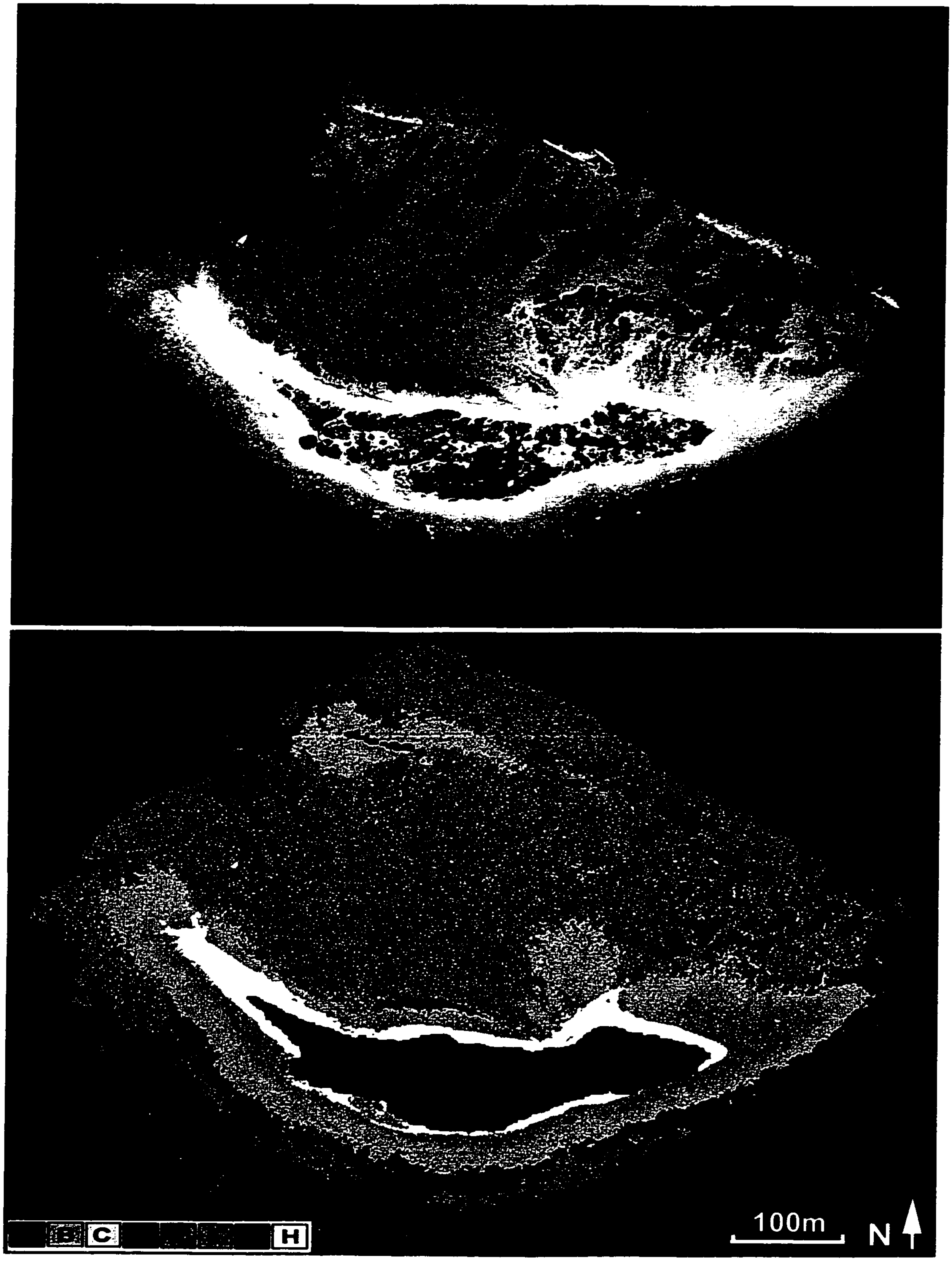

C
H
100m
N

Figure 3-9: Subset of the thematic map showing the main shallow marine benthic assemblages surrounding Baradal Cay. Black pixels are areas which were removed from the classification process using a mask. The black arrows indicate areas of obvious misclassifications. All three arrows indicate mixed coral communities (A) misclassified as deep water (G). *Refer to Table 3-2 for a complete description of classes and Figure 3-6 for legend symbols.*

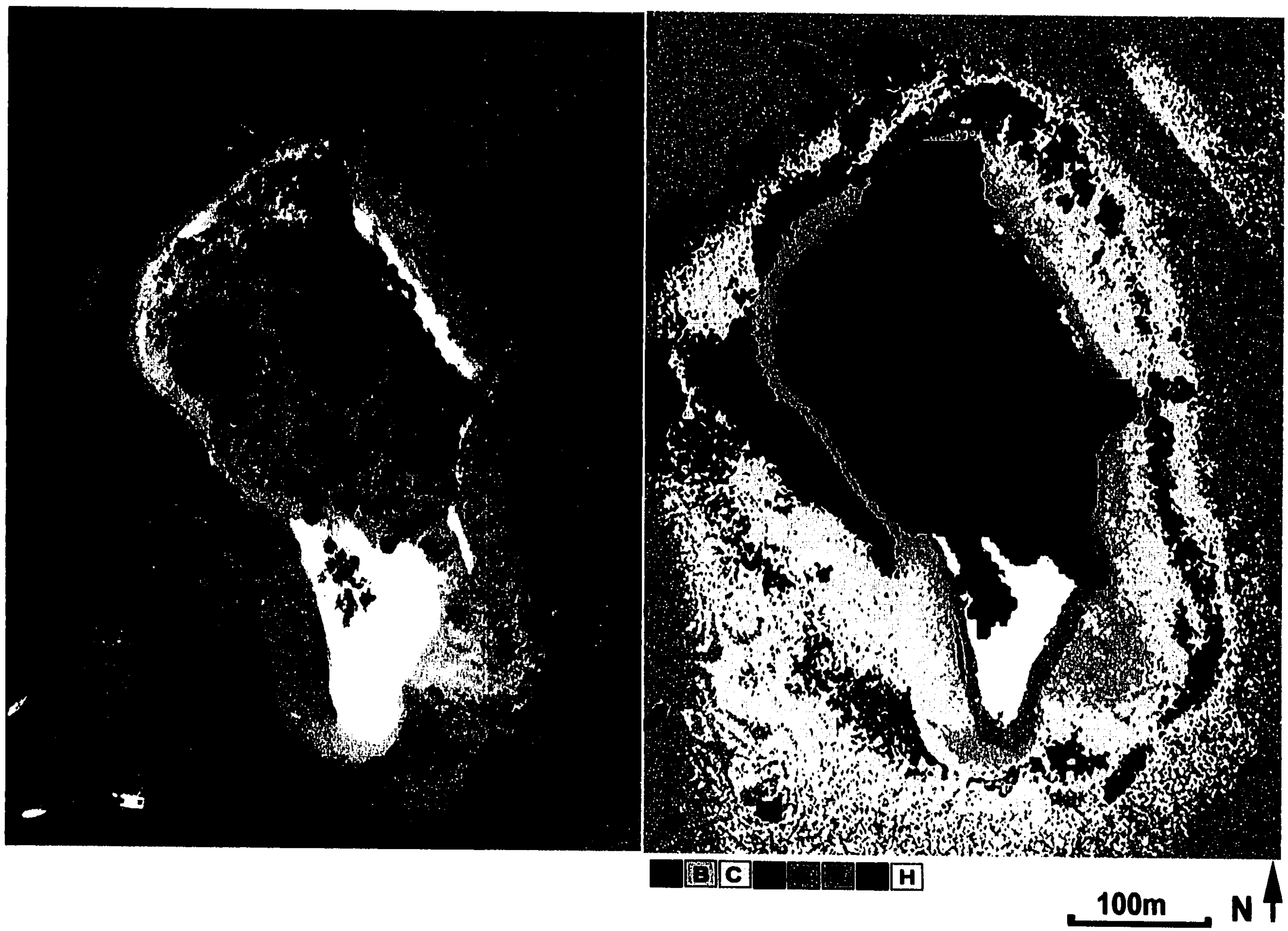

B
C
H
100m
N

Figure 3-10: Subset of the thematic map showing the main shallow marine benthic assemblages surrounding Jamesby Cay. Black pixels are areas that were removed from the classification process using a mask. The black arrows indicate areas of obvious misclassifications. All arrows indicate mixed coral communities (A) misclassified as deep water (G). *Refer to Table 3-2 for a complete description of classes and Figure 3-6 for legend symbols.*

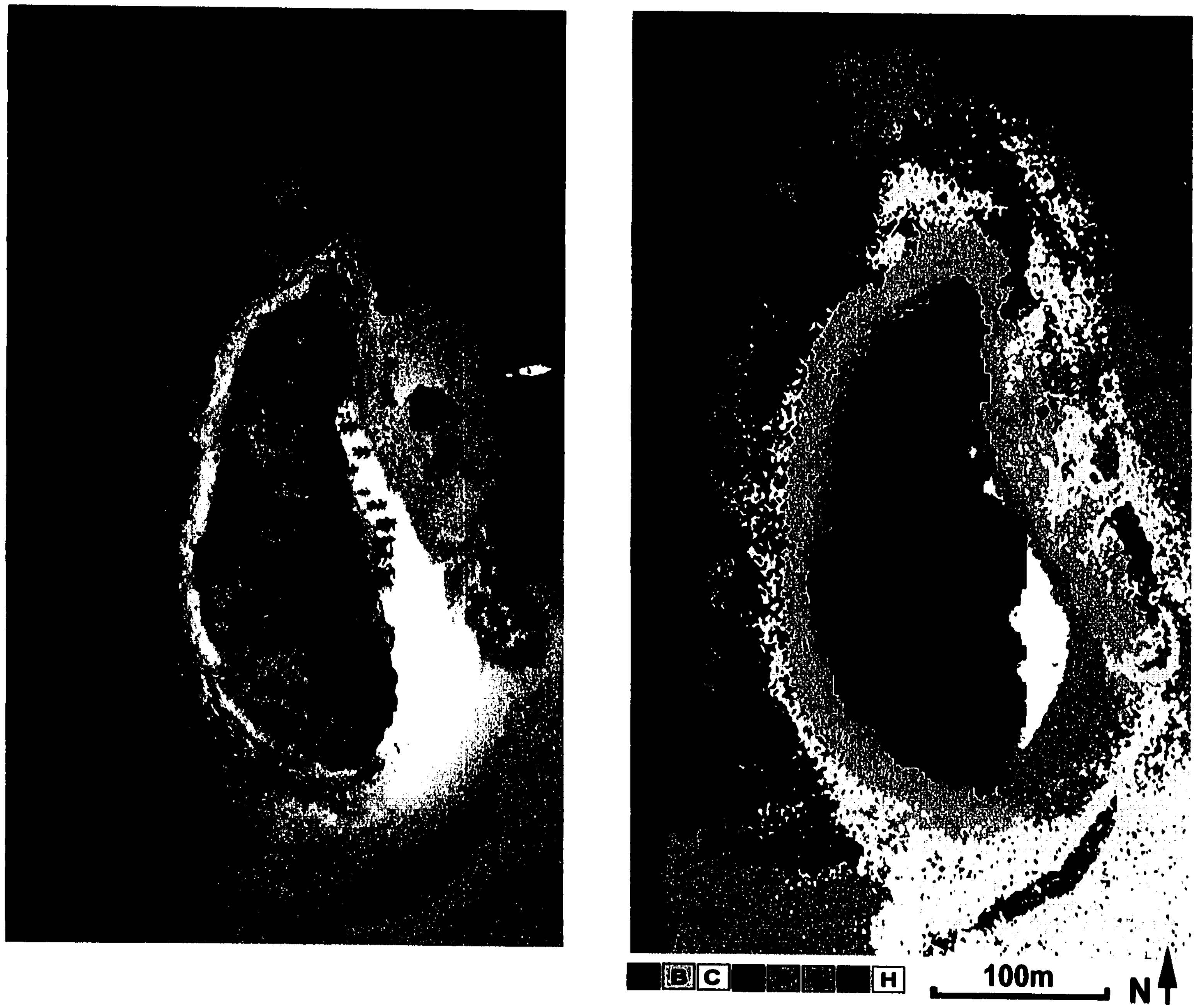

B
C
H
100m
N

Figure 3-11: Subset of the thematic map showing the main shallow marine benthic assemblages surrounding Petit Bateau Cay. Black pixels are areas that were removed from the classification process using a mask. The black arrows indicate areas of obvious misclassifications. The top arrow indicates a depth gradient on a sandy bottom misclassified as a mixed coral community (A). All other arrows indicate mixed coral communities (A) misclassified as deep water (G). *Refer to Table 3-2 for a complete description of classes and Figure 3-6 for legend symbols.*

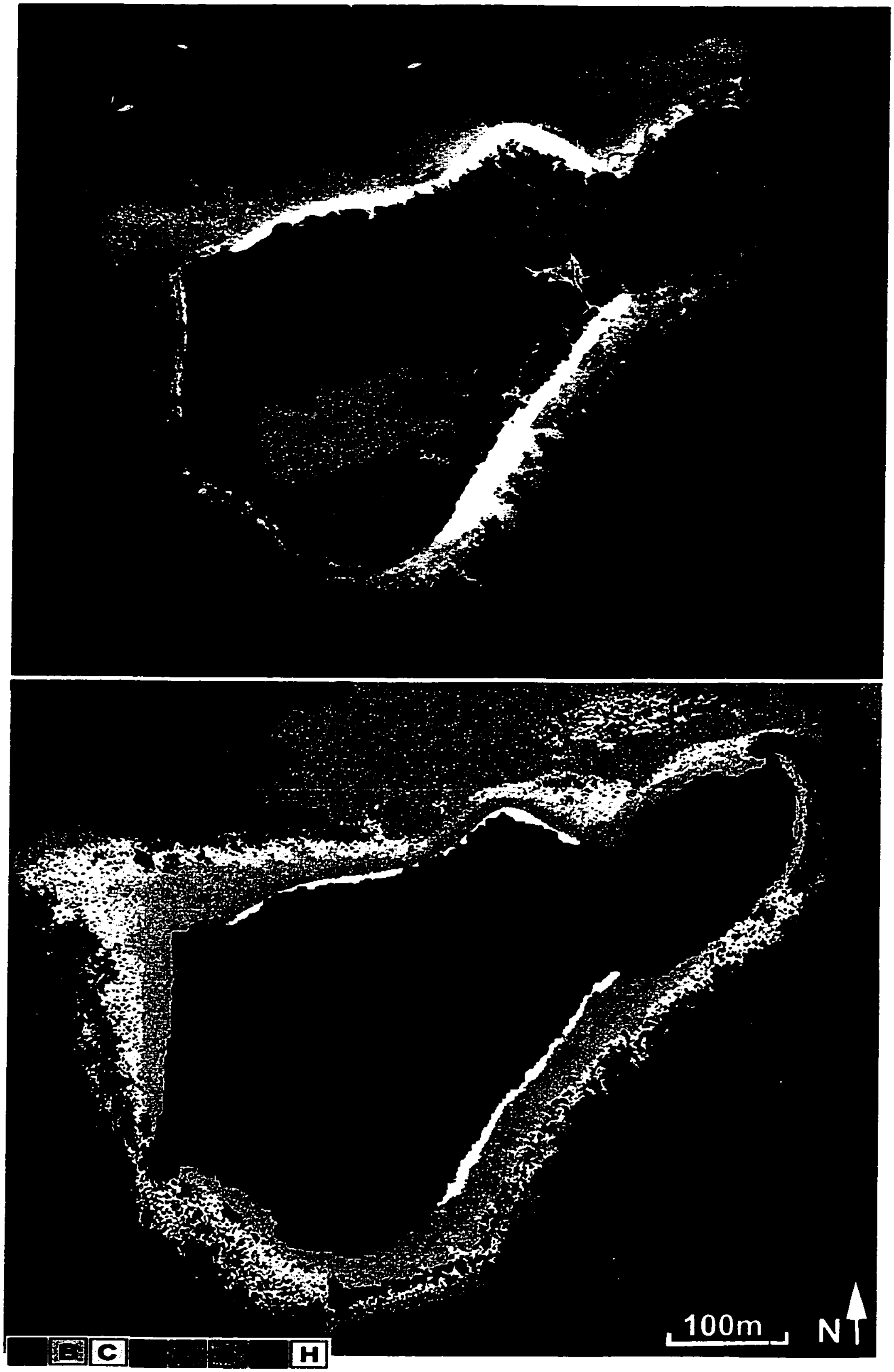
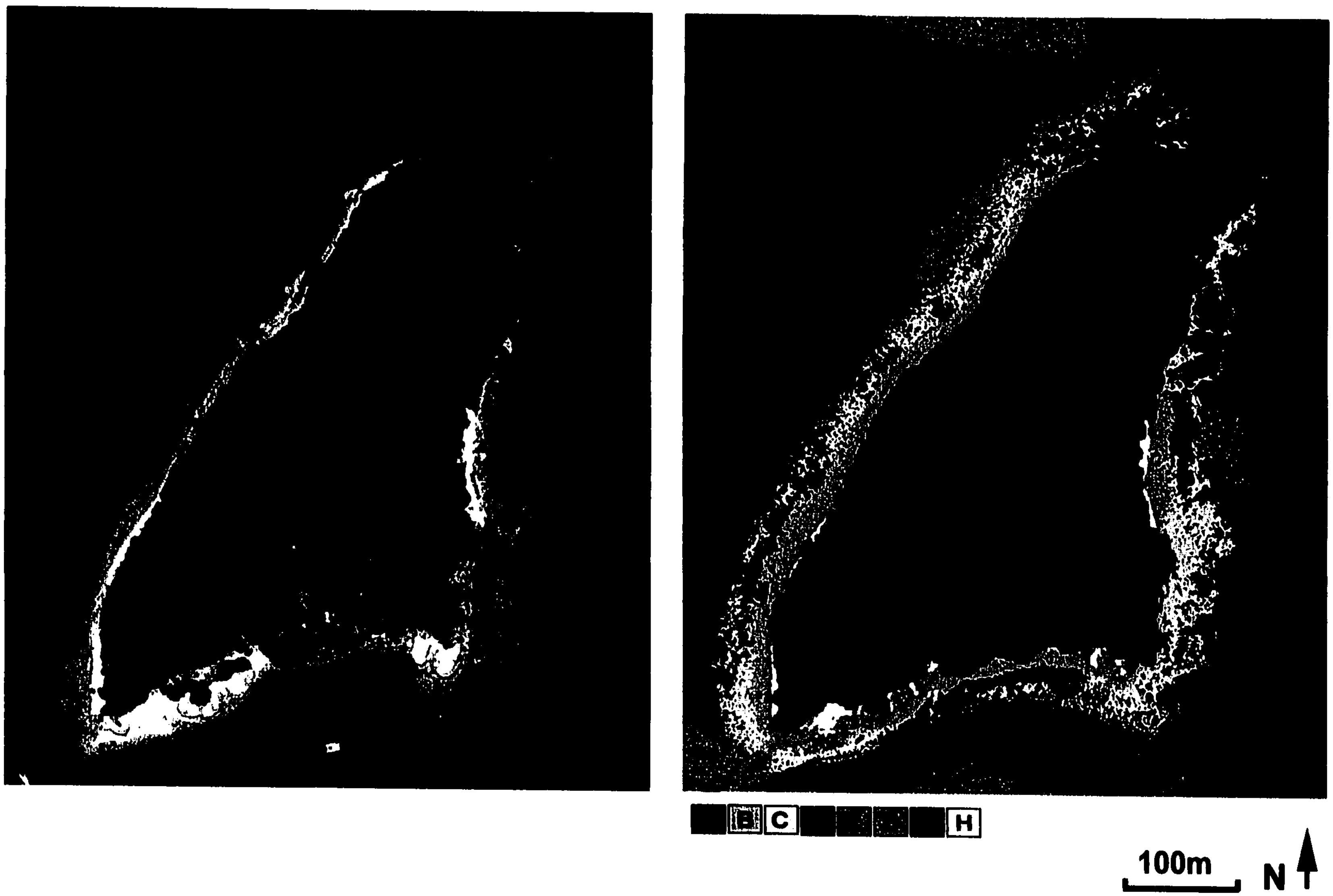

100m
N
B
C
H

Figure 3-12: Subset of the thematic map showing the main shallow marine benthic assemblages surrounding Petit Rameau Cay. Black pixels are areas which were removed from the classification process using a mask. The black arrows indicate areas of obvious misclassifications. The top arrow indicates a depth gradient on a sandy bottom misclassified as a mixed coral community (A). The other two arrows indicate mixed coral communities (A) misclassified as deep water (G). *Refer to Table 3-2 for a complete description of classes and Figure 3-6 for legend symbols.*


B
C
H
100m
N

3.5 Discussion

The results obtain in this study is comparable or better than other studies using scanned aerial photographs (Thamrongnawasawat, 1996; Manière et Jaubert, 1985; Chauvaud *et al.*, 1998; Manière *et al.*, 1994; Pasqualini *et al.*, 1997; and Sheppard *et al.* 1995). The final classification obtained is similar to that obtained by Sheppard *et al.* (1995). We obtained fewer but comparable classes with greater accuracy. It is difficult to compare with the other studies because these studies did not always incorporate an accuracy assessment, while others have used geomorphologic classes mixed with benthic classes or have limited their survey to the very shallow reef flat (0-1 m). Geomorphology is easily interpreted from aerial photography without much, if any, ground thruthing. Ecological assemblages, however, are more difficult to classify since the species and substrate can be highly variable, and several distinct assemblages may be present in each geomorphological zone (Fagerstrom, 1987). Coral reef habitat mapping requires more than a general knowledge of the study area, it requires extensive ground thruthing to identify ecological assemblages present on the field. An important aspect of this study is the systematic approach at defining habitat classes. This approach permits a natural grouping of the habitats and provides the quantitative description of each component based on standard reef sampling techniques. The following sections will discuss in more details the selection of mapping accuracy threshold, habitat discrimination using aerial photographs, changes in the TCMP and the sources of errors in this study.

3.5.1 Accuracy Requirements

It is difficult to select a threshold accuracy requirement for successful habitat mapping using remote sensing methods. In most situations, it is unrealistic to evaluate the map accuracies with the same criteria as generally accepted by the scientific community. Coral reefs habitats commonly show a complex and intermingled biotic and abiotic components with a gradational transition between habitats making them difficult to map using remote sensing. Coral reef habitats also typically show a gradation with depth and wave exposure. Accuracies of 95% or greater are unrealistic for remote sensing of marine habitats because of the degree of natural uncertainty in the placement of boundaries between these highly gradational habitats (Mumby *et al.*, 1997). Nevertheless, these authors have suggested that an accuracy of 65-70% is adequate for this type of mapping. The decision of the threshold acceptable accuracy is largely dependent on the goal of the project and the use that will be made of the thematic maps. Since the purpose of this study was to demonstrate the use of a low cost methodology using archived aerial photographs, it was judged that an accuracy of 70% or greater was acceptable. This will provide adequate preliminary information on the shallow marine habitats of the Tobago Cays and will serve as the basis of future studies.

A common way of assessing the accuracy is using an error matrix. It should be remembered that such procedures are based on training data only. Therefore, it only indicates how well the statistics extracted from these areas can be used to categorise that same area. Good results suggest that training areas are homogeneous, training classes are spectrally separable, and that the classification strategy being employed works well in the training area (Lillesand and Kiefer, 2000). It indicates little about how the classifier performs elsewhere in an image. The training area accuracies are overly optimistic since they are derived from limited data sets (Lillesand and Kiefer, 2000). The overall accuracy measures obtained from error matrix are all in agreement, the Kappa coefficient of 85%, overall accuracy of 87% and the Tau coefficient of 85% (Table 3-3). Using the more global scale of reliability, we obtained a reliability of 69% (Table 3-4). This method provides insight on the source of errors in the classification process. Some of the factors that received low scores cannot be changed (specular reflection, topography, slope, bathymetry and bottom assemblage) but other such as the quality of the scanning process and the total field area and number of field sites could be adjusted to obtain better classification results. Somewhere in between these two accuracy assessment methods is probably the true accuracy of our thematic map.

3.5.2 Habitat discrimination using scanned aerial photographs

The most common problems in using remote sensing to map marine environments are the effects of the variable water depth and turbidity (Sheppard *et al.*, 1995; Chauvaud *et al.*, 1998; Pasqualini *et al.*, 1997). There is an exponential attenuation of light radiation with increasing water depth, the blue radiation penetrates deeper than the green and the red radiation does not penetrate more than a few meters. This often results in a variation of the spectral signature for a same benthic assemblage or bottom type with varying depth. The coral class (A) had the largest error of omission with a producer accuracy of only 53%. From a map producer point of view only 53% of the testing sites were classified as mixed coral community, therefore the classification was not very efficient at classifying the coral areas in the TCMP. The mixed live coral community class is present in a wide depth range from 0.2 m to approximately 30 m, thus throughout the depth range of the classification (0-10 m). The deep water class (G) has one of the largest errors of commission with a user accuracy of 74%. The user of this map will find that 26% of the time the area identified as deep water on the map (class G) will not be a deep water area on the field. The deep water class was mainly misclassified for the mixed live coral community (class A). A closer examination of the error matrix and the classified map of the TCMP reveal that these classification errors can mainly be attributed to the increase in water depth. The misclassification of deep water for hard coral is more evident on the fringing reefs surrounding the Cays and the fore-reef areas because of the steeply sloping shelves and the greater water depth variability (Figs. 3-6 to 3-13). The shallow backreef, reef crest and lagoon zones of the Horseshoe Reef and Petit Tabac as well as the shallow areas surrounding the Cays do not show this misclassification problem. These areas are shallow (<4 m) and do not have much variation in water depth. This classification cannot be used reliably to map the mixed coral communities in the Tobago Cays in areas deeper than 4 meters.

Except for the mixed live coral community class, all other classes are reliable from a user and producer's perspective. The 9-26% commission errors obtained for the mixed live coral community class, the dead coral substratum with mixed algae class, the seagrass dominated class and the macro algae dominated can be mainly attributed to confusion of these classes amongst themselves. The dead coral substratum class has the largest error of commission with 26%. Coral reef habitats are dominated by plants and animals which are similar in size and contain similar pigments, thus are very difficult to distinguish using remote sensing (Sheppard, 1995). Recent research has been conducted to determine the spectral signature of coral reefs using ground measurements from an *in situ* hand held spectroradiometer (Hardy *et al.*, 1992; Holden and LeDrew 1998a; Miyazaki *et al.*, 1995; Nadaoka *et al.*, 1998). The spectral signature of coral, macro algae and seagrass is very similar (reflection peak at 0.575-0.600 μm and absorption peak between 0.650-675 μm) because of the presence of chlorophyll in the tissues. Areas of dead corals commonly encrusted with red coralline algae also have a similar signature (Holden and LeDrew, 1998a). The Red and NIR bands can potentially be used to discriminate between seagrass, algae and corals. Unfortunately these regions of the electromagnetic spectrum are strongly absorbed by the water and penetration is limited to about 1m for NIR band and 3 m for the red band (Harris and Kowalik, 1994). Where distinguishing peaks exist within penetrating spectrum, only the very narrow spectral bands available from hyperspectral scanners may potentially detect these differences. It is therefore not surprising to find that coral reef habitats are difficult to distinguish using remote sensing mapping techniques.

A closer look at the classified image reveals that contextual errors can be found and not been accounted for in the error matrix. These errors are often found in areas for which little or no ground surveys are available. It is nevertheless possible to detect these possible misclassification errors based on the general knowledge modern reef environments. Most of the large wave breaking areas has been removed from the classification using masks. Small surf areas, which were omitted from these masks (i.e. Horseshoe Reef north of boat passage), were misclassified as sand dominated areas (Fig. 3-7a). The seagrass class is obviously overclassified but this is not reflected in the error matrix because of the limited amount of testing sites. It is obvious that seagrass should be a common class in the shallow lagoon and in protected areas surrounding the Cays but not in high-energy environments, such as the fore-reef area or even in the proximal back-reef (Fig. 3-7). For example, in the north east region of the Horseshoe Reef the classification process has assigned a large amount of pixels to the seagrass class. Even if those areas were not specifically visited on the field, it is unlikely that these areas are seagrass dominated. These areas are most likely confused with the sand dominated class (E) containing a low macro algae cover. Seagrass and macro algae are considered as transient components (i.e. lasting a short term) while hard corals and gorgonians are considered as non-transient components (Thamrongnawasawat, 1996). It is therefore expected that important changes in the seagrass and macro algae habitats may have occurred between the aerial photography survey (March 1991) and the field survey (May 1999). This makes it even more difficulty to assess the accuracy of these two classes.

3.5.3 Changes in the TCMP

Because of the absence of prior quantitative surveys on the reefs of Tobago Cays a comparison of our results with Lewis (1975) is limited. Nevertheless, we will comment on the most obvious changes and speculate on the causative agents. The two major changes observed in the shallow waters of the TCMP since the early 1970 are: i) near absence of live *Acropora palmata*, and ii) increased abundance of fleshy macro algae near Baradal Cay. The hard coral species assemblage for the reefs in the TCMP is very similar to that described by Lewis (1975) and typical of similar reef types in the Caribbean (Milliman, 1975). The main difference in coral composition is the near absence of live *Acropora palmata* from the reef crest, the shallow fore-reef, the backreef areas and the fringing reefs of the TCMP.

Thus, *A. palmata*, which once flourished and dominated the shallow reefs of the TCMP has now virtually disappeared as a reef builder. Throughout much of its range *A. palmata* has been subject to the white band disease (mid 1980), from the Florida Keys, Puerto Rico and the Virgin Islands, Antigua, St.Martin, Curacao, Nicaragua, Panama, Bahamas, Tobago, and Bermuda (Santavy and Peters, 1997). The WBD is the most likely cause of the *A. Palmata* dieoff in the shallow waters of the TCMP.

From the classification scheme and the field data it is possible to observe that there is a dominance of the macro algae class principally on the east and north-east sides of Baradal (Fig. 3-6). This fleshy macro algae dominance was not observed by Lewis (1975) at the time of his survey. The massive reduction in the abundance of *Diadema antillarum* in the Caribbean (Lessios *et al.*, 1983, Bak and Nieuwland, 1995) combined with reductions in fish grazers due to over fishing are frequently cited as causes of fleshy algae dominance (Hay, 1984 and Done, 1992). Another likely factor in the degradation of the reef is the discharge of raw sewage by visiting yatches in the back reef area of the Tobago Cays. The east side of Baradal is a very shallow and protected area of the TCMP, which is probably an ideal location for nutrient accumulation and flourishing macro algae growth.

3.5.4. Sources of errors

The main sources of errors in this study are from the discrepancy in the date of the aerial photographs survey (1991) and the field survey (1999), the non-availability of differential GPS, and the restriction to one field survey session. Data for the training and testing sites are ideally collected on two separate field trips (Mumby and Astaire, 1999; Sheppard *et al.*, 1995). First the training sites are collected, from which are derived a classification scheme using cluster analysis. Second, the testing sites and additional testing sites (if needed) are collected using the predetermined classification scheme. We were limited to collecting all the field data in one field season; some of the difficulties and errors encountered in the projects could have been greatly reduced. Ground sampling units should allow for errors in the location of that particular pixel as well as the reflectance value of that pixel to be spread over the adjacent pixels. For ground thruthing of remote sensing data the scale of sampling is set by the pixel size of the image and the errors in locating that particular pixel on the ground (Jensen, 1996). Even if we had an excellent spatial resolution (50 cm) one of the most difficult task was to locate the field sites on the aerial photographs because of the unavailability of differential GPS for our study area. We used 1 m^2 field quadrates that correspond to training sites of 4 x 4 pixels. Choosing larger homogeneous field sites readily visible on the aerial photography and placing more emphasis on habitat transition and boundaries would help to reduce this problem. Another source of errors is the presence of scanning artefacts. A better desktop scanner, which accepts large format photography, could be used. Photogrametric scanners could not be considered for this study since most of these scanners do not operate on paper prints. There is always a possibility of improving accuracy and reliability of a map but it is constrained by time, budget and the initial objective of the project.

3.5.4. Future studies

It is clear that airborne hyperspectral imagery could provide a more detailed and accurate coral reef habitat mapping. Hyperspectral sensors provide excellent spatial, spectral, radiometric and temporal resolutions that can be adjusted for specific applications.

Significant research efforts have been put into building a spectral library for reef substrates (Myers *et al.*, 1999; Holden and LeDrew, 1998). This spectral library will increase the interpretability and facilitate the used of hyperspectral imagery in this area of research. Despite its great potential, this option is costly and requires extensive calibration. Another alternative that is worth exploring is the newly available imagery from the IKONOS satellite. Imagery from this first commercial high resolution satellite has good spatial (4 m), spectral and radiometric (11 bit) resolutions. The greater spatial and spatial resolutions of these digital sensors coupled with the capacity of applying a depth correction algorithm as well as applying a radiometric correction to reduce the atmospheric effects would increase the precision and the accuracy of coral reef habitat mapping. Finally, it would be interesting to perform a change detection analysis using recent aerial photographs (or other type of digital images) of the Tobago Cays to document changes in the benthic environments since 1991. It would be especially interesting to document the loss and possible recovery and/or replacement *of Acropora palmata* as a major reef builder on these shallow reefs.

3.6 Conclusions

Our results demonstrate the potential use of scanned aerial photography and standard image processing techniques for shallow tropical habitat mapping. An important aspect of this study is the systematic approach at defining habitat classes. This approach permits a natural grouping of the habitats and provides the quantitative description of each component based on standard reef sampling techniques. The major findings of this study are:

1. Hierarchical Cluster Analysis of benthic cover measured using field quadrates is a rapid and effective method for surveying shallow marine habitats and obtaining a

systematic habitat classification scheme. The ground survey results provided a quantitative inventory of the main benthic assemblages and bottom types of the TCMP.

2. The overall classification accuracy measures obtained from the error matrix are all in agreement with a Kappa coefficient of 85%, an overall accuracy of 87% and a Tau coefficient of 85%.
3. The coral class (A) had the largest error of omission with a producer accuracy of only 53%. Deep water areas (class F) are commonly confused with corals at depth of 4 meters or more. All other classes have lower commission errors (9-26%).
4. The mixed live coral community class, the dead coral substratum with mixed algae class, the seagrass dominated class and the macro algae dominated class are confused mainly amongst these same four classes. This confusion is most likely due to the fact that coral reef habitats are dominated by plants and animals that contain similar photosynthetic pigments.
5. The seagrass class is obviously over-classified but this is not reflected in the error matrix because of the limited amount of testing sites. The seagrass class is most likely confused with the sand dominated class (E) containing a low macro algae cover. Seagrasses and macro algae are difficult reef habitat components to map because of their seasonal and transient nature.
6. The two major changes in the TCMP since Lewis (1975) are: the near absence of live *Acropora palmata* from high energy shallow reefs areas of the TCMP and the dominance of fleshy macro algae surrounding Baradal Cay.

The results and the accuracy obtain from this project are possibly inadequate for fine scale resource management purposes but they are quite acceptable as a preliminary working document and comparable to previous studies using scanned aerial photographs. This research provides valuable information on the shallow marine habitat composition and distribution in the Tobago Cays, where minimal resources and information were available. This survey will facilitate the monitoring through time and the evaluation of the efficiency of the management of the TCMP. The methods developed here proved to be cost-effective and suitable for a wide variety of applications in developing countries where aerial photography surveys are often available in the archives and could be put to good use.

CHAPTER 4: General Conclusions

The reefs of the Tobago Cays are important to the local economy of the surrounding Islands (e.g. Union, Mayreau). Over the past 15 years a number of informal reports have indicated that the conditions of the reefs in Tobago Cays have suffered from deterioration. A marine park has recently been established for the Tobago Cays, nevertheless limited documentation is available on these reefs. Our research provides valuable information on the shallow marine habitat composition and distribution in the Tobago Cays as well as an indication of the current health condition of the Horseshoe Reef. These are essential in the protection and management of the coral reef ecosystem of the TCMP and provide the necessary baseline information for long term monitoring and that can be used to assess the management efficiency of the TCMP.

For the first time, the current condition of the Horseshoe Reef was established using the AGRRA methodology. This survey also contributes to the Caribbean wide AGRRA database and establishing a regional baseline of coral condition in the Western Atlantic and Gulf of Mexico. Using the indicators established by the AGRRA protocol, the results obtained from our survey suggest that the Horseshoe Reef is a relatively healthy reef but is also showing signs of disturbances.Establishing and enforcing fishing regulations and monitoring water quality in the Tobago Cays Marine Park are a critical step to avoid future degradation in the health of the reefs. Even if the Horseshoe Reef is relatively isolated from direct human influences, the most likely factors in the degradation of the reef are over fishing and the discharge of raw sewage by visiting yatches in the back reef area of the Tobago Cays.

Because of the absence of earlier quantitative surveys on the reefs of Tobago Cays we can only speculate on the possible causes of the observed changes or degradation of these reefs.

Our study also demonstrates the potential use of scanned aerial photography and standard image processing techniques for shallow tropical habitat mapping, regardless of the limitations imposed by this technique. This research provides a digital thematic map, with known accuracy, of the shallow marine habitats of the Tobago Cays. The thematic map provides a visual, digital and quantitative inventory of the major habitats that can be easily upgraded for long term monitoring purposes. The methods developed here prove to be cost-effective and suitable for a wide variety of applications in developing countries where aerial photography surveys are often available in the archives. Scanned aerial photographs coupled with standard image processing techniques are an adequate interim technology awaiting higher resolution and cost effective remote sensing options.

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APPENDIX 1: Additional information for Chapter 2

APPENDIX 1A: Detailed AGRRA method.

The detailed methodology was provided by the Atlantic and Gulf Rapid Reef Assessment (AGRRA) Organising Committee and is also available on the AGRRA website (AGRRA, 2000).

1.0 Selection of reef and sites

For the purposes of AGRRA, a REGION is defined as the coarsest scale category (100 km scale); followed by an AREA (10 km scale); a REEF (1 km scale); and a SITE (0.1 km scale). We recognise that reefs vary greatly in size, complexity, depth, profile, and coverage per km of coastline throughout the region. What follows are our recommended procedures for selecting survey sites, however we fully understand that it will be necessary to modify these procedures to accommodate the special conditions at any single site. It is vital for the success of AGRRA that these procedures are followed as closely as possible and that all modifications to them be carefully noted when the data are compiled.

The method for selection of REEFS to assess will be influenced by their abundance and distribution in your area. If the extent and/or number of REEFS (fringing, patch, barrier) is so limited that they can all be assessed in a reasonable time frame there is no problem. However, if the extent and/or number of REEFS is larger, then they should be subdivided or "stratified" and representative examples selected from each. Use the best, locally available sources of information (benthic maps, aerial photographs, charts, local knowledge, reconnaissance by Manta tow-board) to subdivide the reefs in your area. Use secondary reef characteristics such as size, depth, and position relative to land to help select representative ones. Alternatively, you can give each reef within a subdivision a number and use a table of random numbers to select which ones to assess. If there are no clear bases for making subdivisions (e.g. a continuous bank barrier or fringing reef several kilometres long), then sites should be located at evenly spaced distances. When choosing REEFS, try to avoid hardgrounds, pavements and other habitats that lack a framework constructed of reef-building corals. Depending on the methods and resources available for your use, REEFS that are selected will generally fall into one of three categories:

1. Unbiased - chosen without local knowledge or published reports;
2. Representative- chosen with the aid of local knowledge to be representative of reefs in that area;
3. Strategic - chosen with local knowledge because it is threatened, suspected to be degraded, or in particularly good condition.

Note: For regional comparisons, it is best to have REEFS that are chosen by either (1) or (2). REEFS that are chosen by (3) can still be assessed, however, they should be clearly flagged as such.

A SITE is defined as an area of habitat that is more or less homogeneous and accessible from a boat anchored or moored in one place. In this initial phase, we are suggesting that you concentrate your efforts on areas of maximum reef development. Generally, this will be in the 1-5 m depth interval (shallow *Acropora palmata* zone) and in the 8-15 m depth interval (shallow fore-reef of maximum coral growth). Beyond these general depth intervals, it is up to the assessors to locate their SITES. For each REEF that is chosen, you should try to survey one SITE within each chosen depth interval.

A SITE description should be prepared for each reef. It is critical to explain in the SITE description how your site was selected and, if needed, why you deviated from the commended selection protocol. The site description should also include information on:

1. location (GPS coordinates)
2. approximate size and shape
3. relief features (e.g., spur and groove)
4. position relative to shoreline
5. orientation as to windward or leeward (or both, if wind direction changes seasonally)
6. depth range corrected for tidal variations
7. where possible, an outline map of reef showing location of SITES, nearby land, etc.

2.0 Corals and Algae Method

I. At each SITE, haphazardly lay the 10 m transect line just above the reef surface in a direction that is parallel to the long axis of the reef.

Note: Be sure to avoid any other transects that are being set by your companions, and stay away from the edges of the reef. Also try to avoid areas with abrupt changes in slope, deep grooves, and large patches of sand or unconsolidated coral rubble. Unusual reef features should only be included to the extent that their relative abundance at the site is reflected. If the reefs are too small for you to avoid sandy patches, subtract the length of the transect line where it crosses the sand from the 10 m total, to allow a later calculation of the number of coral heads encountered/m of reef surface, and note this length on your slate.

II. Approximate coral cover by swimming along the transect line and using a measuring device to roughly estimate how many meters of the line are draped over live coral. Be sure to include all living stony corals covered by the line, regardless of size or species density. Record the live coral coverage (to the nearest 10 cm), and then continue with your survey.

III. Swim towards the other end of the transect, stop at the first coral head, cluster, or thicket of the appropriate species that is located directly beneath the transect line, is at least 25 cm wide, and which is either in original growth position or has become reattached to the substratum. Record each of the following:

A. Name (genus and species)

B. Record the water depth at the top of the corals at the beginning and end of each transect. In cases where bottom topography is very irregular, record the water depth at the top of each coral beneath the transect line at each major change (>1 m) in depth.

C. Using a measuring device, measure to the nearest 10 cm, its maximum projected diameter (live + dead areas) in plan view and maximum height (live + dead areas) above the substratum.

D. Estimate the percent (%) of the coral that is "recently dead" and the % of the coral that is "long dead". "Recently dead" is defined as any non-living parts of the coral in which the corallite structures are white and either still intact or covered over by a layer of fine mud. "Long dead" is defined as any non-living parts of the coral in which the corallite structures are either gone or covered over by organisms that are not easily removed (certain algae and invertebrates). Remember to only estimate mortality as viewed from above in "plan" or "map" view. If it is entirely "long dead", indicate this on your data sheet as 100% "long dead".

E. Quickly scan over the surviving portions of the ENTIRE coral colony and note if there are any diseases and/or bleached tissues present. Characterise any diseases by the disease colour categories listed in Appendix 1B. Underline any of these sources of disease (not bleaching) that are visible in plan view and which contributed to your estimate of "% recently dead". For more information about coral diseases see McCarthy and Peter's website (2000). Characterise any bleaching as approximate area of live tissues that are affected and by approximate severity of discoloration. Severely bleached coral tissues in many species are translucent, but you can still see the polyps above the skeleton. Bleached tissues should not be included with the "recently dead" estimates.

F. Whenever possible, record any other sources of recent mortality that can still be unambiguously identified: possibilities include sediments, storm damage, parrotfish bites, damselfish bites and/or algal gardens, predation on the soft tissues by snails like *Coralliophila abbreviata* or the bristle worm *Hermodice carunculata*, various effects of adjacent benthic algae, and any other spatial competitors (e.g., *Erythropodium caribaeorum*, other stony corals). Underline any of these sources that are visible in plan view and which contributed to your estimate of "% recently dead".

G. While examining the entire coral head, count and record the number of damselfish or the total area of damselfish algal gardens on each head.

IV. Go to the next appropriate coral and repeat the measurements above. Continue evaluating each coral head (>25 cm) until you reach the other end of the transect.

V. Turn around and go back towards the other end of the transect placing the 25 X 25 cm quadrate to estimate relative algal abundance. Place the quadrate every two meters directly below the transect line starting at 1 m (1, 3, 5, 7, 9 m). If a suitable area is not available at this mark, first try placing the quadrate within 1m in front of, then 1 m behind the mark, then 1 m to either side. If there are still no suitable areas available, draw a line through the space on your data sheet. Remember to avoid conspicuous patches of sand, macroalgae and benthic animals (other stony corals, gorgonian holdfasts, sponges, ascidians, etc.). Use your hands to remove any sediment that could cover crustose coralline algae below turf algae. For each quadrate, record each of the following:

A. 1.Substratum type (as pavement or dead coral).

2.The % of macroalgae

3.The % of turf algae

4.The % of living crustose coralline algae (pink or reddish in colour - include any that are visible below turf algae or macroalgae, even though your total will exceed 100%).

5.The % other (e.g. invertebrates, sand, or bare areas)

B. Use the plastic ruler to approximate the average canopy height of the macroalgae present within the quadrate. Note: For those who find it easier to measure relative algal percentages, draw a line through the "% other" category and simply record the relative (rather than absolute) % of each of the three algal groups, this is a simplification only.

VI. Continue placing and assessing quadrates until you reach the other end of the transect. Under usual conditions, 5 quadrates should be measured along each 10 m transect. If you will be setting more than 10 transects/site, you may want to scale back on the number of quadrates per transect so that you don't end up with more than 50 quadrates/SITE.

VII. Using the 1 m measuring device for scale, swim a belt transect along the 10 m transect line that was just surveyed for corals and algae. Count every *Diadema* that you can see within 1/2 m of each side of the transect line. Because this species is cryptic, you must inspect all shelter-providing spaces along the transect. (Be prepared to poke your head under the bases of large corals or into crevices.)

VIII. After you complete a transect, collect the line and haphazardly reset the next transect line, at least 1 m laterally away from its previous position. Remember to avoid other lines, and whenever possible, abrupt changes in slope, large areas of sand and rubble, and any other unusual reef features.

IX. Repeat the above steps for each transect.

X. You can continue to reset transects in new positions as many times as safe diving practices permit during any given dive. However, a bare minimum of 50 quadrates and 100 coral heads should be assessed at each SITE. Obviously, appropriate sample sizes will depend on the variance in the local habitats--so we cannot prescribe "a one size fits all protocol".

Note: In some cases, coral density extremes will require modifying the number of transects laid. If coral density is low, lay enough transects to evaluate 100 individual corals (you may have to conduct additional dives). For example, if a site averages 2 corals per 10 m transect line, you need to set 50 transects at that site. If coral density is unusually low, be sure that you are working on a reef rather than an assemblage of corals on a pavement. If coral density is unusually high, set enough transects to evaluate about 200 corals. For example, if you average 20 corals per 10-m transect, you should lay 10 transects per site. Evaluate every coral head along the transect (don't skip any). Space the transects to ensure that you have a representative sample of the site.

XI. After surveying, enter data into a database, then check and verify their accuracy. Back up data regularly and store in a safe place.

Note: We suggest using a standard point-count method to assess large clusters or thickets in which colony boundaries are not distinguishable. There are many point count methods in common use. For example, you can haphazardly lay transects (using either a tape measure or rope with every 25 cm marked off) over the cluster or thicket and identify recent death, old death, or living coral tissue every 25 cm. The maximum diameter and height should be determined for the entire cluster or thicket.

3.0 Fish method

The AGRRA protocol for fishes includes two distinct methods that should both be applied at each site. Each method provides different types of data. The fish survey requires a minimum of two divers. One will count and record fishes, while the second will assist in the deployment of transect tapes and will retrieve tapes for repeated use. A larger team may be able to increase the number of divers counting fish relative to the number assisting (i.e., a team of four could include 3 observers and one tape manager).

Note: The transect lines to be set for the fish may also be used for the benthic assessments. In these cases, the fish will be counted before benthic assessments are made, and the benthic assessments should still use 10 m segments rather than the full 30 m transect. All transects used for fish assessment should be located within the same depth intervals specified for the benthic assessment (1-5 m and 8-15 m). Transects for fish will tend to be further apart and may range deeper and shallower than transects for benthic organisms. The integration of fish and benthic sampling, while beneficial, will require close coordination between team members for the two parts. It is recommended that the fish observations be conducted between 10:00 and 14:00 hours if at all possible, when visibility underwater is at a maximum due to overhead sunlight. Many fishes are wary of humans, hence it is necessary to keep away from other people while making these observations.

3.1 Belt transect methods for defined species list

1. Lay a 30 m transect line by first placing the weighted end of the line on the bottom, and then swimming in a straight line while releasing it from the reel as you count the fish. This minimises the disturbance to the fishes prior to their being counted. Periodically fixing on an object in the distance as you swim will help you swim in a straight line.
2. Count and record fish found within a 2 m wide visually estimated belt transect as you swim out the full 30 m transect line. Carry a data sheet in standard format, and a 1-m wide T-bar to ensure accurate monitoring of the 2 m wide belt. Hold the T-bar ahead of

you angled downward at about 45 degrees, and try to focus your gaze on the several meters of the transect ahead of the T-bar. Count only those SPECIES listed in Appendix 5 and do not count juvenile parrotfishes or grunts less than 5cm in total length. This list of species has been chosen to provide coverage of a number of the species most likely to be affected by human impacts, while preserving a relatively consistent search image. This should enhance the precision of transect data.

SELECTED FAMILIES- include EVERY SPECIES within the following families:
Surgeonfish (e.g., *Acanthurus bahianus, A. chirurgus, A. coeruleus*)
Parrotfish (e.g., *Sparisoma viride, S. aurofrenatum, S. rubripinne, Scarus taeniopterus*)
Grunt (e.g., *Haemulon flavolineatum, H. chrysargyreum, H. sciurus, H. plumieri*)
Snapper (e.g., *Lutjanus griseus, L. apodus, L. mahogoni, Ocyurus chrysurus*)
Grouper (e.g., *Epinephelus guttatus, E. fulvus, E. cruentatus, E. striatus*)
Angelfish (e.g., *Pomacanthus paru, P. arcuatus, Holocanthus tricolor, H. ciliarus*)
Butterflyfish (e.g., *Chaetodon capistratus*)
Triggerfish (e.g., *Balistes vetula, Melichthys niger*)

ALSO COUNT the following five species:
Yellowtail damselfish (*Microspathodon chrysurus*)
Hogfish (*Lachnolaimus maximus*)
Spanish hogfish (*Bodianus rufus*)
Barracuda (*Sphyraena barracuda*)
Bar jack (*Caranx ruber*)

3. Estimate the size of each fish and assign them to the following size categories (<5 cm, 5-10, 10-20, 20-30, 30-40, >40 cm) using a 1 m T-bar with 5 cm increments to assist in estimating sizes. Large groups of individuals of a species will be classified by attempting to put them into one or more size categories as necessary. By remembering to keep effort equivalent on all segments of the transect, you can limit the tendency to count all members of a school crossing the transect, instead of just those members which happen to be within the transect as counting of that segment takes place.

Note: Sample the transect belt giving uniform attention to each successive 2-m segment. This requires swimming at a more or less constant rate, and looking consistently about 2 m ahead, except when actually recording data. It is permissible to pause while recording data, and then to start swimming again. It is important to swim in a consistent manner while actually sampling the fish. A speed that counts each 30 m transect in 10 minutes should be attempted. High densities of counted species will slow this rate in some cases. Fish observers should be trained to estimate fish lengths by using consistency training methods both on land and underwater. The diver will be tempted to count all members of a school as they swim across the transect unless he/she concentrates on giving equal effort to sampling each successive portion of the transect. Only those school members that are actually within the 2m wide strip of that segment of the transect is included in the census.

4. When you reach the end of the transect line, stop the survey and recoil the transect line.
5. Continue conducting haphazardly-positioned 30 m transects at least 5 m laterally away from the previous position. Repeat the above steps for each transect.
6. Conduct a minimum of ten (10) transects at each site.

3.2 Rover Diver census

After finishing the belt transects (or concurrently depending on the number of surveyors), conduct a roving diver census of ALL SPECIES of fishes following the methodology of Reef Environmental Education Foundation (REEF, 2000).

1. The Rover diver census is conducted within the general area where the belt transects are set.

2. Swim around the reef SITE for approximately 30 minutes and record ALL fish species observed. Use all knowledge you have of fish habits, and search under overhangs, in caves, and so on. The objective is to find the maximum number of species that you can in 30 minutes of search time.
3. Estimate the density of each species by using logarithmic categories: Single (1 fish), Few (2-10 fishes), Many (11-100 fishes), or Abundant (>100 fishes).

4.0 Coral Recruitment method (Optional)

Several other useful assessments may be easily integrated into the core portion of the protocol given above. These optional components, while not part of the core methods, can yield additional information that may lead to a better understanding of the condition of a reef. These optional components include fish bites, coral recruitment, and the stationary method for assessing fish communities. The only one included here is the coral recruitment method since it was used in our study. Coral recruitment is an important indicator of a reef's regeneration potential and is approximated by counting the number of small (<2 cm) corals attached to the bottom within the 25 x 25 cm square quadrates.

1. Count all small (maximum diameter 2 cm), stony corals (Scleractinians and Millepora) that you can see within the 25 X 25 cm quadrates at the same time as the estimates of algal abundance are made.
2. Whenever possible, record their scientific names at least to the level of genus.
3. If time permits, you can increase the sample size of the observations by swimming in a haphazard fashion around the reef being surveyed and placing the 25 x 25 cm

quadrate on the substratum in areas lacking large (> 25 cm diameter) sessile invertebrates.

4. Try to repeat for a total of at least 80 squares (an overall sample of 5 square meters of reef surface).

Note: Proper training and good eyesight (or corrective lenses) are essential to accurately detect the presence of small corals due to their inconspicuous size and nature.

5.0 Material

1. A 10 m long transect line (for coral). --> A 10 m polypropylene line marked at the 1, 3, 5, 7, and 9 m intervals (with cables-ties, electrical tape or permanent ink) to which a small dive weight has been attached at each end.
2. A 1 m long measuring device (for coral). --> A polypropylene line marked at 10 cm intervals (as above), plus a loop at one end to go around the wrist of your non-writing hand. Alternatively, a short metric measuring tape or a PVC stick marked in 10 cm intervals can be used.
3. A 25 x 25 cm quadrate (for algae and small corals). --> Construct quadrates using 1/2" PVC water pipe and elbows (with holes drilled in them to let the air out). String can be used to make a grid on the quadrate.
4. A small plastic ruler tied algal quadrate (for algae). --> Trim the ruler to have a narrow tapered point, but still be legible, at the basal 5 cm.
5. Underwater data templates (all). --> The most efficient method consists of photocopying the data template onto both sides of white underwater paper (contact

J.L. Darling Corporation, phone: 206-922-5000, fax: 206-922-5300; address: 2614 Pacific Hwy East, Tacoma, WA 98424-1017). This approach is more expensive (about $52.00 U.S./100 sheets), but data are more likely to be entered in the correct column since the template is reproduced on every data sheet. Roving diver census sheet are to be ordered directly from REEF. Appendix 8 has an example of the data sheet designed for the fish and coral transects.

6. Underwater slate (all). --> Any 81/2 x 11 slate will do for the coral survey but a specially designed slate is available for the fish from REEF (to fit their rover diver templates)
7. At least two 30m fibreglass transect lines with a 3 lb (fish). --> weight attached at one end of each line. Commercially available PVC surveying tapes are suitable for the transect line, or a 30 m nylon cord attached to a homemade reel will work. A clip can be attached to the reel and suspended from the diver's belt, which allows for the tape to deploy freely as the diver swims.
8. A graduated T-bar or other measuring device (fish). -->Construct a T-bar using 1" diameter PVC pipe and a T connector available at hardware stores. It has a 60 cm long handle and two equal length arms providing a total width across the top of 1 m. Use PVC electrical tape or paint to create a scale along one of the arms showing 5, 10, 20, 30, 40 cm lengths.

APPENDIX 1B: Standardised abbreviations for AGRRA coral surveys

Corals

AC = *Acropora cervicornis*
AP = *Acropora palmata*
AG = *Agaricia agaricites*
AT = *Agaricia tenuifolia*
CN = *Colpophyllia natans*
DCY= *Dendrogyra cylindrus*
DIC = *Dichocoenia stokesii*
DC = *Diploria clivosa*
DL = *Diploria labyrinthiformis*
DS = *Diploria strigosa*
MIC= *Millepora complanata*
MA = *Montastraea annularis*
MAF = *Montastraea annularis faveolata*
MFR = *Montastraea annularis franksi*
MC = *Montastraea cavernosa*
MD = *Madracis mirabilis*
MM = *Meandrina meandrites*
MY=*Mycetophyllia* sp.
MU= *Mussa angulosa and other sp.*
PA = *Porites astreoides*
PP = *Porites porites*
SB = *Solenastrea bournoni*
SI = *Stephanocoenia intersepta*
SS = *Siderastrea siderea*

Bleaching

P = Pale
PB = Partly Bleach
BL = Total Bleach

Diseases

BB = Black band
WB = White band
YB = Yellow band/blotch
UK = Unknown

site	coral no.	transect	depth	Coral Cover (cm)	Sand Cover (cm)	CORR CORAL COVER	Coral Sp.	Max Diam (cm)	Max Height (cm)	% old	%recent	%TOTAL	Disease	Bleaching	Damselfish	%macro	%turf	%crustose	%other	Avg Canopy Hgt (cm)	# recruits	recruit sp.
A	1	1	12.8	470	100	522.2222222	MA	100	80	75	0	75	0	PB	0	60	10	20	20	1.5	0	
A	2	1	12.8				MA	40	70	5	0	5	0	0	0	50	30	10	10	2	0	
A	3	1	12.8				MAF	40	100	55	0	55	0	0	0	50	20	10	20	2	0	
A	4	1	12.8				CN	60	25	5	0	5	0	0	0	60	20	20	20	2	0	
A	5	1	12.8				MA	30	10	5	0	5	0	0	0	20	10	40	60	2	0	
A	6	1	12.8				CN	120	120	0	0		0	0	0							
A	7	1	12.8				PP	30	20	20	0	20	0	0	0							
A	8	1	12.8				SS	50	20	0	0		0	PB	0							
A	9	1	12.8				MA	50	70	60	0	60	0	0	0							
A	10	2	12.2	300	0	300	MA	100	120	50	0	50	0	0	0	50	0	0	50	15	0	
A	11	2	12.2				MA	80	60	40	0	40	0	0	0	50	10	10	30	2	0	
A	12	2	12.2				MA	80	70	50	0	50	0	0	0	30	10	40	10	1	0	
A	13	2	12.2				MA	50	50	80	0	80	0	0	0	20	10	60	10	1	0	
A	14	2	12.2				MA	30	50	10	0	10	0	PB	0	40	10	30	20	1	0	
A	15	2	12.2				MA	40	30	60	0	60	0	0	0							
A	16	2	12.2				PA	50	20	0	0		0	0	0							
A	17	2	12.2				MFR	40	30	0	0		0	0	0							
A	18	2	12.2				PA	30	10	0	0		0	0	0							
A	19	3	12.2	330	30	340.2061856	PA	50	10	15	0	15	0	0	0	70	10	20	0	1	0	
A	20	3	12.2				PP	30	10	40	0	40	0	0	0	60	10	30	0	1	0	
A	21	3	12.2				PA	30	10	10	0	10	0	0	0	60	10	10	20	2	0	
A	22	3	12.2				PA	50	30	0	0		0	0	0	50	10	30	10	1	0	
A	23	3	12.2				PP	50	20	0	0		0	0	0	50	10	10	30	1	0	
A	24	3	12.2				MC	50	30	20	0	20	0	0	0							
A	25	4	11.6	350	100	388.8888889	MA	100	40	20	0	20	0	0	0	50	0	0	50	1.5	0	
A	26	4	11.6				PP	80	30	20	0	20	0	0	0	50	10	10	30	2	0	
A	27	4	11.6				PA	70	30	35	0	35	0	0	0	30	10	40	10	1	0	
A	28	4	11.6				MD	30	10	10	0	10	0	0	0	20	10	60	10	1	0	
A	29	4	11.3				MA	40	30	5	0	5	0	0	0	40	10	30	20	1	0	
A	30	4	11.6				PA	30	10	10	0	10	0	0	0							
A	31	4	11.6				PA	30	10	30	0	30	0	0	0							
A	32	5	12.8	300	150	352.9411765	PP	30	20	0	0		0	0	0	30	40	30	20	1.5	0	
A	33	5	12.8				MA	30	20	5	0	5	0	0	0	30	50	30	0	1.2	0	
A	34	5	12.8				PA	40	20	25	0	25	0	PB	0	20	60	15	15	1	0	
A	35	5	12.8				PA	30	10	75	0	75	0	0	0	0	75	30	0	0	0	
A	36	5	12.8				PP	40	30	20	0	20	0	0	0	20	40	30	10	1	0	
A	37	5	12.8				MC	50	30	30	0	30	0	0	0							
A	38	5	12.8				MA	50	50	40	0	40	0	0	0							
A	39	5	12.8				MA	150	120	55	0	55	0	P	0							
A	40	5	12.8				MA	30	60	5	0	5	0	PB	0							
A	41	5	12.8				MA	45	70	40	0	40	0	0	0							
A	42	5	12.8				PA	30	10	5	0	5	0	0	0							
A	43	6	9.4	350	100	388.8888889	PP	30	20	20	0	20	0	0	0	0	0	0	0	0	0	
A	44	6	9.4				MA	120	100	5	0	5	YB	0	2	50	0	30	20	2	0	
A	45	6	9.4				PP	30	30	0	0		0	0	0	50	20	30	0	1	0	
A	46	6	9.4				CN	50	40	0	0		0	0	0	30	0	40	30	1	0	
A	47	6	9.4				PA	30	20	0	0		0	0	0	30	10	30	30	1	0	
A	48	6	9.1				PA	30	30	0	0		0	0	0							
A	49	7	9.1	340	180	414.6341463	PA	40	10	0	0		0	0	0	50	20	30	0	1	0	
A	50	7	9.1				PP	40	30	10	0	10	0	0	0	60	10	20	20	1	0	
A	51	7	9.1				MAF	30	20	5	0	5	0	0	0	60	10	30	10	1	0	

A	52	7	9.1				MAF	70	50	35	0	35	0	0	0	60	10	10	20	1	0
A	53	7	9.1				PA	30	10	5	0	5	0	0	0	50	10	0	30	2	0
A	54	7	9.1				PA	30	20	0	0		0	0	2						
A	55	7	9.1				PP	30	30	10	0	10	0	0	0						
A	56	7	9.1				MA	40	40	60	0	60	0	0	2						
A	57	7	9.1				MA	60	40	65	0	65	0	0	2						
A	58	7	9.1				MA	70	60	90	0	90	0	0	0						
A	59	7	9.1				MA	30	50	75	0	75	0	0	0						
A	60	7	9.1				MA	40	35	80	0	80	0	0	0						
A	61	7	9.1				PP	30	20	30	0	30	0	0	0						
A	62	7	9.1				PP	30	20	40	0	40	0	0	1						
A	63	7	9.1				MA	55	50	20	0	20	0	0	2						
A	64	8	11.6	380	120	431.8181818	MA	50	60	15	0	15		PB	3	40	10	10	40	2	1
A	65	8	11.6				MA	60	20	5	0	5		PB	0	10	20	60	10	1	0
A	66	8	11.6				MA	25	20	10	0	10		P	1	80	10	10	0	1	0
A	67	8	11.6				MAF	100	60	5	0	5	YB		0	70	10	20	20	1	0
A	68	8	11.6				MA	50	30	70	0	70		PB	1	50	10	10	30	1	0
A	69	8	11.6				MAF	100	60	70	0	70		PB	0						
A	70	8	11.6				MA	50	40	20	0	20	YB		1						
A	71	8	11.6				MA	60	30	20	0	20			1						
A	72	9	12.2	450	40	468.75	MA	120	110	25	5	30	YB	0	0	0	0	0	0	0	0
A	73	9	12.2				PA	50	20	30	0	30	0	0	0	50	10	20	20	1	0
A	74	9	12.2				MA	70	60	90	0	90	0	0	3	50	0	30	20	1	0
A	75	9	12.2				PA	50	20	0	30	30	0	0	0	40	10	30	20	1	0
A	76	9	12.2				MA	100	50	20	0	20	0	0	2	70	0	20	0	2	0
A	77	9	12.2				MFR	50	70	20	0	20	0	0	1						
A	78	9	12.2				MA	50	40	30	0	30	0	0	0						
A	79	9	12.2				PP	30	30	20	0	20	0	0	0						
A	80	9	12.2				MIC	60	40	5	0	5	0	0	0						
A	81	9	12.2				MA	70	50	65	0	65	0	0	2						
A	82	9	12.2				MA	30	50	60	0	60	0	0	0						
A	83	9	12.2				CN	40	50	0	0		0	0	0						
A	84	9	12.2				PP	40	30	0	0		0	0	1						
A	85	9	12.2				PA	25	15	0	0		0	0	0						
A	86	9	12.2				MA	35	50	10	0	10	YB	0	1						
A	87	9	12.2				MA	25	40	30	0	30	0	0	0						
A	88	10	12.2	550	100	611.1111111	MA	30	35	5	0	5	0	PB	1	40	10	0	50	1	0
A	89	10	12.2				MY	40	10	30	0	30	0		0	70	10	0	20	1	0
A	90	10	12.2				MA	130	100	20	0	20	0	PB	0	20	10	60	10	2	0
A	91	10	12.2				MA	60	50	15	0	15	0		1	25	10	55	10	2	0
A	92	10	12.2				MA	50	60	25	0	25	0		0	40	0	50	10	2	0
A	93	10	12.2				AG	25	20	10	0	10	0		0						
A	94	10	12.2				MA	50	60	10	0	10	0	PB	0						
A	95	10	12.2				MA	130	100	8	0	8	0	PB	3						
A	96	10	12.2				CN	70	20	0	0		0		0						
A	97	10	12.2				MA	120	80	8	2	10	0		0						
A	98	10	12.2				MAF	80	50	0	0		0	PB	0						
A	99	10	12.2				CN	130	50	40	0		0		2						
A	100	11	10.4	380	100	422.2222222	PP	40	30	8	0	8	0	0	0	50	0	30	20	2	0
A	101	11	10.4				MA	40	50	8	0	8	0	P	1	60	20	10	20	2	0
A	102	11	10.4				PP	35	40	5	0	5	0	0	0	50	20	20	10	1	0
A	103	11	10.4				MA	50	60	0	2	2	0	P	0	50	40	0	10	1	0
A	104	11	10.4				MA	100	120	25	10	35	0	0	0	30	10	50	20	1	0
A	105	11	9.8				CN	130	40	0	70	70	0	0	0						

A	106	11	9.8				MA	100	130	30	0	30	0	0	2						
A	107	11	10.4				PA	40	10	5	0	5	0	0	0						
A	108	11	10.4				PA	50	15	0	0		0	0	0						
B	1	1	4.6	250	0	250	PA	40	20	20	0	20	0	0	0	0	20	70	10		0
B	2	1	4.6				PP	50	30	80	0	80	0	0	0	0	10	80	10		0
B	3	1	4.6				PA	50	10	0	0		0	0	0	20	10	60	10	1	0
B	4	1	4.6				AP	100	70	100		100	0	0	0	30	29	40	10	1	0
B	5	1	4.6				MIC	30	30	0	0		0	0	0	10	40	50	0	1	0
B	6	1	4.6				PA	60	60	0	0		0	0	0						
B	7	1	4.6				PP	30	30	0	0		0	0	0						
B	8	1	4.6				AP	90	90	100		100	0	0	0						
B	9	2	3.0	270	0	270	PA	25	5	0	0		0	0	0	10	10	80	0	1	0
B	10	2	3.0				PA	30	10	10	0	10	0	0	0	0	10	70	20		0
B	11	2	3.0				PA	60	30	10	0	10	0	0	0	0	10	80	10		0
B	12	2	3.0				PA	30	20	40	0	40	0	0	0	20	20	60	0	1	0
B	13	2	3.0				MIC	30	30	0	0		0	0	0	0	10	80	10		0
B	14	2	3.0				PA	60	30	20	0	20	0	0	0						
B	15	2	3.0				PA	30	5	10	0	10	0	0	0						
B	16	3	4.3	320	0	320	AP	130	100	100		100	0	0	0	0	10	80	10		
B	17	3	4.3				PA	50	40	20	0	20	0	0	1	80	0	20	0	1	0
B	18	3	4.3				PP	100	70	20	0	20	0	0	0	10	10	80	0	1	0
B	19	3	4.3				PA	50	15	5	0	5	0	0	0	20	10	60	10	1	0
B	20	3	4.3				MA	60	70	30	0	30	0	0	0	70	10	20	0	2	0
B	21	3	4.3				PP	60	30	3	0	3	0	0	0						0
B	22	3	4.3				PP	70	30	10	0	10	0	0	1						
B	23	3	4.3				MA	80	60	15	0	15	0	0	0						
B	24	3	4.3				PA	40	15	0	0		0	0	0						
B	25	3	4.3				PA	80	30	5	0	5	0	P	0						
B	26	4	3.0	300	0	300	MIC	50	40	0	0		0	0	0	0	10	80	10		0
B	27	4	3.0				PA	40	30	30	0	30	0	0	0	0	10	80	10		0
B	28	4	3.0				MIC	30	20	0	0		0	0	0	0	10	80	10		0
B	29	4	3.0				PP	30	30	90	0	90	0	0	0	10	20	70	0	1	0
B	30	4	3.0				MIC	30	20	0	0		0	0	0	10	20	60	10	1	0
B	31	4	3.0				PA	40	15	15	0	15	0	0	0						
B	32	4	3.0				PA	40	10	15	0	15	0	0	0						
B	33	4	3.0				PA	40	15	30	0	30	0	0	0						
B	34	4	3.0				PA	30	10	20	0	20	0	0	0						
B	35	4	3.0				AP	150	100	100		100	0	0	0						
B	36	5	4.0	220	0	220	PA	25	10	0	0		0	0	0	20	20	60	0	1	0
B	37	5	4.0				PA	25	20	5	0	5	0	0	0	0	10	80	10		1
B	38	5	4.0				AP	100	80	100		100	0	0	0	0	10	70	20		3
B	39	5	4.0				PA	50	10	10	0	10	0	0	0	10	10	70	10	1	0
B	40	5	4.0				PA	30	15	20	0	20	0	0	0	30	0	70	0	2	0
B	41	6	3.0	300	0	300	PP	30	20	20	0	20	0	0	1	0	10	80	10		2
B	42	6	3.0				PA	50	20	5	0	5	0	0	0	10	10	80	0	1	0
B	43	6	3.0				PA	40	25	10	0	10	0	0	1	0	10	80	10		0
B	44	6	3.0				PA	30	30	5	0	5	0	0	0	10	10	80	0	1	0
B	45	6	3.0				PA	30	20	5	0	5	0	0	0	0	10	80	10		1
B	46	6	3.0				PA	50	20	20	0	20	0	0	0						
B	47	6	3.0				AP	120	80	100		100	0	0	0						
B	48	7	3.7	170	0	170	MIC	50	25	50	0	50	0	0	0	0	20	80	10		0
B	49	7	3.7				PA	30	20	10	5	15	0	0	1	40	10	40	0	2	2
B	50	7	3.7				AP	50	60	100		100	0	0	0	0	10	80	10		1
B	51	7	3.7				PA	60	50	20	0	20	0	0	2	0	10	70	0		0

B	52	7	3.7				MIC	60	50	15	0	15	0	0	0	0	10	90	10		0
B	53	7	3.7				MIC	60	70	60	0	60	0	0	0						
B	54	8	4.0	210	0	210	AP	120	40	100		100	0	0	0	0	10	90	0		0
B	55	8	4.0				AP	110	60	100		100	0	0	0	10	10	70	10	1	0
B	56	8	4.0				PA	30	15	5	0	5	0	0	0	10	10	80	0	1	1
B	57	8	4.0				PP	30	10	30	0	30	0	0	0	60	10	30	0	2	0
B	58	8	4.0				AP	150	100	100		100	0	0	0	60	0	20	20	2	0
B	59	8	4.0				AG	30	10	0	0		0	0	0						
B	60	8	4.0				PA	60	20	60	0	60	0	0	0						
B	61	8	4.0				MIC	50	40	20	0	20	0	0	2						
B	62	8	4.0				PP	60	30	30	0	30	0	0	0						
B	63	9	3.7	350	0	350	MIC	60	30	20	0	20	0	0	0	10	20	60	10	1	0
B	64	9	3.7				PA	35	25	25	0	25	0	0	0	20	10	60	20	2	0
B	65	9	3.7				PP	50	20	20	0	20	0	0	0	10	10	70	10	1	0
B	66	9	3.7				PA	40	30	5	0	5	0	0	0						0
B	67	9	3.7				PA	35	30	5	0	5	0	0	0						0
B	68	9	3.7				PA	30	25	10	0	10	0	0	0						
B	69	9	3.7				PA	70	30	20	0	20	0	0	2						
B	70	9	3.7				PA	40	30	20	0	20	0	0	0						
B	71	9	3.7				PA	30	15	10	0	10	0	P	0						
B	72	10	3.0	340	0	340	PP	60	40	10	0	10	0	0	0	10	10	60	20	2	1
B	73	10	3.0				PP	30	30	60	0	60	0	0	0	10	20	70	0	1	3
B	74	10	3.0				PA	30	20	20	0	20	0	0	0	60	10	20	10	2	0
B	75	10	3.0				PA	30	10	20	0	20	0	0	0						
B	76	10	3.0				PP	60	30	40	0	40	0	0	0						
B	77	10	3.0				PA	55	30	5	0	5	0	0	0						
B	78	10	3.0				PP	120	30	75	0	75	0	0	0						
B	79	10	3.0				PP	50	30	85	0	85	0	0	0						
B	80	11	3.7	350	0	350	MIC	30	20	60	0	60	0	0	0	0	20	60	20		1
B	81	11	3.7				MIC	35	25	0	0		0	0	0	0	10	80	10		2
B	82	11	3.7				PA	50	20	10	0	10	0	0	0	0	10	70	20		3
B	83	11	3.7				PA	80	30	15	0	15	0	P	0						
B	84	11	3.7				MIC	40	30	25	0	25	0	0	0						
B	85	11	3.7				PA	45	30	5	0	5	0	0	0						
B	86	11	3.7				PA	25	10	0	50	50	0	0	0						
B	87	11	3.7				PA	40	20	0	50	50	0	0	0						
B	88	11	3.7				PA	40	10	60	5	65	0	0	0						
B	89	11	3.7				PA	60	30	2	0	2	0	0	0						
B	90	12	3.4	340	0	340	PA	30	10	5	0	5	0	0	0	60	10	30	0	2	0
B	91	12	3.4				PA	45	40	80	0	80	0	0	0	20	10	70	0	2	0
B	92	12	3.4				PA	40	15	2	0	2	0	0	0	40	0	40	20	2	0
B	93	12	3.4				PA	40	20	5	0	5	0	0	0						
B	94	12	3.4				MA	80	90	5	0	5	0	0	0						
B	95	13	2.7	280	0	280	PA	30	20	10	0	10	0	0	0	10	10	70	10	1	1
B	96	13	2.7				MIC	80	35	20	0	20	0	0	0	20	10	60	10	1	0
B	97	13	2.7				MIC	80	30	70	0	70	0	0	0	10	20	60	10	1	2
B	98	13	2.7				PA	30	20	10	0	10	0	0	0						
B	99	13	2.7				PA	35	35	20	0	20	0	0	0						
B	100	14	4.6	350	0	350	PP	25	15	0	5	5	0	0	0	50	10	10	30	2	0
B	101	14	4.6				PA	25	20	0	0		0	0	0	60	10	10	0	2	0
B	102	14	4.6				MA	120	100	40	0	40	YB	0	0	60	0	20	0	2	0
B	103	14	4.6				PP	30	20	0	0		0	0	0						
B	104	14	4.6				PP	30	20	40	0	40	0	0	0						
B	105	14	4.6				PP	50	25	0	2	2	0	0	0						

B	106	14	4.6				PA	35	20	10	0	10	0	0	0						
B	107	14	4.6				PP	150	60	20	0	20	0	0	0						
B	108	14	4.6				PP	110	30	35	0	35	0	0	0						
B	109	14	4.6				MA	60	40	10	0	10	0	0	0						
C	1	1	9.8	400	160	476.1904762	MA	40	60	0	2	2	0	0	0						
C	2	1	9.8				MA	40	50	0	2	2	0	0	0	30	20	40	10	2	0
C	3	1	9.8				DS	100	60	5	0	5	0	0	0	40	20	30	10	2	1
C	4	1	9.8				PP	30	15	20	0	20	0	0	0	60	0	0	20	2	0
C	5	1	9.8				PP	30	20	5	0	5	0	0	0	40	10	50	0	2	0
C	6	1	9.8				PA	30	20	0	2	2	0	0	0	50	0	10	30	2	0
C	7	1	9.8				PA	30	20	30	0	30	0	0	2						
C	8	1	9.8				MA	25	50	15	0	15	0	P	0						
C	9	1	9.8				MA	100	90	90	0	90	0	PB	0						
C	10	1	9.8				PP	110	60	19	5	24	0	0	0						
C	11	1	9.8				MA	150	60	0	30	30	0	PB	0						
C	12	2	9.1	340	160	404.7619048	PA	30	10	10	0	10	0	0	0						
C	13	2	9.1				SS	40	10	10	0	10	0	0	0	30	10	20	40	2	0
C	14	2	9.1				PP	40	15	15	0	15	0	0	0	20	10	40	30	2	0
C	15	2	9.1				PA	40	0	0	0		0	0	0	10	0	60	10	2	1
C	16	2	9.1				PP	30	5	5	0	5	0	0	0	60	10	0	30	2	1
C	17	2	9.1				PP	45	25	25	0	25	0	0	0	30	40	10	10	1	0
C	18	2	9.1				MA	130	45	45	5	50	0	PB	0						
C	19	2	9.1				PP	45	0	0	10	10	0	0	0						
C	20	2	9.1				MA	35	90	90	0	90	WB	0	0						
C	21	2	9.1				PP	120	35	35	0	35	0	0	0						
C	22	2	9.1				MA	100	15	15	10	25	0	PB	0						
C	23	2	9.1				MC	40	0	0	2	2	0	0	0						
C	24	2	9.1				PP	80	40	40	0	40	0	0	0						
C	25	3	9.4	350	280	486.1111111	PP	50	20	5	0	5	0	0	0						
C	26	3	9.4				PP	70	20	2	0	2	0	0	0	50	10	20	20	2	0
C	27	3	9.4				PP	50	30	2	0	2	0	0	0	60	10	10	20	2	0
C	28	3	9.4				PP	30	20	5	0	5	0	0	0	30	30	40	0	2	0
C	29	3	9.4				PP	30	20	10	0	10	0	0	0	30	20	40	10	2	0
C	30	3	9.4				PP	30	20	5	0	5	0	0	0	30	10	30	30	2	0
C	31	3	9.4				PP	40	20	5	0	5	0	0	0						
C	32	4	8.8	530	0	530	PP	30	10	30	0	30	0	0	0						
C	33	4	8.8				PP	60	15	30	0	30	0	0	0	70	10	10	10	2	0
C	34	4	8.8				PP	40	20	40	0	40	0	0	0	80	0	20	0	3	0
C	35	4	8.8				PP	300	120	20	5	25	0	0	0	60	10	20	10	2	0
C	36	4	8.8				PP	50	20	3	10	13	0	0	0	30	25	25	20	2	0
C	37	5	8.2	350	280	486.1111111	MA	60	90	30	5	35	0	0	1	70	10	20	0	3	0
C	38	5	8.2				DS	40	30	40	0	40	0	0	0	90	0	0	10	3	0
C	39	5	8.2				MA	60	65	5	10	15	0	0	2	20	30	20	30	1	2
C	40	5	8.2				PP	30	20	0	0		0	0	0	30	20	20	30	1	0
C	41	5	8.2				PA	30	20	15	0	15	0	0	0	50	10	40	0	2	0
C	42	5	8.2				MA	80	70	30	0	30	0	0	0	70	0	0	30	1	0
C	43	5	8.2				MA	50	30	60	0	60	0	0	0						
C	44	5	8.2				DS	70	70	100		100	0	0	0						
C	45	5	8.2				MA	70	70	0	10	10	0	0	0						
C	46	5	8.2				DCY	170	90	50	0	50	0	0	2						
C	47	6	8.2	340	60	361.7021277	MA	70	50	30	0	30	0	0	0						
C	48	6	8.2				MA	70	60	8	0	8	0	0	2	20	20	60	0	2	0
C	49	6	8.2				MA	50	50	10	0	10	0	0	0	50	10	40	0	1	0
C	50	6	8.2				PP	50	30	65	0	65	0	0	0	0	10	70	20		1
																70	0	20	10	1	0

C	51	6	8.2				MA	25	40	5	0	5	0	0	0	0	10	80	10		1
C	52	6	8.2				MA	120	50	70	5	75	0	PB	0						
C	53	6	8.2				MA	60	60	25	5	30	0	0	2						
C	54	6	8.2				PP	120	30	25	5	30	0	0	0						
C	55	6	8.2				MA	140	50	35	0	35	0	0	1						
C	56	7	7.9	340	0	340	MA	30	40	5	0	5	0	0	0	10	10	70	10	2	1
C	57	7	7.9				MA	30	70	0	2	2	0	0	0	0	10	70	20	1	2
C	58	7	7.9				MA	30	50	40	0	40	0	0	0	90	0	10	0	3	0
C	59	7	7.9				MA	50	50	20	0	20	0	0	0	90	0	10	0	3	0
C	60	7	7.9				MA	45	50	30	0	30	0	PB	0	40	10	50	0	3	0
C	61	7	7.9				PP	200	90	90	0	90	0	0	0						
C	62	7	7.9				MA	60	60	20	0	20	0	0	0						
C	63	7	7.9				MAF	30	50	5	0	5	0	0	0						
C	64	7	7.9				MA	70	50	35	0	35	0	0	0						
C	65	7	7.9				MA	120	80	60	0	60	0	PB	0						
C	66	8	8.8	350	100	388.8888889	MA	60	60	35	0	35	0	0	0	0	30	60	10		2
C	67	8	8.8				MA	40	40	10	5	15	0	0	0	10	30	50	10	1	0
C	68	8	8.8				MA	90	70	30	5	35	0	0	0	20	30	50	0	1	0
C	69	8	8.8				MA	70	35	65	5	70	0	0	0	60	10	20	10	2	1
C	70	8	8.8				PP	120	50	80	0	80	0	0	0	20	20	50	10	1	0
C	71	8	8.8				MA	50	70	60	15	75	0	0	0						
C	72	8	8.8				PP	150	60	50	0	50	0	0	0						
C	73	8	8.8				MA	100	50	70	0	70	0	0	0						
C	74	8	8.8				CN	40	20	5	5	10	0	0	0						
C	75	8	8.8				MA	30	15	70	0	70	0	0	0						
C	76	9	7.9	260	180	317.0731707	MA	150	40	35	5	40	0	0	0	70	10	20	0	2	1
C	77	9	7.9				MA	50	50	10	0	10	0	0	0	80	10	10	0	2	2
C	78	9	7.9				MA	80	60	15	0	15	0	0	0	70	10	30	0	1	0
C	79	9	7.9				MA	100	50	45	0	45	0	0	0	30	10	60	0	1	0
C	80	9	7.9				MA	40	30	60	0	60	0	0	1	20	10	50	20	1	0
C	81	9	7.9				MA	50	30	70	0	70	0	0	0						
C	82	9	7.9				MA	40	40	35	0	35	0	0	2						
C	83	10	9.1	440	120	500	MA	60	50	60	5	65	0	0	1	90	0	0	10	2	0
C	84	10	9.1				PP	80	20	80	0	80	0	0	0	20	0	40	40	1	0
C	85	10	9.1				MA	70	40	8	0	8	0	0	1	20	20	50	10	1	0
C	86	10	9.1				MA	90	70	5	5	10	0	0	0	30	10	50	10	2	0
C	87	10	9.1				DS	70	30	0	35	35	0	0	1	60	10	20	10	2	0
C	88	10	9.1				PA	35	10	0	0		0	0	0						
C	89	10	9.1				PP	40	15	40	5	45	0	0	0						
C	90	10	9.1				MA	80	50	5	0	5	0	0	1						
C	91	10	9.1				SS	25	11	0	10	10	0	0	0						
C	92	10	9.1				MA	50	30	5	0	5	0	0	0						
C	93	10	9.1				PP	40	10	30	0	30	0	0	0						
C	94	10	9.1				PP	30	20	15	0	15	0	0	0						
C	95	11	9.8	410	220	525.6410256	MA	70	50	5	0	5	0	0	1	0	0	0	0	0	0
C	96	11	9.8				PP	30	20	20	0	20	0	0	0	50	10	10	30	1	0
C	97	11	9.8				PA	45	20	25	0	25	0	0	0	10	0	10	20	2	0
C	98	11	9.8				PP	40	20	5	0	5	0	0	0	10	20	50	20	1	0
C	99	11	9.8				PP	40	10	10	0	10	0	0	0	20	20	60	0	1	0
C	100	11	9.8				PP	40	30	25	0	25	0	0	0						
C	101	11	9.8				PP	30	20	0	0		0	0	0						
C	102	11	9.8				PP	35	20	5	5	10	0	0	0						
C	103	11	9.8				PP	50	20	15	5	20	0	0	0						
C	104	11	9.8				MA	70	50	15	0	15	0	0	0						

D	1	1	3.6	180	0	180	PP	150	30	15	5	20	0	0	0	20	10	70	0	2	0	
D	2	1	3.6				MA	60	40	10	5	15	0	0	0	70	10	20	0	2	0	
D	3	1	3.6				PP	50	30	75	10	85	0	0	0	0	20	60	20	0	0	
D	4	1	3.6				MA	70	40	75	0	75	0	0	2	0	70	30	0	0	0	
D	5	1	3.6				MA	40	20	0	0		0	0	0	50	30	20	0	2.5	0	
D	6	1	3.6				PP	40	30	40	0	40	0	0	0							
D	7	1	3.6				MA	30	40	65	10	75	0	0	1							
D	8	1	3.6				MA	60	50	0	70	70	0	0	0							
D	9	2	3.0	320	0	320	MA	150	90	30	5	35	0	0	0							
D	10	2	3.0				MA	90	70	20	0	20	0	0	0							
D	11	2	3.0				PA	40	30	0	0		0	0	1							
D	12	2	3.0				PA	30	10	30	10	40	0	0	0							
D	13	2	3.0				PP	180	30	80	0	80	0	0	0							
D	14	2	3.0				PP	25	30	0	0		0	0	0							
D	15	2	3.0				PP	120	30	25	0	25	0	0	0							
D	16	3	2.4	320	0	320	MA	80	50	10	30	40	0	0	1	5	15	80	0	1	0	
D	17	3	2.4				PP	130	70	50	0	50	0	0	0	0	20	70	10	0	2	PA, AG
D	18	3	2.4				MA	60	40	50	0	50	0	0	0	0	25	75	0	0	1	
D	19	3	2.4				MA	50	40	50	0	50	0	0	2	0	20	70	0	0	0	
D	20	3	2.4				MA	40	40	5	0	5	0	0	0	0	20	80	0	0	0	
D	21	3	2.4				MA	50	30	20	10	30	0	0	1							
D	22	3	2.4				MA	40	70	30	0	30	0	0	0							
D	23	3	2.4				MA	50	50	20	0	20	0	0	0							
D	24	3	2.4				MA	90	80	10	0	10	0	0	0							
D	25	4	2.4	350	0	350	PP	70	30	30	0	30	0	0	0	0	20	70	10	0	0	
D	26	4	2.4				MA	80	50	5	5	10	0	0	1	20	20	60	0	2	0	
D	27	4	2.4				CN	30	10	0	30	30	0	0	0	0	30	70	0	0	0	
D	28	4	2.4				MA	55	60	0	10	10	0	0	0	0	10	80	10	0	0	
D	29	4	2.4				MAF	100	30	10	0	10	0	0	2	0	50	30	20	0	0	
D	30	4	2.4				MA	70	50	10	0	10	0	0	0							
D	31	4	2.4				MIC	40	30	25	10	35	0	0	0							
D	32	4	2.4				PA	50	30	10	0	10	0	0	0							
D	33	5	3.0	260	0	260	MA	70	60	45	0	45	0	0	0	0	20					
D	34	5	3.0				MA	90	70	20	0	20	0	0	2	0	20	80	0	0	0	
D	35	5	3.0				DS	60	50	20	10	30	0	0	0	0	50	50	0	0	0	
D	36	5	3.0				MA	60	30	80	0	80	0	0	0	0	20	70	10	0	0	
D	37	5	3.0				PA	40	10	5	0	5	0	0	0	50	10	40	5	3	0	
D	38	5	3.0				MIC	120	60	30	0	30	0	0	0	10	20	60	10	10	0	
D	39	5	3.0				MA	45	30	5	0	5	0	PB	0							
D	40	6	2.7	320	0	320	PA	40	20	50	0	50	0	0	0	0	40	60	0	0	0	
D	41	6	2.7				MA	40	40	50	0	50	0	0	0	60	10	20	10	2	0	
D	42	6	2.7				PA	30	10	5	0	5	0	0	1	0	50	50	0	0	0	
D	43	6	2.7				MIC	25	20	5	0	5	0	0	0	70	10	20	0	3	0	
D	44	6	2.7				PA	50	20	5	0	5	0	0	0	0	45	45	10	0	0	
D	45	6	2.7				PA	40	20	30	0	30	0	0	0							
D	46	6	2.7				MIC	30	20	5	0	5	0	0	0							
D	47	6	2.7				MIC	50	30	0	0		0	0	0							
D	48	6	2.7				MIC	35	30	0	0		0	0	0							
D	49	6	2.7				PA	30	10	0	5	5	0	0	2							
D	50	7	3.0	320	0	320	PP	130	40	50	0	50	0	0	0	5	30	65	0	1.5	0	
D	51	7	3.0				MA	80	50	45	0	45	0	PB	0	10	20	70	0	2	0	
D	52	7	3.0				PA	50	10	5	0	5	0	0	0	20	15	55	10	3	0	
D	53	7	3.0				MA	50	90	50	5	55	0	0	1	10	20	70	0	3	0	
D	54	7	3.0				PP	50	30	20	0	20	0	0	0	0	20	80	0	0	0	

D	55	7	3.0				MA	40	50	40	5	45	0	0	0							
D	56	7	3.0				MA	100	70	20	5	25	0	0	0							
D	57	8	3.6	390	0	390	MA	30	30	30	0	30	0	0	0	0	25	75	0	0	0	
D	58	8	3.6				PA	30	10	40	0	40	0	0	0	0	20	70	10	0	0	
D	59	8	3.6				MA	45	50	10	0	10	0	0	0	20	50	30	0	1.5	0	
D	60	8	3.6				MA	30	30	15	0	15	0	0	0	10	20	50	20	3	0	
D	61	8	3.6				PP	70	30	40	0	40	0	0	0	20	60	20	0	3	0	
D	62	8	3.6				MA	30	25	5	0	5	0	0	1							
D	63	8	3.6				PP	120	30	25	2	27	0	0	0							
D	64	8	3.6				PP	40	20	10	0	10	0	0	0							
D	65	8	3.6				MA	40	50	10	0	10	0	0	2							
D	66	8	3.6				MA	30	20	30	0	30	0	0	0							
D	67	9	4.3	330	0	330	MAF	180	60	40	20	60	0	0	2	1	50	20	10	1	0	
D	68	9	4.3				PP	150	70	15	0	15	0	0	1	0	25	80	10		0	
D	69	9	4.3				MA	50	60	10	0	10	0	0	0	10	10	90	10	2	0	
D	70	9	4.3				MA	80	70	5	5	10	0	0	0	3	35	80	15	1	0	
D	71	9	4.3				MA	70	60	0	0		0	0	0	2	75	60	7	2	0	
D	72	9	4.3				MA	60	70	20	10	30	0	0	0							
D	73	10	2.4	300	0	300	MA	50	60	60	0	60	0	0	1	60	25	5	10	2	0	
D	74	10	2.4				MA	60	70	45	0	45	0	0	0	30	60	10	0	3	0	
D	75	10	2.4				MA	40	20	40	0	40	0	0	0	10	10	65	15	4	0	
D	76	10	2.4				MAF	40	10	60	0	60	0	0	3	5	75	20	0	1	0	
D	77	10	2.4				MA	40	40	5	0	5	0	0	1	25	65	10	0	2	0	
D	78	10	2.4				MA	80	70	40	10	50	0	0	0							
D	79	10	2.4				PP	50	20	0	0		0	0	1							
D	80	10	2.4				AG	30	20	10	0	10	0	0	0							
D	81	10	2.4				PP	130	50	20	0	20	0	0	2							
D	82	11	2.4	360	0	360	MAF	120	30	50	0	50	YB	0	1	0	50	40	10	0	0	
D	83	11	2.4				PP	60	30	3	0	3	0	0	0	0	20	80	0	0	0	
D	84	11	2.4				MA	120	90	25	0	25	0	0	0	0	20	60	20	0	0	
D	85	11	2.4				MAF	60	40	20	0	20	0	0	2	0	20	70	10	0	0	
D	86	11	2.4				PA	60	20	10	0	10	0	0	0	5	15	80	0	1.5	1	AG
D	87	11	2.4				MAF	30	20	5	0	5	0	0	0							
D	88	11	2.4				MA	70	60	0	0		0	0	1							
D	89	11	2.4				MAF	120	100	20	0	20	0	0	0							
D	90	11	2.4				MA	60	80	5	0	5	0	0	0							
D	91	11	2.4				MA	150	80	10	0	10	0	0	0							
D	92	12	1.2	330	0	330	MA	60	40	10	0	10	0	0	1							
D	93	12	1.2				PA	50	20	20	0	20	0	0	0							
D	94	12	1.2				PA	50	40	0	0		0	0	0							
D	95	12	1.2				MA	70	60	20	0	20	YB	0	0							
D	96	12	1.2				PP	60	30	20	0	20	0	0	0							
D	97	12	1.2				MA	60	60	5	0	5	0	0	2							
D	98	12	1.2				MA	60	40	5	0	5	0	0	0							
D	99	12	1.2				MIC	40	30	15	0	15	0	0	0							
D	100	12	1.2				PP	100	30	80	0	80	0	0	0							
D	101	13	4.6	320	20	326.5306122	MA	70	60	75	0	60	25	P	1							
D	102	13	4.6				PP	40	20	85	5	25	0		1							
D	103	13	4.6				PP	32	22	15	0	22	0	P	1							
D	104	13	4.6				MA	135	80	50	5	85	0	P	3							
D	105	13	4.6				MA	50	75	2	2	77	0		0							
D	106	13	4.6				PP	60	30	30	2	32	0		2							
D	107	13	4.6				MA	40	55	55	0	55	0	P	0							
D	108	13	4.6				PP	60	30	5	5	35	0	P	0							

D	109	13	4.6				PP	60	33	10	0	33	0	P	0							
E	1	1	14	180	120	204.5454545	PA	50	20	10	0	10	0	0	0	0	25	75	0		0	
E	2	1	14				MC	40	30	35	0	35	0	0	0	5	20	75	0	1.5	0	
E	3	1	14				SS	40	30	25	0	25	BB	0	0	0	20	70	10		3	AG,PP
E	4	1	14				MAF	100	20	40	0	40	0	0	0	0	60	40	0		0	
E	5	1	14				MAF	40	15	50	0	50	0	2	0	5	20	75	0	2	1	AG
E	6	1	14				CN	60	25	5	0	5	0	0	0							
E	7	1	14				MAF	80	20	60	0	60	0	0	0							
E	8	1	14				MAF	80	30	40	0	40	0	0	0							
E	9	2	9.8	250	80	271.7391304	MAF	70	20	95	0	95	0	1	0	5	90	5	0	2	0	
E	10	2	9.8				CN	100	40	0	0		0	0	0	10	10	70	10	1.5	1	AG
E	11	2	9.8				DS	50	40	5	0	5	0	0	0	10	35	45	10	3	0	
E	12	2	9.8				PA	50	10	70	0	70	0	1	0	60	10	30	0	3	0	
E	13	2	9.8				PA	25	10	40	0	40	0	0	0	5	10	45	40	2.5	0	
E	14	2	9.8				SS	30	30	50	0	50	0	0	0							
E	15	2	9.8				MC	160	100	90	0	90	0	0	0							
E	16	2	9.8				MFR	30	30	25	0	25	BB	0	0							
E	17	3	9.1	320	90	351.6483516	MA	30	30	0	10	10	0	0	0	5	20	75	0	1	0	
E	18	3	9.1				PA	40	20	0	0		0	0	0	60	10	10	20	3	0	
E	19	3	9.1				PA	30	10	0	15	15	0	0	0	40	10	40	10	2	0	
E	20	3	9.1				MA	30	50	5	0	5	0	0	0	10	70	20	0	3	0	
E	21	3	9.1				PA	25	10	5	0	5	0	0	0	0	5	95	0		0	
E	22	3	9.1				PP	40	30	85	0	85	0	0	0							
E	23	3	9.1				PA	30	10	10	0	10	0	0	0							
E	24	3	9.1				PP	50	20	35	0	35	0	0	0							
E	25	3	9.1				MFR	30	50	15	0	15	0	0	0							
E	26	3	9.1				PP	30	20	0	0		0	0	0							
E	27	3	9.1				PA	35	10	10	0	10	0	0	0							
E	28	3	9.1				SS	30	20	55	0	55	0	0	0							
E	29	3	9.1				MAF	150	100	60	15	75	BB	0	0							
E	30	4	13.7	280	180	341.4634146	MC	40	10	15	0	15	0	0	2	30	10	55	5	4	0	
E	31	4	13.7				MA	50	30	80	0	80	0	PB	3	2	15	83	0	1	0	
E	32	4	13.7				MFR	50	20	0	0		0	PB	0	30	10	60	0	1.5	0	
E	33	4	13.7				MFR	40	30	10	0	10	0	0	0	10	5	65	20	2	0	
E	34	4	13.7				SS	140	80	65	0	65	0	0	0	20	20	50	10	3	0	
E	35	4	13.7				AG	50	10	70	0	70	0	0	0							
E	36	4	13.7				MC	50	40	60	0	60	0	0	0							
E	37	4	13.7				AG	110	90	40	0	40	0	PB	1							
E	38	4	13.7				MC	40	70	80	0	80	0	0	0							
E	39	5	10.7	280	200	350	PP	80	40	35	0	35	0	0	0	25	0	70	5	2	2	AG
E	40	5	10.7				PA	50	30	25	0	25	0	0	0	50	0	50	0	3	0	
E	41	5	10.7				PP	40	25	2	0	2	0	0	0	25	20	30	30	3	0	
E	42	5	10.7				DL	50	55	30	5	35	0	0	0	0	0	0	0	0	0	
E	43	5	10.7				PA	40	25	0	0		0	0	0	0	0	0	0	0	0	
E	44	5	10.7				MAF	60	30	45	0	45	0	0	0							
E	45	5	10.7				PA	60	25	65	0	65	0	0	0							
E	46	6	12.2	190	130	218.3908046	PP	50	40	45	0	45	0	0	0	0	80	20	0		0	
E	47	6	12.2				SS	60	60	85	0	85	0	0	0	10	5	85	0	2	0	
E	48	6	12.2				PA	40	40	40	0	40	0	0	0	5	35	60	0	1	0	
E	49	6	12.2				SS	30	20	2	0	2	0	0	0	10	30	50	10	2	0	
E	50	6	12.2				MD	40	30	15	0	15	0	P	0	0	60	40	0		0	
E	51	6	12.2				CN	60	20	0	60	60	0	0	0							
E	52	6	12.2				MAF	150	60	25	20	45	0	0	2							
E	53	6	12.2				MAF	110	40	25	5	30	0	0	2							

E	54	7	12.2	360	180	439.0243902	MAF	80	75	20	0	20	0	PB	0	80	0	20	20	2.5	0	
E	55	7	12.2				MD	30	35	65	0	65	0	0	2	5	30	65	0	1	0	
E	56	7	12.2				PP	30	15	25	0	25	0	0	2	60	10	30	30	1	0	
E	57	7	12.2				MAF	30	60	10	0	10	0	0	1	8	60	30	0	2.5	0	
E	58	7	12.2				PA	40	25	15	0	15	0	0	0	0	90	5	5		0	
E	59	7	12.2				PA	30	20	2	0	2	0	0	0							
E	60	7	12.2				PA	60	50	80	0	80	0	0	1							
E	61	7	12.2				PA	40	10	10	0	10	0	0	2							
E	62	7	12.2				PA	55	20	5	5	10	0	0	0							
E	63	7	12.2				MA	25	20	50	0	50	0	0	0							
E	64	7	12.2				PP	30	20	30	0	30	0	0	0							
E	65	7	12.2				PA	30	10	0	8	8	0	0	2							
E	66	7	12.2				PA	30	20	0	20	20	0	0	0							
E	67	7	12.2				PA	30	20	15	25	40	0	0	2							
E	68	7	12.2				SS	80	30	20	0	20	0	0	2							
E	69	8	11.6	190	120	215.9090909	CN	125	60	65	0	65	0	0	1	10	20	70	0	3	0	
E	70	8	11.6				PP	35	25	8	0	8	0	0	0	3	20	60	15	1	0	
E	71	8	11.6				PP	25	15	75	0	75	0	0	0	5	10	85	0	3	0	
E	72	8	11.6				PP	32	25	18	0	18	0	0	0	30	10	60	0	3	0	
E	73	8	11.6				MAF	30	12	1	0	1	0	0	0	90	0	0	10	5	0	
E	74	8	11.6				PA	25	20	10	0	10	0	0	0							
E	75	8	11.6				PP	30	22	10	0	10	0	0	0							
E	76	8	11.6				PP	45	30	15	0	15	0	0	0							
E	77	9	11.9	300	180	365.8536585	MFR	30	40	30	0	30	0	0	0	2	0	98	0	1.5	0	
E	78	9	11.9				PA	25	10	0	0		0	0	0	30	10	65	25	2	1	PA
E	79	9	11.9				PA	30	10	60	0	60	0	0	0	5	15	80	0	2	1	PA
E	80	9	11.9				MC	45	40	10	0	10	0	0	2	3	40	57	0	2	0	
E	81	9	11.9				MFR	40	20	10	0	10	BB	0	0	5	95	0	0	1.2	0	
E	82	9	11.9				SS	40	40	0	2	2	0	P	0							
E	83	9	11.9				PA	25	20	5	0	5	0	0	0							
E	84	9	11.9				SS	35	30	25	5	30	BB	0	0							
E	85	9	11.9				MFR	30	25	2	0	2	0	0	0							
E	86	9	11.9				MAF	70	20	20	0	20	0	0	0							
E	87	10	9.1	180	180	214.2857143	PP	125	45	15	0	15	0	0	1	60	20	10	10	1.2	0	
E	88	10	9.1				PA	40	30	35	0	35	YB	P	0	25	20	55	0	1.3	0	
E	89	10	9.1				MAF	32	25	0	0		0	0	0	100	0	0	0	7	0	
E	90	10	9.1				MA	90	145	70	0	70	0	P	0	0	5	95	0		0	
E	91	10	9.1				MA	25	30	15	2	17	0	P	0	10	20	50	20	1.2	0	
E	92	10	9.1				MA	45	40	5	5	10	0	P	0							
E	93	10	9.1				PP	28	20	33	0	33	0	0	0							
E	94	10	9.1				PP	32	22	5	0	5	0	0	0							
E	95	10	9.1				PP	30	20	45	0	45	0	0	0							
E	96	11	8.2	150	180	178.5714286	MA	25	22	8	0	8	0	P	0	50	15	15	20	1.2	0	
E	97	11	8.2				PA	28	15	5	0	5	0	0	0	10	20	50	20	1.2	0	
E	98	11	8.2				PP	25	18	5	0	5	0	0	0	90	0	10	0	4	0	
E	99	11	8.2				MA	55	65	65	2	67	0	0	0	0	0	0	0	0	0	
E	100	11	8.2				PP	75	50	15	0	15	0	0	0	10	40	30	20	3	0	
E	101	11	8.2				PP	25	22	10	0	10	0	0	0							

Site	Common Name	Scientific Name	0-5 (2.5) n	6-10 (8cm) n	11-20 (15.5cm) n	21-30 (25.5cm) n	31-40 (35.5cm) n	>40 (50cm) n	SUM of size	N	AVERAGE	perturbations	variance	SEM
	Angelfish								31	2	15.5	0	0	0
	French	*Pomacanthus paru*	0	0	0	0	0	0	0			0		
	Gray	*Pomacanthus arcuatus*	0	0	0	0	0	0	0			0		
	Rock Beauty	*Holocanthus tricolor*	0	0	0	0	0	0	0			0		
	Queen	*Holocanthus ciliarus*	0	0	2	0	0	0	31			0		
	Butterflyfish								70.5	6	11.75	84.375	16.875	1.67705
	Foureye	*Chaetodon capistratus*	0	3	1	0	0	0	39.5			56.25		
	Banded	*Chaetodon striatus*	0	0	2	0	0	0	31			28.125		
	Spotfin	*Chaetodon ocellatus*	0	0	0	0	0	0	0			0		
	Reef	*Chaetodon sedentarius*	0	0	0	0	0	0	0			0		
	LongSnout	*Chaetodon aculeatus*	0	0	0	0	0	0	0			0		
	Grunt								25.5	1	25.5	0	0	0
	Porkfish	*Anisotremus virginicus*	0	0	0	0	0	0	0			0		
	White	*Haemulon plumieri*	0	0	0	0	0	0	0			0		
	Bluestriped	*Haemulon sciurus*	0	0	0	0	0	0	0			0		
	French	*Haemulon flavolineatum*	0	0	0	0	0	0	0			0		
	Tomtate	*Haemulon aurolineatum*	0	0	0	0	0	0	0			0		
	Smallmouth	*Haemulon chrysargyreum*	0	0	0	1	0	0	25.5			0		
	Caesar	*Haemulon carbonarium*	0	0	0	0	0	0	0			0		
	Spanish	*Haemulon macrostomum*	0	0	0	0	0	0	0			0		
	Sailors Choice	*Haemulon parra*	0	0	0	0	0	0	0			0		
	Parrotfish								1682	104	16.17	7302.9	70.9018	0.82568
	Stoplight	*Sparisoma viride*	0	13	8	7	4	0	548.5			2975.1		
	Redfin	*Sparisoma rubripinne*	0	0	0	0	0	0	0			0.0		
	Redband	*Sparisoma aurofrenatum*	0	9	10	11	2	0	578.5			2309.7		
	Princess	*Scarus taeniopterus*	0	9	6	3	0	0	241.5			864.9		
	Striped	*Scarus croicensis*	0	5	7	1	1	0	209.5			797.7		
	Queen	*Scarus vetula*	0	4	3	0	0	0	78.5			268.6		
	Redtail	*Sparisoma chrysopterum*	0	0	0	1	0	0	25.5			87.0		
	Midnight	*Scarus coelestinus*	0	0	0	0	0	0	0			0.0		
	Rainbow	*Scarus guacamaia*	0	0	0	0	0	0	0			0.0		
	Greenblotch	*Sparisoma atomarium*	0	0	0	0	0	0	0			0.0		
	Blue	*Scarus coeruleus*	0	0	0	0	0	0	0			0.0		
	Seabass								25.5	1	25.5	0	0	0
	Tiger	*Mycteroperca tigris*	0	0	0	0	0	0	0			0		
	Red Hind	*Epinephelus guttatus*	0	0	0	1	0	0	25.5			0		
	Graysby	*Epinephelus cruentatus*	0	0	0	0	0	0	0			0		
	Nassau	*Epinephelus striatus*	0	0	0	0	0	0	0			0		
	Black	*Mycteroperca bonaci*	0	0	0	0	0	0	0			0		
	Rock Hind	*Epinephelus adscensionis*	0	0	0	0	0	0	0			0		
	Coney	*Epinephelus fulvus*	0	0	0	0	0	0	0			0		
	Yellowfin	*Mycteroperca venenosa*	0	0	0	0	0	0	0			0		
	Yellowmouth	*Mycteroperca interstitialis*	0	0	0	0	0	0	0			0		
A	**Snapper**								0	0	0	0	0	#DIV/0!
	Schoolmaster	*Lutjanus apodus*	0	0	0	0	0	0	0			0		
	Gray	*Lutjanus griseus*	0	0	0	0	0	0	0			0		
	Mutton	*Lutjanus analis*	0	0	0	0	0	0	0			0		
	Mahogany	*Lutjanus mahogani*	0	0	0	0	0	0	0			0		
	Yellowtail	*Ocyurus chrysurus*	0	0	0	0	0	0	0			0		
	Lane	*Lutjanus synagris*	0	0	0	0	0	0	0			0		
	Cubera	*Lutjanus cyanopterus*	0	0	0	0	0	0	0			0		
	Surgeonfish								258	16	16.13	818.75	54.5833	1.84701
	Ocean Surgeonfish	*Acanthurus bahianus*	0	0	4	2	1	0	148.5			552.734375		
	Doctorfish	*Acanthurus chirurgus*	0	3	3	0	0	0	70.5			199.21875		
	Blue Tang	*Acanthurus coeruleus*	0	1	2	0	0	0	39			66.796875		
	Leatherjacket								0	0	0	0	0	#DIV/0!
	Queen Triggerfish	*Balistes vetula*	0	0	0	0	0	0	0			0		
	Black Durgon	*Melichthys niger*	0	0	0	0	0	0	0			0		
	Orangespotted Filefish	*Cantherhines pullus*	0	0	0	0	0	0	0			0		
	Other								119	12	9.917	414.4166667	37.6742	1.77187
	Yellowtail Damselfish	*Microspathodon chrysurus*	4	2	6	0	0	0	119			414.4166667		
	Spanish Hogfish	*Bodianthus rufus*	0	0	0	0	0	0	0			0		
	Great Barracuda	*Sphyraena barracuda*	0	0	0	0	0	0	0			0		
	Bar Jack	*Caranx ruber*	0	0	0	0	0	0	0			0		
	Blue Runner	*Caranx chrysos*	0	0	0	0	0	0	0			0		
	Hogfish	*Lachnolaimus maximus*	0	0	0	0	0	0	0			0		
	Angelfish								0	0	0	0	0	#DIV/0!
	French	*Pomacanthus paru*	0	0	0	0	0	0	0			0		
	Gray	*Pomacanthus arcuatus*	0	0	0	0	0	0	0			0		
	Rock Beauty	*Holocanthus tricolor*	0	0	0	0	0	0	0			0		
	Queen	*Holocanthus ciliarus*	0	0	0	0	0	0	0			0		
	Butterflyfish								46.5	3	15.50	0	0	0
	Foureye	*Chaetodon capistratus*	0	0	1	0	0	0	15.5			0		
	Banded	*Chaetodon striatus*	0	0	2	0	0	0	31			0		
	Spotfin	*Chaetodon ocellatus*	0	0	0	0	0	0	0			0		
	Reef	*Chaetodon sedentarius*	0	0	0	0	0	0	0			0		
	LongSnout	*Chaetodon aculeatus*	0	0	0	0	0	0	0			0		
	Grunt								15.5	1	15.50	0	#DIV/0!	#DIV/0!
	Porkfish	*Anisotremus virginicus*	0	0	0	0	0	0	0			0		
	White	*Haemulon plumieri*	0	0	0	0	0	0	0			0		
	Bluestriped	*Haemulon sciurus*	0	0	1	0	0	0	15.5			0		
	French	*Haemulon flavolineatum*	0	0	0	0	0	0	0			0		
	Tomtate	*Haemulon aurolineatum*	0	0	0	0	0	0	0			0		
	Smallmouth	*Haemulon chrysargyreum*	0	0	0	0	0	0	0			0		
	Caesar	*Haemulon carbonarium*	0	0	0	0	0	0	0			0		
	Spanish	*Haemulon macrostomum*	0	0	0	0	0	0	0			0		
	Sailors Choice	*Haemulon parra*	0	0	0	0	0	0	0			0		
	Parrotfish								1966	147	13.37	5404.4	37.0186	0.50181
	Stoplight	*Sparisoma viride*	0	31	32	5	1	0	907			2264.7		

	Redfin	*Sparisoma rubripinne*	0	0	0	0	0	0	0			0.0		
	Redband	*Sparisoma aurofrenatum*	0	1	18	7	0	0	465.5			1139.5		
	Princess	*Scarus taeniopterus*	0	5	2	0	1	0	106.5			643.0		
	Striped	*Scarus croicensis*	0	22	7	3	0	0	361			1108.1		
	Queen	*Scarus vetula*	0	7	4	0	0	0	118			220.2		
	Redtail	*Sparisoma chrysopterum*	0	0	0	0	0	0	0			0.0		
	Midnight	*Scarus coelestinus*	0	0	0	0	0	0	0			0.0		
	Rainbow	*Scarus guacamaia*	0	0	0	0	0	0	0			0.0		
	Greenblotch	*Sparisoma atomarium*	0	1	0	0	0	0	8			28.9		
	Blue	*Scarus coeruleus*	0	0	0	0	0	0	0			0.0		
B	**Seabass**								0	0	0	0	0	#DIV/0!
	Tiger	*Mycteroperca tigris*	0	0	0	0	0	0	0			0		
	Red Hind	*Epinephelus guttatus*	0	0	0	0	0	0	0			0		
	Graysby	*Epinephelus cruentatus*	0	0	0	0	0	0	0			0		
	Nassau	*Epinephelus striatus*	0	0	0	0	0	0	0			0		
	Black	*Mycteroperca bonaci*	0	0	0	0	0	0	0			0		
	Rock Hind	*Epinephelus adscensionis*	0	0	0	0	0	0	0			0		
	Coney	*Epinephelus fulvus*	0	0	0	0	0	0	0			0		
	Yellowfin	*Mycteroperca venenosa*	0	0	0	0	0	0	0			0		
	Yellowmouth	*Mycteroperca interstitialis*	0	0	0	0	0	0	0			0		
	Snapper								0	0	0	0	0	#DIV/0!
	Schoolmaster	*Lutjanus apodus*	0	0	0	0	0	0	0			0		
	Gray	*Lutjanus griseus*	0	0	0	0	0	0	0			0		
	Mutton	*Lutjanus analis*	0	0	0	0	0	0	0			0		
	Mahogany	*Lutjanus mahogani*	0	0	0	0	0	0	0			0		
	Yellowtail	*Ocyurus chrysurus*	0	0	0	0	0	0	0			0		
	Lane	*Lutjanus synagris*	0	0	0	0	0	0	0			0		
	Cubera	*Lutjanus cyanopterus*	0	0	0	0	0	0	0			0		
	Surgeonfish								1231.5	85	14.49	700.9882353	8.3451	0.31333
	Ocean Surgeonfish	*Acanthurus bahianus*	0	4	15	0	0	0	264.5			183.7438062		
	Doctorfish	*Acanthurus chirurgus*	0	0	1	0	0	0	15.5			1.02366782		
	Blue Tang	*Acanthurus coeruleus*	2	4	59	0	0	0	951.5			516.2207612		
	Leatherjacket								15.5	1	15.50	0	#DIV/0!	#DIV/0!
	Queen Triggerfish	*Balistes vetula*	0	0	0	0	0	0	0			0		
	Black Durgon	*Melichthys niger*	0	0	0	0	0	0	0			0		
	Orangespotted Filefish	*Cantherines pullus*	0	0	1	0	0	0	15.5			0		
	Other								994	63	15.78	563.8888889	9.09496	0.37995
	Yellowtail Damselfish	*Microspathodon chrysurus*	0	3	45	4	0	0	823.5			563.0401235		
	Spanish Hogfish	*Bodianus rufus*	0	0	11	0	0	0	170.5			0.848765432		
	Great Barracuda	*Sphyraena barracuda*	0	0	0	0	0	0	0			0		
	Bar Jack	*Caranx ruber*	0	0	0	0	0	0	0			0		
	Blue Runner	*Caranx chrysos*	0	0	0	0	0	0	0			0		
	Hogfish	*Lachnolaimus maximus*	0	0	0	0	0	0	0			0		
	Angelfish								0	0	0	0	0	#DIV/0!
	French	*Pomacanthus paru*	0	0	0	0	0	0	0			0		
	Gray	*Pomacanthus arcuatus*	0	0	0	0	0	0	0			0		
	Rock Beauty	*Holocanthus tricolor*	0	0	0	0	0	0	0			0		
	Queen	*Holocanthus ciliarus*	0	0	0	0	0	0	0			0		
	Butterflyfish								0	0	0	0	0	#DIV/0!
	Foureye	*Chaetodon capistratus*	0	0	0	0	0	0	0			0		
	Banded	*Chaetodon striatus*	0	0	0	0	0	0	0			0		
	Spotfin	*Chaetodon ocellatus*	0	0	0	0	0	0	0			0		
	Reef	*Chaetodon sedentarius*	0	0	0	0	0	0	0			0		
	LongSnout	*Chaetodon aculeatus*	0	0	0	0	0	0	0			0		
	Grunt								0	0	0	0	0	#DIV/0!
	Porkfish	*Anisotremus virginicus*	0	0	0	0	0	0	0			0		
	White	*Haemulon plumieri*	0	0	0	0	0	0	0			0		
	Bluestriped	*Haemulon sciurus*	0	0	0	0	0	0	0			0		
	French	*Haemulon flavolineatum*	0	0	0	0	0	0	0			0		
	Tomtate	*Haemulon aurolineatum*	0	0	0	0	0	0	0			0		
	Smallmouth	*Haemulon chrysargyreum*	0	0	0	0	0	0	0			0		
	Caesar	*Haemulon carbonarium*	0	0	0	0	0	0	0			0		
	Spanish	*Haemulon macrostomum*	0	0	0	0	0	0	0			0		
	Sailors Choice	*Haemulon parra*	0	0	0	0	0	0	0			0		
	Parrotfish								5668	356	15.64	19118.0	53.8535	0.38894
	Stoplight	*Sparisoma viride*	0	15	24	22	11	0	1443.5			7353.2		
	Redfin	*Sparisoma rubripinne*	0	0	0	0	0	0	0			0.0		
	Redband	*Sparisoma aurofrenatum*	0	3	30	19	0	0	973.5			2022.7		
	Princess	*Scarus taeniopterus*	0	16	14	13	5	0	854			4170.0		
	Striped	*Scarus croicensis*	0	13	20	0	0	0	414			759.3		
	Queen	*Scarus vetula*	0	33	64	4	1	0	1393.5			2710.9		
	Redtail	*Sparisoma chrysopterum*	0	9	0	0	0	0	72			525.4		
	Midnight	*Scarus coelestinus*	0	0	0	0	0	0	0			0.0		
	Rainbow	*Scarus guacamaia*	0	0	0	0	0	0	0			0.0		
	Greenblotch	*Sparisoma atomarium*	0	27	13	0	0	0	417.5			1576.4		
	Blue	*Scarus coeruleus*	0	0	0	0	0	0	0			0.0		
C	**Seabass**								50	1	50.00	0	0	0
	Tiger	*Mycteroperca tigris*	0	0	0	0	0	0	0			0		
	Red Hind	*Epinephelus guttatus*	0	0	0	0	0	0	0			0		
	Graysby	*Epinephelus cruentatus*	0	0	0	0	0	1	50			0		
	Nassau	*Epinephelus striatus*	0	0	0	0	0	0	0			0		
	Black	*Mycteroperca bonaci*	0	0	0	0	0	0	0			0		
	Rock Hind	*Epinephelus adscensionis*	0	0	0	0	0	0	0			0		
	Coney	*Epinephelus fulvus*	0	0	0	0	0	0	0			0		
	Yellowfin	*Mycteroperca venenosa*	0	0	0	0	0	0	0			0		
	Yellowmouth	*Mycteroperca interstitialis*	0	0	0	0	0	0	0			0		
	Snapper								0	0	0	0	0	#DIV/0!
	Schoolmaster	*Lutjanus apodus*	0	0	0	0	0	0	0			0		
	Gray	*Lutjanus griseus*	0	0	0	0	0	0	0			0		
	Mutton	*Lutjanus analis*	0	0	0	0	0	0	0			0		
	Mahogany	*Lutjanus mahogani*	0	0	0	0	0	0	0			0		
	Yellowtail	*Ocyurus chrysurus*	0	0	0	0	0	0	0			0		

Lane	*Lutjanus synagris*	0	0	0	0	0	0	0			0		
Cubera	*Lutjanus cyanopterus*	0	0	0	0	0	0	0			0		
Surgeonfish								147.5	10	14.75	50.625	5.625	0.75
Ocean Surgeonfish	*Acanthurus bahianus*	0	1	6	0	0	0	101			48.9375		
Doctorfish	*Acanthurus chirurgus*	0	0	0	0	0	0	0			0		
Blue Tang	*Acanthurus coeruleus*	0	0	3	0	0	0	46.5			1.6875		
Leatherjacket								0	0	#DIV/0!	0	0	#DIV/0!
Queen Triggerfish	*Balistes vetula*	0	0	0	0	0	0	0			0		
Black Durgon	*Melichthys niger*	0	0	0	0	0	0	0			0		
Orangespotted Filefish	*Cantherines pullus*	0	0	0	0	0	0	0			0		
Other								312	19	16.42	552.6315789	30.7018	1.27117
Yellowtail Damselfish	*Microspathodon chrysurus*	0	3	12	4	0	0	312			552.6315789		
Spanish Hogfish	*Bodianthus rufus*	0	0	0	0	0	0	0			0		
Great Barracuda	*Sphyraena barracuda*	0	0	0	0	0	0	0			0		
Bar Jack	*Caranx ruber*	0	0	0	0	0	0	0			0		
Blue Runner	*Caranx chrysos*	0	0	0	0	0	0	0			0		
Hogfish	*Lachnolaimus maximus*	0	0	0	0	0	0	0			0		
Angelfish								0	0	0	0	0	#DIV/0!
French	*Pomacanthus paru*	0	0	0	0	0	0	0			0		
Gray	*Pomacanthus arcuatus*	0	0	0	0	0	0	0			0		
Rock Beauty	*Holocanthus tricolor*	0	0	0	0	0	0	0			0		
Queen	*Holocanthus ciliarus*	0	0	0	0	0	0	0			0		
Butterflyfish								46.5	3	15.5	0	0	0
Foureye	*Chaetodon capistratus*	0	0	0	0	0	0	0			0		
Banded	*Chaetodon striatus*	0	0	3	0	0	0	46.5			0		
Spotfin	*Chaetodon ocellatus*	0	0	0	0	0	0	0			0		
Reef	*Chaetodon sedentarius*	0	0	0	0	0	0	0			0		
LongSnout	*Chaetodon aculeatus*	0	0	0	0	0	0	0			0		
Grunt								87.5	5	17.5	80	20	2
Porkfish	*Anisotremus virginicus*	0	0	0	0	0	0	0			0		
White	*Haemulon plumieri*	0	0	0	0	0	0	0			0		
Bluestriped	*Haemulon sciurus*	0	0	0	0	0	0	0			0		
French	*Haemulon flavolineatum*	0	0	0	1	0	0	25.5			64		
Tomtate	*Haemulon aurolineatum*	0	0	0	0	0	0	0			0		
Smallmouth	*Haemulon chrysargyreum*	0	0	4	0	0	0	62			16		
Caesar	*Haemulon carbonarium*	0	0	0	0	0	0	0			0		
Spanish	*Haemulon macrostomum*	0	0	0	0	0	0	0			0		
Sailors Choice	*Haemulon parra*	0	0	0	0	0	0	0			0		
Parrotfish								3490	180	18.37	11989.2	63.4879	0.57805
Stoplight	*Sparisoma viride*	0	26	26	25	7	0	1497			6335.0		
Redfin	*Sparisoma rubripinne*	0	0	0	0	0	0	0			0.0		
Redband	*Sparisoma aurofrenatum*	0	2	17	18	3	0	845			2150.8		
Princess	*Scarus taeniopterus*	0	0	12	2	1	0	272.5			493.9		
Striped	*Scarus croicensis*	0	9	5	4	0	0	251.5			1212.1		
Queen	*Scarus vetula*	0	3	14	11	2	0	592.5			1584.1		
Redtail	*Sparisoma chrysopterum*	0	0	0	0	0	0	0			0.0		
Midnight	*Scarus coelestinus*	0	0	0	0	0	0	0			0.0		
Rainbow	*Scarus guacamaia*	0	0	0	0	0	0	0			0.0		
Greenblotch	*Sparisoma atomarium*	0	2	1	0	0	0	31.5			223.2		
Blue	*Scarus coeruleus*	0	0	0	0	0	0	0			0.0		
D ***Seabass***								25.5	1	25.5	0	#DIV/0!	#DIV/0!
Tiger	*Mycteroperca tigris*	0	0	0	0	0	0	0			0		
Red Hind	*Epinephelus guttatus*	0	0	0	0	0	0	0			0		
Graysby	*Epinephelus cruentatus*	0	0	0	1	0	0	25.5			0		
Nassau	*Epinephelus striatus*	0	0	0	0	0	0	0			0		
Black	*Mycteroperca bonaci*	0	0	0	0	0	0	0			0		
Rock Hind	*Epinephelus adscensionis*	0	0	0	0	0	0	0			0		
Coney	*Epinephelus fulvus*	0	0	0	0	0	0	0			0		
Yellowfin	*Mycteroperca venenosa*	0	0	0	0	0	0	0			0		
Yellowmouth	*Mycteroperca interstitialis*	0	0	0	0	0	0	0			0		
Snapper								15.5	1	15.5	0	#DIV/0!	#DIV/0!
Schoolmaster	*Lutjanus apodus*	0	0	0	0	0	0	0			0		
Gray	*Lutjanus griseus*	0	0	0	0	0	0	0			0		
Mutton	*Lutjanus analis*	0	0	0	0	0	0	0			0		
Mahogany	*Lutjanus mahogani*	0	0	0	0	0	0	0			0		
Yellowtail	*Ocyurus chryaurus*	0	0	1	0	0	0	15.5			0		
Lane	*Lutjanus synagris*	0	0	0	0	0	0	0			0		
Cubera	*Lutjanus cyanopterus*	0	0	0	0	0	0	0			0		
Surgeonfish								831.5	53	15.69	623.1132075	11.9829	0.47549
Ocean Surgeonfish	*Acanthurus bahianus*	0	1	20	0	0	0	318			59.82778569		
Doctorfish	*Acanthurus chirurgus*	0	0	0	0	0	0	0			0		
Blue Tang	*Acanthurus coeruleus*	0	3	25	4	0	0	513.5			563.2854219		
Leatherjacket								46.5	3	15.5	0	0	0
Queen Triggerfish	*Balistes vetula*	0	0	0	0	0	0	0			0		
Black Durgon	*Melichthys niger*	0	0	1	0	0	0	15.5			0		
Orangespotted Filefish	*Cantherines pullus*	0	0	2	0	0	0	31			0		
Other								774.5	51	15.19	432.9803922	8.65661	0.41206
Yellowtail Damselfish	*Microspathodon chrysurus*	2	0	48	0	0	0	749			326.6074587		
Spanish Hogfish	*Bodianthus rufus*	0	0	0	1	0	0	25.5			106.3729335		
Great Barracuda	*Sphyraena barracuda*	0	0	0	0	0	0	0			0		
Bar Jack	*Caranx ruber*	0	0	0	0	0	0	0			0		
Blue Runner	*Caranx chrysos*	0	0	0	0	0	0	0			0		
Hogfish	*Lachnolaimus maximus*	0	0	0	0	0	0	0			0		
Angelfish								0	0	0	0	0	#DIV/0!
French	*Pomacanthus paru*	0	0	0	0	0	0	0			0		
Gray	*Pomacanthus arcuatus*	0	0	0	0	0	0	0			0		
Rock Beauty	*Holocanthus tricolor*	0	0	0	0	0	0	0			0		
Queen	*Holocanthus ciliarus*	0	0	0	0	0	0	0			0		
Butterflyfish								85.5	6	14.25	46.875	9.375	1.25
Foureye	*Chaetodon capistratus*	0	1	2	0	0	0	39			42.1875		
Banded	*Chaetodon striatus*	0	0	2	0	0	0	31			3.125		

	Spotfin	*Chaetodon ocellatus*	0	0	1	0	0	0	15.5			1.5625		
	Reef	*Chaetodon sedentarius*	0	0	0	0	0	0	0			0		
	LongSnout	*Chaetodon aculeatus*	0	0	0	0	0	0	0			0		
	Grunt								15.5	1	15.5	0	#DIV/0!	#DIV/0!
	Porkfish	*Anisotremus virginicus*	0	0	0	0	0	0	0			0		
	White	*Haemulon plumieri*	0	0	0	0	0	0	0			0		
	Bluestriped	*Haemulon sciurus*	0	0	0	0	0	0	0			0		
	French	*Haemulon flavolineatum*	0	0	1	0	0	0	15.5			0		
	Tomtate	*Haemulon aurolineatum*	0	0	0	0	0	0	0			0		
	Smallmouth	*Haemulon chrysargyreum*	0	0	0	0	0	0	0			0		
	Caesar	*Haemulon carbonarium*	0	0	0	0	0	0	0			0		
	Spanish	*Haemulon macrostomum*	0	0	0	0	0	0	0			0		
	Sailors Choice	*Haemulon parra*	0	0	0	0	0	0	0			0		
	Parrotfish								2998	186	16.11828	7591.4	41.0346	0.4697
	Stoplight	*Sparisoma viride*	0	27	31	7	1	0	910.5			2783.1		
	Redfin	*Sparisoma rubripinne*	0	0	0	0	0	0	0			0.0		
	Redband	*Sparisoma aurofrenatum*	0	1	19	7	0	0	481			689.3		
	Princess	*Scarus taeniopterus*	0	1	28	17	4	0	1017.5			3075.5		
	Striped	*Scarus croicensis*	0	0	15	2	0	0	283.5			181.8		
	Queen	*Scarus vetula*	0	1	5	0	0	0	85.5			67.8		
	Redtail	*Sparisoma chrysopterum*	0	0	0	0	0	0	0			0.0		
	Midnight	*Scarus coelestinus*	0	0	0	0	0	0	0			0.0		
	Rainbow	*Scarus guacamaia*	0	0	0	0	0	0	0			0.0		
	Greenblotch	*Sparisoma atomarium*	0	12	8	0	0	0	220			793.9		
	Blue	*Scarus coeruleus*	0	0	0	0	0	0	0			0.0		
E	**Seabass**								127.5	5	25.5	0	0	0
	Tiger	*Mycteroperca tigris*	0	0	0	0	0	0	0			0		
	Red Hind	*Epinephelus guttatus*	0	0	0	1	0	0	25.5			0		
	Graysby	*Epinephelus cruentatus*	0	0	0	4	0	0	102			0		
	Nassau	*Epinephelus striatus*	0	0	0	0	0	0	0			0		
	Black	*Mycteroperca bonaci*	0	0	0	0	0	0	0			0		
	Rock Hind	*Epinephelus adscensionis*	0	0	0	0	0	0	0			0		
	Coney	*Epinephelus fulvus*	0	0	0	0	0	0	0			0		
	Yellowfin	*Mycteroperca venenosa*	0	0	0	0	0	0	0			0		
	Yellowmouth	*Mycteroperca interstitialis*	0	0	0	0	0	0	0			0		
	Snapper								15.5	1	15.5	0	#DIV/0!	#DIV/0!
	Schoolmaster	*Lutjanus apodus*	0	0	0	0	0	0	0			0		
	Gray	*Lutjanus griseus*	0	0	0	0	0	0	0			0		
	Mutton	*Lutjanus analis*	0	0	0	0	0	0	0			0		
	Mahogany	*Lutjanus mahogoni*	0	0	0	0	0	0	0			0		
	Yellowtail	*Ocyurus chrysurus*	0	0	1	0	0	0	15.5			0		
	Lane	*Lutjanus synagris*	0	0	0	0	0	0	0			0		
	Cubera	*Lutjanus cyanopterus*	0	0	0	0	0	0	0			0		
	Surgeonfish								242.5	15	16.166667	93.33333333	6.66667	0.66667
	Ocean Surgeonfish	*Acanthurus bahianus*	0	0	10	0	0	0	155			4.4		
	Doctorfish	*Acanthurus chirurgus*	0	0	1	0	0	0	15.5			0.4		
	Blue Tang	*Acanthurus coeruleus*	0	0	3	1	0	0	72			88.4		
	Leatherjacket								51	2	25.5	0	0	0
	Queen Triggerfish	*Balistes vetula*	0	0	0	0	0	0	0			0		
	Black Durgon	*Melichthys niger*	0	0	0	0	0	0	0			0		
	Orangespotted Filefish	*Cantherines pullus*	0	0	0	2	0	0	51			0		
	Other								256	17	15.058824	52.94117647	3.30882	0.44118
	Yellowtail Damselfish	*Microspathodon chrysurus*	0	1	16	0	0	0	256			52.94117647		
	Spanish Hogfish	*Bodianthus rufus*	0	0	0	0	0	0	0			0		
	Great Barracuda	*Sphyraena barracuda*	0	0	0	0	0	0	0			0		
	Bar Jack	*Caranx ruber*	0	0	0	0	0	0	0			0		
	Blue Runner	*Caranx chrysos*	0	0	0	0	0	0	0			0		
	Hogfish	*Lachnolaimus maximus*	0	0	0	0	0	0	0			0		

	SITE A		SITE B		SITE C		SITE D		SITE E		Total								
Fish Species	1st survey	2nd survey	1st survey	2nd survey	1st survey	2nd survey	1st survey	2nd survey	1st survey	2nd survey	# of 0 counts	# survey sp. Obs.	sightings	sighting frequency (%SF)	s	f	m	a	Density
Queen Angelfish	s	0	0	0	0	0	0	0	s	s	7	3	0.3	30	3	0	0	0	1.0
Rock Beauty	0	0	0	0	0	0	0	0	f	0	9	1	0.1	10	0	1	0	0	2.0
Banded Butterflyfish	f	0	f	m	f	f	f	0	f	0	3	7	0.7	70	0	6	1	0	2.1
Foureye Butterflyfish	f	f	s	0	f	0	f	0	f	f	3	7	0.7	70	1	6	0	0	1.9
Spotfin Butterflyfish	0	0	0	0	f	0	0	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Smooth Trunkfish	0	0	0	s	0	f	0	0	0	s	7	3	0.3	30	2	1	0	0	1.3
Spotted Drum	0	0	0	0	0	s	s	s	0	s	6	4	0.4	40	4	0	0	0	1.0
Sharptail Eel	0	0	0	0	0	0	0	0	0	s	9	1	0.1	10	1	0	0	0	1.0
Yellow Goatfish	f	s	m	m	m	m	m	m	f	m	0	10	1	100	1	2	7	0	2.6
Bluestriped Grunt	0	0	0	f	0	0	f	0	0	0	8	2	0.2	20	0	2	0	0	2.0
French Grunt	f	s	0	0	f	f	f	f	f	0	3	7	0.7	70	1	6	0	0	1.9
Smallmouth Grunt	s	s	0	f	f	f	f	0	m	0	3	7	0.7	70	2	4	1	0	1.9
Spanish Hogfish	0	0	s	0	0	0	0	s	0	0	8	2	0.2	20	2	0	0	0	1.0
Sharpnose Puffer	s	0	s	s	s	s	f	s	f	s	1	9	0.9	90	7	2	0	0	1.2
Southern Stingray	0	0	0	0	0	0	0	0	0	s	9	1	0.1	10	1	0	0	0	1.0
Mojarra,Yellowfin	0	0	0	0	0	0	f	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Spotted Eagle Ray	0	0	0	0	0	0	0	0	s	0	9	1	0.1	10	1	0	0	0	1.0
Harlequin Bass	f	0	0	0	f	f	0	0	0	0	7	3	0.3	30	0	3	0	0	2.0
Orange filefish	f	0	0	f	s	0	0	0	0	0	7	3	0.3	30	1	2	0	0	1.7
Orangespotted Filefish	0	0	0	0	0	0	f	f	s	0	7	3	0.3	30	1	2	0	0	1.7
Scrawled Filefish	0	0	0	0	0	0	0	0	0	s	9	1	0.1	10	1	0	0	0	1.0
Slender Filefish	s	0	0	0	0	0	0	0	0	0	9	1	0.1	10	1	0	0	0	1.0
Black Durgon	0	0	0	0	0	0	f	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Fairy Basslet	0	0	0	0	0	0	0	0	0	s	9	1	0.1	10	1	0	0	0	1.0
Redlip Blenny	f	s	m	m	f	f	m	m	0	0	2	8	0.8	80	1	3	4	0	2.4
Blue Chromis	m	a	m	a	a	a	a	a	m	m	0	10	1	100	0	0	4	6	3.6
Brown Chromis	a	a	a	a	a	a	a	a	a	a	0	10	1	100	0	0	0	10	4.0
Sergeant Major	m	f	m	m	0	0	m	m	0	f	3	7	0.7	70	0	2	5	0	2.7
Bridled Goby	s	f	0	0	f	0	0	0	f	s	5	5	0.5	50	2	3	0	0	1.6
Masked/Glass Goby	f	f	0	f	f	0	f	f	f	0	3	7	0.7	70	0	7	0	0	2.0
Bluehead wrasse	m	0	a	m	m	m	a	m	m	m	1	9	0.9	90	0	0	7	2	3.2
Creole Wrasse	m	s	m	0	m	m	a	a	a	m	1	9	0.9	90	1	0	5	3	3.1
Puddingwife	s	0	0	s	f	f	f	f	0	s	3	7	0.7	70	3	4	0	0	1.6
Slippery Dick	f	0	f	0	0	0	0	0	0	0	8	2	0.2	20	0	2	0	0	2.0
Silversides	0	0	m	a	0	0	0	a	0	0	7	3	0.3	30	0	0	1	2	3.7
Clown wrasse	f	f	f	f	f	f	f	f	f	f	0	10	1	100	0	10	0	0	2.0
Yellowhead Wrasse	m	m	m	m	m	m	m	0	m	f	1	9	0.9	90	0	1	8	0	2.9
Yellowcheek Wrasse	0	0	0	0	s	0	0	0	0	0	9	1	0.1	10	1	0	0	0	1.0
Beaugregory	f	0	0	0	0	0	0	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Bicolor Damselfish	m	m	m	m	a	m	m	0	m	m	1	9	0.9	90	0	0	8	1	3.1
Cocoa Damselfish	0	0	0	f	0	0	f	0	0	0	8	2	0.2	20	0	2	0	0	2.0
Dusky Damselfish	s	f	f	0	f	0	0	0	0	0	6	4	0.4	40	1	3	0	0	1.8
Threespot Damselfish	m	m	m	m	m	m	m	m	0	m	1	9	0.9	90	0	0	9	0	3.0
Yellowtail Damselfish	m	m	m	m	m	m	m	m	m	m	0	10	1	100	0	0	10	0	3.0
Bucktooth Parrotfish	s	0	0	0	0	0	0	0	0	0	9	1	0.1	10	1	0	0	0	1.0
Greenblotch Parrotfish	0	0	0	0	m	m	0	f	m	f	5	5	0.5	50	0	2	3	0	2.6
Princess Parrotfish	m	m	m	0	a	m	0	m	m	m	2	8	0.8	80	0	0	7	1	3.1
Queen Parrotfish	f	0	m	m	0	m	m	m	m	m	2	8	0.8	80	0	1	7	0	2.9
Redband Parrotfish	m	m	m	m	m	m	m	m	m	m	0	10	1	100	0	0	10	0	3.0
Redfin Parrotfish	0	0	0	f	0	0	0	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Redtail Parrotfish	f	0	0	0	0	0	0	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Stoplight Parrotfish	m	m	m	m	m	m	m	m	m	m	0	10	1	100	0	0	10	0	3.0
Striped Parrotfish	m	m	0	m	0	0	f	f	f	f	3	7	0.7	70	0	4	3	0	2.4
Blue Tang	m	f	m	m	m	f	m	m	f	f	0	10	1	100	0	4	6	0	2.6
Doctorfish	m	f	0	0	0	0	0	0	f	f	6	4	0.4	40	0	3	1	0	2.3
Ocean Surgeonfish	f	0	m	m	f	f	f	f	f	0	2	8	0.8	80	0	6	2	0	2.3
Great Barracuda	0	0	0	s	0	0	0	0	0	0	9	1	0.1	10	1	0	0	0	1.0
Glasseye Snapper	0	0	0	0	0	0	s	s	s	f	6	4	0.4	40	3	1	0	0	1.3
Barred Hamlet	0	0	0	0	0	s	0	0	s	0	8	2	0.2	20	2	0	0	0	1.0
Shy Hamlet	s	0	0	0	0	0	0	0	0	s	8	2	0.2	20	2	0	0	0	1.0
Yellowtail Hamlet	f	f	0	0	f	f	f	f	f	f	2	8	0.8	80	0	8	0	0	2.0
Bar Jack	0	0	m	f	0	0	0	0	0	0	8	2	0.2	20	0	1	1	0	2.5
Gray Snapper	s	0	0	0	0	0	0	0	0	0	9	1	0.1	10	1	0	0	0	1.0
Mahogany Snapper	f	f	f	f	f	f	f	0	m	m	1	9	0.9	90	0	7	2	0	2.2
Schoolmaster	0	0	f	0	0	0	0	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Yellowtail Snapper	0	0	0	s	m	m	0	0	0	f	6	4	0.4	40	1	1	2	0	2.3
Blackbar Soldierfish	0	0	0	0	0	0	0	f	0	0	9	1	0.1	10	0	1	0	0	2.0
Longjaw Squirrelfish	0	0	0	0	0	0	0	0	s	0	9	1	0.1	10	1	0	0	0	1.0
Longspine Squirrelfish	f	f	f	f	f	f	f	f	f	0	1	9	0.9	90	0	9	0	0	2.0
Trumpetfish	f	s	m	m	f	f	m	m	f	m	0	10	1	100	1	4	5	0	2.4
Rainbow Runner	0	0	f	0	0	0	0	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Spotted Moray	0	0	0	0	0	0	0	s	0	s	8	2	0.2	20	2	0	0	0	1.0
Coney	s	0	0	0	0	0	0	0	0	0	9	1	0.1	10	1	0	0	0	1.0
Graysby	0	0	s	s	0	0	f	0	f	f	5	5	0.5	50	2	3	0	0	1.6
Red Hind	s	s	0	0	0	0	0	0	0	0	8	2	0.2	20	2	0	0	0	1.0
Rock Hind	0	0	0	0	f	0	0	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Yellowmouth Grouper	0	0	0	0	0	0	0	0	0	s	9	1	0.1	10	1	0	0	0	1.0
Tobaccofish	0	s	0	0	0	0	0	0	0	0	9	1	0.1	10	1	0	0	0	1.0
Cero	0	0	f	0	0	0	0	0	0	0	9	1	0.1	10	0	1	0	0	2.0
Sand Diver	s	s	0	0	0	0	0	0	0	0	8	2	0.2	20	2	0	0	0	1.0
Creole-fish	0	f	f	f	m	a	s	0	f	f	2	8	0.8	80	1	5	1	1	2.3

s= single (1 fish)
f= few (2-10 fishes)
m= many (11-100 fishes)
a= abundant (>100 fishes)

APPENDIX 2

Coral Reef Remote Sensing: A Literature Review

APPENDIX 2: Coral Reef Remote Sensing Literature Review

There is a critical need for detailed monitoring and assessment of reef habitats in order to document where and how coral reefs are threatened and to understand what measures are needed to safeguard them. There are a variety of reef protecting organisations (such as AGRRA, Coral Cays, ReefBase, Caricomp, Reef Check, and GCRMN) some of which have developed specific techniques for assessing and monitoring coral reefs. The choice of monitoring method is usually a compromise between cost and detailed information. There is wide a range of options from satellite imagery to map reef location (low cost and moderate detail) to running underwater transects to measure reef health (high cost and high detail). The optimal approach is through multilevel sampling, where information obtained from limited detailed high-resolution sampling is extrapolated to large areas based on low-resolution data of wide coverage. The goal is to use as much information as possible to improve assessments at a regional scale, such as the Caribbean. Satellite imagery is a low cost, coarse scale way of mapping coral reefs. It is an effective way of building a comprehensive database locating reef distribution and provides information on sea surface temperature, wave patterns, primary production and pollution monitoring (Clark, 1993). The aim of this section is to give the reader a clear understanding of remote sensing and the limitations involved in mapping of tropical marine habitats. This literature review allowed us to determine the potential sensors to be used for coral mapping and evaluate the cost of image acquisition. The availability, cost and technology of satellite imagery is constantly evolving, therefore, updated information should be obtained from referenced websites. At the time of this review we did not decided to acquire satellite imagery for reasons that will be outlined in this section. We nevertheless think that this remote sensing literature review contains valuable information for other researchers considering the use of remote sensing techniques for mapping coastal habitats.

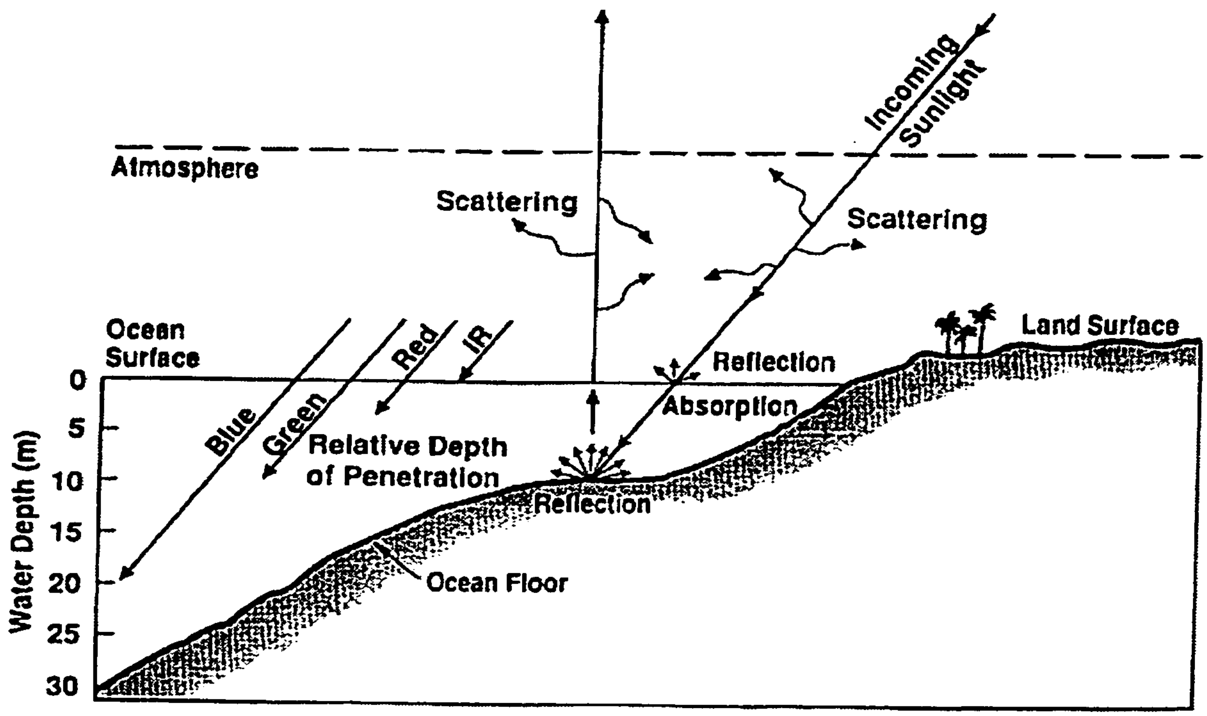
1.1 Basic remote sensing concepts

Remote sensing is the acquisition of information about an object, area, or event, based on measurements taken at some distance from it. Passive satellites sensors typically record reflected sunlight in the visible (0.38-0.75 µm) and near infrared (0.76-1.00 µm) portions of the electromagnetic spectrum (Lillesand and Kiefer, 2000). Since the source of radiation for passive sensors is the sun, data collection is restricted to daylight hours with clear skies. When sunlight enters the earth's atmosphere only a wavelength-dependent portion of that light is transmitted to the earth's surface because of absorption scattering by particles and gases in the atmosphere. The shorter wavelengths of the blue area of spectrum is mostly affected by Rayleigh scattering (Lillesand and Kiefer, 2000). Of the fraction of the light that reaches the earth's surface, some of the energy is absorbed, some is transmitted and some is reflected. The reflected portion of the energy reflected upward passes through the atmosphere again and suffers additional losses due to absorption and scattering before reaching the satellite. It is the reflected radiation that is recorded on photographic film and digital sensors. When incident sunlight hits water a small portion is reflected by the air-water interface but most of the visible wavelengths enters the water and is absorbed. This absorption is wavelength dependent, wavelengths longer than 0.9 µm (reflected infrared) are totally absorbed within the first few centimetres of waters while shorter wavelengths of visible light penetrate much deeper (Fig.1) (Harris and Kowalik, 1994). The presence of suspended sediment particles in the water column can cause additional reflection. If the water is shallow and clear enough, the shorter wavelength portion of the electromagnetic spectrum will be reflected off the bottom and travel through the absorbing water column again. Any fraction of the upwelling light that survives will pass again into the atmosphere, suffering loss at the sea surface, as well as absorption and scattering in the atmosphere before reaching the satellite (Fig.1). It is this portion of the sunlight reflected off the water bottom in which we are interested for mapping coral reef habitats using remote sensing.

Water and atmosphere introduce noise/error into remotely sensed data. Water depth correction algorithms have been developed to reduce the effect of water column when using digital imagery. Lyzenga (1978, 1981) developed a model-based approach to compensate for variation in depth. The Lyzenga method, derived for clear water, assumes that light attenuation follows an exponential decay curve with increasing depth. This model can usually be applied to clear waters with uniform bottom substrate. Atmospheric attenuation can be reduced by applying radiometric corrections based on a model atmosphere (Cracknell and Hayes, 1993), for this, atmospheric variables at the time of image acquisition must be known. The best correction results for both water and atmosphere attenuations are obtained by calibrating the remote sensing data with *in situ* biophysical measurements made at the same time that the remote sensor data are collected (Jensen, 1996; Holden and LeDrew, 1998b). The correction of these two parameters is important when dealing with data from multiple sensors or multi-temporal imagery.

Remote sensing images of the earth surface acquired from either aircraft or spacecraft platforms are readily available in digital format. The data is composed of discrete

Figure 1: Diagram showing the passage of the sunlight from the atmosphere to the earth's surface and ocean floor back to the satellite. (from Harris and Kowalik, 1994)



Incoming Sunlight
Atmosphere
Scattering
Scattering
Ocean Surface
Land Surface
Blue
Green
Red
IR
Reflection
Absorption
Relative Depth of Penetration
Reflection
Ocean Floor
Water Depth (m)
0
5
10
15
20
25
30

picture elements, pixels, and radiometrically it is quantified into discrete brightness levels (Jensen, 1996). Data that is not recorded in digital form can be converted into discrete data by use of digitising equipment (e.g. scanner). The scanner transforms the colour in the photograph into a digital number into three different bands, red, green, and blue (Green *et al.*, 1996). Once digitised these aerial photographs can be imported in any standard remote sensing software and processed in the same way as satellite images.

Information on the basic remote sensing concepts can be obtained from introductory remote sensing manuals such as Lillesand and Kiefer (2000), and Jensen (1996). Following are commonly used remote sensing terms in this review:

Spatial resolution is a measure of the area on the ground covered by each sampling unit (pixel) and is dependent on altitude and sensor design, also known as the pixel size.

Swath width is the total width of the area on the earth's surface covered by the scanner. Together with the spatial resolution it determines the degree of detail and the size of the area covered.

Temporal resolution is the time interval between consecutive overpasses of a fixed point by a satellite.

Bands are the location of spectral measurement on the electromagnetic spectrum. Many sensors collect electromagnetic radiation in several distinct bands (e.g. blue band).

Spectral resolution refers to the number and width of the bands.

Radiometric resolution refers to the number of digital levels used to express the data collected by the sensor, sometimes alternatively referred to as the dynamic range.

The radiometric resolution of most sensors is such that the level of light intensity recorded for each pixel in each wave band can have a value between 0 (no reflectance) and 255 (100% reflectance); each value being referred to as a digital number (DN). Frequently the radiometric resolution is expressed in terms of number of binary digits, or bits, necessary to represent the range of available brightness values. Thus data with 8 bit radiometric resolution has 256 levels of brightness.

Image interpretation refers to the process of determining or making educated guesses about the significance of features recognised in an image. Successful interpretation relies on your background knowledge including field observations, map and literature, discussions with people who are familiar with the geographic area, experience in other areas, and common sense. Interpretation uses the following characteristic features that appear in satellite images or aerial photographs: scale or size, the grey tone or colour, the two or three-dimensional shape, the texture, the pattern and relationship of associated features (Harris and Kowalik, 1994). Texture is the frequency of tone or colour change of an area. Pattern is the order spatial arrangement of features. These interpretations can be hand drawn by tracing on overlays superimposed on the image that can later be converted into a digital thematic map by using a digitising table. If a digital copy of the image is available a computer based statistical classification algorithm can be used to extract useful thematic information based on the digital numbers associated with each pixel of the image.

1.2 Considerations for remote sensing of coral reefs

Many factors need to be considered when choosing a satellite and sensor type to study coral reef habitats. Submerged coral reef ecosystems are difficult to monitor remotely due to the spectral discrimination of optically similar substrates, and the specific problems of optical attenuation of radiation caused by the overlying water column (Holden and LeDrew, 1998). Imagery varies according to its spatial, spectral, radiometric and temporal resolutions. Considerations should also be given to what time of year would yield the best imagery and exhibit the least atmospheric distortion as well as the most appropriate sun angle to minimise sun glare. The sensor should be chosen based on the following criteria: i) ability to discriminate land from water areas, ii) good water penetration, iii) excellent spatial and spectral resolutions to be able map the sea bottom types with clear boundaries, and iv) cost effectiveness (Harris and Kowalik, 1994). These topics will be discussed in the following sections. Characteristics of potential remote sensing technology available for coral reef mapping as well as their advantages and disadvantages are listed in Table1 and will discussed in the following sections. A description of sensor and platform abbreviations as well as the main marine applications for sensors are summarised in Table 2.

The discrimination of exposed land from submerged areas is useful in reef mapping. Water absorbs infrared and looks very dark on images, the land reflects infrared and looks very bright. Infrared and near infrared bands are available in SPOT HRV, Landsat TM and MSS, IRS LISS-3, but is not available in SPOT PAN and IRS PAN. Colour Infrared film is also available in aerial photography survey missions.

Table 1: Characteristics of potential remote sensing technology for coral reef mapping. (compiled by the author from various internet sites).

TECHNOLOGY	SPECIFICATIONS	ADVANTAGES	DISADVANTAGES
Aerial photography	▶true color aerial photographs acquired March 1991 at a scale of 1:10000 ▶scanned at a resolution of 600dpi giving us a ground resolution of approximately 50cm.	▶excellent spatial resolution ▶good water penetration ▶digital copy can be obtained by scanning prints. This is done in 3 distinct bands, which can be analyzed using standard image processing software. ▶digitized aerial photographs are proven to be an affordable and efficient tool for reef mapping.	▶the cost of commanding aerial photography mission ▶using archived aerial photographs does not give us the flexibility of selecting the acquisition date to correspond with the field survey. ▶aerial photographs need to be mosaicked to cover entire study area. ▶geometric distortions ▶limited spectral resolution
Landsat TM	▶30m resolution on all bands except band 6 at 75m ▶185km swath, 18 days cycle, synchronous ▶8bit data ▶Bands:(in microns) 1-0.45-0.52 4-0.76-0.90 7-2.08-2.35 2-0.52-0.60 5-1.55-1.75 3-0.63-0.69 6-10.4-12.5	▶good spectral resolution (includes a blue and a green band) ▶good water penetration ▶ability to buy portion of scene or specific bands only	▶spatial resolution is inadequate for small scale mapping of coral reefs ▶prevalence of clouds in scenes
SPOT HRV	▶20 to 27.2m resolution (off nadir viewing) ▶60km swath, 26days cycle, sun synchronous ▶8bit data ▶Bands:(in microns) 1-0.50-0.59 3-0.79-0.89 2-0.61-0.68	▶adequate spatial resolution ▶off nadir viewing increases the revisit time to about 5days/cycle	▶ spatial resolution is inadequate for small scale mapping of coral reefs ▶poor spectral resolution (lacks a blue band) ▶needs to be programmed to acquire scene, poor archives ▶prevalence of clouds in scenes
SPOT PAN	▶10 to 13.6m resolution (off nadir viewing) ▶60km swath, 26 days cycle, sun synchronous ▶8bit data ▶Band 1: 0.51-0.73 microns	▶good spatial resolution ▶off nadir viewing increases the revisit time to about 5days/cycle	▶inadequate spectral resolution ▶needs to be programmed to acquire scene, poor archives ▶prevalence of clouds in scenes

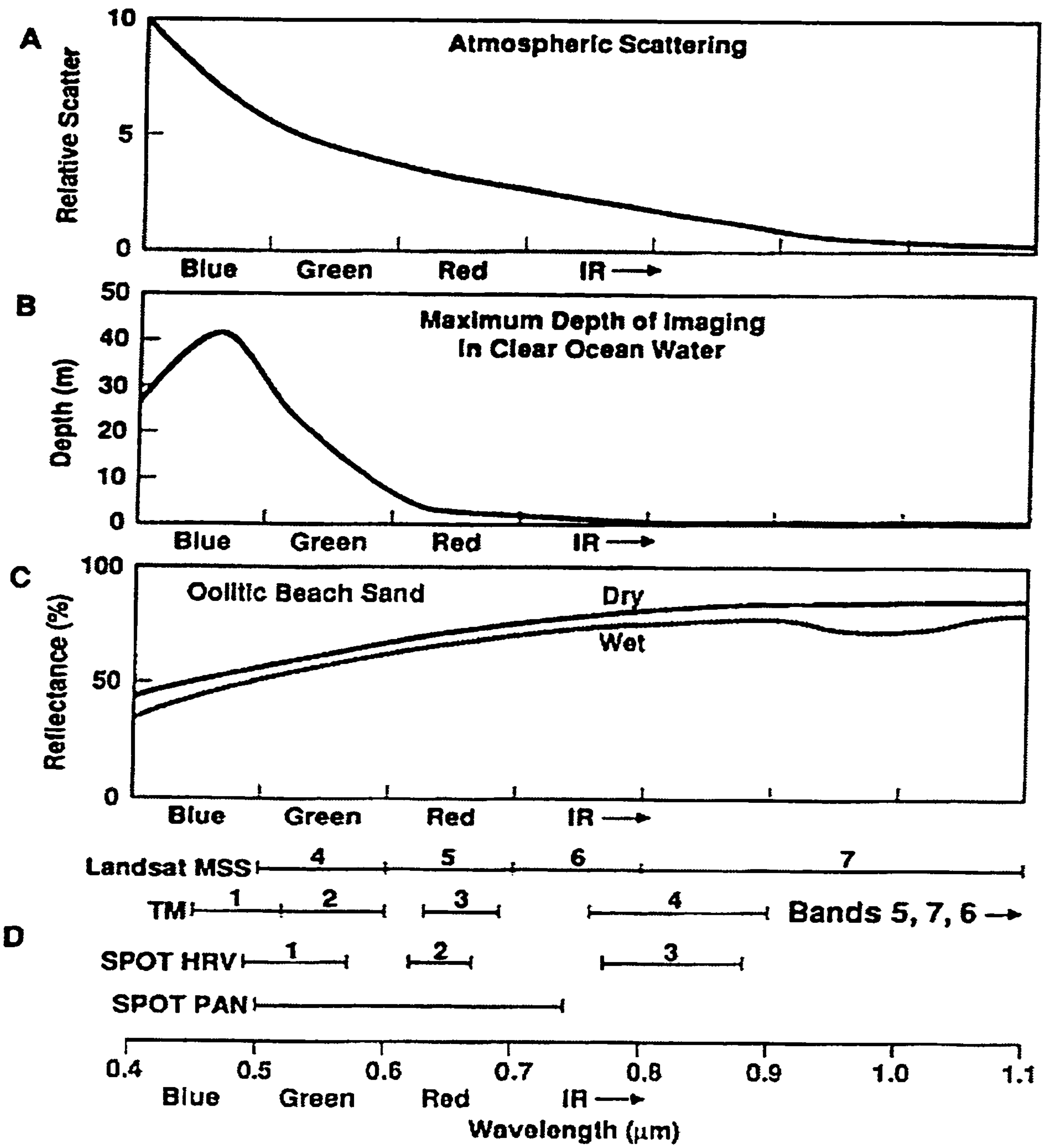
Continued...

TECHNOLOGY	SPECIFICATIONS	ADVANTAGES	DISADVANTAGES
IRS-1C & -1D LISS-3	▶23.5m resolution, resampled to 20m pixel detail (channel 1-3), 70m resolution (channel 4) ▶swath width 120-140km, 24day cycle, sun synchronous ▶8bit data ▶Bands: (in microns) 1-0.52-0.596 3-0.77-0.866 2-0.62-0.686 4-1.55-1.706	▶adequate spatial resolution ▶with oblique viewing capacity (visit every 5 days)	▶ spatial resolution is inadequate for small scale mapping of coral reefs ▶poor spectral resolution (lacks a blue band) ▶no data prior to December 1995, poor archive ▶lower radiometric resolution (6 bit) ▶prevalence of clouds in scenes
IRS-1C & -1D PAN	▶5.8m resolution (resampled to 5m) ▶63-70km swath width ▶ 24day cycle, sun synchronous, with oblique viewing capacity (visit every 5 days) ▶6bit data (resampled to 8bit) ▶Band 1: 0.50-0.75 microns	▶good spatial resolution ▶oblique viewing capacity with a revisit time of about 5 days	▶inadequate spectral resolution ▶no data prior to December 1995, poor archive ▶ lower radiometric resolution (6 bit) ▶prevalence of clouds in scenes
IKONOS 2	▶**4-MS:** 4m resolution multispectral ▶Bands: (microns) 1-0.45-0.53 3-0.64-0.72 2-0.52-0.61 4-0.77-0.88 ▶**1-P** : 1m resolution panchromatic ▶Band 1: 0.45-0.90 microns	▶good spatial resolution ▶good spectral resolution (includes a blue an a green band) ▶high radiometric resolution, 11-bit ▶high revisit frequency	▶ no data prior to December 1999, poor archive ▶prevalence of clouds in scenes

Table 2 : Description of sensor and platform abbreviations. The main marine applications for each sensor are also included.

Sensor	Name or Platform	Main marine applications
CASI-Compact Airborne Spectrographic Imager	Airborne	Habitat mapping
IKONOS	IKONOS	
HRV- Haute Résolution Visible PAN- Panchromatique	SPOT-Satellite pour l'Observation de la Terre	
TM- Thematic Mapper MSS-Multispectral-Spectral Scanner	LANDSAT- Land Remote Sensing Satellite	
LISS- Linear Imaging Self-Scanning Sensor PAN- Panchromatic	IRS- India Remote Sensing Satellite Systems	
MERIS- Medium Resolution Imaging Spectrometer	ENVISAT- Environmental Satellite	Ocean Color / Sea Surface Temperature
OCTS- Ocean Color and Temperature Scanner	ADEOS- Advanced Earth Observing Satellite	
SeaWiFS- Sea-Viewing Wide Field-of-View Sensor	NASA SeaStar – National Aeronautics Space Administration	
CZCS- Coastal Zone Color Scanner	NIMBUS-7	
AVHRR-Advanced Very High Resolution Radiometer	NOAA- National Oceanic and Atmospheric Administration	

Figure 2: Interaction of the visible and reflected infrared sunlight with (A) the atmosphere, (B) water, and (C) land. These interactions are strongly wavelength dependent. (D) Wavelength bands of the Landsat and SPOT satellites. (from Harris and Kowalik, 1994)


A
B
C
D
Atmospheric Scattering
Relative Scatter
10
5
0
Blue
Green
Red
IR
Maximum Depth of Imaging
in Clear Ocean Water
Depth (m)
50
40
30
20
10
0
Oolitic Beach Sand
Dry
Wet
Reflectance (%)
100
50
0
Landsat MSS
4
5
6
7
TM
1
2
3
4
Bands 5, 7, 6
SPOT HRV
1
2
3
SPOT PAN
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Wavelength (μm)

The depth of light penetration in the water is a function of water clarity and sun elevation. Usually clear water and high sun elevation (11h00 a.m. - 1h00 p.m.) provide the best results. Overflight reflectance at the water surface also reduces the image usefulness (Meinesz *et al.*, 1991). Overflight time and angle should be carefully considered to reduce the specular reflection (sun spots), which cannot be removed by filtering techniques.

The water column above the corals is of variable depth and quality. The complex geomorphologic structure of coral reef environment is responsible for its greatly variable bathymetry. Distinguishing between bathymetric or substrate variation can be difficult because of the interaction of visible light with water. Bathymetric data from the study area is extremely useful in image interpretation. The optical properties of seawater limit the penetration of the light spectrum to about the first 10 to 20 meters, depending on organic and inorganic particulate matter within the water column (Harris and Kowalik, 1994). Because of the interaction of the visible light with the water, the only part of the light spectrum that penetrates the water, to an acceptable depth, is the visible wavelength region between 0.40 μm (blue) and 0.60 μm (green) (Fig.1). SPOT HRV has a green band that can penetrate up to 5m while SPOT PAN can penetrate the water up to depths of 11m in clear waters (Fig.2) (Harris and Kowalik, 1994). Landsat TM has two bands which can penetrate the water making it possible to better characterise and differentiate the bottom types, of which the blue band can penetrate to a depth of up to 18 m (Fig.2). Other systems lack the separation of colour in the shorter visible wavelengths and often the deep water will be confused with dark bottom types such as corals and seagrass (Harris and Kowalik, 1994). Remote detection of submerged corals is complicated by the fact that the spectral signatures of individual coral heads are strongly influenced by the surrounding corals and other substrates as well as the overlying water column often within a single pixel. In areas where large tidal ranges exist, the mapping of reefs at low tide can eliminate the effect of the water column absorption. The reef flat and backreef zones are usually located in shallower waters and are easier to map using remote sensing. Reef slopes are problematic when using vertically positioned sensors; the usefulness of the data is reduced by sea bottom slopes greater than 5% (Meinesz *et al.*, 1991). Although this region is more difficult to map using remote sensing methods the reef slope comprises an important surface of the reef.

Some regions of the electromagnetic spectrum are more useful to characterise coral reef ecosystem. When using hyperspectral systems (e.g. CASI) this information is essential since the band location, number and width are usually variable and project specific. With spaceborne sensors these are pre-selected and usually limited to some wide bands (3-7), nevertheless this information can be useful in selecting the appropriate sensor. Recent research has been conducted to determine the spectral signature of coral reefs using ground measurements from an *in situ* hand held spectroradiometers (Hardy, 1992; Holden and LeDrew, 1998a; Miyazaki *et al.*, 1994; Nadook *et al.* 1998). Miyazaki *et al.* (1994) found that the spectral reflectance of the corals in Okinawa Japan showed a narrow absorption band in the 0.660-0.680 μm (red) spectral region and a very strong spectral reflectance from about 0.700 μm (NIR) toward the longer wavelength range. These absorption and reflectance peak regions were not observed for bottom sands and bare rocks. Nadaoka et al. (1998) also conducted research on the spectral reflectance characteristics of these Japanese coral reefs and observed a common feature in the collected spectra. They observed a mild reflection peak around 0.575-0.600 µm and a sharp negative absorption peak at 0.650 or 0.675 µm. Holden and LeDrew (1998a) have also come to very similar conclusions for the reefs in Fiji, where they found an absorption peak at 0.675 µm for all substrates housing algae. The absorption peaks can be attributed to the presence of symbiotic algae, zooxanthellae, in the coral tissues. These peaks which have a characteristic absorption band around 0.650 µm and 0.675 µm because to the presence of chlorophyll in the zooxanthellae tissues. The surrounding sandy and silty sea bottoms have larger reflectance and do not have this characteristic chlorophyll absorption peaks. They also found that seaweed and seagrass show an absorption peak in that same spectral region but it is not as distinct as in the live corals. It must be noted that the dead corals encrusted with red coralline algae also show a minor negative peak at 0.650 µm since the red algae contains some chlorophyll (Holden and LeDrew, 1998a). We can conclude that the Red and NIR bands are important to potentially discriminate between healthy corals, coralline turf, macro algae, sand bottoms and dead corals. Unfortunately this region of the electromagnetic spectrum is strongly absorbed by the water, thus penetration is limited to about 1m for NIR and 3 m for the red band. A basic spectral signature library of Caribbean coral reefs is being built using hyperspectral datasets, which will enable us to increase our understanding of the application of remote sensing to coral reefs.

The Tobago Cays area is relatively small and includes five Cays and a bank, covering an area of about 4 km X 4 km (see Chapter 1). The substrates present in the area are; seagrass, bare sand, algae, rock pavement, dead corals, and live corals (hard and soft). A total of seven distinct marine regions can also be distinguished; back reef, reef crest, fore reef, fringing reef, lagoon and patch reefs. The Horseshoe Reef is a bank barrier reef which can be separated into three main coral zones; a shallow *Millepora* and encrusting red algae (0-2 m), a deeper mixed coral head zone (2-12 m) and an even deeper foliaceous zone (12-25 m). Detailed mapping of the area requires good spatial resolution that needs to be smaller the smallest unit to be mapped during ground thruthing. Ideally we would like to resolve individual coral heads but a more realistic goal may be to map coral zones. Reef zonation is characterised by a specific assemblage of coral species and growth forms. Recent research has found that the spectral reflectance response of healthy branching and massive corals, regardless of morphology are not statistically different (Holden et LeDrew, 1998a). According to Hopley (1996) the spectral characteristics of reef surfaces, however, vary greatly with the colony morphology, with greater shadowing associated with the more intricate life forms. He suggested that these characteristics are sufficient to allow the differentiation of life forms using remote sensing techniques. These two contradicting studies were conducted at different scales (*in-situ* vs airborne). This could mean that reef zonation identification may only be distinguishable at a larger more general scale since there is no significant spectral difference but rather an overall textural difference across the reef.

Present day spaceborne satellites are unable to provide the resolution required for monitoring changes in biotic cover and reef health. Excellent satellite spatial resolution is needed to accurately map coral reef habitats with good precision. Jensen (1996) suggested that for a feature to be identified its image should comprise at least 20-50 pixels (spatial resolution= $area^2/min\#pixels^{1/2}$). Thus spatial resolution needed to map reef zonation will be of approximately 10-20 meters, and for individual coral heads would be well under the one-meter resolution. These approximations do not account for the effects of water attenuation. Only a few present day satellite sensors offer the spatial resolution for mapping reef zonations (Table 1). It is difficult to measure the rate of change from either natural or anthropogenic causes using reef zones, at this scale the changes are often too slow and are only detectable weeks after the causative event (Hopley, 1996). Mumby *et al.* (1998d) have suggested an optimal pixel size of 3-4 meters for surveying tropical marine environments. This resolution should be small enough to detect the spatial and temporal changes of texture of many reef habitats and would be sufficient to remove some of the unwanted small scale variability in the data (background noise), nevertheless this remains to be tested. Hopley (1996) suggested a much finer resolution ranging from 20 cm to 100 cm for reef habitat mapping, corresponding to the size of coral colonies on the targeted reefs. Major reef habitats can only be separated into their component species assemblage (biotic cover) using expensive airborne sensors such as CASI or again more traditional aerial photographs (Mumby *et al.*, 1998c; Thamrongnawasawat, 1996).

In addition to adequate spatial resolution, good spectral resolution is required for detailed mapping of coral reef habitats. As an example CASI data (<1 m spatial resolution) give better results than aerial photographs, which have a much finer spatial resolution but do not have adequate spectral resolution. Hyperspectral sensors have a much greater potential since they provide both good spatial and spectral resolutions (variable according to applications) for mapping coral reefs. Satellite sensors in the panchromatic mode have a good spatial resolution but poor spectral resolutions since they are sensing over the entire visible electromagnetic range between 0.5-0.75 μm (Fig.2; Table 1). The Indian satellite IRS

PAN has the best spatial resolution available at 5 m followed by SPOT PAN with 10 m. Panchromatic sensors provide the best spatial resolution if spatial details are required but is not ideal for substrate discrimination and water penetration. Multispectral sensors typically have a lower spatial resolution than panchromatic sensors but they offer greater spectral resolution, sensing over distinct spectral ranges (bands) of the electromagnetic spectrum (Fig.2; Table 1).

There is a diversity of opinions on the choice of the best sensor for mapping reef environments. It comes down to choose a sensor according to your specific needs and budget limitations. Mumby *et al.* (1997) compared the cost effectiveness of various sensors including fused products for mapping marine tropical environments in the Caribbean. They concluded that fused Landsat TM/SPOT PAN images are not a cost-effective option since they do not provide the corresponding improvement and accuracy. They concluded that the most accurate and cost effective satellite sensor for mapping areas smaller than 60 km is SPOT XS but in area greater than 60 km Landsat TM is preferred. SPOT XS is less expensive than SPOT PAN and offers greater habitat mapping accuracy. Hopley (1996) has suggested that the two most promising sensors for coral reef mapping were SPOT PAN and Landsat TM. Of the two, SPOT sensor is more desirable due to its greater spatial resolution but he did not make any reference to the scale of the study and cost. Because the choice of a sensor is project specific, there is no perfect sensor and compromises between resolution and costs need to be made.

Reefs are very complex and heterogeneous habitats because of their geometry, zonations, variability in growth forms, and species distribution. Satellite remote sensing is not well suited for mapping reef biotic cover but is none the less an appropriate and cost effective way of mapping major physiographic habitats, geomorphology and regional reef studies (Mumby *et al.*, 1997). To obtain more detailed biotic information on coral reefs, high resolution images such as those obtained from aerial photographs or airborne hyperspectral sensors are required.

1.3 Potential sensors for coral reef mapping

Sensors that have been fully exploited or could potentially be exploited in small scale reef mapping are discussed in this section (Table 1 and Table 2). A good review of the work done on remote sensing of coral reef habitats is provided by Holden and LeDrew (1998) and Mumby *et al.* (1998). Recent studies (i.e. post-1980) have largely concentrated on the application of Landsat TM data to map coral reef and submerged features. A few studies have also tested the capabilities of SPOT HRV and SPOT PAN. The use of both IRS and IKONOS data has potential for coral reef mapping but have not yet been explored. The Indian Space Research Organisation successfully launched IRS-1C in December of 1995 and its twin IRS-1D in September of 1997. Panchromatic and multispectral imagery from the IRS-1C and 1D are available to the public. The spatial resolution of IRS panchromatic and multispectral data is 5.8 m and 23.5 m respectively. The IRS multispectral sensor does not have a blue band; it only starts sensing at 0.52 µm (green), which is not optimal for water penetration. It also has a reduced radiometric resolution of 6 bits (64 shades of grey). This may not be ideal to discriminate between spectrally similar objects such as reef substrates. The most important obstacle with IRS data at the time of our survey was the absence of a ground receiving station covering the Grenadine area. A ground receiving station is now recently operating in Panama. The IKONOS commercial sensor has great potential for mapping coral reef habitats. This satellite was finally launched, after much delay, in September of 1999. Data is now accessible to the public since January of 2000 following a 3 months calibration period. The first commercial high resolution satellite, IKONOS, has excellent spatial resolution in multispectral (4 m) and panchromatic (1 m) modes, both green and blue bands, radiometric resolution of 11 bits, and is available at reasonable cost. The use of airborne hyperspectral data (e.g. CASI) has recently gained interest in the remote sensing community. These sensors provide exceptional spatial, spectral, radiometric and temporal resolutions, which can be adjusted according to specific need. The acquisition of airborne data, however, is very costly and requires extensive calibration and expertise. Despite its great potential, this option could not be considered for our research project because of financial limitations.

An interesting option is the fusion of panchromatic and multispectral imagery. The main goal of fusing two images is to take the best spatial resolution from one image and the best spectral resolution from a second image and to combine them into a single image with superior information (Mumby et al. 1997). Careful consideration must be given when merging these data, images must be as similar as possible (i.e. dates, tides, sun elevation, atmospheric conditions, and wind/ocean surface patterns). Two possible fusion options exist with IRS PAN; the first is with Landsat TM and the second is with IRS LISS-3. The fusion with Landsat data will provide better spectral resolution than with LISS-3. But the fusion with LISS will have the advantage of being taken by the same sensor and at the same time, eliminating many temporal factors. The digital merging of SPOT PAN with Landsat TM is also possible. This has been tested on land applications but little has been done on marine environments. Using fused data from Western Australia, Wyllie and Evans (1994) concluded that fused imagery provided reduced depth (15-20 m) of penetration but increased spatial details. Mumby *et al.* (1997) compared the cost effectiveness of various sensors, including fused Landsat TM and SPOT PAN for mapping marine tropical environments in the West Indies. They concluded that this is not a cost-effective option since it does not provide the corresponding improvement and accuracy. Detailed and updated information on products and pricing of satellite imagery is available through the distributors respective webpages, SpaceImaging is the official distributor of IRS, Landsat and IKONOS imageries while Radarsat International is the distributor for SPOT imagery (SpaceImaging, 2000; RSI, 2000).

The archived imagery dating back to the early 1990 is usually available for a fraction of the price. Imagery acquired between 1990 and 1992 could have been used to compare with aerial photos of the Tobago Cays area from March of 1991. A few archive images, however, are available for SPOT because the satellite does not continuously record information along its path unless it has been programmed to do so. On the other hand there is a great archival system for Landsat TM dating back to 1972 for Landsat 1-2-3 and 1982 for Landsat 4-5-6 since these satellites automatically record data along its path. Nevertheless, image acquisition in the Caribbean is also greatly limited by cloud cover. A search conducted in the DALI catalogue by Radarsat International (K669/J325) for panchromatic and multispectral SPOT images and through SpaceImage archives for Landsat TM imagery revealed that no scenes with less than 10-20% cloud cover were available for the Tobago

Cays area. Because of scarcity of cloud free archived imagery, the option of comparison with aerial photography and subsequent change detection analysis was impossible for this project.

From the above review of potential sensors it is possible to conclude no sensors are optimal for small scale reef mapping. Satellite data acquisition in tropical regions is also greatly limited by the prevalence of clouds. Landsat TM lacks the spatial resolution, IRS lacks the radiometric resolution and panchromatic data and SPOT XS lacks the spectral resolution. The IKONOS imagery has a great potential for coral reef mapping but was not available at the time of our study. The acquisition of hyperspectral imagery for this project was limited by financial constraints. For the above reasons, we opted not to use satellite imagery for this project and instead used colour aerial photographs (1:10 000) that were readily available and better suited for detailed habitat mapping of the Tobago Cays (see Chapter 1 and Chapter 3).

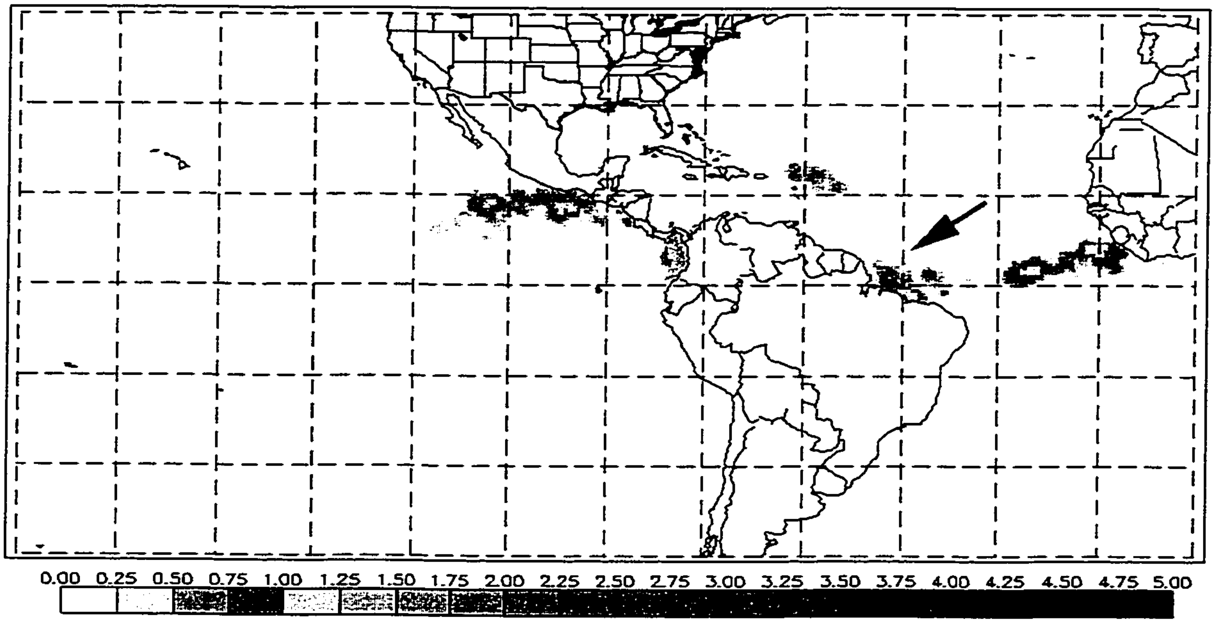
1.4 Potential sensors for large scale ocean monitoring

Satellite sensors developed for oceanographic applications can shed useful information for a regional scale coral reef monitoring, the most important ones being reviewed below. Some satellites such as the Advanced Very High Resolution Radiometer (AVHRR) and Coastal Zone Colour Scanner (CZCS) have been developed for oceanographic sciences, such as studies in upwelling, primary productivity and sea surface temperatures (SST) of the ocean and will be briefly discussed here in the context of large scale coral reef monitoring. A more comprehensive review of these sensors can be obtained from Holden and LeDrew (1998b).

Ocean colour can be converted into a measurement of chlorophyll pigment concentration to identify primary production levels in the vicinities of coral reefs and may be able to detect some pollutants as well as suspended sediment concentration loads over the marine domain (e.g. eutrophication at the river outflow of the Amazon). The first observations of ocean colour from space were carried out by the experimental Coastal Zone Colour Scanner (CZCS) from 1978 to 1986 aboard NASA's Nimbus-7 satellite. This instrument provided global and regional data sets, which yielded a wealth of new information about the distribution and seasonal variability of primary productivity. The Advanced Earth Observation Satellite (ADEOS) was launched successfully in August of 1996. The ocean colour and temperature scanner (OCTS) is one of the eight sensors on board of ADEOS; it has eight bands in the visible and NIR but has a spatial resolution of 700m at nadir. OrbView-2 spacecraft (formerly SeaStar) was launched in August of 1997 carrying the SeaWiFS instrument. SeaWiFS collects broad multispectral remotely sensed imagery and is the first privately owned remote sensing satellite to be launched and operated. It provides valuable information for global change research and large scale environmental monitoring with a resolution of 1000 m (NASA, 2000). The Medium Resolution Imaging Spectrometer (MERIS) will be launched by the European Space Agency in June 2001. The primary mission of MERIS is the measurement of sea colour in the oceans and in coastal areas. MERIS is a 15 band programmable imaging spectrometer with a spectral range restricted to the visible and NIR portions of the spectrum (0.390-1.040 μm), with unidirectional spectral bandwidth ranging between 0.00125 and 0.030 μm. MERIS will have a high spectral and radiometric resolution and will have a maximum spatial resolution of 300 m. Further information can be obtained at the European Space Agency website (ESA, 2000).

Sea surface temperatures (SST's) are being routinely obtained from satellites operated by the U.S. National Oceanic and Atmospheric Administration (NOAA) (Strong, 1992). These measurements are obtained from the Advanced Very High Resolution Radiometer (AVHRR) sensor on all NOAA's polar orbiting satellites and therefore permit coverage of all oceans (Strong 1992). AVHRR data are being used extensively in analyses of the relationship between sea surface temperature anomalies (hot spots) and coral bleaching events. Since January of 1997, NOAA/NESDIS'S Oceanic Research and Application Division has set-up an interactive website to help coral reef scientists monitor bleaching events (Strong 1998; Goreau and Hayes, 1994). Coral reef "hot spots" are special anomaly charts that highlight regions where sea surface temperature (SST) equals or exceeds the annual monthly maximum climatological value by 1°C, these are areas where bleaching is most likely to prevail. A typical anomaly chart for the Caribbean is given in Figure 3. Anomalies greater than 1.0 °C are represented in shades of yellow and oranges with anomalies between 0.25-1.0°C in purple-blue (Fig. 3). These charts have a 50km resolution grid throughout all tropical seas. Satellite values that are observed to lie just below this critical level are purple or blue, indicating bleaching may be about to begin if local conditions permit. The hot spot website went on line experimentally at the beginning of 1997 and is an essential information source for reef scientists. More information is available on the National Oceanic & Atmospheric Administration website (NOAA, 2000).

Figure 3: Potential coral reef bleaching hotspots for the Western hemisphere for June of 1999 at a resolution of 50km (red arrow indicates the general location of our study area). Anomalies greater than 1.0 ^{0}C are represented in shades of yellow and oranges with anomalies between 0.25-1.0 ^{0}C in purple-blue (from NOAA, 2000).



0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00

APPENDIX 3: Additional information for Chapter 3

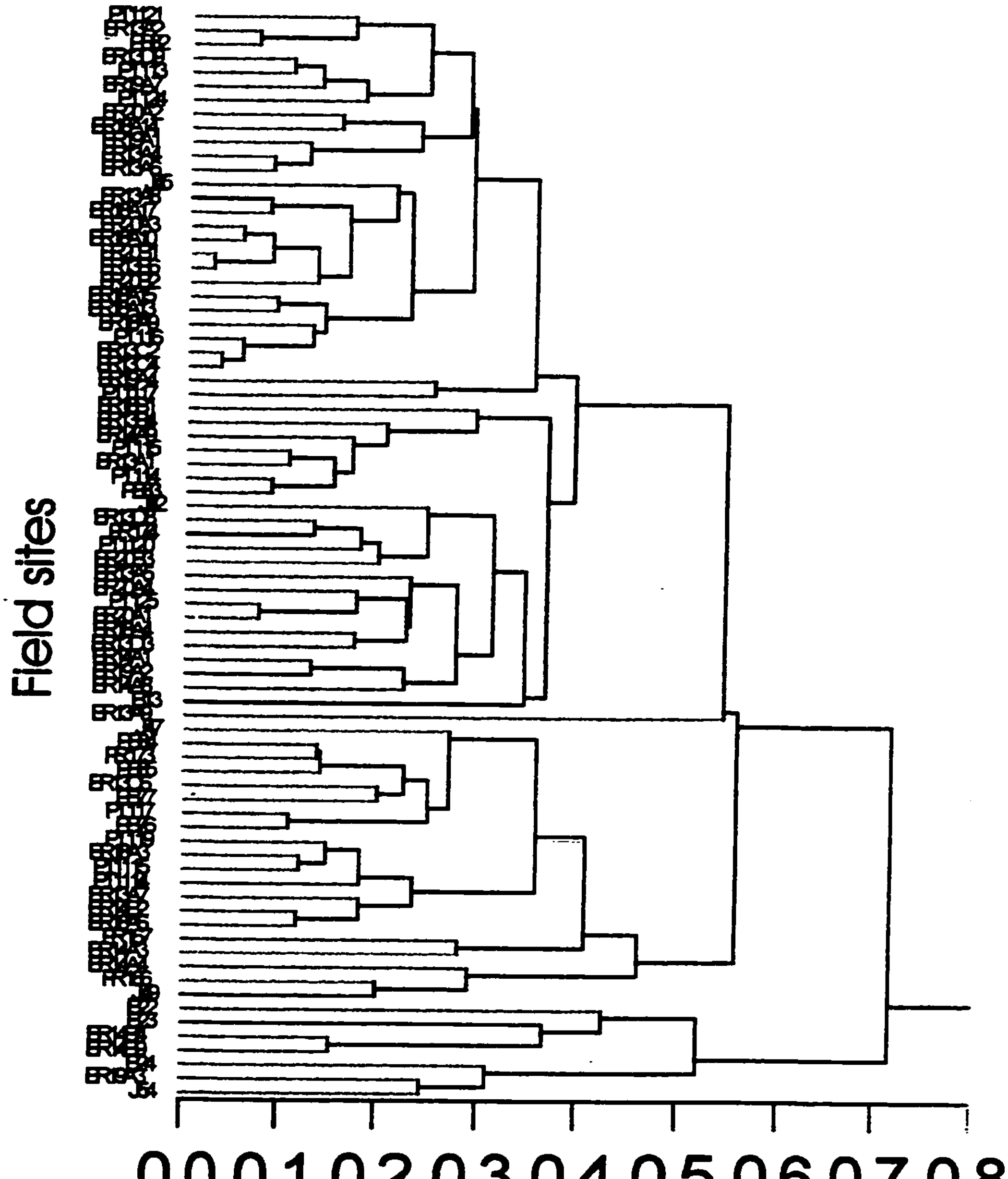
SITE NAME	trans.	quad.	class	depth	b-rock	dcoral	rubbleB	rubbleE	sandFM	sandC	Mud	PP	Sap	PA	DS	DC	MA	MF	MR	gorg	sponge	Thalas	Syrin.	gr. fleshy	gr. calcified	br. fleshy	rb-branch	coralline	Turf
Baradal	1	1	C	0.15	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0
Baradal	1	2	F	0.4	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0	0	0	20	0
Baradal	1	3	A	0.6	0	9.75	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	5	0	3	2	0	0.25	0	0
Baradal	1	4	D	1	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	4	0	15	0	0	2	0	0
Baradal	1	5	C	1.6	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0	0	0	9	0	13	0.5	0	0	0	0
Baradal	1	6	C	2.5	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	13.5	0	6	0.5	0	0	0	0
Baradal	1	7	C	3	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	7	0	1	0	0	0	0	0
Baradal	1	8	E	4	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0
Baradal	2	1	na	0.05	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
Baradal	2	2	C	0.3	0	0	0	0	11	0	0	0	3	0	0	0	0	0	0	0	0	9	0	1	0.5	0	0	0	0.5
Baradal	2	3	C	0.6	0	0	4	2	7.75	0	0	1	0.25	0	0	0	0	0	0	0	0	4	0	3	1	0	0	0	2
Baradal	2	4	A	0.8	0	0	0	12	2.5	0	0	2	0	0	0	0	0	0	0	0	0	2	0	3	0.5	2	1	0	10
Baradal	2	5	B	1	0	6	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	6	3	2	0	8	0
Baradal	2	6	C	2	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	11	0	6	0	0	0	0	0
Baradal	2	7	E	2.5	0	0	0	0	0	24.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0
Baradal	2	8	C	3	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	11	0	4	0	0	0	0	0
Baradal	3	1	E	0.15	0	0	7	6	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baradal	3	2	D	0.65	0	0	1	0	13	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	7.75	0	0	3	0	0
Baradal	3	3	D	1	0	0	0	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	2	1	0
Baradal	3	4	D	1.15	0	0	0	0	14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0.5	0	0	0	0
Baradal	3	5	D	1.3	0	0	1	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.5	0	0	1	0.5	0
Baradal	3	6	D	2	0	0	1	0	0	15	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	6	0	0	0
Baradal	3	7	C	2.5	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	7	3	0	0	0	0	0	0
Baradal	3	8	C	2.8	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	9	3	0	0	0	0	0	0
Baradal	3	9	C	3	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	12	4	0	0	0	0	0	0
Baradal	3	10	E	3.5	0	0	0	0	0	20.5	0	0	0	0	0	0	0	0	0	0	0	0	0.5	4	0	0	0	0	0
Baradal	3	11	E	4	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Jamesby	4	1	na	0.15	23	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	24	0.5	0
Jamesby	4	2	A	0.5	2	5	0	0	0	0	0	3	0	0.5	2	0	0	0	2	0.5	2	0	0	1.5	2	0	5	7	0
Jamesby	4	3	D	1.5	0	3	0	0	0	7	0	0	0	0	0	0	0	0	0	0.25	0.75	0	0	1	12	0	1	0	0
Jamesby	4	4	B	2	0	6	0	0	0	4	0	0	0	0.5	0	0	0	0	0	0.5	1	0	0	0	3	0	9	1	2
Jamesby	4	5	A	2.8	0	16	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	16	0
Jamesby	4	6	B	3	0	11	0	0	0	7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0	3	11	0
Jamesby	4	7	A	3.75	0	3	0	0	0	4	0	0	0	0	0	0	10	0	0	2	0	0	0	3	4	0	2	0	0
Jamesby	4	8	B	4.75	0	6	0	0	0	6	0	0	0.5	0	0	0	0	0	0	0.5	0	0	0	1	3	0	4	0	2
Jamesby	4	9	A	5	0	0	0	0	0	16.75	0	0.25	0	1	0	0	0	0	0	1	0	0	0	1	2	0	3	0	0
Jamesby	4	10	E	6.5	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jamesby	5	1	F	0.25	0	2	0	22	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	15
Jamesby	5	2	F	0.3	0	0	0	22	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	20
Jamesby	5	3	E	0.5	0	1	0	1	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Jamesby	5	4	D	0.6	0	1	0	17	2	0	0	2.75	0	0.25	0	0	0	0	0	0	0	0	0	0	10	0	7	2	0
Jamesby	5	5	D	1	0	0	0	10	6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	8	2	8
Jamesby	5	6	D	1.7	0	0	0	14	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	6	8
Jamesby	5	7	E	1.6	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jamesby	6	1	na	0.15	24	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	12
Jamesby	6	2	D	0.3	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	18	3	0
Jamesby	6	3	D	1	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	10	1	10
Jamesby	6	4	D	2.5	0	0	0	10	0	5	0	0	0	0.75	0	0	0	0	0	0.25	0	0	0	0	4	0	5	0	10
Jamesby	6	5	D	3.5	0	0	4	0	0	5	0	0	0	0.5	0	0	0	0	0	0.5	0	0	0	0	3	0	12	0	0
Jamesby	6	6	E	4.3	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Jamesby	6	7	D	4.5	0	0	0	0	0	14	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	0
Jamesby	6	8	E	6	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBateau	7	1	F	0.3	0	0	0	21.5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	21.5
PBateau	7	2	D	0.6	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	22	1	0
PBateau	7	3	D	1	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	15	0	0
PBateau	7	4	D	1.2	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	12.75	2.25	0
PBateau	7	5	D	2.5	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	11	0	0
PBateau	7	6	A	4	0	6	0	0	4	0	0	0	0	0.5	0	0	4	0	0	0	0	0	0	0	2	0	8.5	4	2
PBateau	7	7	A	6	0	3	0	0	0	6	0	0	0.5	0.5	0	0	0.5	0	0.5	3	0	0	0	0	1	0	8	0	0
PBateau	7	8	E	8	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
PBateau	8	1	C	0.05	0	0	0	12.5	4.5	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	1	0	0.5	0	12.5

PBateau	8	2	A	0.2	0	18	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	4	14
PBateau	8	3	A	0.4	0	15	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	4	5	0	1	6	9
PBateau	8	4	A	1.4	0	4	0	0	6	0	0	2	0	2	0	0	2.5	0	0	0	0	0	0	0	6.5	0	0	0	4
PBateau	8	5	A	2.5	0	6	0	0	0	9	0	0	0	0	0	0	5.5	0	0	0	0	0	0	0.5	4	0	5	1	0
PBateau	8	6	D	5	0	3	0	0	12	0	0	0	0	0.25	0	0	0	0	0.25	1.5	0	0	0	0	4	0	3	0	0
PBateau	8	7	E	7.5	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
PBateau	9	1	F	0.1	0	0	20.5	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	2	18.5
PBateau	9	2	F	0.3	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	1	19
PBateau	9	3	B	0.6	0	22	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	19
PBateau	9	4	B	1.1	0	17.5	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	2	0	1	0	17.5
PBateau	9	5	B	2	0	10	0	6	2	0	0	0	0	0.5	0	0	0.25	0	0	0.25	0	0	0	0	3	3	0	0	16
PBateau	9	6	B	3.5	0	12	0	0	3	0	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0	1	0	6	0	16
PBateau	9	7	E	5	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PBateau	10	1	E	0.15	0	0	0	1	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5	0	1
PBateau	10	2	C	0.65	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	12	0	1	0	0	0	0	0
PBateau	10	3	C	0.8	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	12	0	2	0	0	0	0	0
PBateau	10	4	C	1.2	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	11	0	3	0	0	0	0	0
PBateau	10	5	C	2	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	11	0	6	0	0	0	0	0
PBateau	10	6	C	3	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	4	2	4	0	0	0	0	0
PBateau	10	7	E	3.5	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTabec	11	1	E	0.25	0	0	0	0.5	0	24.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5
PTabec	11	2	D	0.6	0	0	0	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	2
PTabec	11	3	A	0.3	0	14	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	4	0	2	8	5
PTabec	11	4	A	0.3	0	12	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	8	4
PTabec	11	5	A	0.6	0	9	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	2	6	0	3	4.5	4.5
PTabec	11	6	A	0.2	0	22	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	11
PTabec	11	7	A	1.5	0	6	0	0	5	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3	0	8	1	5
PTabec	11	8	B	2	0	7	0	0	13	0	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	6
PTabec	11	9	A	1	0	10	0	0	9	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	10
PTabec	11	10	E	1	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
PTabec	11	11	B	1	0	21	0	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	1.5	0.5	0	0	8	13
PTabec	11	12	B	0.5	0	10	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	5	0	0
PTabec	11	13	E	1.5	0	0	0	2	21	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
PTabec	11	14	A	1.5	0	6	0	0	10.5	0	0	0.5	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	4	2
PTabec	11	15	A	1	0	7	0	0	9.5	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	5	1	6
PTabec	11	16	B	1	0	19	0	0	2	0	0	0.25	0	0.75	0	0	0	0	0	1	0	0	0	0	0	0	2	2	17
PTabec	11	17	A	0.5	0	13	0	0	0	4	0	0	0	0.5	0	0	0	0	1	0	0	0	0	0	2	0	3	2	4
PTabec	11	18	B	0.5	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	13	6
PTabec	11	19	B	0.5	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	8	0
PTabec	11	20	A	0.5	0	7	0	0	0	0	0	0	0	3	0	0	0	0	6	3	0	0	0	0	3	0	2	7	0
PTabec	12	21	A	1.5	0	17	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	17
PTabec	12	1	E	0.15	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTabec	12	2	E	0.4	0	0	0	4	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
PTabec	12	3	B	0.4	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	20
PTabec	12	4	A	0.4	0	17	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	2	15
PTabec	12	5	A	0.3	0	10	0	0	0	0	0	2	0	0	5	0	0	0	2	0	0	0	0	3	2	0	1	1	9
backreef(M1)	3ABCI	1	A	0.5	0	10.5	0	0	0	0	0	0	0	3	0	0	0	0	0	0.5	0	0	0	0	3	0	8	2.5	6
backreef(M1)	13A	2	A	0.5	0	18	0	0	0	0	0	0	0	6.75	0	0	0	0	0	0	0	0	0	0.25	0	0	0	4	14
backreef(M1)	13A	3	E	1.2	0	0	1	0	8	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
backreef(M1)	13A	4	A	1.7	0	11	0	0	0	0	0	0	0	0.5	0	0	10	0	0	1	0	0	0	0	0.5	0	2	8	3
backreef(M1)	13A	5	A	0.5	0	9	0	0	0	0	0	0	0	0	0	0	11	0	0	4	0	0	0	0	0	0	1	2	7
backreef(M1)	13A	6	A	0.4	0	11	0	0	0	0	0	0	0	0.25	0	0	5	3	0	3	0	0	0	0	3	0	0	9	2
backreef(M1)	13A	7	A	2.5	5	0	0	0	0	16	0	0	0	2	0	0	0	0	0	1	0	0	0	0	2	0	0	0	3
backreef(M1)	13A	8	A	1.2	0	16	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	4	0	0	10	6
backreef(M1)	13A	9	A	1.2	0	5	0	0	1	0	0	0	0	2	0	0	2	0	3	0	0	0	0	0	4	0	0	2	3
backreef(M1)	13B	2	E	2	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
backreef(M1)	13B	3	E	2.2	0	1	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
backreef(M1)	13B	4	A	1.2	0	10	0	0	0	0	0	0	0	1.5	0	0	0	0	0	0.5	0	0	0	0	5	0	8	1	9
backreef(M1)	13B	5	D	1.5	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	12	0	8	1	3
backreef(M1)	13B	6	A	1.5	0	16	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	2	0	0	14	2
backreef(M1)	13B	7	E	2	0	0	0	0	13	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
backreef(M1)	13D	2	E	1.6	0	0	0	0	12	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3

backreef(M1)	13D	3	A	1.5	0	15	0	0	0	0	0	0	0	0	0	0	9	0	0	1	0	0	0	0	0	0	0	2	13
backreef(M1)	13D	4	D	2.5	0	18	0	2	0	5	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	2.5	0	16	0	0
backreef(M1)	13D	5	E	2	0	0	0	0	10	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
backreef(M1)	13D	6	B	2	0	11	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	1.75	0	9
backreef(M1)	13D	7	B	1	0	12	0	0	5	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	2	0	5	2	5
backreef(M1)	13D	8	A	0.8	0	8	0	0	0	0	0	0	0	0	0	0	6	0	0	3	0	0	0	0	5	0	2	1	5
backreef(M1)	13D	9	A	0.8	0	15	0	0	0	0	0	0	0	1	0	0	7	0	0	0	0	0	0	0	2	0	4	4	5
backreef(M1)	13D	10	B	0.8	0	10	0	0	14	0	0	0	0	0.5	0	0	0	0	0	0.5	0	0	0	0	3	0	3	0	4
backreef(M1)	13C	2	A	0.4	0	22.75	0	0	0	0	0	0	0	1	0	0	0.25	0	0	0.5	0.5	0	0	0	0	0	0	10	14
backreef(M1)	13C	3	E	0.6	0	0	0	1	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
backreef(M1)	13C	4	A	1	0	24	0	0	0	0	0	0	0	0	0	0	1.5	0	0	0	0.5	0	0	0	0	0	0	10	14
backreef(M1)	13C	5	E	1.5	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
backreef(M1)	13C	6	A	1.6	0	10	0	0	7	0	0	0	0	2	1	0	0	0	0	3	0	0	0	0	4	0	5	1	0
backreef(M1)	13C	7	E	2	0	5	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
backreef	14AB	1	A	1.5	0	13	0	0	0	1	0	0	0	0	0	0	8	0	0	2	0	0	0	0	4	0	3	0	0
backreef	14A	2	E	2	0	20	0	0	0	20	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
backreef	14A	3	A	1.8	0	10	0	5	0	3	0	0	0	5	0	0	0	0	0	2	0	0	0	0	0	0	0	0	5
backreef	14A	4	A	2.4	0	4	0	1	18	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
backreef	14A	5	E	1.8	0	0	0	9	14.5	0	0	0	0	1	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	9
backreef	14A	6	F	2.3	0	0	0	15	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	12
backreef	14A	7	B	1.2	0	22	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	9	9	9
backreef	14A	8	A	1.3	0	10	0	4	0	3	0	0	0	0	0	0	7	0	1	0	0	0	0	0	7	0	3	0	0
backreef	14A	9	A	1.3	0	10	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	15	6	2
backreef	14B	2	A	1.8	0	8	0	0	0	13	0	0	0	2	0	0	0	0	0	1	0	0	0	0	1	0	1	0	11
backreef	14B	3	E	2	0	0	0	5	0	17	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	5
backreef	14B	4	A	2.4	0	0	0	11	12	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	10
backreef	14B	5	E	1.8	0	0	0	7	15	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	7
backreef	14B	6	B	1.6	0	10	0	10	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0	5	0	15
backreef	14B	7	F	2.3	0	0	0	20	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
backreef	14B	8	E	1.2	0	7	0	0	17	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
backreef	14B	9	A	1.3	0	0	0	9	11	0	0	0	0	3	0	1	0	0	0	1	0	0	0	0	0	0	0	1	8
backreef	14B	10	E	1.8	0	0	0	4	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4
backreef	14B	11	E	2	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
backreef	18A	0	E	1.2	0	0	0	0	24.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0
backreef	18A	1	E	1.4	0	0	0	0	12	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
backreef	18A	2	E	1.2	0	0	0	0	9	9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	0	2	0	0
backreef	18A	3	A	1.5	0	9	0	0	0	13	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0	3	1	5
backreef	18A	4	A	0.5	0	18	0	0	0	2	0	0	0	0	0	0	10	0	0	3	0	0	0	0	2	0	2	1	5
backreef	18A	5	D	0.8	0	23	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	14	0	5	1	3
backreef	18A	6	A	0.8	0	9	0	3	0	13	0	0	0	2	0	0	0	0	0	3	0	0	0	0	2	0	0	1	9
backreef	18A	7	B	1	0	23	0	0	0	2	0	0	0	0	0	0	0	0	0	6	0	0	0	0	6	0	0	12	5
backreef	18A	8	B	0.5	0	22	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0	2	10	8
backreef	18A	9	A	1	0	23	0	0	0	0	0	0	0	1	0	0	0	0	0	4	0	0	0	0	0	0	0	15	4
backreef	18A	10	A	0.5	0	18	0	0	0	0	0	0	4	1	0	0	0	0	0	2	0	0	0	0	0	0	1	10	5
backreef	18A	11	B	0.6	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	15	4
backreef	18A	12	E	3	0	6	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4
backreef	18A	13	A	1.2	0	20	0	0	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	3	0	0	11	6
backreef	18A	14	A	2	0	15	0	2	0	0	0	0	0	3	3	0	0	0	0	1	0	0	0	0	3	0	0	6	8
backreef	18A	15	A	0.4	0	20	0	0	0	0	0	0	0	2	0	0	0	0	3	2	0	0	0	1	0	0	0	10	5
backreef	18A	16	B	0.3	0	18	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	2	10	2
backreef	18A	17	A	0.5	0	16	0	0	0	0	0	1	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	10	6
backreef	18B	1	A	1.2	0	13	0	2	0	6	0	0	0	0	0	0	3	0	0	1	0	0	0	1	10	0	4	0	0
backreef	18B	2	D	0.3	0	24	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	4	12	3	0
backreef	18B	3	B	1.3	0	16	0	0	0	9	0	0	0	0.5	0.25	0	0.25	0	0	1	0	0	0	0	4	4	4	0	0
backreef	18B	4	E	1.4	0	0	0	0	15	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
backreef	18B	5	D	0.3	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	6	6	0	5	0
backreef	18B	6	E	1.1	0	0	0	1	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
backreef	18B	7	E	1.2	0	0	0	2	22.5	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
backreef	18B	8	D	0.5	0	0	0	21	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	5	10	6	0	0
backreef	19A	0	B	1	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	5	17	0
backreef	19A	1	A	0.5	0	14	0	0	0	0	0	0	0	0	0	0	10	0	1	0	0	0	0	0	3	0	0	7	4
backreef	19A	2	A	1.2	0	12	0	0	3	0	0	0	0	3	0	0	5	0	0	2	0	0	0	0	1	0	6	5	0

backreef	19A	3	A	2.2	0	4	0	15	6	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	3	0	5	3	11
backreef	19A	4	A	2	0	22	0	0	3	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	3	2	17
backreef	19A	5	B	1	0	24	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	8	14	2
backreef	19A	6	B	0.8	0	25	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	2	16	2
backreef	19A	7	A	1.8	0	18	0	0	2	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	8	6	6
backreef	20A	0	B	1	0	20	0	0	0	0	0	0	0	1	0	0	0	0	0	4	0	0	0	0	0	0	0	14	6
backreef	20A	1	A	1	0	12	0	0	0	0	0	0	0	7	0	0	1	0	1	0	0	0	0	0	4	0	0	1	5
backreef	20A	2	A	0.6	0	13	0	4	0	0	0	0	0	2	0	0	0	0	2	3	0	0	0	0	3	0	0	6	
backreef	20A	3	A	1	0	16	0	0	0	0	0	0	0	3	0	0	0	0	3	1	0	0	0	0	1	0	0	11	4
backreef	20A	4	A	2	0	10	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	2	0	0	0	8
backreef	20B	1	A	0.3	0	18	0	0	0	0	0	0	0	1	0	0	2	0	4	2	0	0	0	0	2	0	0	14	0
backreef	20B	2	A	0.5	0	14	0	3	0	0	0	0	0	0	0	4	0	0	2	1	0	0	0	0	0	0	0	14	0
backreef	20B	3	A	1	0	9	0	2	0	0	0	2	0	3	0	0	0	0	0	3	0	0	0	0	6	0	0	9	0
petit Rameau	15	1	E	0.1	0	0	8	0	7	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
petit Rameau	15	2	D	0.5	0	0	0	4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	12	0	0
petit Rameau	15	3	D	1.2	0	0	1	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	2	0	0
petit Rameau	15	4	D	2	0	0	0	2	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	3	0	0
petit Rameau	15	5	D	4	0	0	0	15	10	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	12	0	0
petit Rameau	15	6	E	5.2	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
petit Rameau	16	1	F	0.1	0	0	24	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
petit Rameau	16	2	B	0.3	0	23	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	3	0	3	3	14
petit Rameau	16	3	D	1.2	0	18	0	1	6	0	0	0	0.5	0	0	0	0	0	0	0.5	0	0	0	0	0	0	18	3	0
petit Rameau	16	4	D	1.4	0	19	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	18	0	0
petit Rameau	16	5	B	2.7	0	14.5	0	0	10	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	10	0	4
petit Rameau	16	6	A	5	0	0	0	0	20	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0	0	0	0
petit Rameau	16	7	A	6	0	10	0	0	9	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	10
petit Rameau	16	8	E	7	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
petit Rameau	17	1	F	0.3	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
petit Rameau	17	2	D	1	0	0	24	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0
petit Rameau	17	3	A	2	0	8	0	0	0	8	0	4	0	0	0	0	0	0	3	2	0	0	0	0	0	0	8	0	0
petit Rameau	17	4	A	2.5	0	6	0	0	0	0	0	0	0	1	0	0	4	0	1	2	0	0	0	0	2	0	4	4	0

LOCATION	SITE #	LATITUDE	LONGITUDE
Petit Bateau	1	12d38'04.20"N	61d21'35.40"W
Petit Bateau	2	12d38'01.20"N	61d21'34.80"W
Petit Bateau	3	12d37'56.40"N	61d21'38.40"W
Petit Bateau	4	12d38'03.00"N	61d21'43.80"W
Jamesby	5	12d37'45.00"N	61d21'37.20"W
Jamesby	6	12d37'42.50"N	61d21'36.60"W
Jamesby	7	12d37'42.50"N	61d21'37.80"W
Jamesby	8	12d37'46.20"N	61d21'37.80"W
Baradal	T1	12d38'00.90"N	61d21'15.12"W
Baradal	T2	12d38'00.66"N	61d21'16.74"W
Baradal	T3	12d38'03.12"N	61d21'20.40"W
Jamesby	T4	12d37'40.92"N	61d21'38.04"W
Jamesby	T5	12d37'42.42"N	61d21'35.70"W
Jamesby	T6	12d37'45.66"N	61d21'36.60"W
Petit Bateau	T7	12d37'54.90"N	61d21'38.64"W
Petit Bateau	T8=2	12d38'01.20"N	61d21'34.80"W
Petit Bateau	T9	12d38'02.70"N	61d21'42.54"W
Petit Bateau	T10=1	12d38'04.20"N	61d21'35.40"W
Petit Tabac	T11	12d37'23.70"N	61d20'50.22"W
Petit Tabac	9	12d37'23.28"N	61d20'20.76"W
Petit Tabac	10	12d37'21.36"N	61d20'56.34"W
Petit Tabac	11	12d37'24.24"N	61d20'59.34"W
Petit Rameau	T15	12d38'09.54"N	61d21'39.54"W
Petit Rameau	T16	12d38'22.80"N	61d21'32.28"W
Petit Rameau	T17	12d38'12.30"N	61d21'29.04"W
backreef(D1)	T13	12d38'04.50"N	61d21'01.80"W
backreef(D1)	T14	12d37'32.76"N	61d21'33.18"W
backreef (D2)	T18	12d37'40.56"N	61d21'16.98"W
backreef (D2)	T19	12d38'15.90"N	61d21'02.52"W
backreef (D2)	T20	12d38'45.78"N	61d21'35.58"W
AGRRA-SiteA	site A	12d38'00.48"N	61d20'56.88"W
AGRRA-SiteB	site B	12d38'00.48"N	61d20'56.68"W
AGRRA-SiteC	site C	12d37'48.06"N	61d21'04.02"W
AGRRA-SiteD	site D	12d38'08.58"N	61d20'55.38"W
AGRRA-SiteE	site E	12d38'08.58"N	61d20'54.46"W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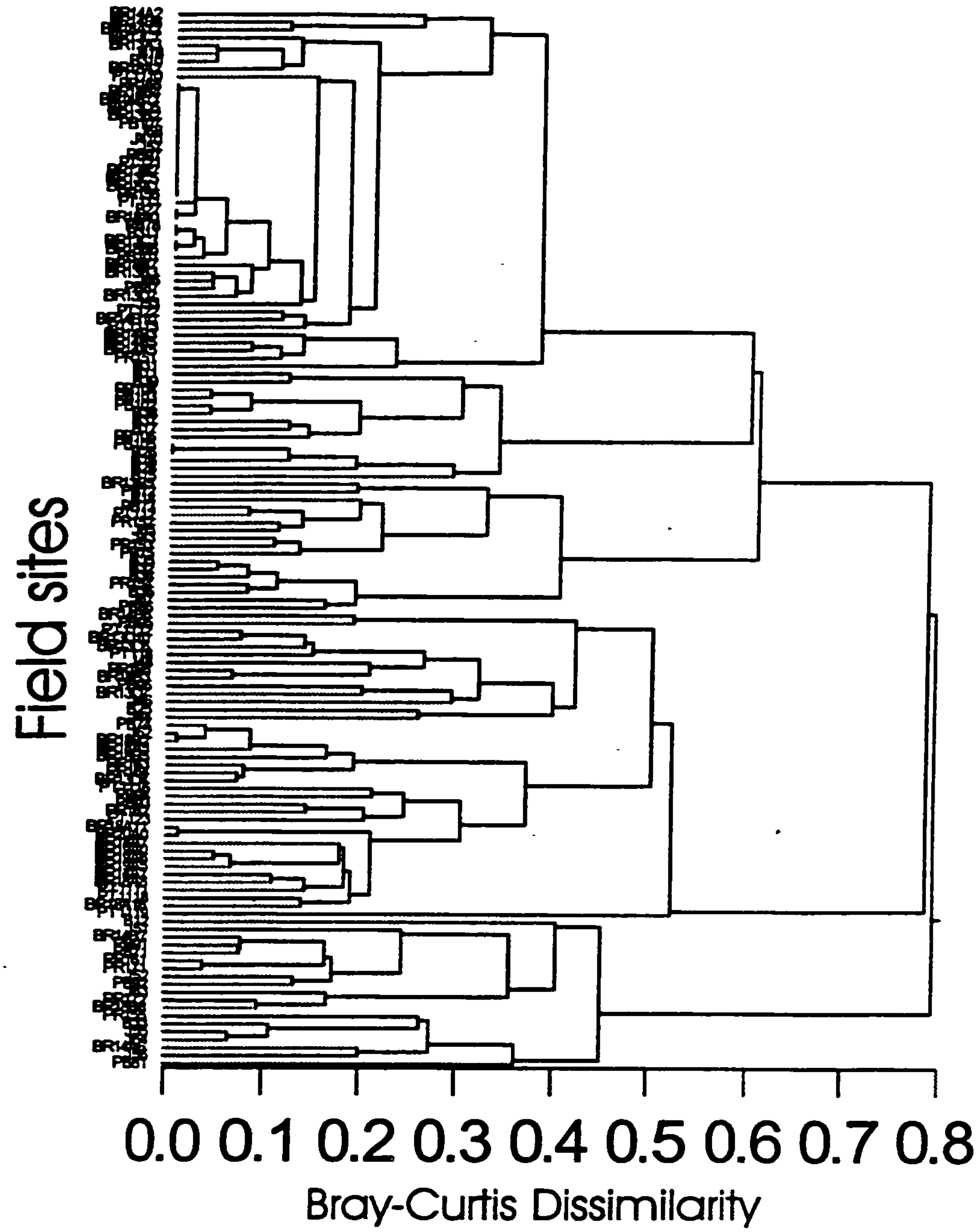
Bray-Curtis Dissimilarity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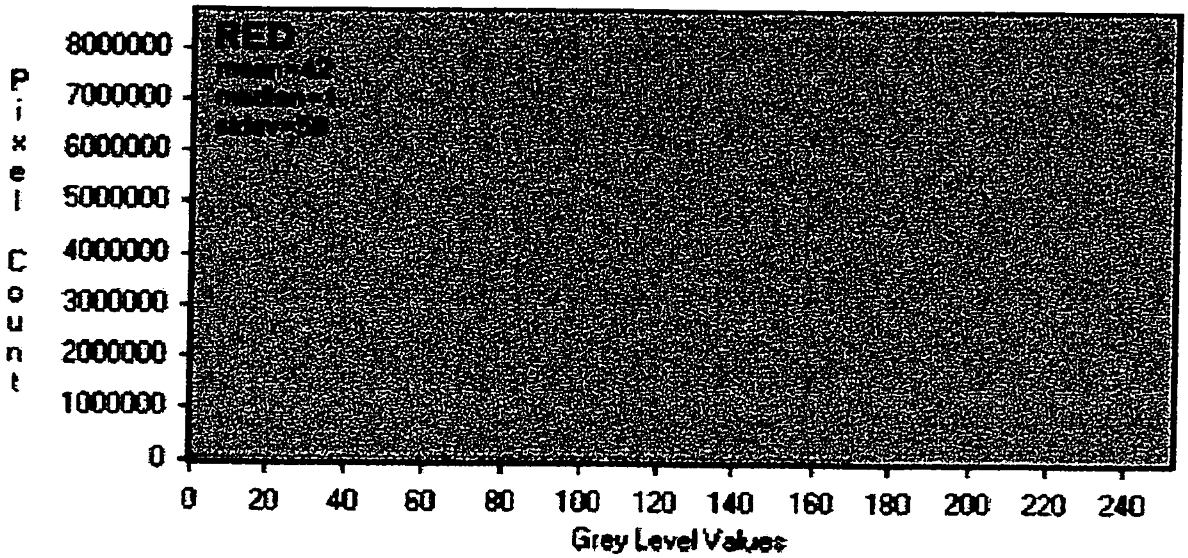
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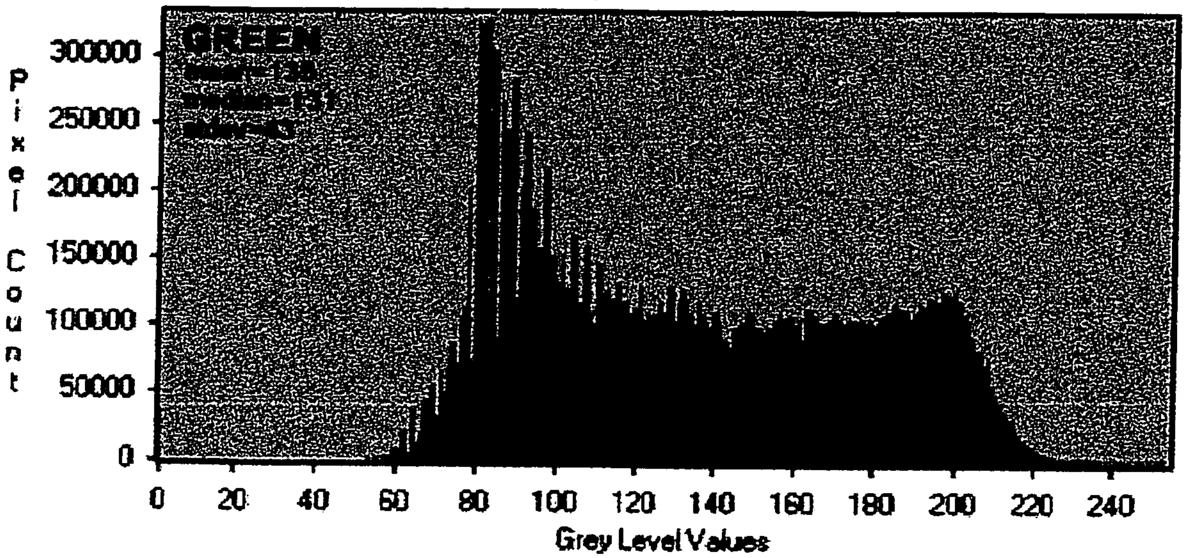
Grey Level Values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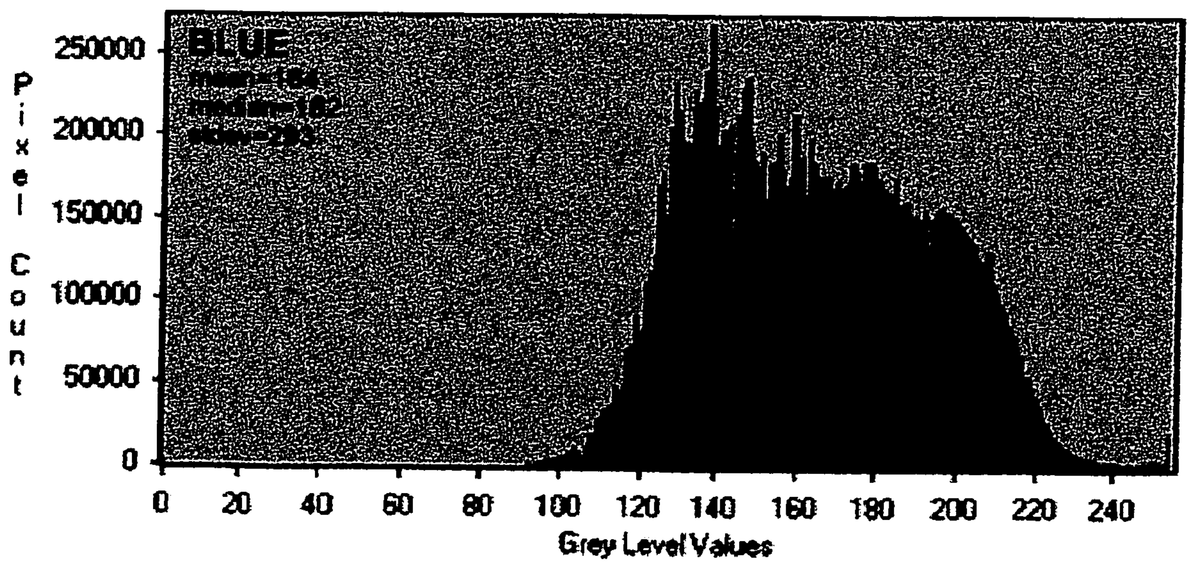
Grey Level Values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Grey Level Values

TRAINING SITE SIGNATURE STATISTICS:

Value: 1
Name: A-Coral
Description: Mixed coral community

Channel	Mean	Std. Dev.
4	27.70772	42.31260
5	86.36117	43.12625
6	87.91112	34.90845

Samples: 3353

Value: 2
Name: B-DCoral
Description: Dead corals and mixed algae community

Channel	Mean	Std. Dev.
4	168.25000	35.82948
5	177.01689	25.54090
6	142.30574	34.11848

Samples: 592

Value: 4
Name: C-Seagrass
Description: Seagrass on sand with minor macroalgae

Channel	Mean	Std. Dev.
4	98.58447	69.41977
5	176.77930	26.76258
6	150.01979	30.32083

Samples: 657

Value: 5
Name: D-Macro
Description: Macroalgae dominated (various substrates)

Channel	Mean	Std. Dev.
4	29.34146	18.82068
5	76.46341	19.38204
6	49.98955	20.93019

Samples: 287

Value: 7
Name: E-Sand
Description: Sand dominted (depth <6m)

Channel	Mean	Std. Dev.
4	52.69384	73.01339
5	164.23459	46.83521
6	180.88379	33.17094

Samples: 5533

Value: 8
Name: F-Rubble
Description: Rubbles\Beach rock dominated

Channel	Mean	Std. Dev.
4	240.34123	13.61443
5	225.38863	12.19784

6	181.61611	18.55195

Samples: 422

Value: 9
Name: G-Deep
Description: Deep water (6m-10m)

Channel	Mean	Std. Dev.
4	0.05180	1.76890
5	66.99702	8.74905
6	87.91559	14.18636

Samples: 23456

Value: 11
Name: H-Beach
Description: Beach sand

Channel	Mean	Std. Dev.
4	255.00000	0.00100
5	255.00000	0.00100
6	254.99733	0.07298

Samples: 1500

TRAINING SITE SEPARABILITY MEASURE: Bhattacharrya Distance

Average Separability: 1.841930
Minimum Separability: 1.158351
Maximum Separability: 2.000000
Signature pair with Minimum Separability: (A-Coral ,D-Macro)

	A-Coral	B-DCoral	C-Seagrass	D-Macro	E-Sand	F-Rubble	G-Deep
B-DCoral	1.765207						
C-Seagrass	1.593330	1.323972					
D-Macro	1.158351	1.925923	1.934957				
E-Sand	1.794575	1.934605	1.453380	1.996965			
F-Rubble	1.999229	1.471047	1.721665	2.000000	1.989259		
G-Deep	1.625103	1.999915	1.999989	1.898775	1.987787	2.000000	
H-Beach	2.000000	1.999999	2.000000	2.000000	1.999999	1.999999	2.000000

CLASSIFICATION REPORT:

Name	Code	Pixels	Image	Thres	Bias
A-Coral	1	3003958	17.41	3.00	1.00
B-DCoral	2	1280339	7.42	3.00	1.00
C-Seagrass	4	2083358	12.07	1.50	0.75
D-Macro	5	190090	1.10	3.00	1.00
E-Sand	7	5295790	30.69	3.00	1.00
F-Rubble	8	205528	1.19	3.00	1.00
G-Deep	9	5137757	29.77	3.00	1.00
H-Beach	11	60454	0.35	3.00	1.00
NULL	0	0	0.00		
	Total	17257274	100.00		