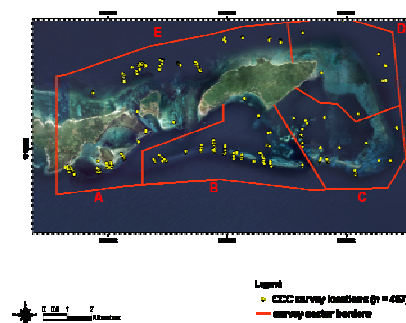


CORAL CAY CONSERVATION

PROJECT BAY ISLANDS

ROATÁN – EAST END & BARBARETTA

**An analysis of baseline marine ecological data
gathered from the eastern region between
April 2004 and March 2006**



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EXECUTIVE SUMMARY

Between April 2004 and March 2006, Coral Cay Conservation (CCC) undertook the third and final phase of Project Bay Islands, in partnership with Proyecto de Manejo Ambiental de Islas de la Bahía (PMAIB). The results of the first two phases have previously been presented in Taylor et al, 2004 (Roatán South Shore) and O'Farrell et al, 2005 (Roatán Northwest).

From the project base on Saint Helene (a.k.a. Santa Helena), teams of survey divers conducted total of 467 survey dives. In all, 36 kilometres of reef were assessed at an average of 500m intervals, from a depth of 28m to approximately 1m.

On each dive, surveyors gathered data on almost 300 variables, including 170 species of fish, 56 species of algae and 42 species of hard corals, as well as recording oceanographic data and the presence of negative impacts, such as anchor damage and sewage. Because the location of each survey site was recorded with a Global Positioning System (GPS) unit, the data could then be overlaid onto maps and analysed spatially as well as statistically.

Coral cover on the eastern reefs was found to be generally lower than at the northwest of the island of Roatán, although staghorn coral (*Acropora cervicornis*) was found to be more abundant. Macroalgal coverage was found to be low to moderate, possibly as a result of the presence of moderate abundances of herbivorous grazers, and the importation by the prevailing current patterns of water from the open seas to the east, which is likely to be low in terrigenous nutrients. Overall, the key areas of ecological health were found south of the island of Barbaretta.

Comparison with work conducted previously in the region implies that the reefs around the east of the island may have been subject to accelerated ecological degradation in recent years, possibly as a result of unregulated fishing of finfishes and commercially important invertebrates, such as lobster and queen conch.

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1 INTRODUCTION

1.1 CORAL CAY CONSERVATION

Effective coastal zone management, including conservation of coral reefs, requires a holistic and multi-sectoral approach, which is often a highly technical and costly process and one that many tropical countries cannot adequately afford. With appropriate training, non-specialist, self-financing volunteer divers have been shown to be able to provide valuable data for coastal zone management at little or no cost to the host country (Hunter and Maragos, 1992; Mumby et al., 1995; Wells, 1995; Darwall and Dulvy, 1996 and Erdmann et al., 1997). This technique has been pioneered and successfully applied by Coral Cay Conservation (CCC), a British not-for-profit organisation.

Founded in 1986, CCC is dedicated to ‘providing resources to protect livelihoods and alleviate poverty through the protection, restoration and sustainable use of coral reefs and tropical forests’ in collaboration with governmental and non-governmental organisations within a host country. CCC does not charge the host country for the services it provides and is primarily self-financed through a pioneering volunteer participatory scheme whereby international volunteers are given the opportunity to join a phase of each project in return for a financial contribution towards the project costs. Under the guidance of qualified and experienced project scientists, the volunteers undergo an intensive training programme in marine life identification and underwater survey techniques, prior to assisting in the acquisition of data. Finances generated from the volunteer programme allow CCC to provide a range of services, including data acquisition, assimilation and synthesis, conservation education, technical skills training and other capacity building programmes. CCC is associated with the Coral Cay Conservation Trust (the only British-based charity dedicated to protecting coral reefs).

This report presents the results from the eastern region of the Bay Island of Roatán, from surveys conducted between April 2004 and March 2006. For a more comprehensive background to the project, please refer to the CCC report Project Bay

Islands – Roatán South Shore (Taylor et al, CCC, 2004); for further information on the region, please refer to Honduras: Caribbean Coast (Harborne et al, CCC, 2001).

1.2 AIMS AND OBJECTIVES

Throughout the course of Project Bay Islands, CCC has developed a programme of surveys, training and conservation education aimed at assessing the status of local reefs and improving environmental awareness amongst neighbouring communities (Harborne et al., in press).

The primary aims of the project were to:

- 1 Map the benthic and fish communities
- 2 Provide data on reef health and threats to current reef health
- 3 Continue the monitoring programme of Project Utila
- 4 Provide training opportunities for local counter-parts and environmental awareness programmes (Table 1).

AIM	OBJECTIVE	ANTICIPATED OUTPUTS
☞ Resource assessment.	❶ Undertake a scientific survey of Roatán's reefs to document the benthic and fish communities. ❷ Conduct studies on climatic, oceanographic and anthropogenic variables affecting the reefs. ❸ Provide management tools and recommendations.	📄 Baseline database and description of reef communities. 📄 Documentation of gross climatic, oceanographic and anthropogenic variables. 📄 Management recommendations.
☞ Reef health assessment.	❶ Undertake 'Reef Check' surveys to quantitatively assess benthic and fish communities and anthropogenic impacts. ❷ Establish a Reef Check database for Roatán. Provide data for the global Reef Check databases. ❸ Provide management tools and recommendations.	📄 Quantitative assessment of reef health. 📄 Data set for comparison with future surveys. 📄 Information on the change of benthic communities over time. 📄 Management recommendations.
☞ Socio-economics.	❶ Undertake a basic assessment of anthropogenic impacts around Roatán. ❷ Provide management tools and recommendations.	📄 Data set for future comparison 📄 Management recommendations.
☞ Training and conservation education.	❶ Provide scientific and SCUBA training for CCC volunteers and local counterparts. ❷ Improve local awareness of marine resources, their use and protection. ❸ Begin to develop a sense of community stewardship in managing the coastal zone.	📄 Trained project members. 📄 Advice on coastal zone management issues around Roatán. 📄 Increased awareness amongst local communities.

TABLE 1 **MAIN AIMS, OBJECTIVES AND ANTICIPATED OUTPUTS OF *PROJECT BAY ISLANDS*, ROATÁN**

The aims of *Project Bay Islands* extended from the work conducted in Utila and continued to develop through the work undertaken around the east of the island. This report is concerned with the baseline data gathered around Saint Helene and Barbaretta.

2 METHODS

2.1 VOLUNTEER TRAINING

Efficient and effective training is a vital component of any volunteer programme in order to allow participants to quickly gain the required identification and survey skills that allow them to collect accurate and useful data. CCC uses an intensive two-week training programme that has been constantly refined since 1990. The programme, outlined below and in Tables 2a & 2b, is designed to provide volunteers who may have no previous biological knowledge with the skills necessary to collect useful and reliable data. The primary aim of the lecture programme is to give the volunteers the ability to discern the specific identification characteristics and relevant biological attributes of the species that they will encounter during their diving surveys. The training programme is co-ordinated by the Project Scientist and the Science Officer and involves two lectures and two dives each day along with de-briefings and evening audio-visual presentations. Volunteers are also encouraged to snorkel and utilise the identification guides to ensure a thorough understanding of the information given in the lectures.

An integral component of the training schedule is a series of testing procedures to ensure that each volunteer achieves a satisfactory standard. Along with the completion of a series of photo ID tests, volunteers are required to take three in-water validation exercises to assess the quality of data collected by CCC volunteers during surveys:

- **Coral Validation**

A series of approximately 25 corals is pointed out during a ‘spot’ dive with a member of science staff to test the ability of volunteers to correctly identify coral species in-situ.

- Benthic Validation

The benthic validation exercise takes place on a representative transect which is set up and previously surveyed by on-site science staff. Volunteers are required to complete the transect as outlined in the baseline survey methodology and identify and quantify all hard and soft corals, algae and sponges with the transect area.

- Fish Validation

Since it is impossible to compare volunteer fish data to a reference data set, validation of fish surveys are conducted by measuring consistency between pairs of surveyors. During a dive, volunteers are required to survey all fish observed within a 20-minute period, including abundance ratings defined by the DAFOR scale outlined in Table 3.

The Bray-Curtis similarity coefficient is used to compare pairs of results recorded by volunteers and science staff during the fish and benthic validations. Volunteers are required to obtain a pass mark of greater than 80% in all tests and validations before being allowed to survey. This minimum standard is maintained by the Project Scientists and Science Officers and the regular presence of CCC head office scientific staff at the expedition bases. CCC has collated a standardised set of lecture notes to ensure these high training standards continue.

	Friday	Saturday	Sunday No diving	Monday	Tuesday	Wednesday	Thursday	Friday
← AM		<u>Lecture 3</u> ► Dangerous marine animals <u>Safety briefings</u> <u>Practical</u> ► Scuba kit allocation ► PADI AOW Elective Dive: PPB with new diver volunteers. ► Rescue Diver modules 1&2	<u>Expedition Camp Duties</u> <u>Lecture 5</u> ► Intro to the biology and ID of marine plants and algae	<u>Lecture 6</u> ► Intro to the Cnidaria - biology and taxonomy <u>Practical 2</u> ► PADI AOW Elective Dive: PPB (6m) with new diver volunteers with brief Reef Orientation – Cnidaria & Algae	<u>Lecture 8i</u> ► Hard coral ID – target groups 1 <u>Lecture 8ii</u> ► Hard coral ID – target groups 2 <u>Practical 4</u> ► Hard coral targets ID (scuba-18m / snorkel)	<u>Lecture 10</u> ► Intro to fish biology, ecology & identification <u>Lecture 11</u> ► Main Fish families <u>Practical 5</u> ► Fish ID – Families (scuba 18m/snorkel) <u>Review</u> ► Fish ID – Families	<u>Lecture 12ii</u> ► Fish ID – target species 2 <u>Practical 7</u> ► Fish ID – target species 2 (scuba-18m) <u>Review</u> ► Fish ID – target species 2	<u>Lecture 13i</u> ► Invert. ID 1 <u>Lecture 13ii</u> ► Invert. ID 2 <u>Practical 9</u> ► Invert. ID (scuba-18m) <u>Review</u> ► Invert. ID
← PM	<u>Orientation</u> ► Welcome & tour of facilities ► Expedition life & duties ► General health & safety ► CCC rules & regulations	<u>Review</u> ► Expedition Skills Development Programme schedule <u>Lecture 4</u> ► Intro to coral reef ecology <u>Practical</u> ► Orientation dive	<u>Practical 1</u> ► Marine plants & algae ID (snorkel) ► Specimen ID – reference collections <u>Review</u> Marine plants and algae	<u>Lecture 7</u> ► Intro to hard corals - biology and life-forms <u>Practical 3</u> ► ID – Cnidaria groups and hard coral life-forms (scuba- 16m / snorkel) <u>Review</u> ► Cnidaria & hard coral life forms	<u>Lecture 9</u> ► Soft corals and sponges – biology and ID <u>Practical 5</u> ► Hard/soft coral and sponges ID (scuba – 16m / snorkel) <u>Review</u> ► Hard/soft coral and sponges ID	<u>Lecture 12i</u> ► Fish ID – target species 1 <u>Practical 6</u> ► Fish ID – target species (scuba 16m) <u>Review</u> ► Fish ID – target species 1	<u>Practical 8</u> ► Fish ID – families and target species (scuba-18m/snorkel) <u>Review</u> ► Fish ID – target species	<u>Review</u> ► ID – coral, fish, inverts & algae <u>Practical Exam</u> ► Hard and soft coral ID –coral trail (scuba-16m/ snorkel)
EVE	<u>Lecture 1</u> ► Country Brief, Local culture and customs <u>Lecture 2</u> ► In-Country Partners and Project Background	<u>Review</u> ► Expedition Skills Development Programme schedule	<u>Review quiz</u> ► CCC health & safety regulations ► CCC dive standards ► Emergency procedures ► Local culture & customs	<u>Revision</u> ► Marine plants and algae <u>Examination</u> ► Marine Plants and algae (spot samples/slides)	<u>Revision</u> ► Hard and soft corals <u>Examination</u> Hard and soft Coral ID	<u>Review</u> ► Fish ID (pictionary) <u>Revision</u> ► Fish families and targets 1 ID	<u>Revision</u> ► Fish families and target species ID. <u>Examination</u> ► Fish ID	<u>Revision</u> ► Invertebrate ID (slides) <u>Lecture 14</u> ► Ropes & knots <u>Self-revision</u> ► ID – coral, fish, inverts & algae

TABLE 2A CCC SCIENCE TRAINING SCHEDULE (SKILLS DEVELOPMENT PROGRAMME) – WEEK 1

	Saturday	Sunday No diving	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday end of training
AM	Review ► ID – inverts & algae ID skills evaluation ► Inverts & algae (scuba 18m / snorkel) Review ► CCC dive standards ► PADI tables & quiz ► Boat safety ► Boat marshalling	Lecture 16 ► Intro to CCC Reef Survey forms, habitat classifications and use of Abundance Scales Practical 11 ► Practice CCC reef survey 2 (snorkel) ► Data entry onto CCC forms	Lecture 19 ► Intro to GPS Practical 14 ► Practice CCC Baseline Survey 3 dive (scuba 18 m) Followed by data entry on to survey forms Review ► GPS & knots	Practical 16 ► Practice Reef Check Survey 2 - fish - (scuba 18 m) Followed by Data entry onto CCC Reef Check forms Review ► Reef Check Belt survey - fish	Lecture 22 ► CCC data validation Review Benthic categories ID Skills validation ► Benthic line - Baseline and Reef Check (scuba-18m) Review Benthic validation assessment	Review ► CCC Reef Survey technique (baseline) Practical 13 ► Practice CCC Reef Survey 3 (scuba 18m) ► Data entry onto CCC forms	Practical 13 ► Practice CCC Baseline Survey dive ► Data entry onto CCC forms Validation retake if required ID skills in water evaluation if required (coral / inverts)	Survey dive + data collation
PM	Lecture 15 ► Intro to CCC Baseline Reef Survey Technique Practical 10 ► CCC Baseline Survey methods (dry run) ► CCC Baseline Survey practice 1 (scuba-16m) Review ► CCC Reef Survey technique (baseline)	Practical 12 ► Practice CCC Reef Survey 3 (snorkel) Review ► CCC Reef Survey technique (baseline) Lecture 17 ► Data entry to CCC computer database – (groups of 4)	Lecture 20 ► Reef Check Intro & Survey Method Practical 15 ► RC Practise Survey – Dry Run – fish, inverts and benthic ► RC Practise Survey 1 – line point (snorkel) Data entry on to CCC Reef Check survey forms and computer – benthic	Practical 17 ► Practice Reef Check Survey 2 -Belt inverts (scuba 16 m) Followed by data entry onto CCC Reef Check forms CCC Reef Check data entry on to computer – fish, inverts (groups of 4). Review ► Reef Check Belt survey - inverts	Review Reef Fish ID Skills validation ► Fish (scuba-10m) Review ► Validation assessment	PADI EFR ► Modules Skills validation ► Retakes if required (fish or benthic) Review ► Validation Assessment ► Practice CCC Baseline Survey dive ► CCC data entry on to forms	PADI EFR ► Modules Practical 14 ► Practice CCC Baseline Survey dive ► Data entry onto CCC forms Validation retake if required ID skills in water evaluation if required (coral / inverts)	Survey dive + data collation Safety brief ► Night-diving procedures
EVE	Revision ► Invertebrate ID (slides) Examination ► Invertebrate ID	Lecture 18 ► CCC data: analysis & uses ID skills evaluation ► Re-takes if required	Review Reef Check line point – survey results ID skills evaluation ► Re-takes if required	Lecture 21 ► Other survey methods: ID skills evaluation ► Re-takes if required	Advanced lecture 1 ► Conservation of coastal and marine habitats (mangrove / seagrass / reefs)	Advanced lecture 4 ► Threats to Reefs 1 Retakes of ID tests if required Data entry - database	Advanced lecture 7 ► Global and regional coral reef initiatives Data entry - database	Data entry – database Optional night dive

TABLE 2B CCC SCIENCE TRAINING SCHEDULE (SKILLS DEVELOPMENT PROGRAMME) – WEEK 2

2.2 BASELINE TRANSECT TECHNIQUE

All CCC projects work from a standard baseline survey technique developed by CCC for the rapid assessment of biological and physical characteristics of reef communities by trained volunteer divers. Following the intensive training programme described above, CCC's techniques have been shown to generate precise and consistent data appropriate for baseline mapping (Mumby et al., 1995). All surveys are co-ordinated by the onsite science staff to ensure accurate and efficient data collection.

CCC's standard baseline transect survey technique utilises a series of plot-less transects, perpendicular to the reef, starting from the 28 metre contour and terminating at the reef crest or in very shallow water. Benthic and fish surveys are focused on life forms or families along with a pre-selected number of target species that are abundant, easily identifiable or ecologically or commercially important.

Because most transects require two or more dives to complete, transect surveys are usually divided up into sections (or 'sub-transects') with surveys of each sub-transect carried out by a team of four trained divers divided into two buddy pairs (A and B) as shown in Figure 1. At the start point of each sub-transect, Buddy Pair B remain stationary with Diver 3 holding one end of a 10 m survey line, whilst Buddy Pair A swims away from them, navigating up or along the reef slope in a pre-determined direction until the 10 m line connecting Diver 1 and 3 becomes taut. Buddy Pair A then remain stationary whilst Buddy Pair B swims towards them. This process is repeated until the end of the planned dive profile, at which point, a sub-surface buoy is tied off to mark the end of that sub-transect and the start point for the next survey team. Survey teams signal to the boat marshal to mark the position of this buoy using a Global Positioning System (GPS).

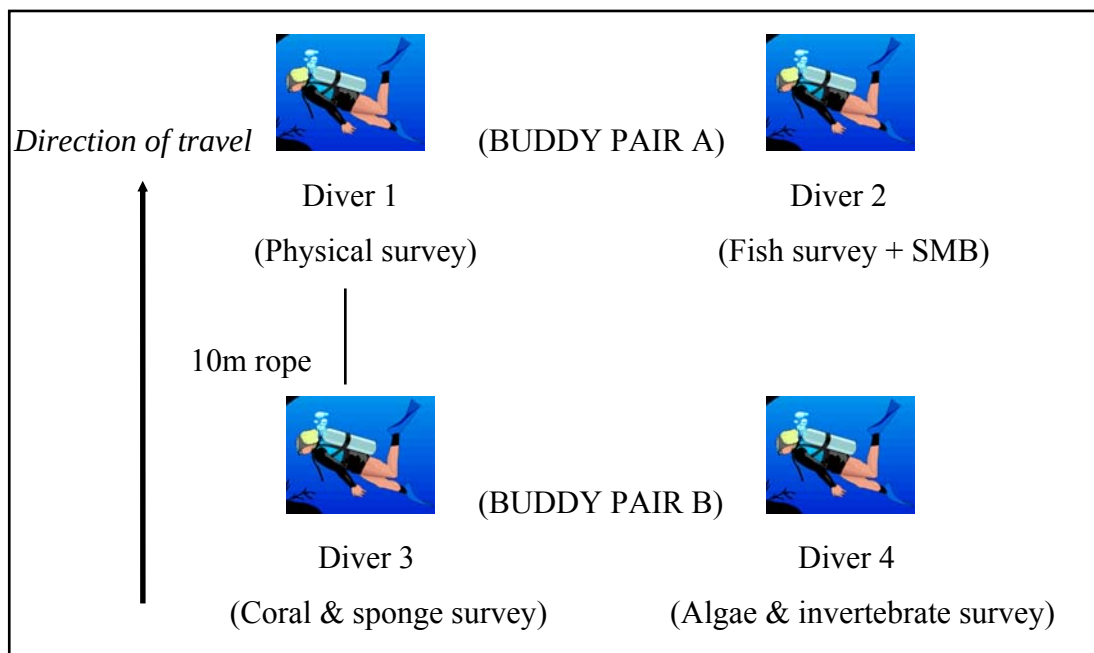


FIGURE 1 SCHEMATIC DIAGRAM OF A BASELINE SURVEY TEAM SHOWING POSITIONS AND DATA GATHERING RESPONSIBILITIES OF DIVERS.

During the course of each sub-transect survey, divers may have traversed two or more apparently discrete habitat types, based upon obvious gross geomorphologic (e.g. forereef, escarpment or lagoon) or biological differences (e.g. dense coral reef, sand or rubble; Figure 2). Data gathered from each habitat type are recorded separately for subsequent analysis. Each species, life form or substratum category within each habitat type encountered is assigned an abundance rating from the scale shown in Table 3.

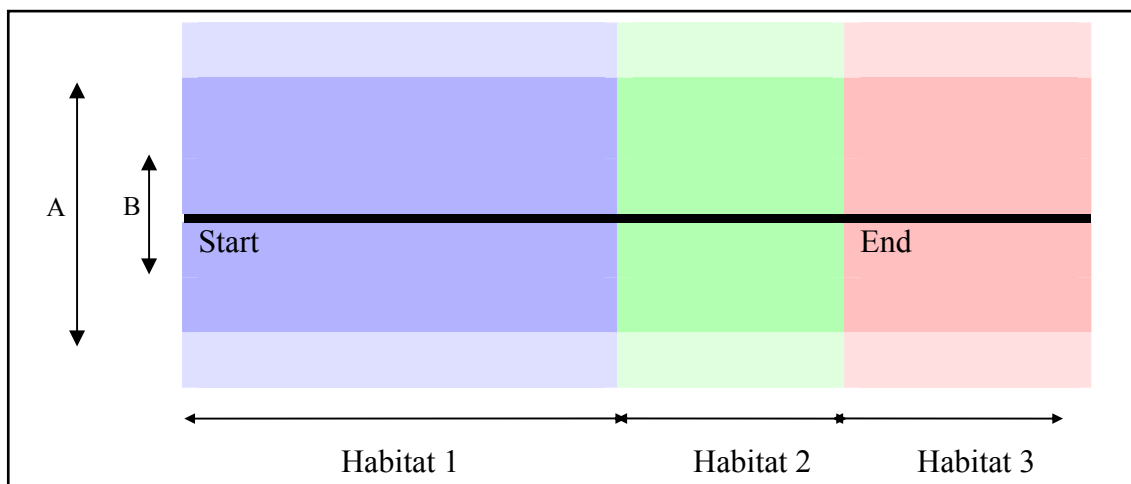


FIGURE 2 SCHEMATIC DIAGRAM (AERIAL ASPECT) OF AN EXAMPLE OF A REEF AREA MAPPED BY DIVERS DURING A SUB-TRANSECT SURVEY. SOLID LINE REPRESENTS IMAGINARY SUB-TRANSECT LINE. DASHED LINES AND SHADED AREAS REPRESENT AREAS SURVEYED (A = 5M WIDE SWATHE SURVEYED BY DIVERS 1, 2 AND 4; B = 2 M WIDE SWATHE SURVEYED BY DIVER 3). BENTHIC DATA FROM HABITATS 1, 2 AND 3 (E.G. REEF, SAND AND RUBBLE) ARE RECORDED SEPARATELY.

Abundance rating	Coral and algae	Approximate percentage cover (from Dahl 1981, in English et al 1997)	Fish and invertebrates (number of individuals)
0	None	0	0
1	Rare	1-10	1-5
2	Occasional	11-30	6-20
3	Frequent	31-50	21-50
4	Abundant	51-75	51-250
5	Dominant	76-100	250+

TABLE 3: ORDINAL SCALE (DAFOR) ASSIGNED TO LIFE FORMS AND TARGET SPECIES DURING BASELINE SURVEYS.

During the course of each survey, certain oceanographic data and observations on obvious anthropogenic impacts and activities are recorded at depth by the divers and from the surface support vessel. Water temperature readings ($\pm 0.5^{\circ}\text{C}$) are taken from the survey boat using a bulb thermometer at the sea surface. The survey team also records the temperature at the maximum survey depth (i.e. at the start of the survey). Similarly, the salinity is recorded using a hydrometer and a water sample taken from both the surface and the maximum survey depth. Water visibility, a surrogate of turbidity (sediment load), is measured both vertically and horizontally. A secchi disc is used on the survey boat to measure vertical visibility through the water column (Figure 3). Secchi disc readings are not taken where the water is too shallow to obtain a true reading. Horizontal visibility through the water column is measured by divers' estimates while underwater. Survey divers qualitatively assessed the strength and direction of the current at each survey site. Direction is recorded as one of eight compass points (direction current is flowing towards) and strength is assessed as being 'None', 'Weak', 'Medium' or 'Strong'. Similarly, volunteers on the survey boat qualitatively assessed the strength and direction of the wind at each survey site. Direction is recorded as one of eight compass points (direction wind is blowing from) and strength is assessed using the Beaufort Scale.

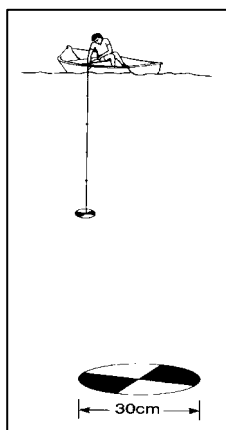


FIGURE 3 THE USE OF A SECCHI DISC TO ASSESS VERTICAL WATER CLARITY. THE SECCHI DISC IS LOWERED INTO THE WATER UNTIL THE BLACK AND WHITE QUARTERS ARE NO LONGER DISTINGUISHABLE. THE LENGTH OF THE ROPE FROM SURVEYOR TO THE DISC IS THEN RECORDED.

Natural and anthropogenic impacts are assessed both at the surface from the survey boat and by divers during each survey. Surface impacts are classified as 'litter', 'sewage', 'driftwood', 'algae', 'fishing nets' and 'other'. Sub-surface impacts are categorised as 'litter', 'sewage', 'coral damage', 'lines and nets', 'sedimentation', 'coral bleaching', 'fish traps', and 'other'. All information is assessed as presence / absence and then converted to binary data for analysis. Any boats seen during a survey are recorded, along with information on the number of occupants and the activity of the vessel. This activity is categorised as 'diving', 'fishing', 'pleasure', or 'commercial'.

Data collected from each sub-transect survey are transferred to recording forms prior to incorporation into CCC's database, which is compatible with a range of Geographic Information System (GIS) software used for spatial analysis. Each form is completed for each individual dive, although there may be more than one biological form depending on the number of habitats observed. The Boat Form holds data on the GPS co-ordinates of the dive along with oceanographic and climate data such as winds, currents, temperatures and salinities. The Physical Form holds data on the maximum and minimum depths of the dive, the aesthetic and biological ratings and also a reef profile drawn from the depths collected every 10 m. Finally the Biological Form(s) contain data on the reef zone, the major biotic and substratum features of the habitat and the ordinal ratings of each life form and target species.

2.3 BASELINE DATA ANALYSIS

2.3.1 OCEANOGRAPHIC, CLIMATIC AND ANTHROPOGENIC IMPACT DATA

Oceanographic and anthropogenic data, including water temperature, salinity, visibility, the strength and direction of currents and wind, natural and anthropogenic impacts, the presence of boats and the biological and aesthetic ratings are summarised graphically and via univariate statistics.

2.3.2 BENTHIC DATA

Benthic data are analysed in order to define the key habitats within the study area. CCC baseline transects are completed in a number of steps and data from each of these steps are recorded on individual forms by survey teams. Each of these forms is referred to as a 'site record'. Multivariate analysis techniques in PRIMER (Plymouth Routines in Multivariate Ecological Research) software are used to cluster the Site Records into several groups, which represent distinct benthic classes. Firstly, the similarity between benthic assemblages from each site record is measured quantitatively using the Bray-Curtis Similarity coefficient without data transformation. This coefficient has been shown to be a particularly robust measure of ecological distance (Faith *et al.*, 1987).

Agglomerative hierarchical cluster analysis with group-average sorting is then used to classify field data. Cluster analysis produces a dendrogram grouping Site Records together based on biological and substratum similarities. Site Records that group together are assumed to constitute a distinct benthic class. Characteristic species or substrata of each class are determined using Similarity Percentage (SIMPER) analysis.

To identify characteristic features, SIMPER calculates the average Bray-Curtis similarity between all pairs of intra-group samples (e.g. between all site records of the first cluster). Since the Bray-Curtis similarity is determined from the algebraic sum of contributions from each species, the average similarity between Site Records of the

first cluster can be expressed in terms of the average contribution from each species. The standard deviation provides a measure of how consistently a given species contributes to the similarity between Site Records. A good characteristic species contributes heavily to intra-habitat similarity and has a small standard deviation. The univariate summary statistics of average abundance of each species, life form and substratum category are also used to aid labelling and description of each benthic class.

Finally, the benthic class of each Site Record is combined with the geomorphological class assigned during the survey to complete the habitat label. The combination of a geomorphological class and benthic class to produce a habitat label follows the format described by Mumby and Harborne (1999).

2.3.3 FISH AND INVERTEBRATE DATA

Fish and invertebrate data are summarised graphically and via univariate statistics, along with more detailed examination of the data using Kruskal-Wallis (KS). Key species, as propounded by Hodgson and Liebler (2002), are examined to indicate the status of reef health and to suggest causes of any degradation.

2.4 GEOGRAPHIC INFORMATION SYSTEM

In a similar way to that in which extensive geographical data can be ‘simplified’ in the form of a topographical map, the development of GIS software and techniques allows marine ecological data to be manipulated in multi-dimensional space. Once appropriate analysis techniques have been applied, land-based managers and decision makers can ‘look below the surface’ without getting wet. The visual nature of GIS outputs facilitates the interpretation of such data by non-technical persons who may nonetheless be key decision makers. Because all CCC teams record the location of each survey on a handheld GPS unit, this allows the surveys to be ‘placed’ relative to each other on a map. Relationships between the data from the various survey sites can then be explored to highlight geographical regions of key interest.

Information can be represented in many ways in a GIS, from simple placement techniques (“this was found here”) to more intricate mapping techniques such as data contouring (“this area is ‘better’ than that area”). It is important to bear in mind that the outputs are produced from the data themselves; the maps are not merely ‘coloured in’ at particular places. This is because the GIS links the map and the database intrinsically, and therefore any data that are required for visual examination can be ‘called up’ on the screen. GIS is therefore not just a mapmaker; it is a tool that allows ongoing interaction between the decision-maker and the data. If further geographic/ecological data are gathered in the future, they can be added to the GIS, building a customisable instrument for visual interpretation of any data that can be represented at any point on Earth, above or below the sea.

The GIS map of Conservation Management Values contained in this report was created with the Inverse Distance Weighted function in the Spatial Analyst of *ArcMap* 8.3 (ESRI software).

3 RESULTS

3.1 SURVEYS CONDUCTED

Between April 2004 and March 2006, CCC survey teams produced 467 individual survey records (Figure 4). In all, 36 kilometres of reef were assessed at an average of 500m intervals, from a depth of 28m to approximately 1m.

On each dive, surveyors gathered data on almost 300 variables, including 170 species of fish, 56 species of algae and 42 species of hard corals, as well as recording oceanographic data and the presence of negative impacts, such as anchor damage and sewage. Because the location of each survey site was recorded with a Global Positioning System (GPS) unit, the data could then be overlaid onto maps and analysed spatially as well as semi-quantitatively. The resultant data have been analysed in a number of ways, namely:

- Results from oceanographic and geomorphological data [3.2]
- The presence and abundance of live hard coral and of other key biological indicators [3.3]
- The definition of ecologically distinct marine habitats [3.4]
- The generation of a management rating for each survey site (*Conservation Management Value*) [3.5]

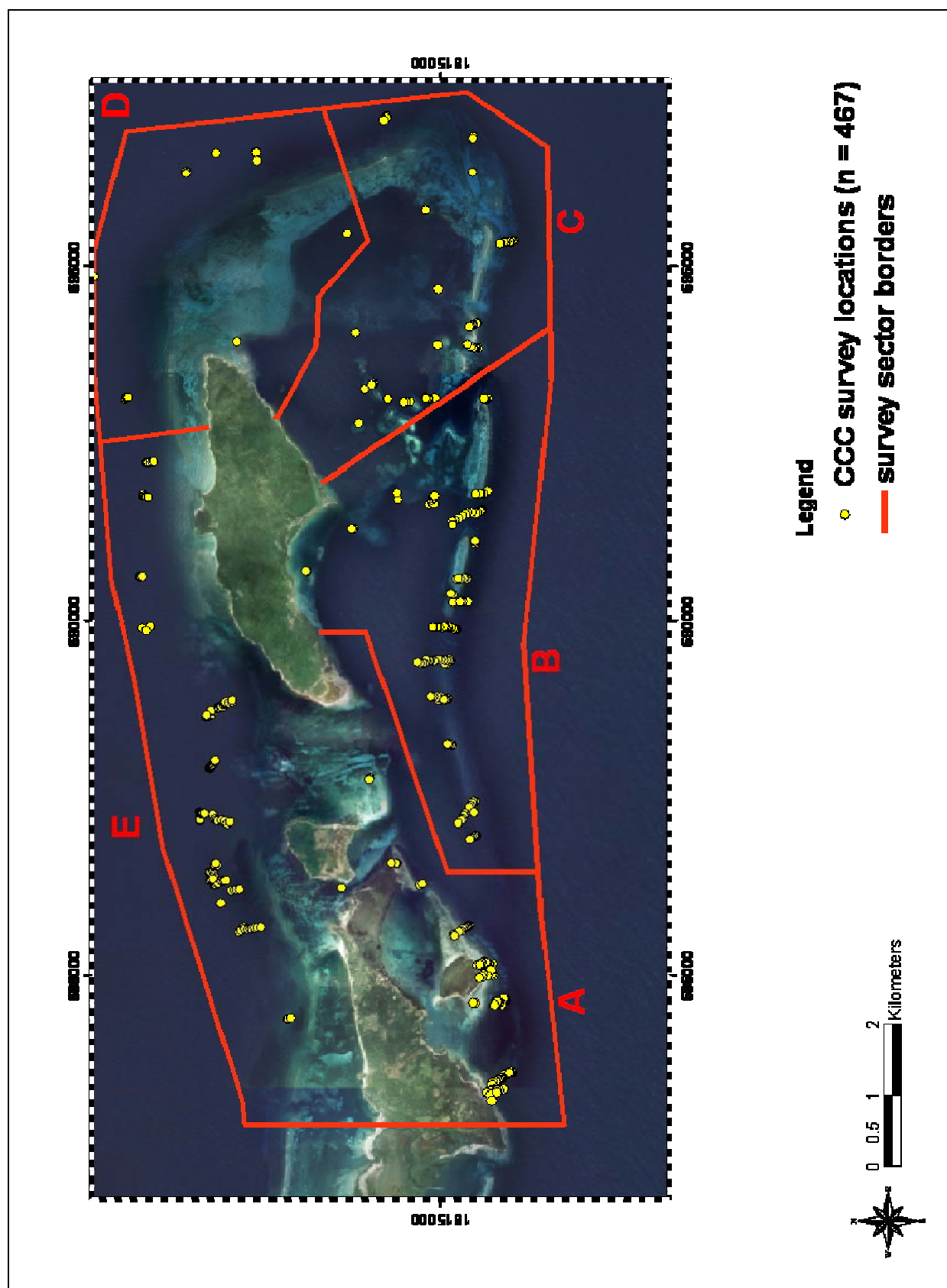


FIGURE 4

CCC SURVEY SITE LOCATIONS AT THE EAST END OF ROATÁN

3.2 RESULTS FROM OCEANOGRAPHIC AND GEOMORPHOLOGIC DATA

3.2.1 REEF PROFILES BY SECTOR

The known start depth of each survey sub-transect can be combined with the known distance of each dive to produce typical reef profiles for each sector (Table 4). It can be seen from these graphs that the steepest reef topography is found in Sector B, which is characterised by rock and coral escarpments; these are vertical at many sites. The shallowest profiles were recorded in Sector C, which is largely characterised by gently sloping topography. Sector E contains a large quantity of distinct spur-and-groove formations, dropping to a depth of below the 28m depth limit of CCC survey dives.

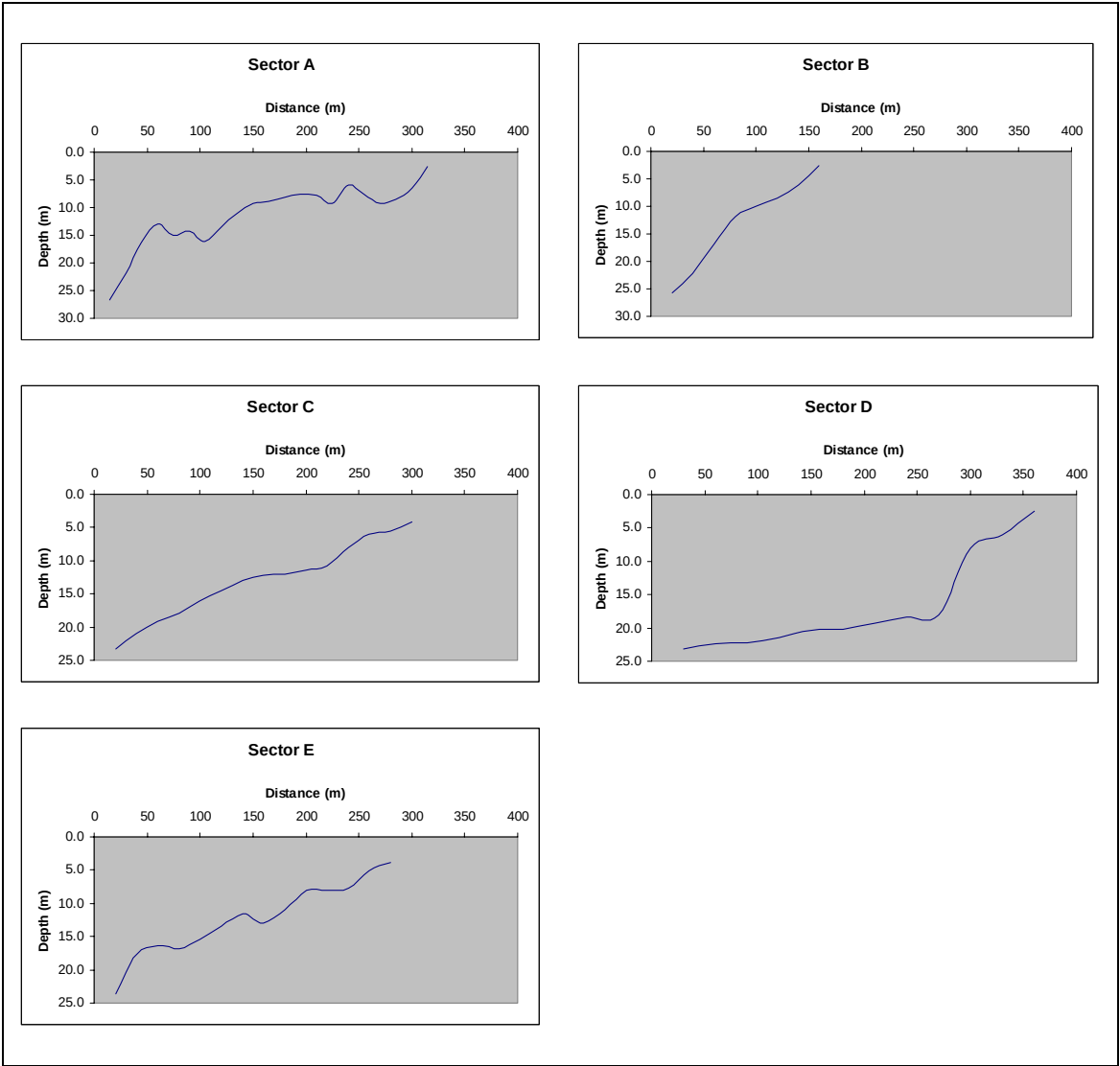


TABLE 4 TYPICAL REEF PROFILES BY SECTOR

3.2.2 WATER TEMPERATURE

Recordings of water temperature have produced results that are largely consistent with those recorded during the first two phases of Project Bay Islands, Roatán (Taylor et al, 2004; O'Farrell et al, 2005), with mean annual sea surface temperature found to be 28.8° C (Figure 5). However, the annual maximum of 29.9° C which was recorded in September 2005 varies from the results reported for 2002/2003, which returned a maximum value of 33.3 ° C, recorded in June. July, August and September had the highest incidences of coral bleaching, with observations being recorded on 31%, 32% and 34% of survey dives respectively. However, other variables may have influenced this result, such as prevalence of species vulnerable to bleaching on the particular transects surveyed in these months. As with previous project outputs, water temperature was found to decrease with increased depth (Figure 6), with the 5-10m depth class once again demonstrating the greatest variation between samples ($\delta = \pm 1.87^{\circ} \text{C}$; n=96).

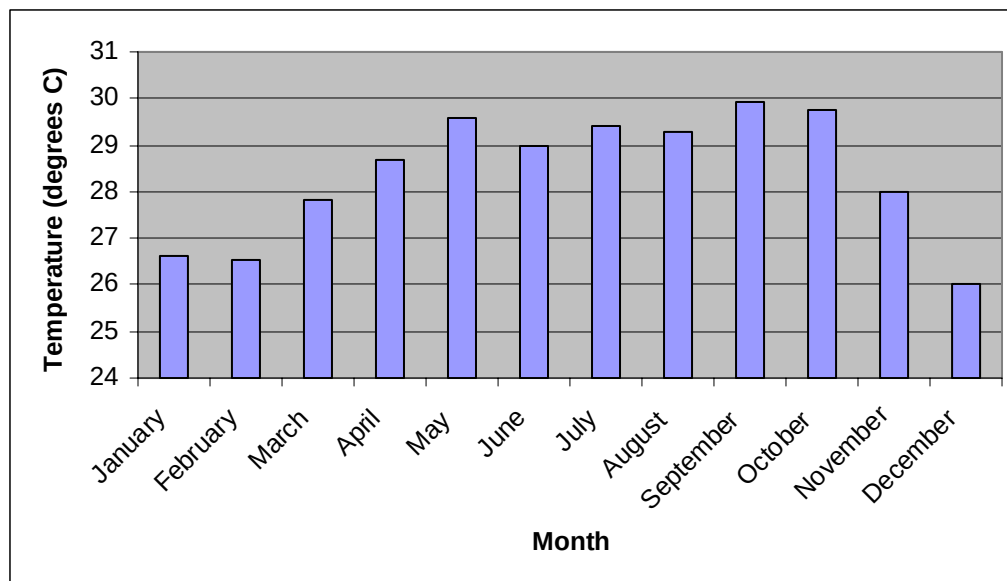


FIGURE 5 ANNUAL FLUCTUATIONS IN MEAN SURFACE WATER TEMPERATURE

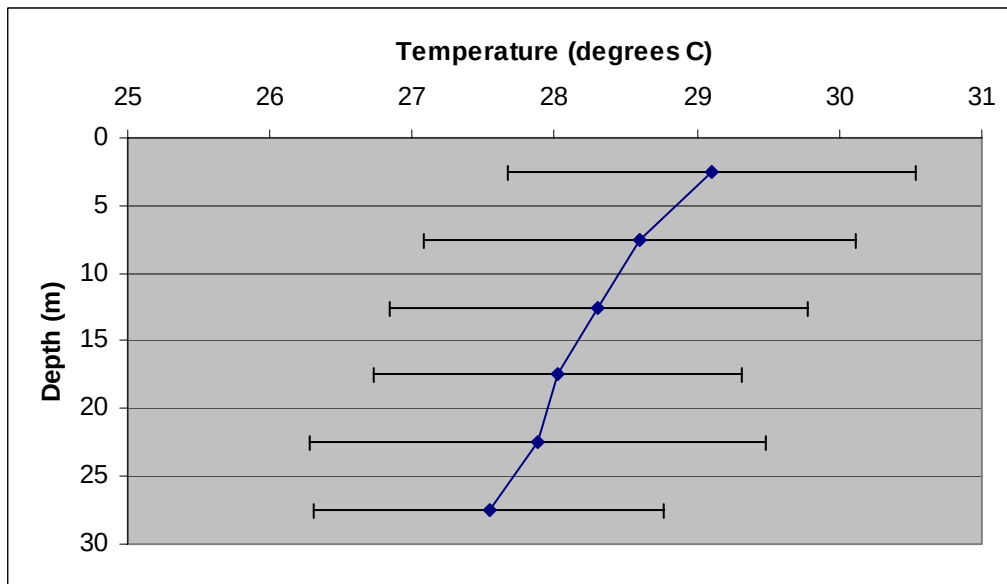


FIGURE 6 MEAN WATER TEMPERATURE IN 5M DEPTH CLASSES

3.2.3 SALINITY

Similarly, values recorded for salinity, both at the surface and within various depth classes are largely consistent with those recorded during the first two phases of the project (Taylor et al, 2004; O'Farrell et al, 2005), with the highest variation being recorded in the 0 – 5m class ($\delta = \pm 3.35$; $n=42$) - Figure 7. Mean salinity was 34.24‰, compared to 34.75‰ for the south shore data and 34.94‰ for the northwest data

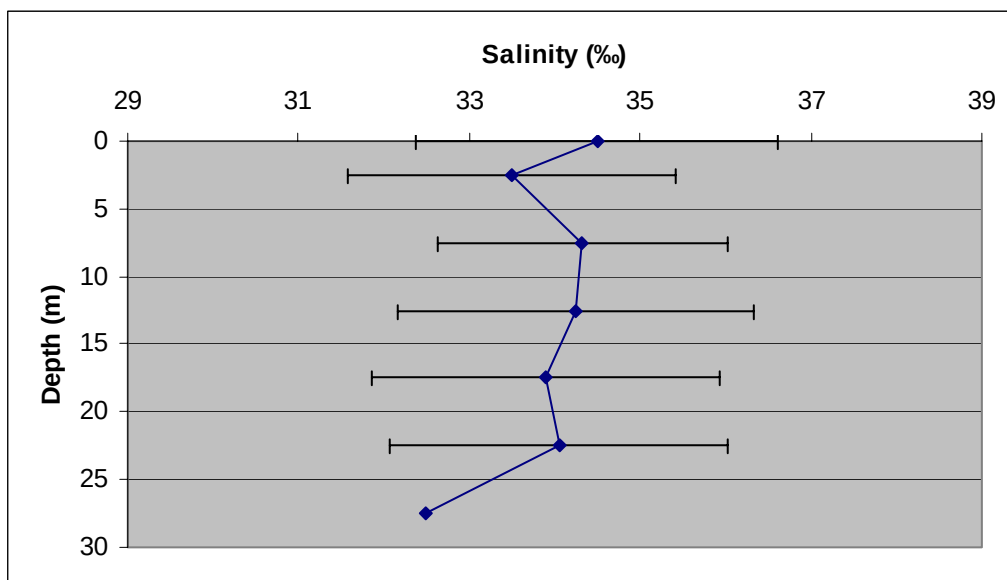


FIGURE 7 MEAN SALINITY IN 5M DEPTH CLASSES

3.2.4 CURRENT STRENGTH AND DIRECTION

The prevailing currents were found to be weak – medium north-westerlies (moving towards the northwest), with this group accounting for 54% of all observations (Figure 8). This current pattern is largely consistent with the overall current pattern of this region of the Caribbean. It can be assumed that many of the larvae for the Helene/Barbaretta region are recruited from reefs to the east, and that the reefs found here, in turn, may produce many of the larvae responsible for the population of the down-current reefs around the northwest of Roatán.

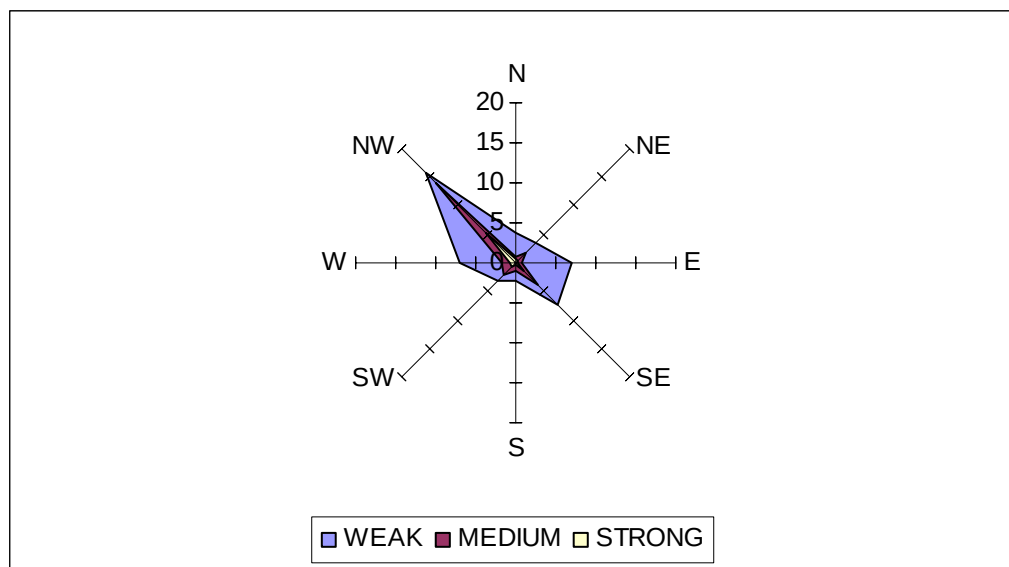


FIGURE 8 CURRENT STRENGTH AND DIRECTION AS A PERCENTAGE OF ALL OBSERVATIONS

3.2.5 WIND STRENGTH AND DIRECTION

By far the dominant wind direction was from the NE – SE, with this range accounting for 82% of all observations (Figure 9). Winds tend to weak, with Beaufort values of 1 -3 accounting for 62% of all observations (Table 5). No wind recorded on 6% of all surveys. The strongest winds were found from June to August (Beaufort 6). In October/November, the winds were found to swing around to the northwest (Figure 10), but returned to the east in December.

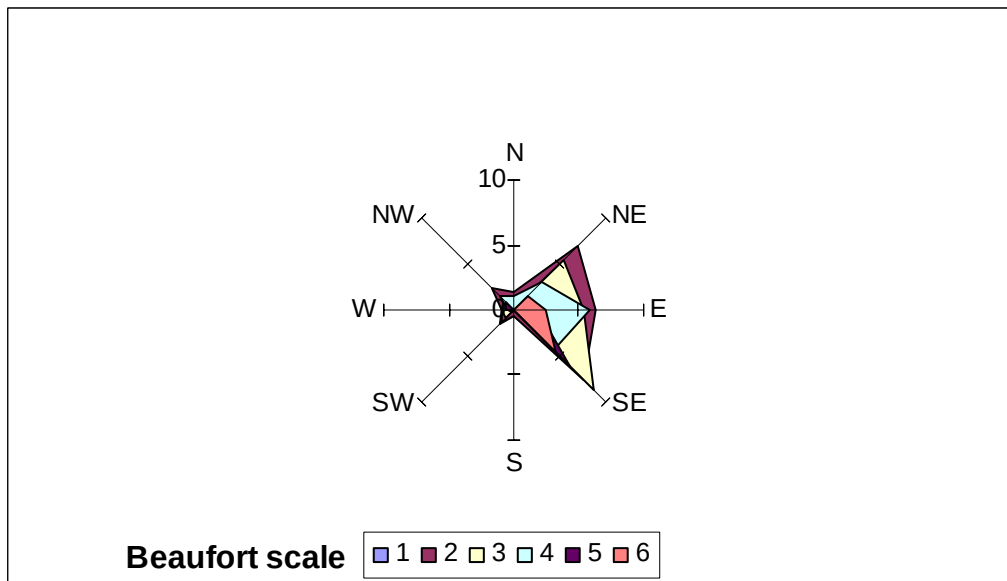


FIGURE 9 WIND STRENGTH AND DIRECTION AS A PERCENTAGE OF ALL OBSERVATIONS

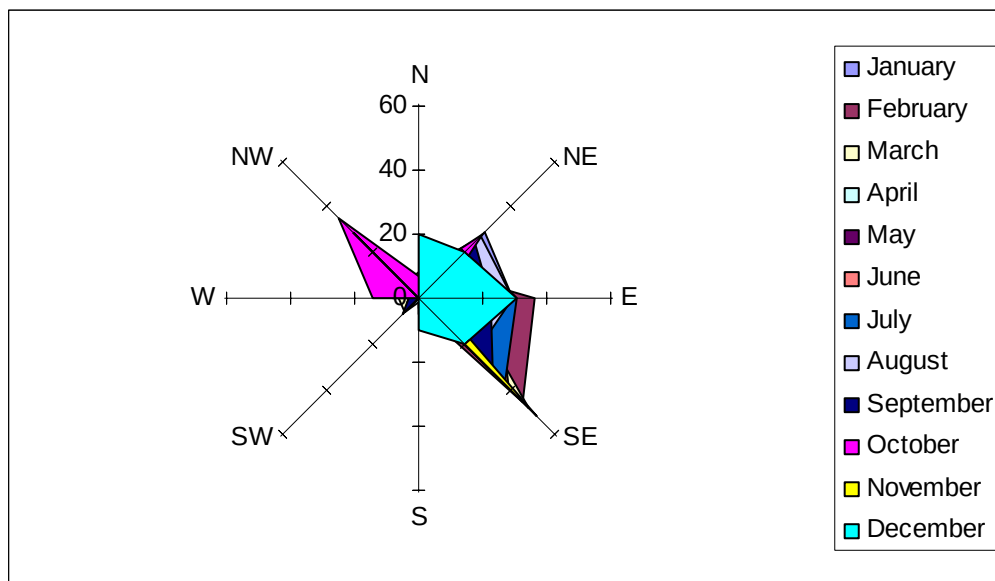


FIGURE 10 WIND DIRECTION BY MONTH
(VALUES ARE EXPRESSED AS A PERCENTAGE OF TOTAL WIND OBSERVATIONS FOR EACH MONTH)

Wind Strength (Beaufort scale)	Description	% of Total Observations	Prevailing
0	Calm (<1 knot)	6	All Year
1	Light Air (1-3 knots)	16	All Year
2	Light Breeze (4- knots)	27	All Year
3	Gentle Breeze (7-10 knots)	19	All Year
4	Moderate Breeze (11-16 knots)	14	All Year
5	Fresh Breeze (17-21 knots)	10	April to August
6	Strong Breeze (22-27 knots)	8	June to August

TABLE 5 OBSERVATIONS OF WIND STRENGTH

3.2.6 BOAT FREQUENCY AND ACTIVITY

Observations for boat activity (Figure 11) vary markedly from those recorded at the northwest of Roatán (O’Farrell et al, 2005). Although the overall mean values for the number of boats recorded per survey were not significantly different (1.3 boats per survey for the east end; 1.24 for the northwest; $p > 0.05$), the activities of the boats were noticeably different (Figure 12), with the majority of the east end boats (61%) involved in fishing, and the majority of northwest boats (66%) involved in tourism-based SCUBA diving.

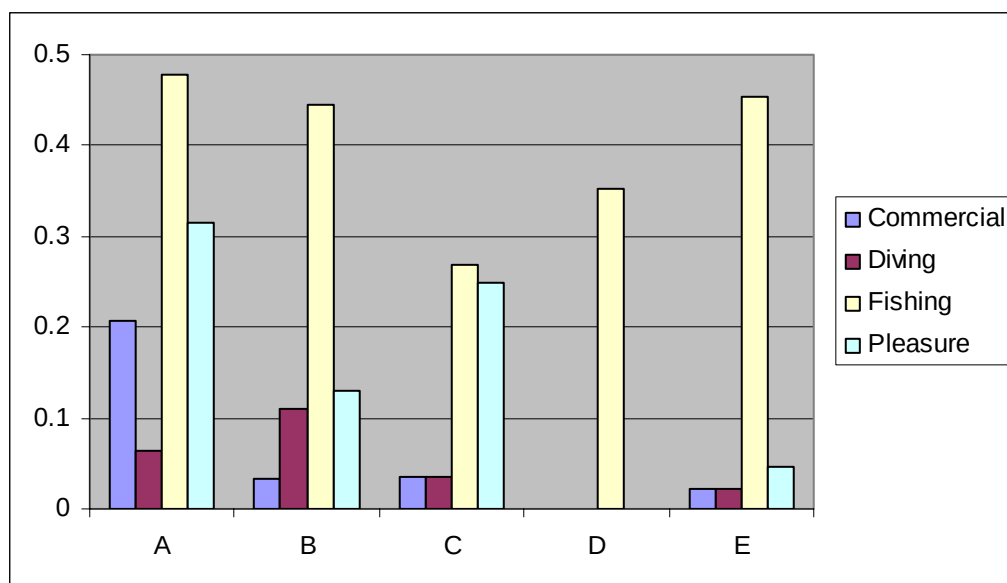
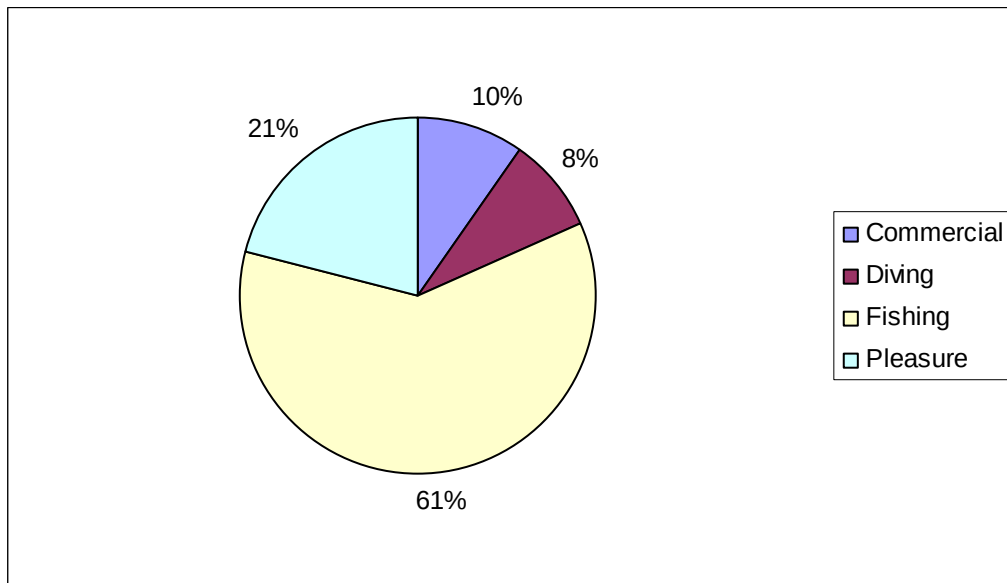
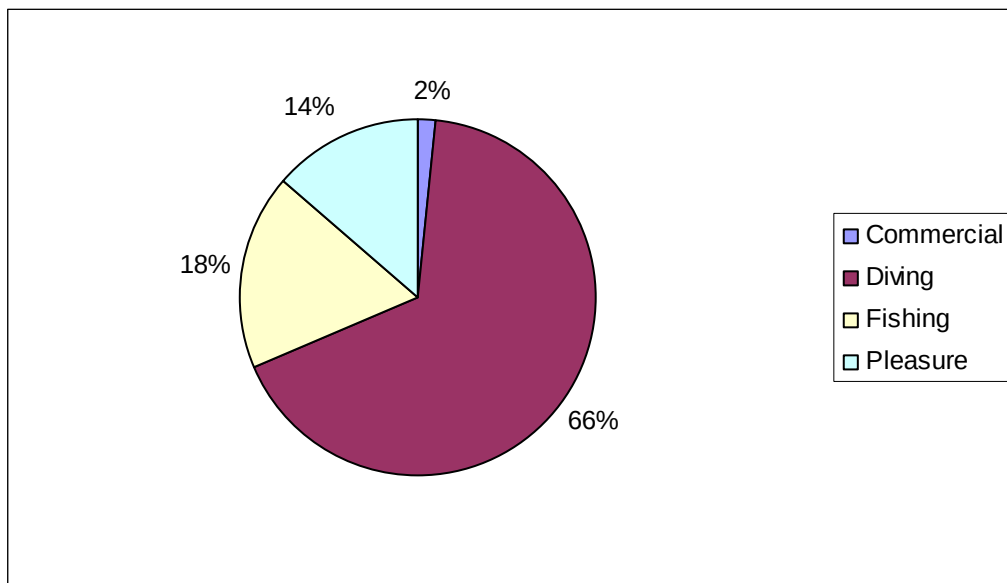


FIGURE 11 OBSERVATIONS OF BOAT ACTIVITY CLASSES BY SECTOR



Roatán east end



Roatán northwest

FIGURE 12 BOAT ACTIVITIES AS A PERCENTAGE OF ALL OBSERVATIONS – DIFFERENCES BETWEEN THE EAST AND NORTHWEST OF ROATÁN.

3.2.7 SUBSURFACE IMPACTS

Put together, hard coral bleaching, damaged coral and sedimentation accounted for 82% of all of the recorded subsurface impacts (Figure 13). In Figure 14, observations of impacts by class are shown graphically for each sector (note that because impacts are not mutually exclusive, combined values of all classes may exceed 100).

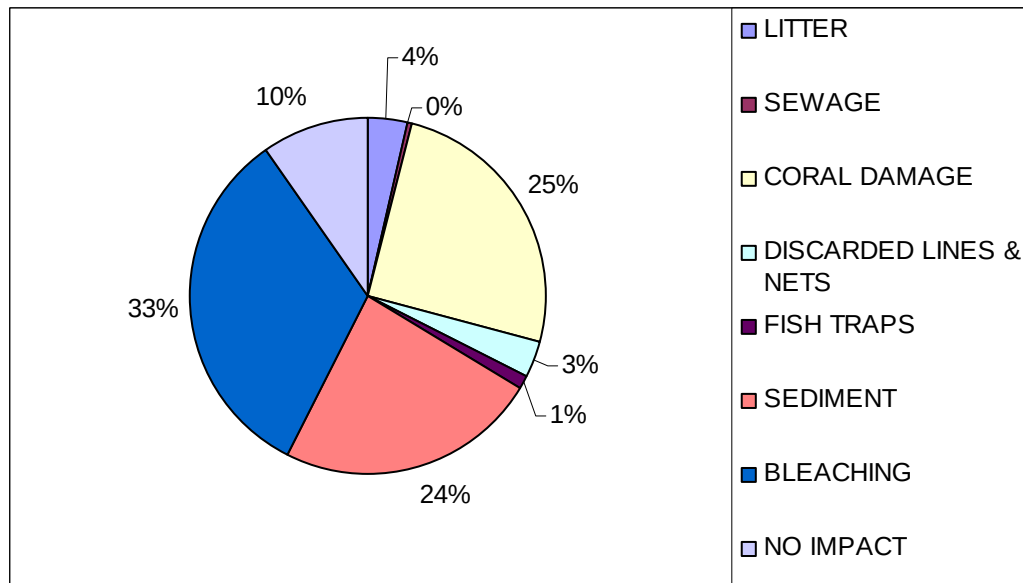


FIGURE 13 SUB-SURFACE IMPACTS BY CLASS
(EXPRESSED AS A PERCENTAGE OF TOTAL IMPACT OBSERVATIONS)

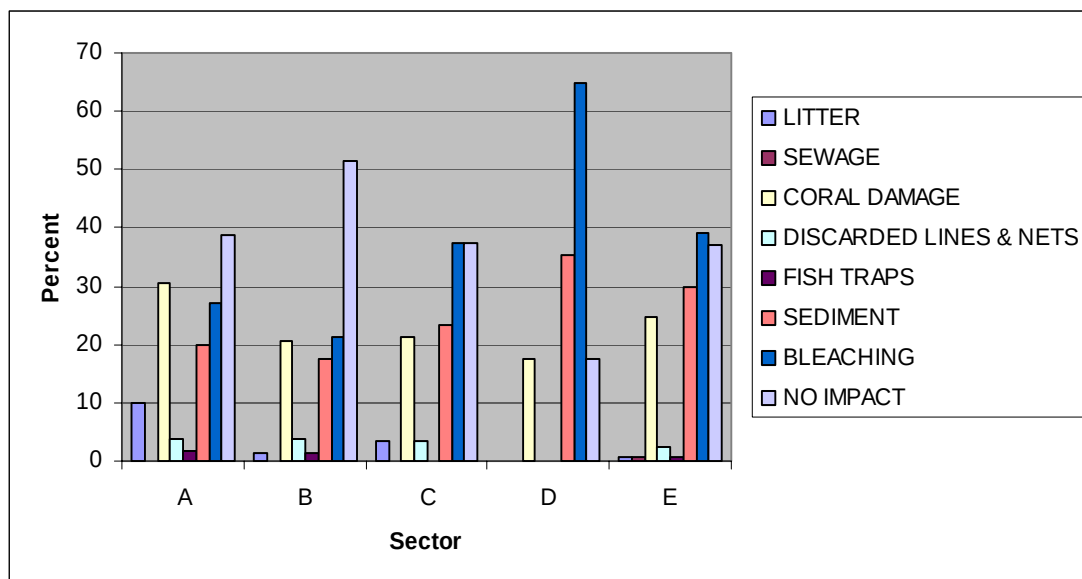


FIGURE 14 PERCENTAGE OF SURVEYS WITHIN EACH SECTOR ON WHICH EACH SUB-SURFACE IMPACT CLASS WAS OBSERVED

3.3 BIOLOGICAL INDICATORS

Certain species have been shown to be effective indicators of overall reef health (Hodgson, 1999). Depending on the particular species, they can highlight histories of overfishing, nutrient pollution, destructive fishing practices and the removal of organisms for sale within the tourism industry (curio collection) or aquarium trade. In this analysis, the indicator organisms have been adapted from those defined by the Reef Check Foundation (www.reefcheck.org) as they have been shown to be robust gauges from which reef health can be inferred.

3.3.1 HARD CORAL COVER

The average hard coral cover values at the east end of Roatán were found to be largely consistent with those values recorded at the west end. Maximum values, however, were found to be higher, with values of DAFOR 4 ($\approx$ 51% - 75% of surveyed benthos) being recorded in 80% of survey sectors in the east end (4 out of 5 - Figure 16), compared with 33% in the west end (2 out of 6). Figure 15 shows the abundance of hard coral cover around the east end, with values being displayed as a colour ramp. Areas which display colours towards the green end of the ramp are those with concentrations of higher DAFOR values; conversely, those towards the red end of the colour ramp are those with concentrations of lower DAFOR values.

The abundance of staghorn coral (*Acropora cervicornis*) was also found to be higher around the east end than the northwest, with sector averages of greater than zero being recorded in 60% of sectors (3 out of 5 – Figure 17) versus 17% of sectors (1 out of 6) respectively. Overall, staghorn coral was recorded on 55% of transects in the east end, compared to 47% of transects in the northwest. In Figure 15, the locations of the survey sites with the highest staghorn coral values are indicated with stars. At the sites marked with white stars (north of the Helene/Barbaretta channel, and ‘Big Bank’), staghorn coral covered 30% to 50% of the surveyed benthos. At the site marked with a turquoise star (near Bentley Bay), coverage was found to be 51% to 75%. These values may be considered to be exceptionally high for this species in the

modern Caribbean: in most regions, the species has not yet recovered from the widescale mortality induced by white band disease in the 1980s.

Conversely, Elkhorn coral (*Acropora palmata*) was recorded on only 4% of transects around the east end (Figure 18), compared to 12% at the northwest end.

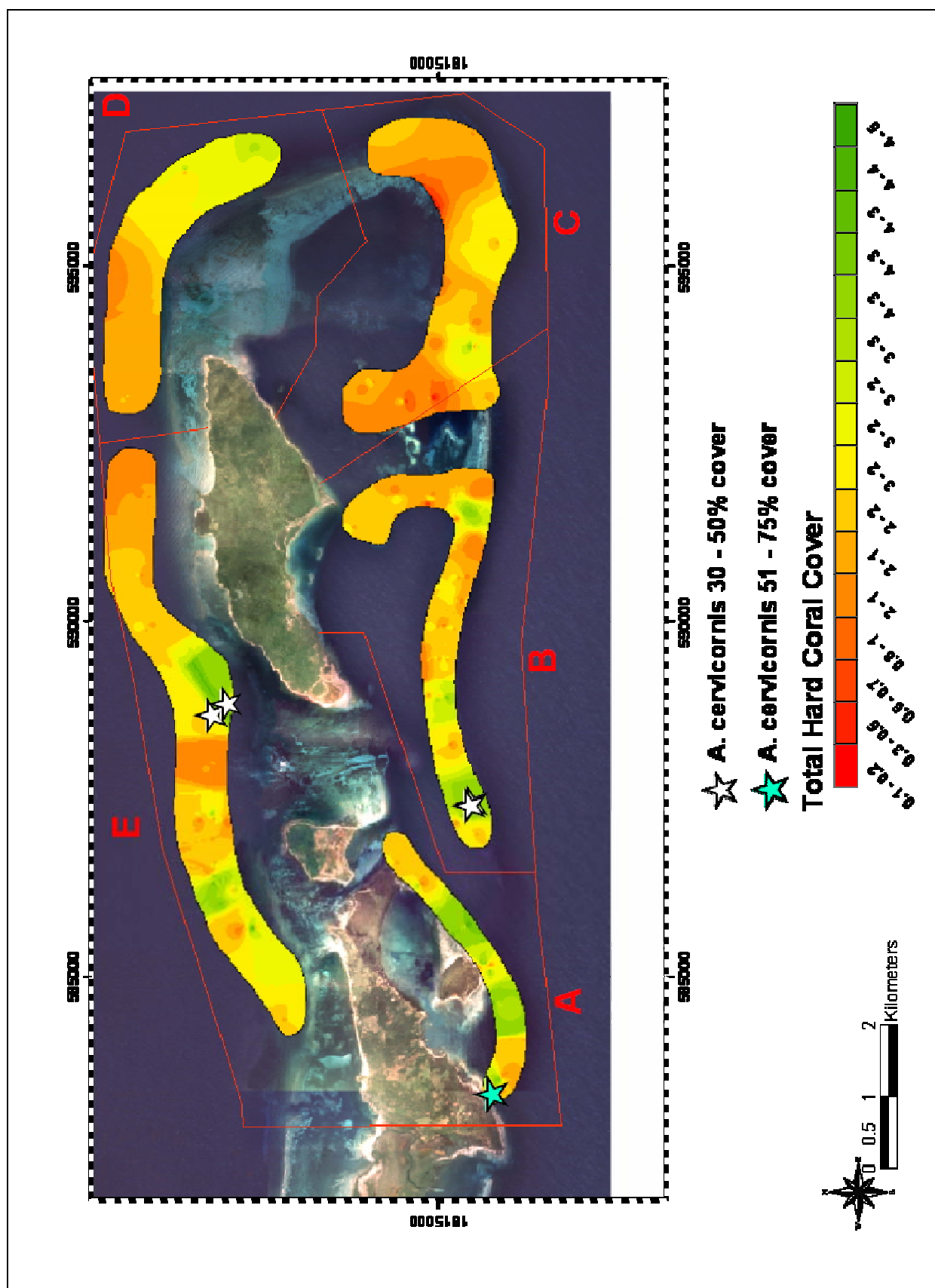


FIGURE 15 HARD CORAL COVER DATA CONTOUR (DAFOR VALUES), WITH KEY STAGHORN CORAL (*A. CERVICORNIS*) LOCATIONS

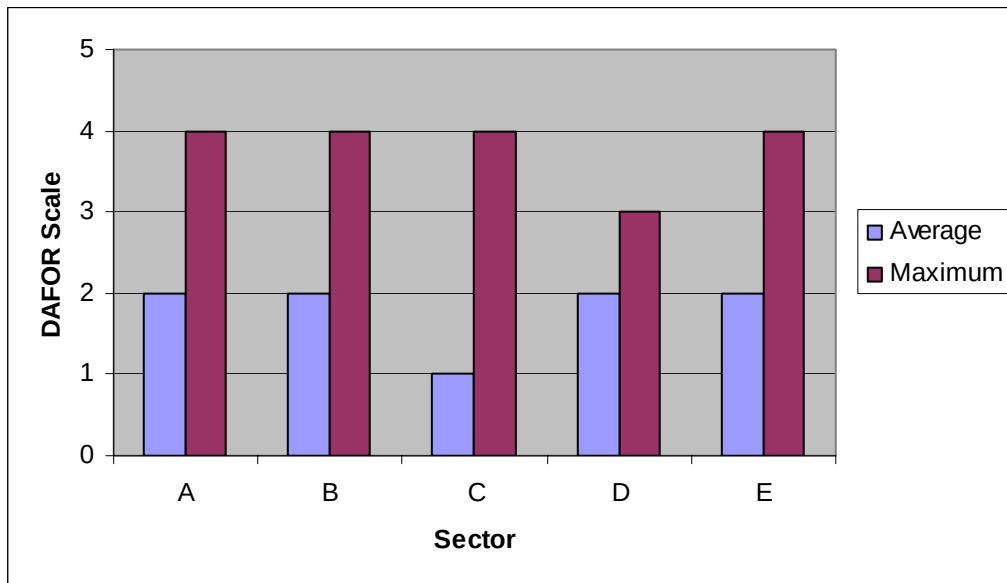


FIGURE 16 TOTAL HARD CORAL ABUNDANCE BY SECTOR

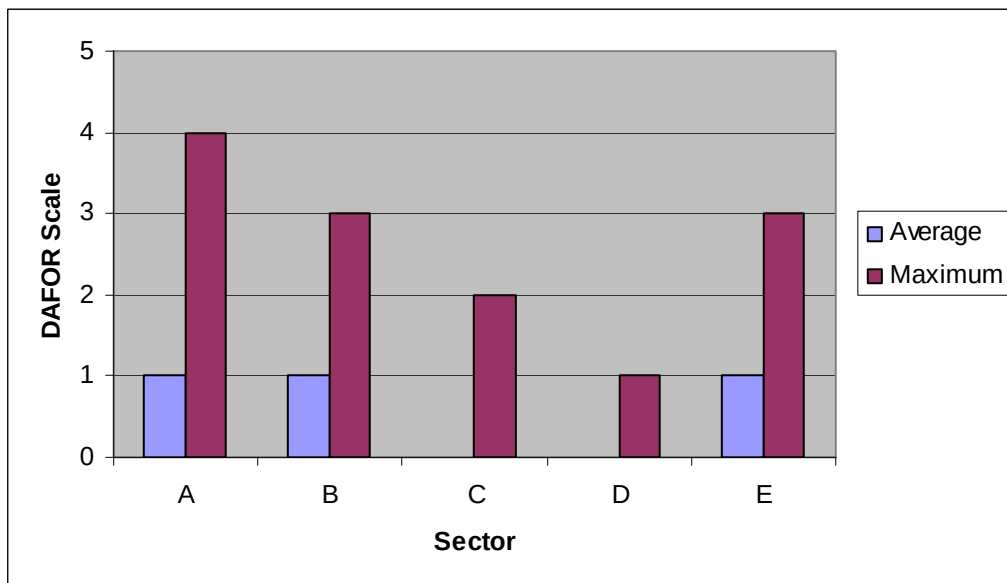


FIGURE 17 STAGHORN CORAL (*ACROPORA CERVICORNIS*) COVER BY SECTOR

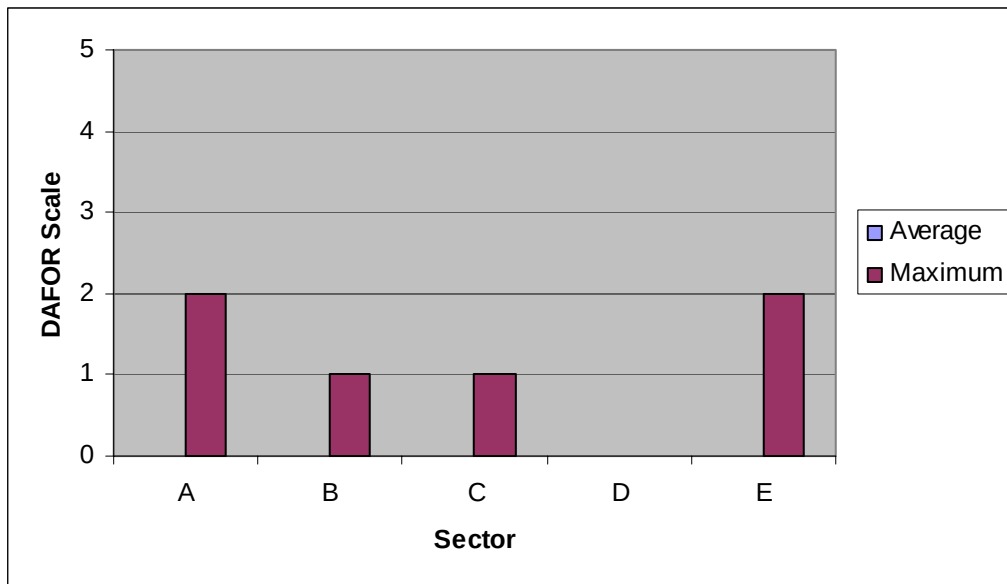


FIGURE 18 ELKHORN CORAL (*ACROPORA PALMATA*) COVER BY SECTOR

The most commonly occurring hard corals have been ranked here according to the percentage of the total number of transects on which they were recorded (Table 6). The justification for this approach is that it is a more accurate reflection of coral diversity than using the DAFOR values. For example, *Scolymia lacera* (solitary disc coral) is, as its common name implies, a small solitary organism, and thus would be very far down the table in terms of area cover, yet it was recorded on 57% of all of the surveys, thus it is widely distributed on the reefs.

Taxonomic Name	Common Name	% of transects on which each coral was observed
<i>Agaricia agaricites</i>	Leaf	90
<i>Montastrea annularis</i> complex	Mountainous star	90
<i>Porites astreoides</i>	Mustard hill	88
<i>Montastrea cavernosa</i>	Cavernous star	85
<i>Meandrina meandrites</i>	Butterprint brain	80
<i>Siderastrea siderea</i>	Smooth starlet	79
<i>Agaricia tenuifolia</i>	Ribbon	76
<i>Porites porites</i>	Club finger	69
<i>Mycetophyllia lamarckiana</i>	Fungus	67
<i>Porites furcata</i>	Finger	66
<i>Madracis decactis</i>	Green cactus	63
<i>Eusmilia fastiagata</i>	Flower	59
<i>Helioseris cucullata</i>	Saucer	58
<i>Scolymia lacera</i>	Solitary disk	57
<i>Acropora cervicornis</i>	Staghorn	55
<i>Diploria labyrinthiformis</i>	Grooved brain	52
<i>Agaricites fragilis</i>	Fragile saucer	51
<i>Stephanocoenia michilini</i>	Blushing star	51
<i>Diploria strigosa</i>	Smooth brain	50
<i>Mycetophyllia danaana</i>	Fat fungus	50
<i>Isophyllastrea rigida</i>	Rough star	48
<i>Manicina areolata</i>	Rose	48
<i>Dichocoenia stokesii</i>	Elliptical star	46
<i>Colpophyllia natans</i>	Giant brain	46
<i>Madracis mirabilis</i>	Yellow pencil	42
<i>Agaricia agaricites</i> var <i>danai</i>	Massive leaf	34
<i>Mycetophyllia aliciae</i>	Thin fungus	33
<i>Porites porites</i> f. <i>divaricata</i>	Thin finger	33
<i>Favia fragum</i>	Golfball	29
<i>Agaricia lamarcki</i> or <i>grahamae</i>	Sheet	20
<i>Millepora</i> spp.	Blade fire coral	16
<i>Madracis formosa</i>	Eight-ray finger	16
<i>Dendrogyra cylindrus</i>	Pillar	15
<i>Mycetophyllia ferox</i>	Grooved fungus	10
<i>Isophyllia sinuosa</i>	Sinuuous cactus	9
<i>Mussa angulosa</i>	Large flower	9
<i>Agaricia undata</i>	Scroll	8
<i>Acropora palmata</i>	Elkhorn	4

TABLE 6 **MOST COMMONLY RECORDED HARD CORAL SPECIES**

3.3.2 CORAL SPECIES REGRESSED AGAINST FISH SPECIES

It has been established that there is a strong correlation between the number of coral species and the number of fish species present within a reefal system (Hodgson and Liebeler, 2002). This pattern is evident on the reefs of eastern Roatán, with the greatest number of fish species being recorded at the sites exhibiting the greatest number of coral species (Figure 19).

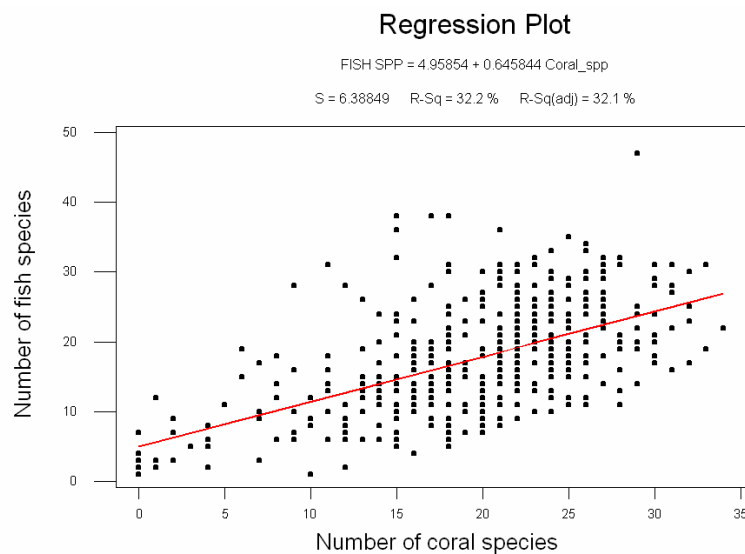


FIGURE 19 **REGRESSION PLOT OF NUMBER OF CORAL SPECIES AGAINST NUMBER OF FISH SPECIES**

3.3.3 LOBSTERS (*PANULIRUS* SPP.)

The displayed maximum value of DAFOR 2 (6 – 20 lobsters) was recorded at only 3% of survey sites in sectors A, B and E (Figure 20). Overall, lobsters were recorded on only 8% of all transects. As with the data from the northwest of Roatán, the average value recorded in all sectors was zero, indicating a high level of fishing pressure and/or habitat destruction.

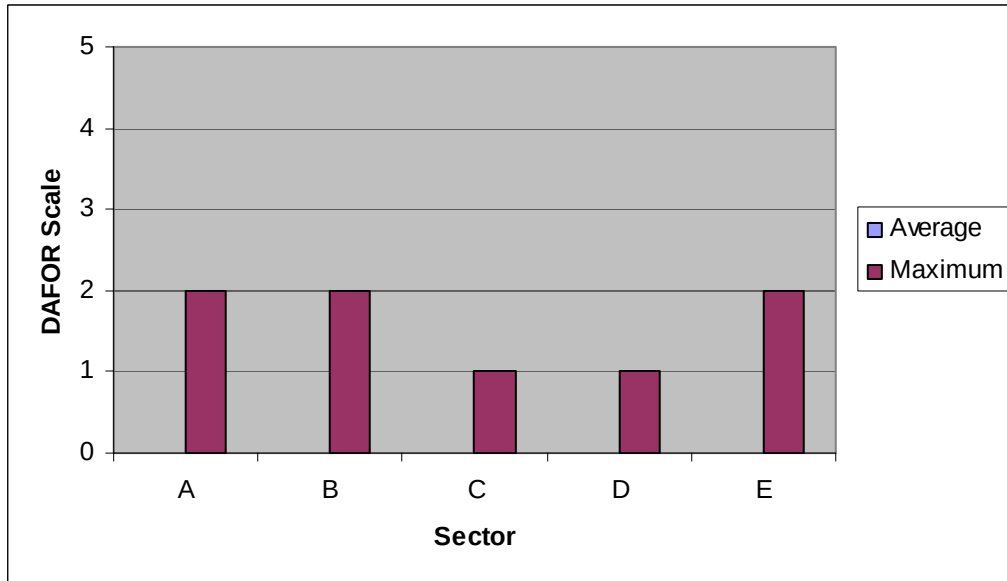


FIGURE 20 LOBSTER (*PANULIRUS* SPP.) ABUNDANCE BY SECTOR

3.3.4 QUEEN CONCH (*STROMBUS GIGAS*)

The maximum value recorded was DAFOR 2 (6 - 20 conch), and the average in all sectors was zero (Figure 21). Zero queen conch were recorded in sector D. Again, this is a similar situation to that of the northwest reefs, indicating a high level of overfishing, with queen conch being recorded on only 3% of all transects.

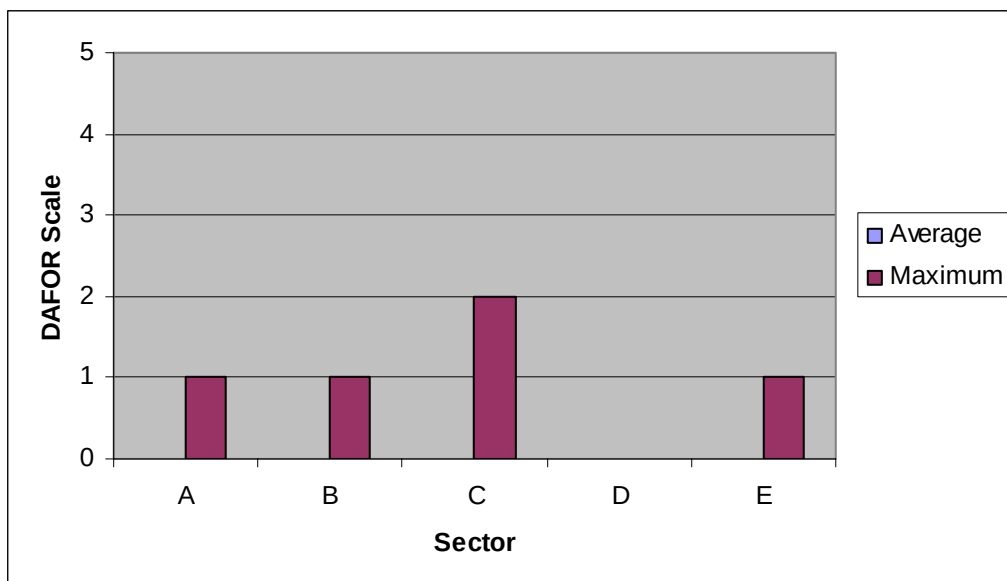


FIGURE 21 QUEEN CONCH (*STROMBUS GIGAS*) ABUNDANCE BY SECTOR

3.3.5 LONG-SPINED SEA URCHIN (*DIADEMA SPP*)

The displayed maximum value of DAFOR 2 was recorded at <1% of survey sites in sectors A and B (Figure 22), with zero long-spined urchins recorded in sector D. The average value across all sectors was zero, as was the case in the northwest. Overall, long-spined urchins were only recorded on 13% of all transects.

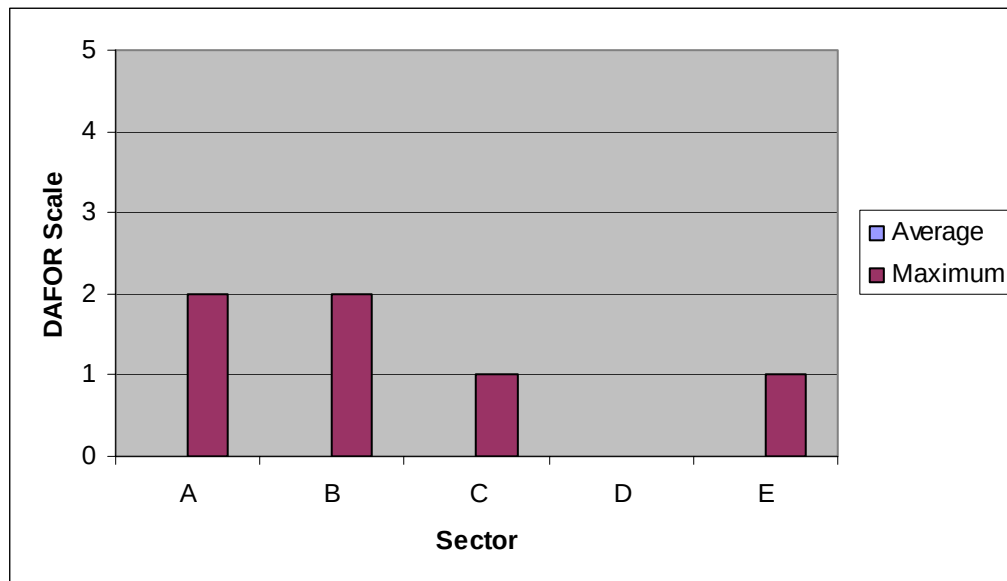


FIGURE 22 LONG-SPINED SEA URCHIN (*DIADEMA SPP*) ABUNDANCE BY SECTOR

3.3.6 REEF URCHINS (*ECHINOMETRA SPP*)

Maximum populations of reef urchins were found to be higher than those for long spined urchins in all sectors, with higher average values also being recorded in sectors A, B and C (Figure 23).

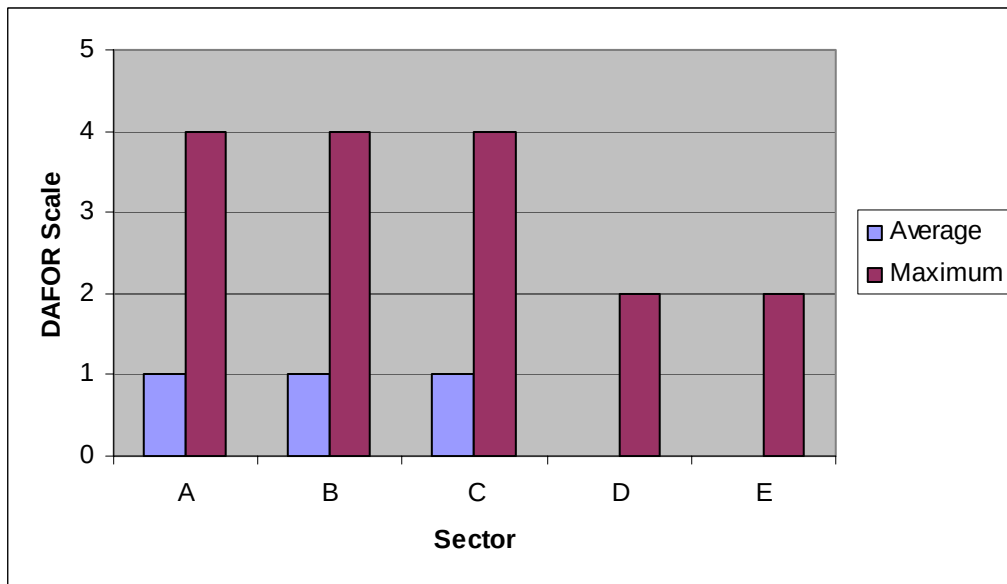
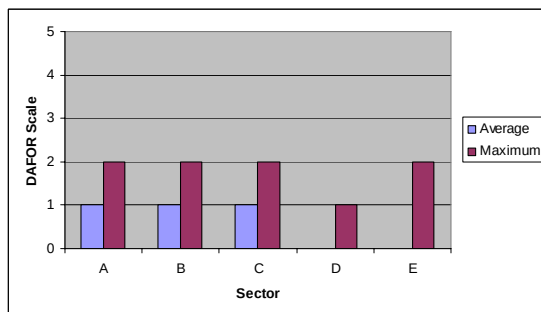


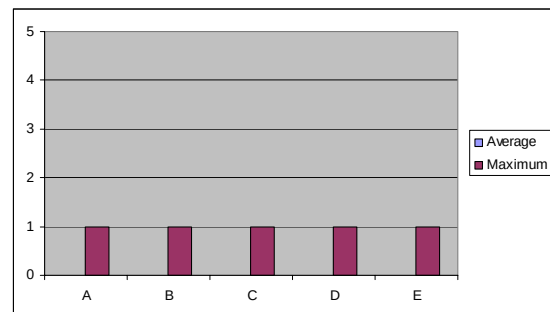
FIGURE 23 REEF URCHINS (*ECHINOMETRA* SPP) ABUNDANCE BY SECTOR

3.3.7 BUTTERFLYFISH (*CHAETODONTIDAE*)

As many butterflyfish are obligate corallivores, and others feed on coral-dependent invertebrates, there is a hypothesis is that if they are unable to feed on healthy coral, their population will decline. The distribution of Foureye butterflyfish by sector (Table 7) largely mirrors the abundance of hard coral in each sector (Figure 16) with the lowest abundance found in sector D. Populations of banded butterflyfish were found to be lower overall. Spotfin butterflyfish (*C. ocellatus*), Longsnout butterflyfish (*C. aculeatus*) and Reef butterflyfish (*C. sedentarius*) were also included in the target species list, but zero of these species were recorded on any survey.



Chaetodon capistratus
Foureye butterflyfish

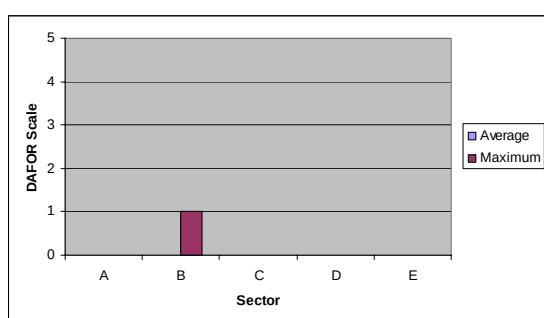


Chaetodon striatus
Banded butterflyfish

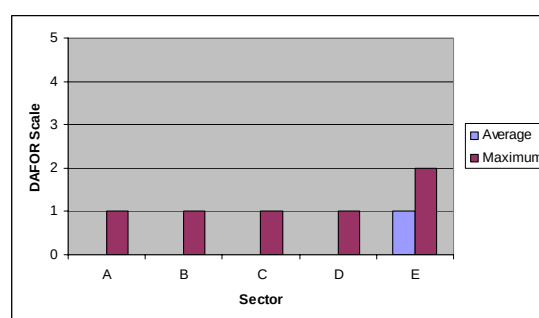
TABLE 7 BUTTERFLYFISH ABUNDANCE BY SECTOR

3.3.8 GROUPERS (SERRANIDAE)

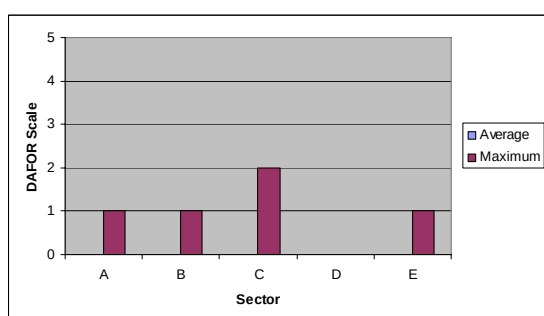
Groupers tend to be long-living, slow maturing species, and as large carnivores of high commercial value, they are particularly vulnerable to fishing pressure. Throughout the reefs of eastern Roatán, grouper populations were found to be low for all species, with no discernible inter-species pattern to distribution by sector. Certain species such as the Yellowmouth grouper (*Mycteroperca cidi*) and the Goliath grouper (*Epinephelus itajara*) being recorded only once each throughout the survey campaign (Table 8). The most commonly observed species were Graysby (*Cephalopholis cruentatus*), Coney (*Cephalopholis fulvus*) and Red Hind (*Epinephelus guttatus*), which were recorded on 22%, 32% and 10% respectively of all transects. Coney was the only species whose average abundance was greater than zero, and even this was only in one sector (E).



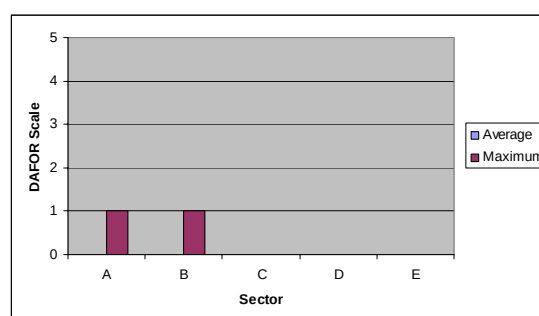
Mycteroperca cidi
Yellowmouth grouper



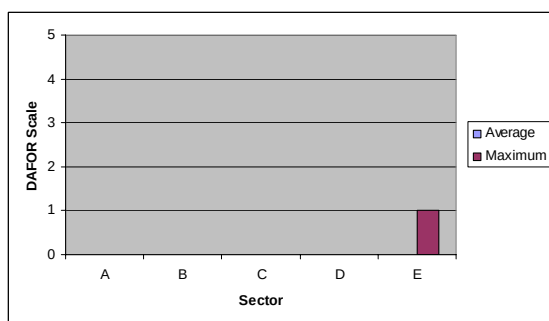
Cephalopholis fulvus
Coney



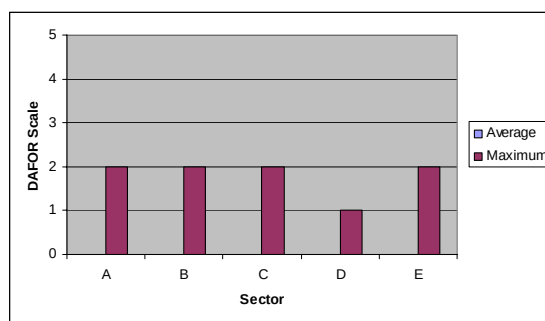
Epinephelus adscensionis
Rock Hind



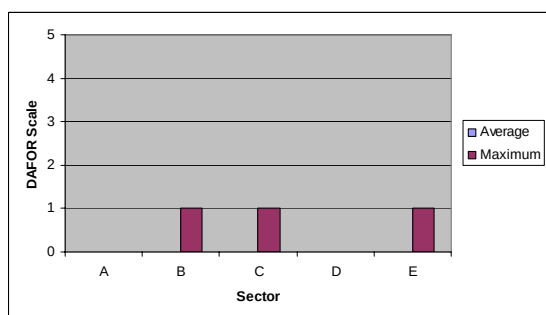
Mycteroperca bonaci
Black grouper



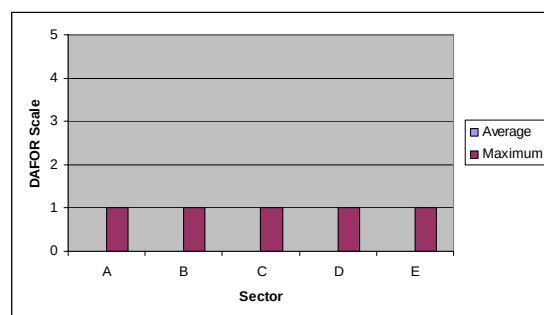
Epinephelus itajara
Goliath grouper



Cephalopholis cruentatus
Graysby



Epinephelus striatus
Nassau grouper



Epinephelus guttatus
Red Hind

TABLE 8 **GROUPE ABUNDANCE BY SECTOR**

3.3.9 SNAPPERS (LUTJANIDAE)

Data were recorded on six species of snapper, namely Schoolmaster snapper (*Lutjanus apodus*), Cubera snapper (*Lutjanus cyanopterus*), Dog snapper (*Lutjanus jocu*), Gray snapper (*Lutjanus griseus*), Mahogany snapper (*Lutjanus mahogoni*) and Mutton snapper (*Lutjanus analis*). Of these, only the Schoolmaster snapper displayed maximum values of greater than DAFOR 1 (<5 individuals) on any survey (Figure 24).

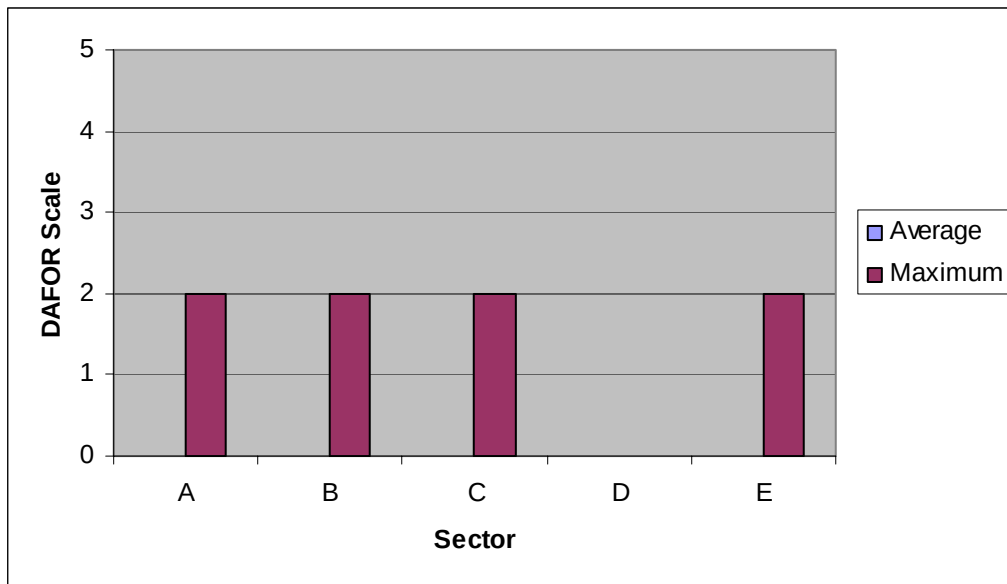
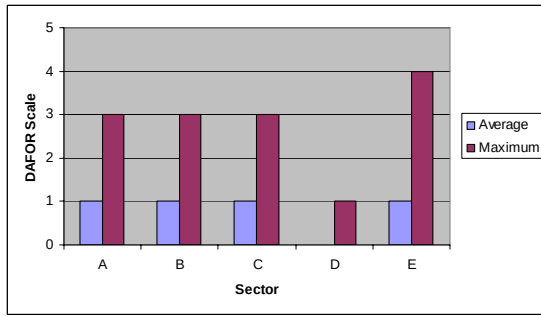


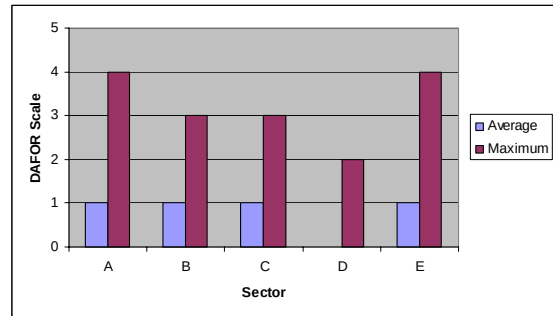
FIGURE 24 SCHOOLMASTER SNAPPER (*LUTJANUS APODUS*) ABUNDANCE BY SECTOR

3.3.10 PARROTFISH (SCARIDAE)

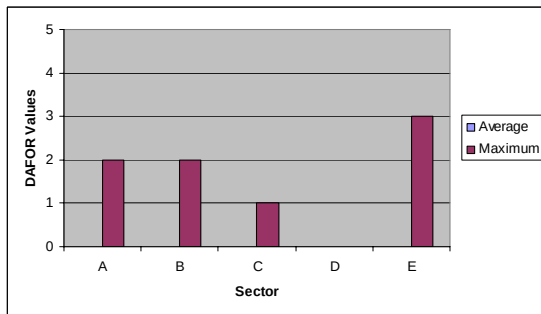
Parrotfish are important grazers on the reef, helping to keep macroalgal abundance in check. The fact that, in Roatán, they are less desirable for human consumption than some other large fish species (Hess Boddard, pers. comm.) may have contributed to their higher abundance. Furthermore, within the classical trophic chain, their herbivorous lifestyle strategy also tends to provide for greater numbers of individuals within a population, compared with the large carnivores. The most abundant species recorded were Princess parrotfish (*Scarus taeniopterus*), Striped parrotfish (*Scarus iserti*) and Redband parrotfish (*Sparisoma aurofrenatum*), all of which had average values of DAFOR 1 (<6 individuals) over all surveys within 4 out of the 5 sectors. In general, the lowest abundances for most of the target species were found in sector D, with zero Blue parrotfish (*Scarus coeruleus*), Rainbow parrotfish (*Scarus guacamaia*) or Bucktooth parrotfish (*Sparisoma radians*) being recorded on any survey in this sector (Table 9).



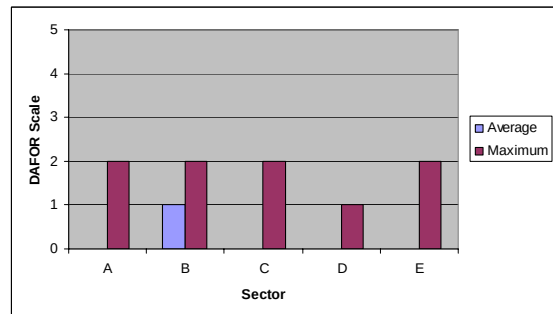
Scarus taeniopterus
Princess parrotfish



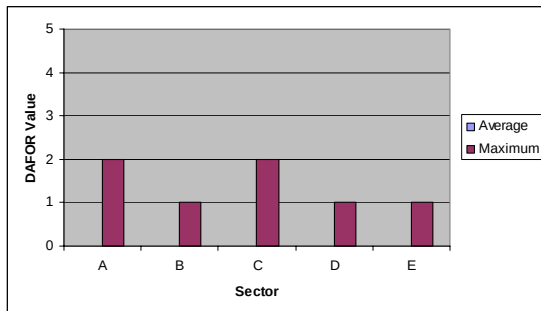
Scarus iserti
Striped parrotfish



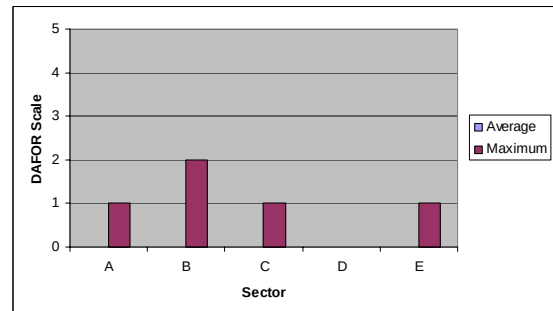
Scarus coeruleus
Blue parrotfish



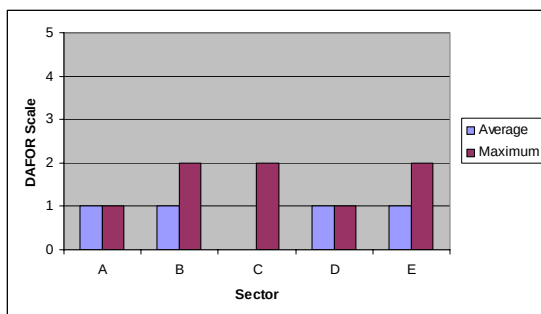
Sparisoma viride
Stoplight parrotfish



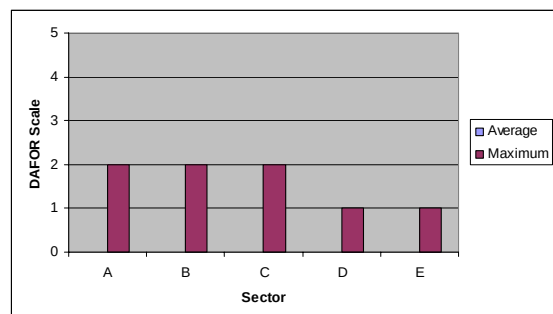
Scarus vetula
Queen parrotfish



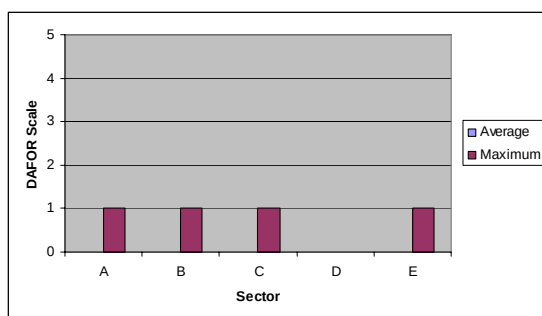
Scarus guacamaia
Rainbow parrotfish



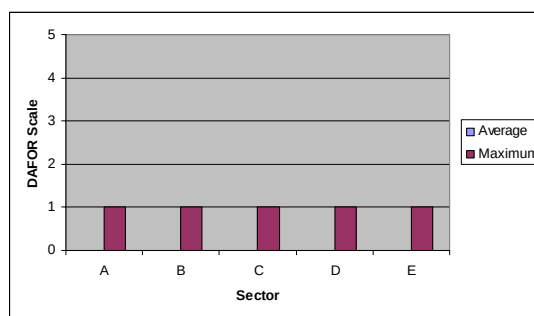
Sparisoma aurofrenatum
Redband parrotfish



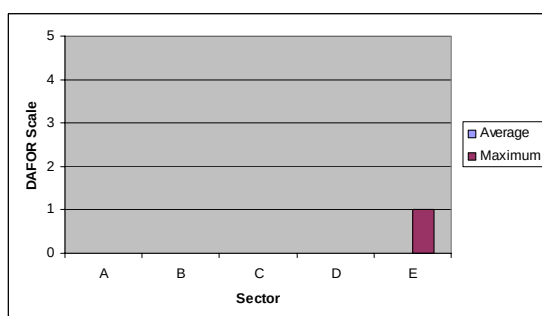
Sparisoma chrysoterm
Redtail parrotfish



Sparisoma radians
Bucktooth parrotfish



Sparisoma atomarium
Greenblotch parrotfish

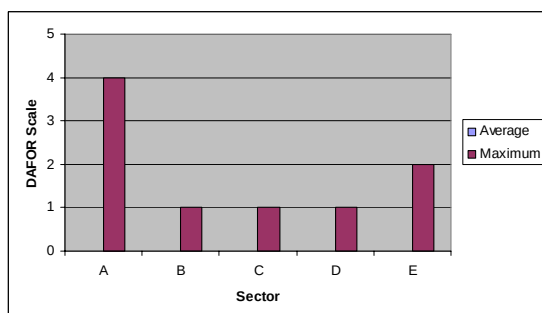


Scarus coelestinus
Midnight parrotfish

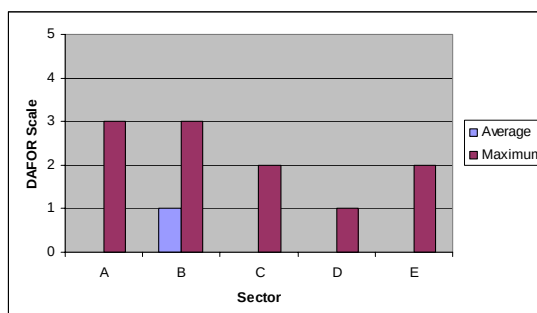
TABLE 9 PARROTFISH ABUNDANCE BY SECTOR

3.3.11 SURGEONFISH (ACANTHURIDAE)

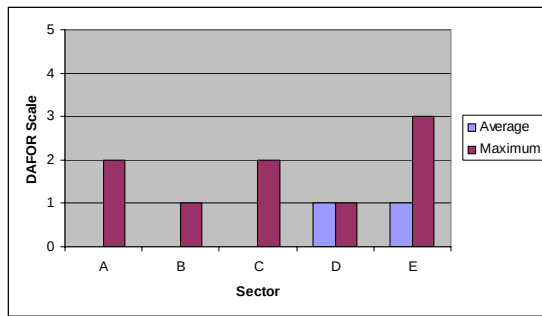
Like parrotfishes, surgeonfishes are important grazers on a reef. Data were recorded on three species, namely Doctorfish (*Acanthurus chirurgus*), Blue tang (*Acanthurus coeruleus*) and Ocean surgeonfish (*Acanthurus bahianus*). Once again, the lowest populations across all species were recorded in sector D (Table 10).



Acanthurus chirurgus
Doctorfish



Acanthurus coeruleus
Blue tang



Acanthurus bahianus
Ocean surgeonfish

TABLE 10 SURGEONFISH ABUNDANCE BY SECTOR

3.3.12 SHARKS

The only sharks observed on any transect were Nurse sharks (*Ginglymostoma cirratum*). Nurse sharks were only recorded on 2% of transects in sectors B and C, and on 1% of transects in sector E (Figure 25). Zero sharks were recorded in sectors A or D.

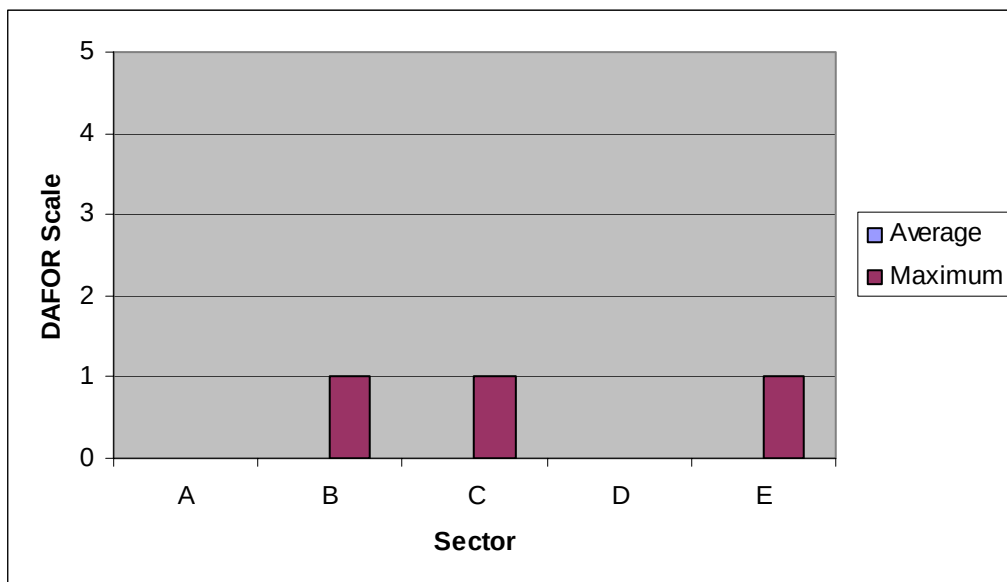


FIGURE 25 NURSE SHARKS (*GINGLYMOSTOMA CIRRATUM*) ABUNDANCE BY SECTOR

3.3.13 MACROALGAE

Average macroalgal abundances were low in all sectors (DAFOR 1; $\approx$ 1% - 10% of surveyed benthos), although very high values were recorded on many individual transects (Figure 26). The highest values (DAFOR 4; $\approx$ 51% - 75% of surveyed benthos) were recorded in sectors A and E, although this was only recorded on 1% and 2% of transects respectively.

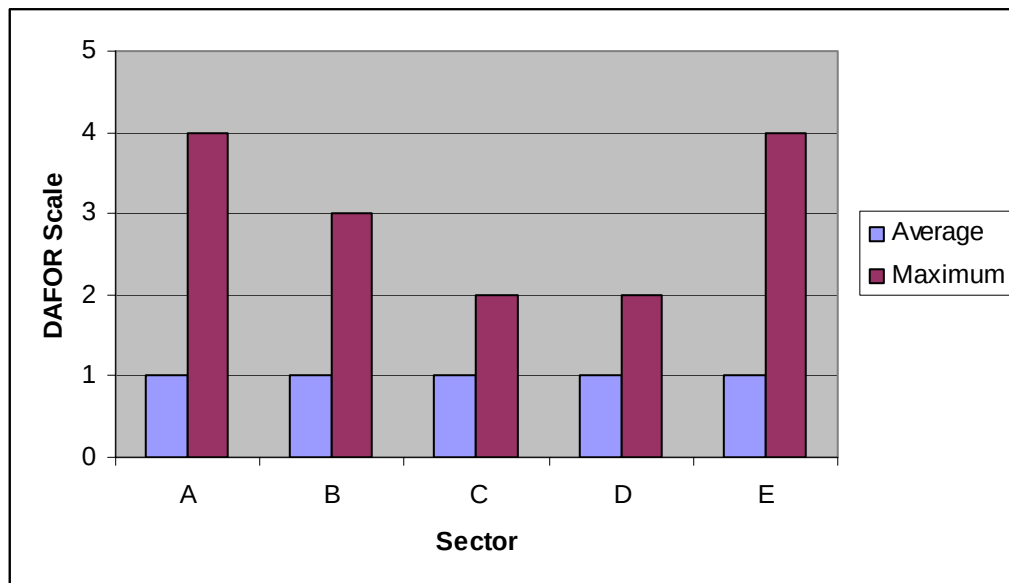


FIGURE 26 MACROALGAL ABUNDANCE BY SECTOR

3.4 HABITAT DEFINITION

In order to allow for comparison of survey sites, they must first be classified into distinct ecological units, or habitats. Each variable in each survey record (the data from each site) is compared statistically against the same variable in every other survey record and the similarity between any two records is calculated using the Bray-Curtis Similarity Coefficient. This similarity is expressed as a percent. Using the ecological analysis package, PRIMER (Plymouth Routines In Multivariate Ecological Research), the survey records are then ranked by these similarities to produce natural groupings or ‘clusters’ from the data (Figure 27). SIMPER is then used to define the key characteristics of each cluster. Ultimately, 10 discreet ecological habitats have been defined for the area. A summary of these is presented in Table 11.

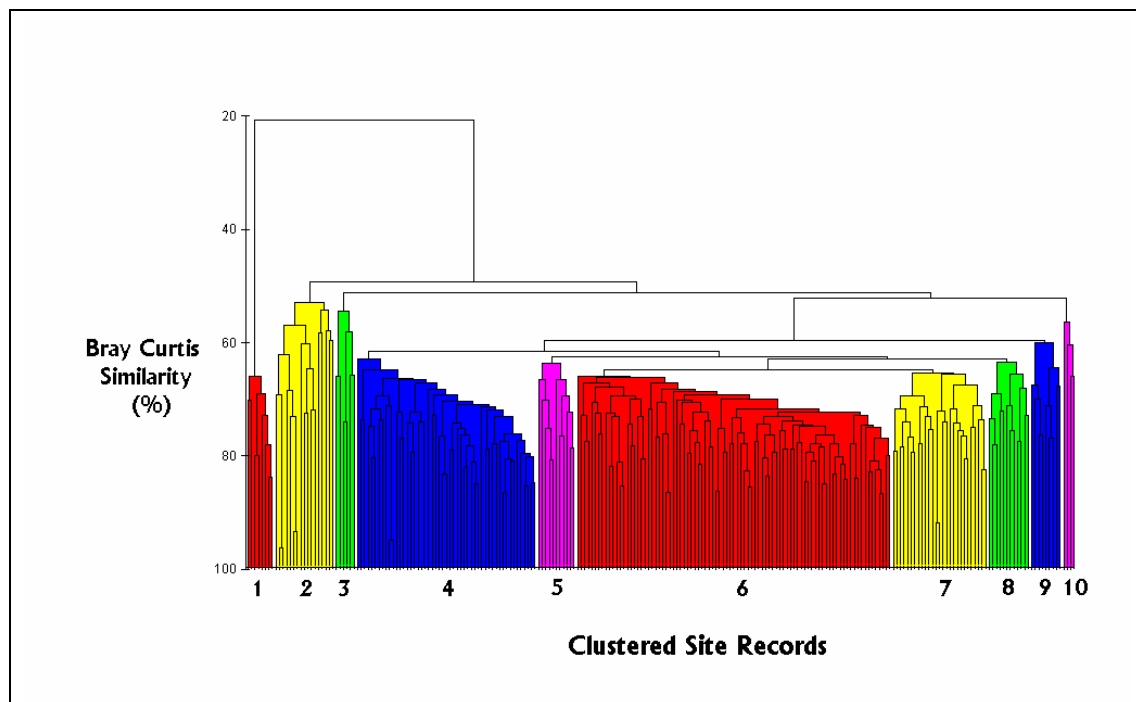


FIGURE 27 PRIMER HIERARCHICAL CLUSTER ANALYSIS OUTPUT, COLOURED TO SHOW THE 10 DISCREET ECOLOGICAL HABITAT CLUSTERS, AS DEFINED FROM A RANDOM SAMPLE (N=270) OF THE SURVEY DATA. EACH VERTICAL LINE WITHIN EACH CLUSTER REPRESENTS AN INDIVIDUAL SITE RECORD.

TABLE 11 MAJOR CHARACTERISTICS OF THE 10 BENTHIC CLASSES DEFINED FROM BASELINE DATA COLLECTED FROM THE REEF AROUND SANTA HELENA. FIGURES IN PARENTHESES INDICATE MEDIAN ABUNDANCES IN ACCORDANCE WITH DAFOR RATINGS ASSIGNED DURING SURVEYS

Habitat	Avg No of Benthic Spp	Avg no of Fish Spp	Avg Shannon Weiner Diversity Index (Benthic)	Avg Shannon Weiner Diversity Index (Fish)	No of Site Records	Average Depth (m)	Substratum	Hard Corals	Octocorals	Sponges	Algae / Seagrass
1 Lagoonal seagrass beds	10	5	2.05	1.26951	12	9.0	Sand (3.5) Mud (0.5)	Total (0.5)	Total (0.5)	Total (1.0)	Seagrass (3.5) <i>Udotea flabellum</i> (1.5))
2 Sand	23	11	2.90	2.14328	44	16	Sand (3.5) Rubble (1.0) Bedrock (1.0)	Total (1.0) Leaf (1.0) Mountainous Star (0.5)	Total (1.0)	Total (1.0)	<i>Dictyota</i> spp. (1.0) <i>Halimeda tuna</i> (1.0)
3 Soft coral with brown and red algae on sandy substrate	30	12	3.32	2.36944	9	6.6	Sand (2.5)	Total (1.5) Elliptical Star (1.0) Mustard Hill (1.0) Smooth Starlet (1.0)	Total (3.0) Sea Plume (2.0) Sae Rod (1.5) Common Seafan (1.0)	Total (1.0)	<i>Styopodium zonale</i> (2.0) <i>Turbinaria</i> spp. (2.0) <i>Dictyota</i> spp. (2.0)
4 High hard and soft coral cover, with sponges	43	21	3.67	2.87843	97	12.6	Bedrock (2.0) Sand (1.5) Dead Coral (1.5) Rubble (1.5)	Total (3.0) Mountainous Star (2.5) Ribbon (2.0) Leaf (2.0) Mustard Hill (1.5)	Total (3.0) Sea Plume (2.5) Sea Rod (1.5) Common Sea Fan (1.0)	Total (2.0) Encrusting (1.5) Vase (1.0)	<i>Dictyota</i> spp. (3.0) <i>Lobophora variegata</i> (2.5) <i>Halimeda goreau</i> (2.0) <i>Halimeda tuna</i> (2.0)
5 Mixed substrate with low biotic cover	30	15	3.38	2.57185	26	21	Bedrock (1.5) Sand (1.5)	Total (1.0) Leaf (1.0) Mustard Hill (1.0) Cavernous Star (1.0)	Total (1.0) Sea Plume (1.0) Sea Rod (1.0)	Total (1.0)	<i>Dictyota</i> spp. (1.5) <i>Lobophora variegata</i> (1.0) <i>Halimeda tuna</i> (1.0)
6 Deep substrate, with moderate hard coral cover	40	20	3.61	2.78359	178	13	Bedrock (1.5) Sand (1.5) Dead Coral (1.0) Rubble (1.0)	Total (2.0) Mountainous Star (1.0) Ribbon (1.0) Leaf (1.0)	Total (1.0)	Total (1.0)	<i>Dictyota</i> spp. (1.5) <i>Lobophora variegata</i> (1.0)

7 Bedrock with mixed hard coral and algae	39	18	3.59	2.74779	53	14	Bedrock (3.0) Sand (1.0)	Total (2.0) Mountainous Star (1.5) Cavernous Star (1.0) Leaf (1.0)	Total (2.0) Sea Plume (2.0) Sea Rod (1.0) Corky Sea Finger (1.0)	Total (1.0)	<i>Dictyota</i> spp. (1.5) <i>Lobophora variegata</i> (1.0) <i>Sargassum hystrix</i> (1.0) <i>Styopodium zonale</i> (1.0)
8 Sand with mixed hard and soft coral	34	17	3.46	2.62148	23	12	Sand (3.0) Bedrock (1.5)	Total (2.0) Mountainous Star (1.5) Leaf (1.0) Butterprint Brain (1.0)	Total (1.5) Sea Plume (1.5) Sea Rod (1.0)	Total (1.5)	<i>Thalassia</i> spp (2.0) <i>Dictyota</i> spp. (2.0) <i>Lobophora variegata</i> (1.5) <i>Rhipocephalus phoenix</i> (1.5)
9 Deep mixed substrate (found mainly on the north side)	31	14	3.39	2.5752	20	18.5	Bedrock (2.0) Sand (1.0)	Total (1.0) Leaf (1.0) Mustard Hill (1.0)	Total (2.5) Sea Plume (2.5) Sea Rod (1.5)	Total (1.5)	<i>Dictyota</i> spp (2.0) <i>Lobophora variegata</i> (1.5)
10 Very high biotic cover, including Anemones (2.0) and Zooanthids (2.0).	44	20	3.70	2.8764	5	17	Bedrock (2.0)	Total (4.0) Mountainous Star (3.5) Leaf (3.0) Ribbon (3.0) Mustard Hill (3.0)	Total (4.0) Sea Plume (3.5) Sea Rod (2.0) Common Sea Fan (2.0)	Total (3.5) Encrusting (3.0)	<i>Halimeda</i> spp (3.0) <i>Lobophora variegata</i> (3.0) <i>Dictyota</i> spp. (3.0) <i>Sargassum hystrix</i> (2.0) <i>Amphiroa</i> spp. (2.0) <i>Galaxaura</i> spp. (2.0) <i>Jania</i> spp. (2.0)

3.5 CONSERVATION MANAGEMENT VALUES

Using five ecological indices, comparisons between site records can now be made in order to highlight key areas of ecological importance. The indices used are the site record values for live hard coral cover, number of benthic species recorded (not including algae), number of fish species recorded, the Shannon-Weiner Biodiversity Index for benthic species (not including algae) and the Shannon-Weiner Biodiversity Index for fish species.

First, an inter-habitat analysis is made to determine the ecological ‘value’ of each habitat relative to the others. To do this, the average value for each of the 5 indices is calculated for each habitat, and these values are then used to determine the overall averages for each index across all habitats. The habitats are then compared against these overall averages to determine the number of indices in which each habitat is above or below the overall average. If, for example, a habitat is below average in all 5 indices, it would score a value of 0; if it was above average in only 1 index, it would score a value of 1, and so on up to a maximum value of 5 (above average in all 5 indices).

Second, an intra-habitat analysis is conducted, with each site record in each habitat being compared against the other site records within that habitat, to determine which sites are the most ecologically ‘valuable’ examples of their particular habitat. The same system is used to do this, with site records scoring values of 0-5.

To calculate the Conservation Management Value of each site, the inter-habitat value is multiplied by the intra-habitat value, producing scores on a scale of 0 to 25. For example, a poor site record (e.g. one that scored a 2) from a good habitat type (e.g. one that scored a 5) would score an overall CMV of 10; whereas an excellent site record (e.g. one that scored a 5) from that habitat would score an overall CMV of 25.

Because the location of each survey has been recorded with a GPS unit, this allows the CMVs to be imported to a Geographic Information System (GIS) to allow for spatial analysis. The density function in the Spatial Analyst of ArcMap (ESRI software) can then be used to highlight areas displaying a particularly high or low

density of the various CMVs. These values can be represented on a colour ramp to facilitate visual interpretation. In the GIS output below (Figure 28), the colour red represents areas where lower CMVs are dominant; the colour green represents areas where higher CMVs are dominant.

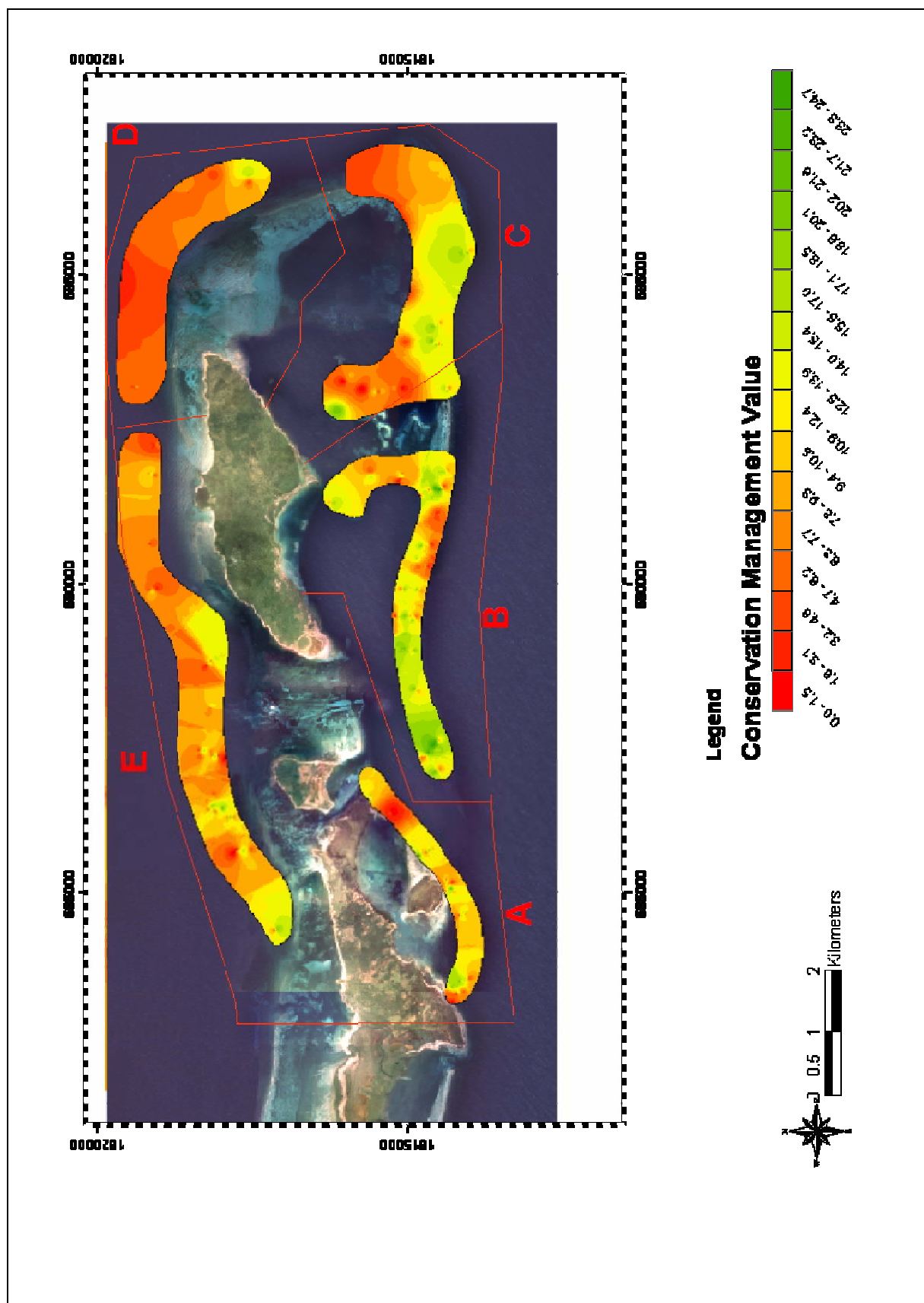


FIGURE 28 CONSERVATION MANAGEMENT VALUES DISPLAYED AS A COLOUR RAMP

4 DISCUSSION

The nature of the variation in boating activity between the east end and the northwest end (O'Farrell et al, 2005) is indicative of differences in the nature reef exploitation between the opposing ends of the island (Figure 12). Saint Helene communities tend to be oriented more towards artisanal fishing (although many young men now work seasonally on the large commercial lobster and shrimp fishing boats, and/or find work on the main island of Roatán in manual labour), whereas the concentration of tourism in the northwest of the island tends to shift the economic balance away from fishing towards the service industries.

The West End Sandy Bay Marine Reserve (WESBMR) has been set up and managed by and for the tourism interests in Roatán and, although there appears to be little real involvement of the local fishing communities in the management decisions taken, anecdotal evidence suggests that the reserve appears to be having a positive impact at an ecological level. After having conducted weeks or months of survey dives around the east end of Roatán, many CCC volunteers have subsequently undertaken recreational dives in and around the WESBMR during the period of 2004 to 2006, and have consistently reported that the abundance of many of the larger, commercially important fish species, such as grouper, jack, barracuda and cero, is notably higher in the west end than around the east. With particular reference to grouper species, this increased abundance may be partially accounted for by the fact that a number of the 'high-end' tourist resorts undertake organised fish-feeding programmes, concentrating the populations within a particular area, and thus making such populations more 'noticeable'.

Overall, however, the fact that many other commercially important species appear to be more abundant in the heavily populated (and utilised) northwest reefs than in the east end does tend to imply that the 'no-take' policy of the WESBMR may be having a positive effect on the biomass of certain fishes, and/or that the uncontrolled fishing practices taking place at the east end of the island are having a negative impact.

Of all of the benthic impact classes on which data were recorded, the most prevalent was found to be coral bleaching (Figure 13), evidence of which was observed on 33% of all transects. Sector D was found to have by far the highest incidence of bleaching (observed on 64% of transects), with lowest being found in sector B (observed on only 21%). It is worth noting that average coral cover was the same within both of these sectors (DAFOR 2; $\approx 11 - 30\%$ of surveyed benthos). Overall, higher incidences of coral bleaching were observed on the northwest reefs (on average, observed on 55% of all transects; O'Farrell et al, 2005) than on the eastern reefs, but as the surveys campaigns were not conducted contemporaneously, this may be accounted for by temporal variation, as is the nature of coral bleaching events.

Although it was not the purpose of this survey campaign to quantitatively determine the extent and nature of such bleaching, the data display a high incidence of the phenomenon, and thus it is suggested that any comprehensive monitoring programme conducted in the future on Roatán should gather specific data on coral bleaching and subsequent mortality/recovery.

In general, coral cover was found to be lower around the east end of Roatán than around the northwest. One exception to this trend was Staghorn coral (*A. cervicornis*), which was found to be more abundant around the east end, with particularly high local abundances found in certain areas, as indicated in Figure 17. Although the eastern reefs have often been hypothesised to be in greater 'health' than the tourism-exploited northwest reefs, most of the data gathered during Project Bay Islands would not support this.

During survey work conducted by other researchers in 2001 in the eastern region (Fonseca et al, 2004), the reefs were found at this time to be in relatively good health (particularly on the southern side of Barbaretta), with high coral cover and frequent sightings of large apex animals, such as dolphins and sharks (particularly *Carcharhinus* spp.). Although variations in survey methodologies between their study and the work presented herein do not allow for direct comparisons, the fact that sightings of sharks (including 'off-transect' sighting reports) were extremely rare in 2004 - 2006 (Figure 25) may hint at the fact that the reefs are succumbing to the ever-increasing fishing pressures noted by Fonseca et al. In fact, the only sharks observed

by CCC survey teams with any degree of frequency were nurse sharks (*Ginglymostoma cirratum*), and these were rare.

Caribbean lobsters (*Panulirus spp.*) have long been exploited as a commercially harvested organism, and the impacts of such intensive targeting are well documented, with populations dropping throughout the region (see, for example, Hodgson and Liebler, 2002). During the campaign conducted by Fonseca et al in 2001, lobsters were observed on 33% of all transects; during the campaign presented herein, lobsters of any species were recorded on only 8% of transects, with the average abundance by transect being zero in all sectors.

Queen conch (*Strombus gigas*) is another commercially exploited species in the region, valued both as a food stuff and for their shells, which are sold in the tourist curio trade. Fonseca et al found that, in 2001, queen conch population densities around Barbaretta (35 individuals per hectare) were second only within the region to those found in Jamaica by Tewfik et al (1998). Although, once again, direct comparisons cannot be made, the data presented herein return an apparently stark figure of 3% for the percentage of transects on which any queen conch were observed during this extensive campaign, implying that the population has declined sharply in the intervening years.

Populations of reef urchins (*Echinometra spp*) were found to be higher (Figure 23) than those of long-spined urchin (*Diadema spp*) (Figure 22), with reef urchins being recorded on 51% of all transects, where long-spined urchins were only recorded on 13% of transects. Reef urchins are not thought to have been as significantly impacted by the pathogen that caused the widescale mortality of long-spined urchins in the early 1980s, and thus, as both urchins may be considered to perform similar ecological functions (in particular, with regard to the grazing of algae), the reef urchin population may have exploited the competitive gap left on the reefs by the demise of the long-spined urchin population. This is supported by the fact that macroalgal abundances were relatively low on the eastern reefs (Figure 26), a phenomenon that may be augmented by the relatively high (if patchily distributed) extant populations of herbivorous grazers, such as parrotfishes., and by the prevalence of current patterns that bring 'clean' water from the open seas of the east (Figure 8), which is likely to be

lower in dissolved organic nutrients than water that has recently succumbed to terrigenous nutrient loading.

Overall, this survey programme has shown the ecologically healthiest areas of reef to be located south of the island of Barbaretta (sectors B and C, Figure 28), echoing the findings of Fonseca et al (2004). These can be considered to be amongst the most important stocks of biological diversity in the area, and should be a key focus of any managerial intervention, such as the creation and management of Marine Protected Areas.

The reefs of Roatán may be considered to be its greatest natural asset. They provide enormous direct economic benefits from reef-associated tourism and fisheries, with indirect benefits arising from, amongst other things, shoreline protection and the production of sand for beaches. If Roatán loses its coral reefs, it will consequently lose much, if not most, of its economic potential. Many of the data gathered during Project Bay Islands have indicated that the reefs of the area may be undergoing ongoing and insidious degradation, and unless action is taken within the very near future to reverse this trend, the outlook for the island is bleak. However, it is not too late for the reefs to be recovered, but this will require strong and decisive managerial action in order to implement and enforce appropriate strategies for the safeguarding of the island's future. There is no reason why the successes that have been achieved in other regions of the Caribbean cannot be replicated in Roatán; the path is not an easy one, but the goal has been proven to be attainable.

5 RECOMMENDATIONS

Analysis of the data gathered during the east-end phase of the Project Bay Islands Roatán survey programme supports the recommendations made upon completion of the northwest phase (O’Farrell et al, 2005), namely:

- The urgent implementation and enforcement of existing management plans to safeguard the reef resources of the east end of Roatán and the island of Barbaretta. This region is currently undeveloped compared to the rest of the island, although it is likely that there will soon be an increased influx of tourism pressure and economic migration of Hondurans.
- The regulation of tourism-associated sources of degradation, such as curio collecting and sport fishing, the continuation of the latter being on a ‘catch-and-release’ basis only.
- The education of Bay Islanders and diving professionals in basic reef ecology, mechanisms and outcomes of reef degradation and solutions.
- The location and protection of key spawning sites for depleted fish stocks, such as those of grouper and snapper. Anecdotal evidence from the fishers of Saint Helene suggests that such sites may be located at a number of areas off the north shore of the island of Barbaretta.
- The building of capacity amongst the Native Bay Islanders of the east end who are the custodians of the reef resources in the area. Inclusion of local communities in the decision making processes regarding their future is generally considered to be central to the success of Marine Protected Areas in remote regions that are difficult to effectively ‘police’ from the outside.

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