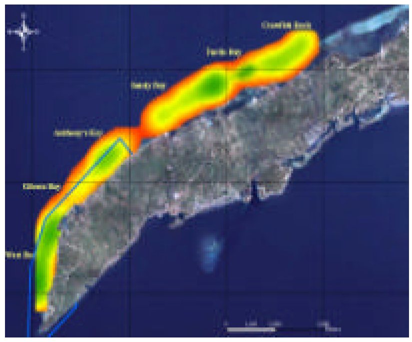
CORAL CAY CONSERVATION

PROJECT BAY ISLANDS
ROATÁN – NORTHWEST SHORE

An interim analysis of baseline marine ecological data gathered from the Northwest Shore region between January 2002 and March 2004



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EXECUTIVE SUMMARY

Coral Cay Conservation (CCC), a UK-Based not-for-profit NGO, has been working in partnership with Proyecto de Manejo Ambiental de Islas de la Bahía (PMAIB) on Roatán since 2000, when the two organisations joined forces to undertake Project Bay Islands - Roatán. In addition to capacity building programmes (such as the training of Honduran counterparts in SCUBA diving and marine ecological surveying) and community education initiatives (such as Schools Educational Open Days), CCC volunteers have undertaken an extensive programme of resource assessment on the coral reefs of the island. This assessment has taken place in three phases:

- 2000 – 2001 South Shore (presented in *Project Bay Islands – Roatán South Shore*, Taylor et al, 2004)
- 2002 – 2004 Northwest Shore (presented herein)
- 2004 – 2006 East End and Barbareta (to be presented upon completion of the project)

The data gathered during this resource assessment have been used to create resource 'maps' of the island, highlighting 'good' areas that need to be protected from degradation, as well as impacted areas that need to be monitored for recovery or decline in response to implemented management plans. In addition, 138 Reef Check surveys have been conducted, with these data contributing to the Reef Check worldwide database of coral reef health.

The extensive community work undertaken by CCC's Project Scientists has resulted in numerous Schools Educational Open Days and beach clean-ups with the local communities, in addition to a series of teacher-training workshops on the neighbouring Bay Islands of Utila and Guanaja (in conjunction with PMAIB). In all, nearly 800 school children of all ages (and frequently their parents) have taken an active role in our environmental education workshops in the towns of Punta Gorda, Coxen Hole, Sandy Bay, French Harbour, Flowers Bay and Gravel Bay. Educational posters have been professionally produced in both Spanish and English, hundreds of

reef collages and drawings have been made by the schools and even the interior of the public hospital in Coxen Hole has been painted.

Since 2000, around 150 Honduran counterparts have been trained under the CCC Marine Scholarship scheme, ranging from weekend-long 'reef-awareness' snorkelling workshops to full 5 week expeditions, learning to dive and to survey side by side with more than a thousand CCC volunteers. These counterparts have come from the local fishing and tourism communities as well as from the Universidad Nacional Autonoma de Honduras (UNAH) and the Universidad Jose Cecilio del Valle, both in Tegucigalpa. This 'passing-on' of knowledge is essential if the momentum gained by Project Bay Islands is to be continued upon the completion of the project.

The coral reefs of the West End of Roatán are very popular with the international tourist diving community and general tourists alike. They provide food and livelihoods for thousands of inhabitants of Roatán, and with appropriate management, they will continue to do so for the foreseeable future. They are an irreplaceable resource of incredible value, both in biological and economic terms. An analysis of key biological indicator species suggests that the reefs may be under a great deal of stress, and that appropriate management action must be undertaken if any decline in reef health is to be halted.

Overall, however, the corals of the reefs are in fair condition, with high coral cover being recorded in a number of sites, most notably in the Turtling (or Turtle) Bay and Crawfish Rock sectors (hard coral accounted for 51-75% on certain transects). Moderate stands of the now rare *Acropora cervicornis* ('staghorn' coral) were recorded in Turtle Bay and West Bay. The most commonly occurring hard coral species were found to be *Millepora* spp. ("fire" corals), *Porites astreoides* ("mustard hill"), *Montastrea annularis* ("boulder star"), *Montastrea cavernosa* ("cavernous star") and *Agaricia agaricites* ("leaf"), all of which were recorded on over 80% of transects.

The data from the surveyed transects underwent hierarchical cluster analysis in PRIMER 5, and then discriminant analysis in MiniTab 13 in order to identify and define discreet ecological 'habitats'. Each individual survey record was then compared statistically against the others within its discreet ‘habitat’. Conservation Management Values were then applied based on 5 indices, and were used to create a Geographic Information System (GIS) data ‘map’ of the region, highlighting key areas of high biodiversity and live hard coral cover. These areas can be considered to be of high ecological value and their protection should be addressed by resource managers within the region.

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ACKNOWLEDGMENTS

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Finally, CCC is very grateful to all of our field staff and volunteers, without whom this project would not have been possible..

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 Northwest Shore area of Roatán, from surveys conducted between January 2002 and March 2004. A synoptic management report (*The Goose that lays the Golden Eggs*) is also available at www.coralcay.org/expeditions/marine/hn1/publications.php. 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 THE *PROJECT BAY ISLANDS*, *ROATÁN*

The aims of *Project Bay Islands* extend from the work done in Utila and continue to develop through the work now being undertaken around the east of the island. This report is concerned with the baseline monitoring data gathered along the Northwest shore of the island. Results of surveys completed around Santa Helena and Barbareta will be documented in the next annual report.

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 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		**Lecture 3** ▶Dangerous marine animals **Safety briefings** **Practical** ▶Scuba kit allocation ▶PADI AOW Elective Dive: PPB with new diver volunteers. ▶Rescue Diver mods 1&2	**Expedition Camp Duties** **Lecture 5** ▶Into to the biology and ID of marine plants and algae	**Lecture 6** ▶Intro to the Cnidaria - biology and taxonomy **Practical 2** ▶PADI AOW Elective Dive: PPB (6m) with new diver volunteers with brief Reef Orientation – Cnidaria & Algae	**Lecture 8i** ▶Hard coral ID – target groups 1 **Lecture 8ii** ▶Hard coral ID – target groups 2 **Practical 4** ▶Hard coral targets ID (scuba-18m / snorkel)	**Lecture 10** ▶Intro to fish biology, ecology & identification **Lecture 11** ▶Main Fish families **Practical 5** ▶Fish ID – Families (scuba 18m/snorkel) **Review** ▶Fish ID – Families	**Lecture 12ii** ▶Fish ID – target species 2 **Practical 7** ▶Fish ID – target species 2 (scuba-18m) **Review** ▶Fish ID – target species 2	**Lecture 13i** ▶Invert. ID 1 **Lecture 13ii** ▶Invert. ID 2 **Practical 9** ▶Invert. ID (scuba-18m) **Review** ▶Invert. ID
⇩PM	**Orientation** ▶Welcome & tour of facilities ▶Expedition life & duties ▶General health & safety ▶CCC rules & regulations	**Review** ▶Expedition Skills Development Programme schedule **Lecture 4** ▶Intro to coral reef ecology **Practical** ▶Orientation dive	**Practical 1** ▶ Marine plants & algae ID (snorkel) ▶Specimen ID – reference collections **Review** Marine plants and algae	**Lecture 7** ▶Intro to hard corals - biology and life-forms **Practical 3** ▶ID – Cnidaria groups and hard coral life-forms (scuba- 16m / snorkel) **Review** ▶Cnidaria & hard coral life forms	**Lecture 9** ▶Soft corals and sponges – biology and ID **Practical 5** ▶Hard/soft coral and sponges ID (scuba – 16m / snorkel) **Review** ▶Hard/soft coral and sponges ID	**Lecture 12i** ▶Fish ID – target species 1 **Practical 6** ▶Fish ID – target species (scuba 16m) **Review** ▶Fish ID – target species 1	**Practical 8** ▶Fish ID – families and target species (scuba-18m/snorkel) **Review** ▶Fish ID – target species	**Review** ▶ID – coral, fish, inverts & algae **Practical Exam** ▶ Hard and soft coral ID –coral trail (scuba-16m/ snorkel)
EVE	**Lecture 1** ▶Country Brief, Local culture and customs **Lecture 2** ▶In-Country Partners and Project Background	**Review** ▶Expedition Skills Development Programme schedule	**Review quiz** ▶CCC health & safety regulations ▶CCC dive standards ▶Emergency procedures ▶Local culture & customs	**Revision** ▶Marine plants and algae **Examination** ▶Marine Plants and algae (spot samples/slides)	**Revision** ▶Hard and soft corals **Examination** Hard and soft Coral ID	**Review** ▶Fish ID (pictionary) **Revision** ▶Fish families and targets 1 ID	**Revision** ▶Fish families and target species ID. **Examination** ▶Fish ID	**Revision** ▶ Invertebrate ID (slides) **Lecture 14** ▶Ropes & knots **Self-revision** ▶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 & use **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.

Since 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 length of rope, whilst Buddy Pair A swim 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 taught. 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).

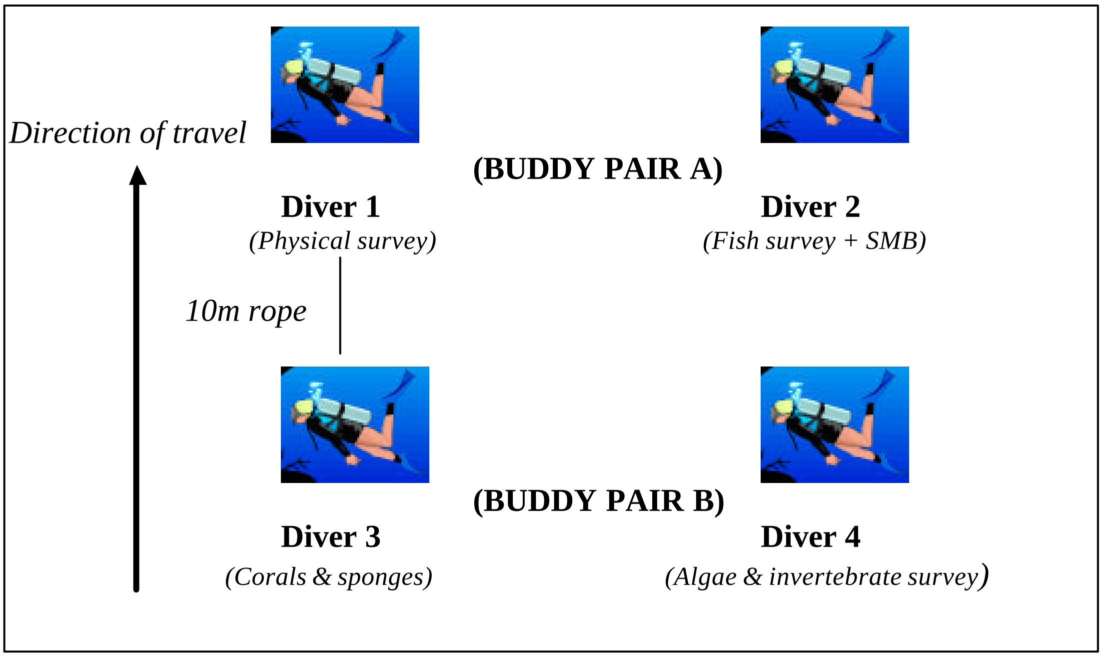

FIGURE 1: SCHEMATIC DIAGRAM OF A BASELINE SURVEY DIVE TEAM SHOWING THE POSITIONS AND DATA GATHERING RESPONSIBILITIES OF ALL FOUR DIVERS.

During the course of each sub-transect survey, divers may have traversed two or more apparently discrete habitat types, based upon obvious gross geomorphological (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 ordinal scale shown in Table 3.

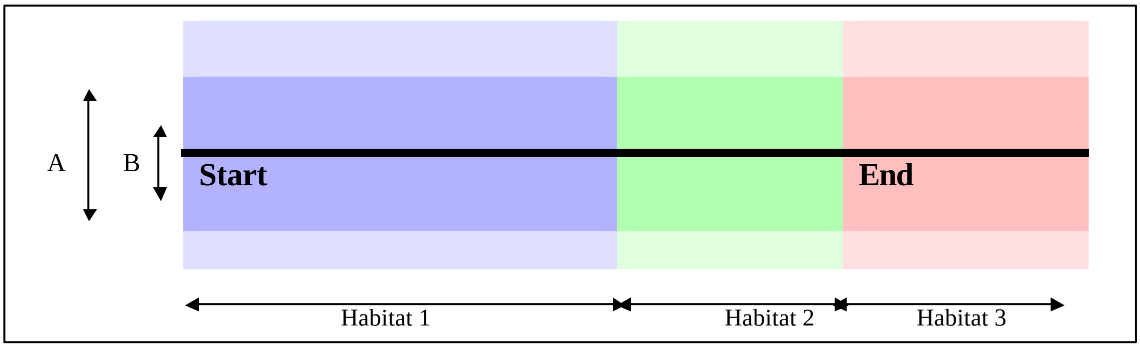

FIGURE 2: SCHEMATIC DIAGRAM (AERIAL ASPECT) OF AN EXAMPLE OF A REEF AREA MAPPED BY DIVERS DURING A SUB-TRANSECT SURVEY. SOLID LINE REPRESENTS IMAGINARY SUB-TRANSECT LINE. DASHED LINES AND SHADED AREAS REPRESENT AREAS SURVEYED (A = 5M WIDE SWATHE SURVEYED BY DIVERS 1, 2 AND 4; B = 2 M WIDE SWATHE SURVEYED 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 (±0.5°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.

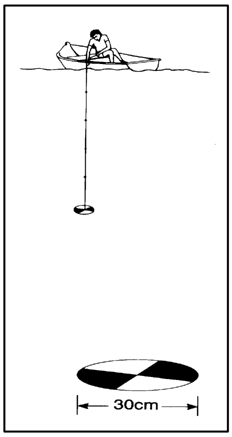

FIGURE 3: THE USE OF A SECCHI DISC TO ASSESS VERTICAL WATER CLARITY**.** The Secchi disc is lowered into the water until the black and white quarters are no longer distinguishable. The length of the rope from surveyor to the disc is then recorded.

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’, ‘dynamite fishing’, ‘cyanide fishing’ 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 REEF CHECK

Reef Check[1] was designed to be used by non-professional divers to assess reef health and hence generates relatively simple, but quantitative, information. In addition to CCC baseline surveys, the standard Reef Check protocol has been modified to allow CCC survey teams to collect data at a higher taxonomic resolution. Such modifications are possible because all CCC volunteers receive intensive ecological training that most regular sport divers are not party to.

The standard Reef Check survey protocol utilises two transects at depths of approximately 3 and 10 m but surveys along a total of 4 depth contours (6,10,16,and 20m) were conducted by CCC survey teams if the reef topography was appropriate. Along each depth contour a 100 m transect is deployed and along it four 20 m long replicate transects were surveyed. The replicate transects followed the designated depth contour in sequence but the start and end points are separated by a 5 m gap. By collecting data from each of the four 20 m sections, four replicates are collected per survey allowing the calculation of a mean per replicate and hence more powerful statistical analysis.

Four types of data are recorded:

1. *Site Description*

Site description sheet is completed which included anecdotal, observational, historical, geographical and other data.

2. *Fish Belt Transect*

Commercially important fish species are sampled from four 5 m wide by 20 m long transects (centred on the transect line). Fish are only counted if they are less than 5 m

[1] Further details at http://www.reefcheck.org

above the transect line, giving a survey area for each transect replicate of 20 x 5 x 5 m = 500 m^3. CCC volunteers in Roatán record data on more fish species than specified by the standard Reef Check protocol. The divers assigned to count fish swam slowly along the transect and then stopped to count target fish every 5 m and then waited three minutes for target fish to come out of hiding before proceeding to the next stop point.

3. *Invertebrate Belt Transect*

Invertebrates surveys concentrate on gathering data on organisms that are targeted as food species or are collected as curios (belt transect centred on the transect line). Quantitative counts are made of each species. In addition, the invertebrate surveyors noted the presence of coral bleaching or unusual conditions along the transects.

4. *Substrate Point Intercept Transect*

Four 20 m long transects are point sampled at 0.5 m intervals to determine the substratum types and benthic community of the reef. The diver examines each point and notes down what lies under each of those points. The standard Reef Check protocol specifies that the categories recorded under each 50 cm point are: hard coral, soft coral, recently killed coral, dead coral, fleshy seaweed, sponge, rock, rubble, sand, silt / clay and 'other'. However, CCC volunteers record hard corals to life form level (along with target species), soft corals to life form level and five categories of algal cover (mixed assemblage, coralline, *Halimeda* spp, 'macro' and 'turf'). Finally, the substratum survey records coral damage and 'other' indicators, such as trash, fishing nets etc. Divers rate the damage caused by each factor using a 0-3 scale (0 = none, 1 = low, 2 = medium, 3 = high). All data are transferred to specially designed recording forms.

The results of the Reef Check data gathered from the northwest shore area of Roatán are not presented herein, but are available in a separate report (O'Farrell *et al*, 2004).

2.4 BASELINE DATA ANALYSIS

2.4.1 Oceanographic, Climate 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.

2.4.2 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).

2.4.3 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 Liebeler (2002), are examined to indicate the status of reef health and to suggest causes of any degradation.

2.5 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 represented 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's 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 Density function in the Spatial Analyst of *ArcMap* 8.3 (ESRI software).

3 RESULTS

3.1 SURVEYS CONDUCTED

Between January 2002 and March 2004, CCC survey teams produced 517 individual survey records (Figure 4). In all, 22 kilometres of reef were assessed at intervals of 250m along the shoreline, from a depth of 28m to approximately 1m.

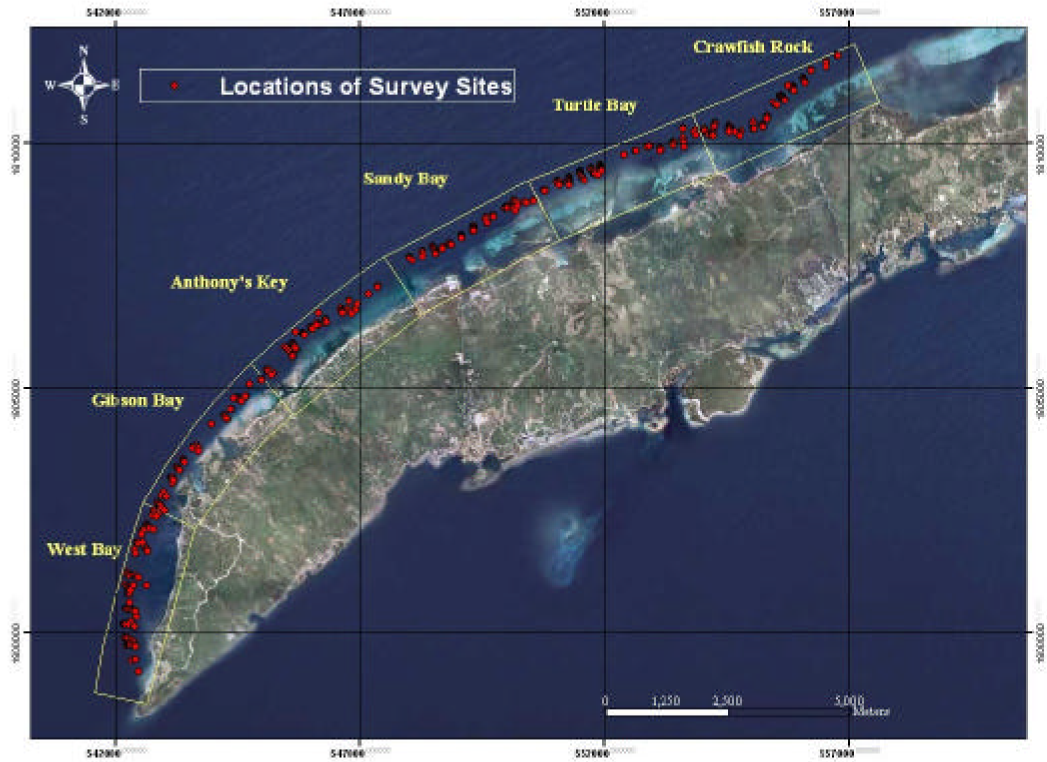

FIGURE 4: THE LOCATIONS OF CCC SURVEYS SITES ALONG THE NORTHWEST SHORE OF ROATÁN.

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 distinct marine habitats [3.4]
- The rating of each survey site relative to others that have been classified within in the same habitat type (*Conservation Management Value*) [3.5]

3.2 RESULTS FROM OCEANOGRAPHIC AND GEOMORPHOLOGICAL DATA

3.2.1 Reef Profiles by Sector

Many of the reefs along the northwest are characterised as fringing reefs with a large lagoonal area between the reef crest and the shore. This lagoonal area is usually composed of a sand substrate with extensive cover of seagrasses, predominantly *Thalassia* and *Syringodium* spp. In Figure 5, the region represented in the graphs is the lower reef slope up to the reef crest, with lagoon extending from this reef crest to the land, and it can be seen that, geomorphologically, the reefs themselves are classic fringing reefs, although the secondary reef wall found offshore in the Anthony's Key sector is less common.

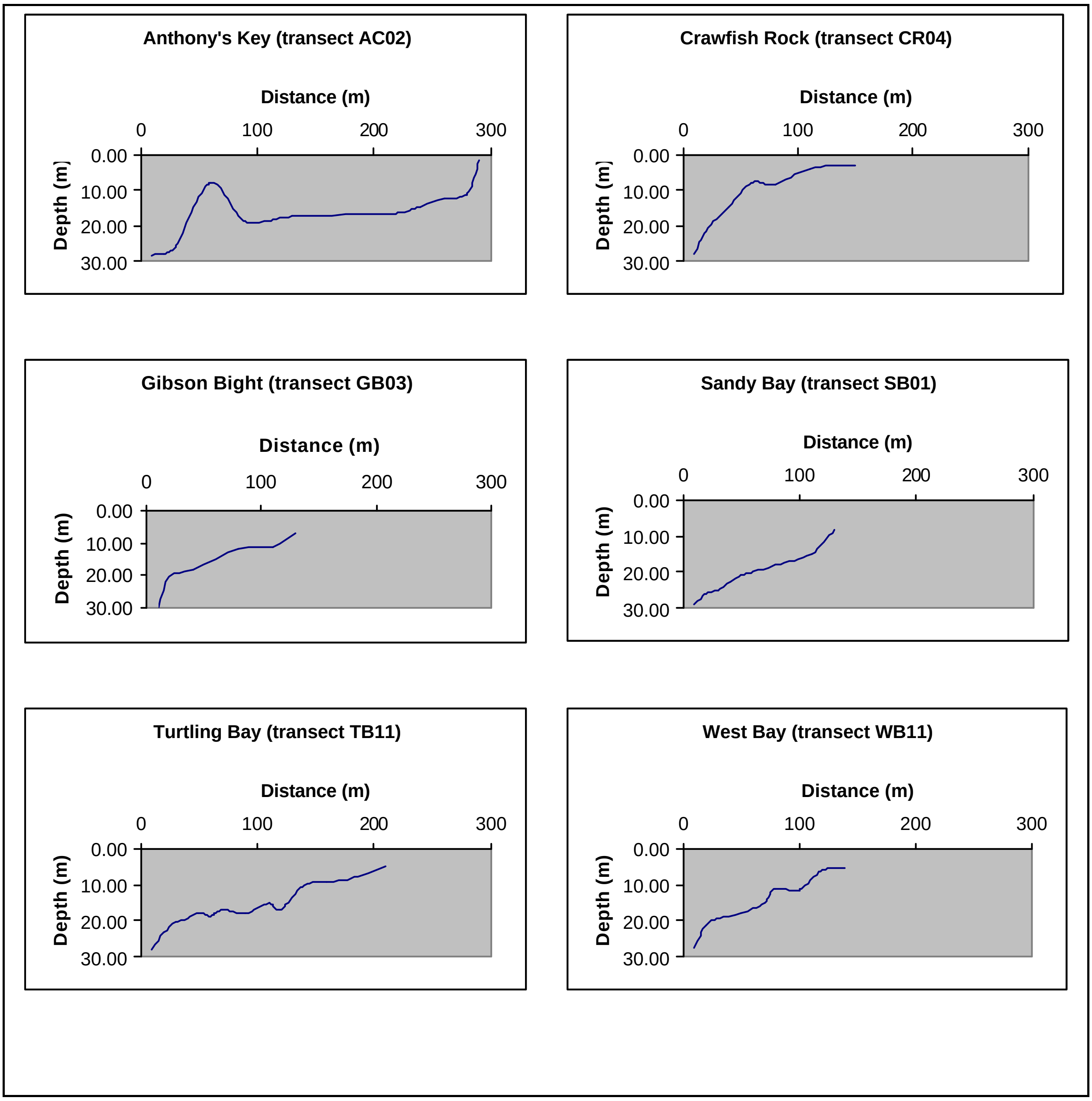

FIGURE 5: REEF PROFILES BY SECTOR

3.2.2 Water Temperature

Recordings of water temperature have produced results that are consistent with those recorded during the first phase of Project Bay Islands, Roatán – South Shore (Taylor et al, 2004). Mean annual sea surface temperature was found to be 28.4º C, with a high of 33.3º C being recorded in June. The mean temperature during June was 30.4ºC (Figure 6). June, July and August also had the highest incidences of coral bleaching, with observations being recorded on 33%, 31% and 30% 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. Predictably, water temperature decreased with increased depth (Figure 7), with the 5-10m depth class demonstrating the greatest variation between samples (d = ±1.76° C; n=77).

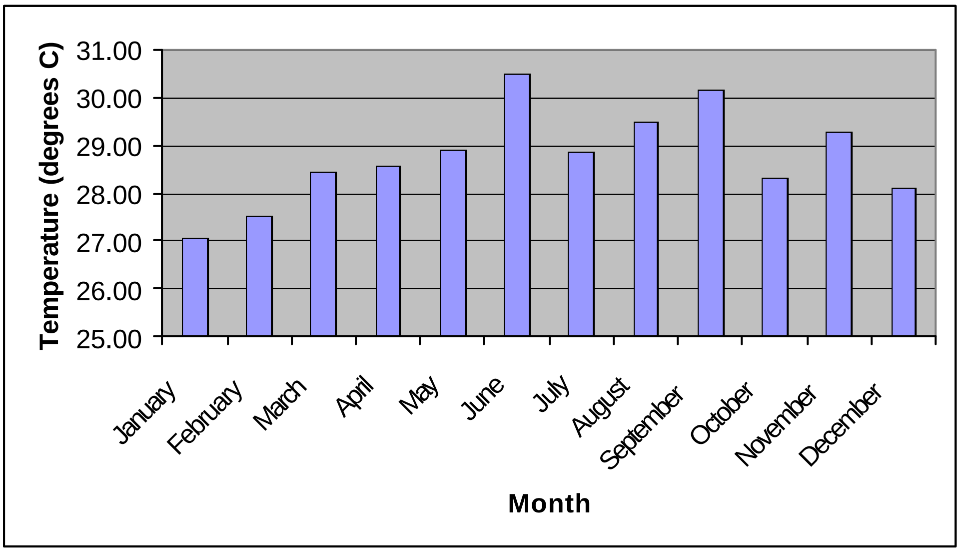

FIGURE 6: ANNUAL FLUCTUATIONS OF MEAN SURFACE WATER TEMPERATURE

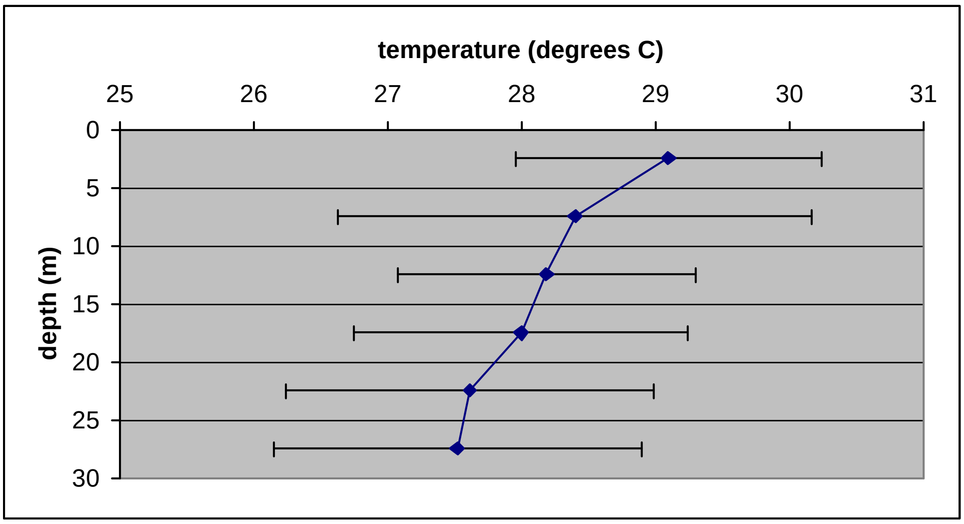

FIGURE 7: MEAN WATER TEMPERATURE IN 5M DEPTH CLASSES.
(Error bars represent standard deviation of samples).

3.2.3 Salinity

Again, values recorded for salinity, both at the surface and within various depth classes are largely consistent with those recorded during the first phase the project (Taylor et al, 2004), although the highest variation was this time recorded in the 0 – 5m class (d = ±3.47; n=36) rather than the 10 – 15 m class (d = ±2.69; n=83). Mean salinity was 34.94‰, compared to 34.75‰ for the south shore data (Figure 8).

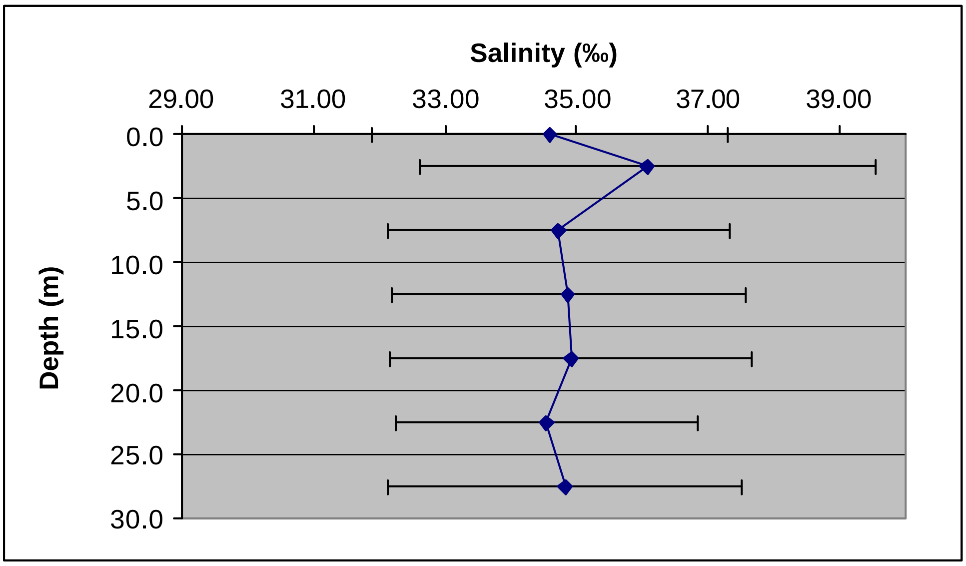

FIGURE 8: MEAN SALINITY IN 5M DEPTH CLASSES.
(Error bars represent standard deviation of samples).

3.2.4 Current strength and direction

The prevailing currents were found to be weak, in a westerly (i.e. moving towards the west) direction. Of the 517 survey records, 64% of currents were recorded as being ‘weak’, with 71% of records being SW –W – NW (Figure 9). This has important ramifications for the location of Marine Protected Areas with regard to larval recruitment, as examined in the Discussion section of this report.

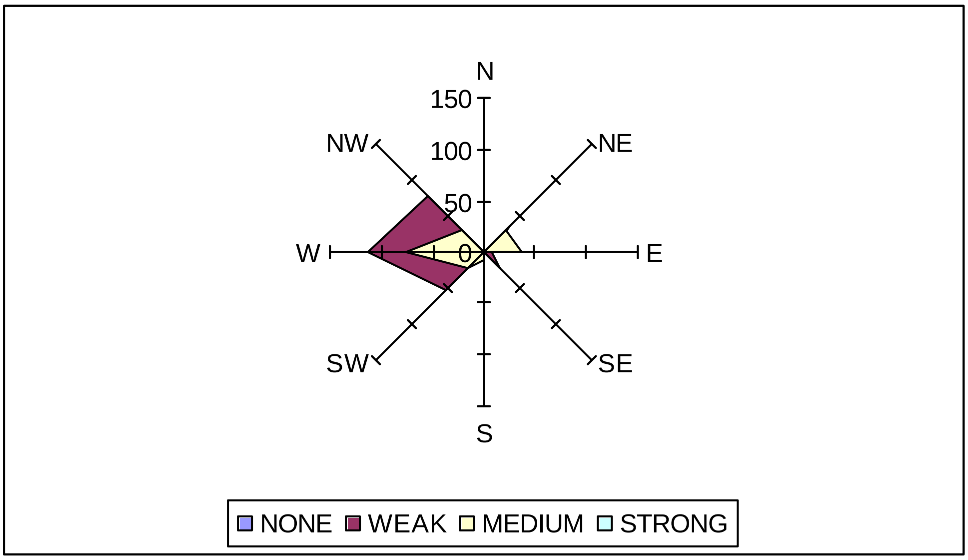

FIGURE 9: CURRENT STRENGTH AND DIRECTION AS A PROPORTION OF ALL OBSERVATIONS

3.2.5 Wind strength and direction

The prevailing winds on Roatán are Easterlies (i.e. coming from the east) (Figure 10), which is consistent with the trade winds experienced in the Caribbean. The strongest winds were experienced between the months of June and August (Table 4), although the maximum wind strength of Beaufort 6 was recorded on only 2% of surveys (Table 5).

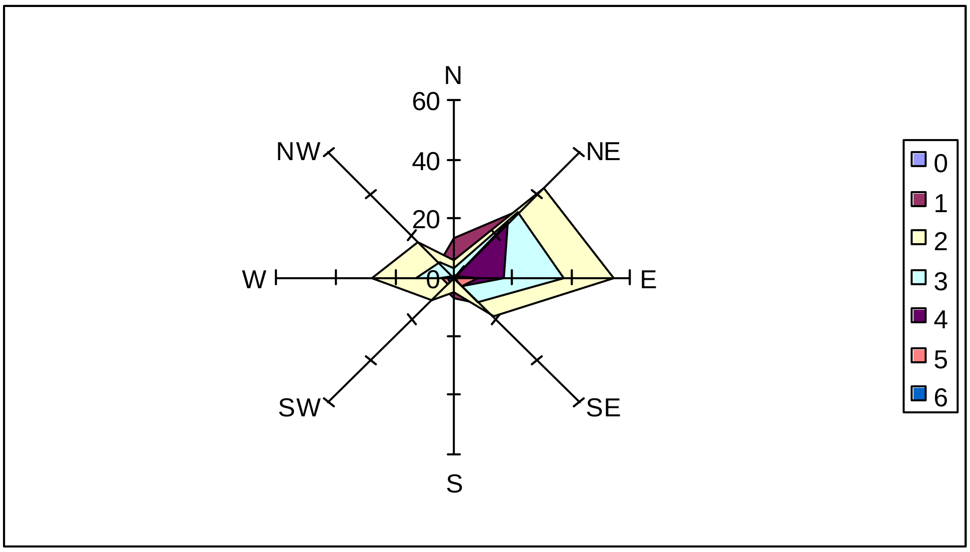

FIGURE 10: WIND STRENGTH AND DIRECTION AS A PROPORTION OF ALL OBSERVATIONS (WIND STRENGTH VALUES ARE MEASURED ON THE BEAUFORT SCALE).

Month	Wind direction	Percentage of observations within each month
January	E - NE	68%
February	E - NE	46%
March	E - NE	48%
April	No distinct direction	N/A
May	No distinct direction	N/A
June	NE - SE	59%
July	E - NE	69%
August	E - NE	52%
September	E - NE	64%
October	E - NE	81%
November	NE	52%
December	NE	56%

TABLE 4: PREVAILING WIND DIRECTION AS A PERCENTAGE OF ALL OBSERVATIONS WITHIN EACH SURVEY MONTH

Wind Strength	Description	No Recordings	%	Observations
0	Calm (<1 knot)	12	2	All year
1	Light Air (1-3 knots)	128	24	All year
2	Light Breeze (4- knots)	184	35	All year
3	Gentle Breeze (7-10 knots)	104	20	All year
4	Moderate Breeze (11-16 knots)	53	10	All year
5	Fresh Breeze (17-21 knots)	22	4	April to August
6	Strong Breeze (22-27 knots)	13	2	July and August

TABLE 5: OBSERVATIONS OF WIND STRENGTH (BEAUFORT SCALE)

3.2.6 Boat frequency and activity

The majority of observed boat traffic recorded was engaged in recreational diving, which is consistent with the high concentration of dive shops around the West End of Roatán. Most of this activity was located within the Gibson Bight, West Bay and Anthony's Key sectors (average 1.65, 1.2 and 1.0 boats observed per survey dive respectively – see Figure 11). These are the three most westerly of the reefal areas analysed in this report and it is inferred that diving pressure may be heaviest within these areas.

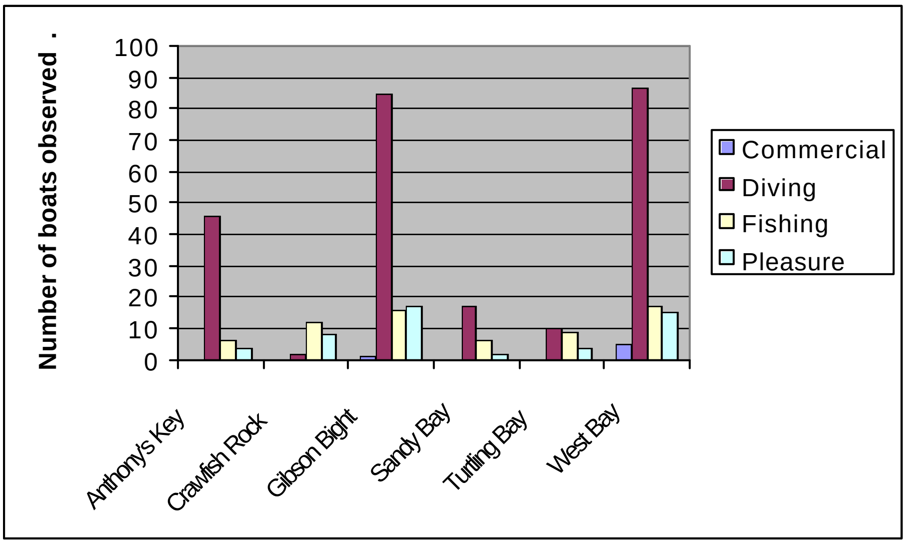

FIGURE 11: OBSERVATIONS OF BOAT ACTIVITY BY SECTOR

3.2.7 Sub-surface impacts

By far the most prevalent sub-surface impact recorded was coral bleaching, which accounted for 55% of all impacts (Figure 12) and was recorded on 28% of all survey dives. The second most prevalent impact recorded was coral damage (e.g. by anchors/divers etc). The highest incidences of coral damage were recorded in West Bay, Gibson Bight and Anthony's Key (19%, 17% and 16% of survey dives respectively). These sectors also exhibited the highest levels of dive boat activity (Figure 11 above), and the correlation between the two variables is statistically significant ($r = 0.784$; $p = 0.043$).

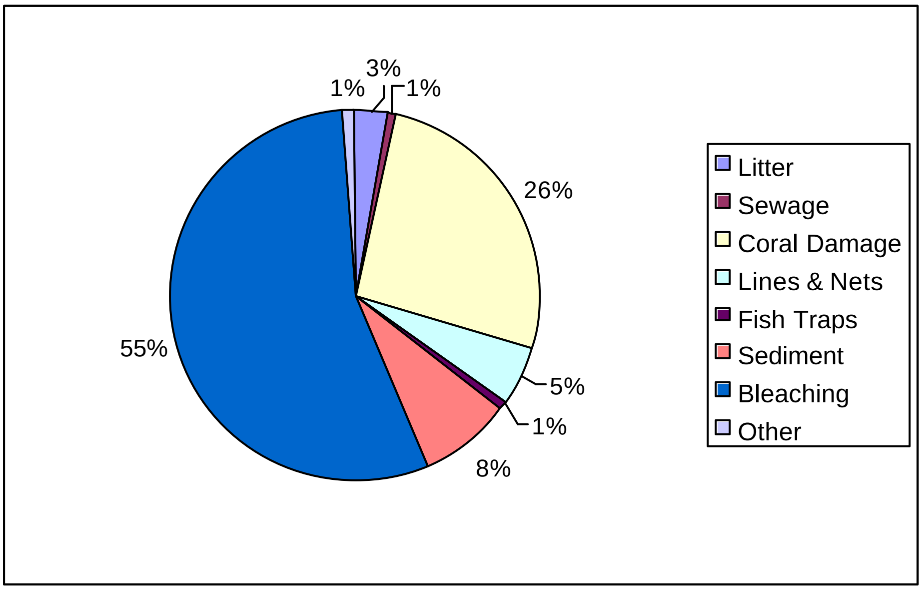

FIGURE 12: OBSERVATIONS OF SUB-SURFACE IMPACT CLASSES AS A PERCENTAGE OF ALL OBSERVATIONS

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 by which reef health can be inferred.

3.3.1 Live Hard Coral Cover

In many places on the northwest reefs, the coral cover is moderate to good for the modern Caribbean (DAFOR 3: approximating 31-50% of the surveyed benthos), with a small number of exceptional sites (51-75%), as illustrated above in the GIS output (Figure 13 and in Figure 15). Staghorn coral (*Acropora cervicornis*) and Elkhorn coral (*Acropora palmata*) were once amongst the major reef building corals in the

Caribbean, but most colonies were killed off in the 1980s by White Band Disease. There has been some recovery of Elkhorn coral since that time, but Staghorn coral has not faired so well (Figure 14). Moderate stands of both species were recorded during the survey programme. Recent unpublished data indicate that extensive stands of *A. cervicornis* are located around Smith Bank and Cordelia Shoal, southwest of the town of Coxen Hole.

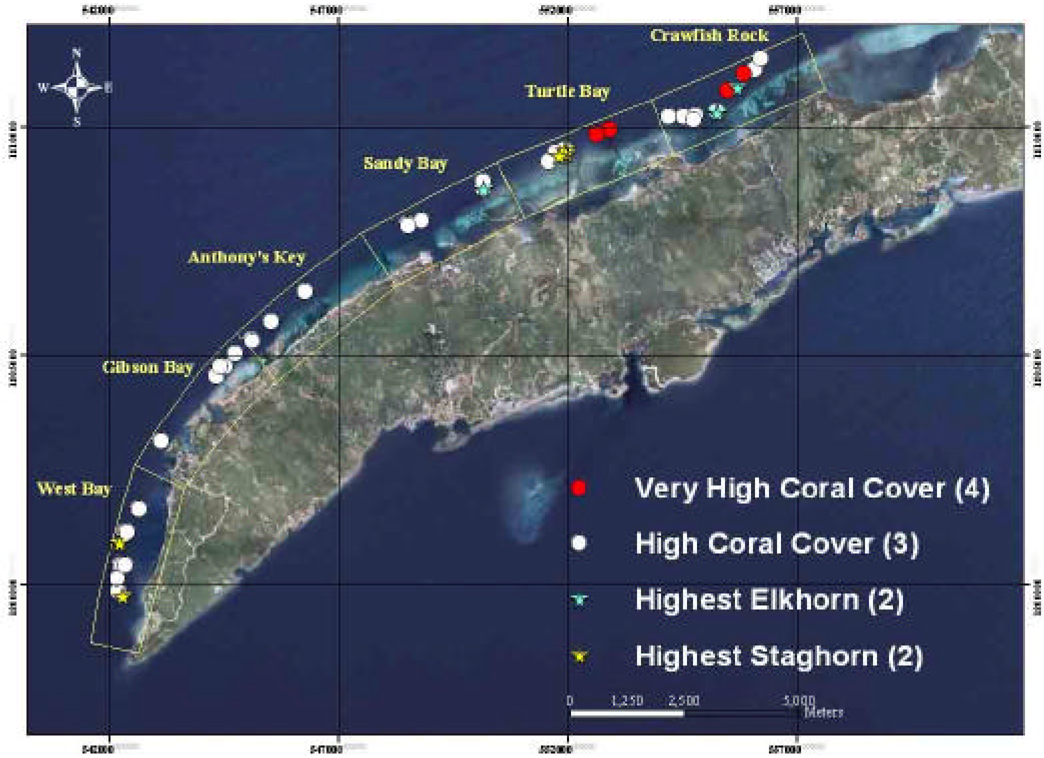

FIGURE 13: KEY LIVE HARD CORAL COVER LOCATIONS. FIGURES IN PARENTHESES INDICATE DAFOR ABUNDANCE RATINGS

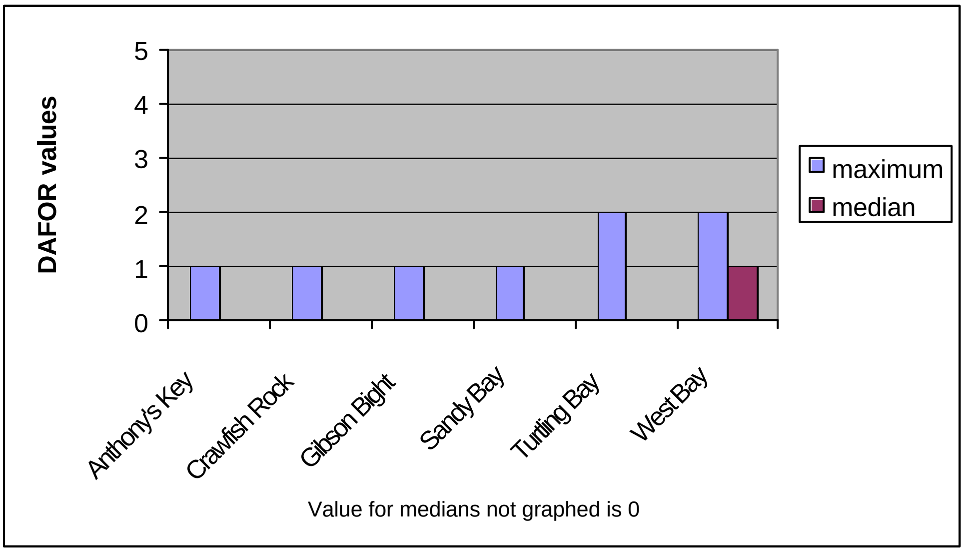

FIGURE 14: STAGHORN CORAL (*ACROPORA CERVICORNIS*) ABUNDANCE BY SECTOR

Overall, coral cover was moderate in most sectors, with average DAFOR values of 2 (approximating 11-30% of the surveyed benthos) being recorded in 4 of the 6 survey sectors (Figure 15). The highest values of DAFOR 4 (approximating 51-75% of the surveyed benthos) were recorded in the Crawfish Rock and Turtling Bay sectors, which are currently outside the boundaries of the West End Sandy Bay Marine Reserve.

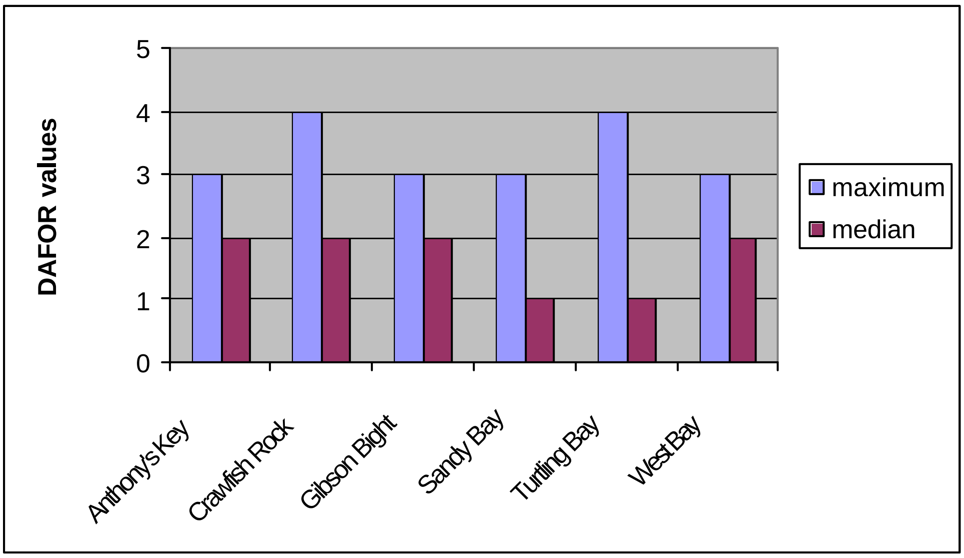

FIGURE 15: TOTAL LIVE HARD CORAL ABUNDANCE BY SECTOR

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 42% 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
Millepora spp	Fire corals	92
Porites astreoides	Mustard hill	91
Montastrea annularis	Mountainous star	90
Montastrea cavernosa	Cavernous star	89
Agaricia agaricites	Leaf	84
Meandrina meandrites	Butterprint brain	78
Siderastrea siderea	Smooth starlet	71
Porites porites	Club finger	68
Mycetophyllia lamarckiana	Fungus	67
Diploria strigosa	Smooth brain	60
Diploria labyrinthiformis	Grooved brain	59
Colpophyllia natans	Giant brain	58
Mycetophyllia danaana	Fat fungus	57
Agaricia tenuifolia	Ribbon	53
Eusmilia fastiagata	Flower	52
Agaricia lamarcki or *grahamae*	Sheet	49
Acropora cervicornis	Staghorn	47
Dichocoenia stokesii	Elliptical star	46
Porites furcata	Finger	45
Madracis decactis	Green cactus	45
Scolymia lacera	Solitary disk	42
Helioseris cucullata	Saucer	39
Mycetophyllia aliciae	Thin fungus	39
Agaricia agaricites var danai	Massive leaf	37
Isophyllastrea rigida	Rough star	35
Stephanocoenia michilini	Blushing star	30
Dendrogyra cylindrus	Pillar	29
Agaricites fragilis	Fragile saucer	28
Madracis mirabilis	Yellow pencil	28
Mycetophyllia ferox	Grooved fungus	21
Agaricites agaricites forma purpurea	Purple leaf	20
Manicina areolata	Rose	17
Mussa angulosa	Large flower	16
Favia fragum	Golfball	15
Madracis formosa	Eight-ray finger	14
Acropora palmata	Elkhorn	12
Isophyllia sinuosa	Sinuous cactus	11

TABLE 6: MOST COMMONLY RECORDED CORAL SPECIES

3.3.2 Coral species regressed against fish species

It has been established that there is a positive 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 northwest Roatán, with the greatest number of fish species being recorded at the sites exhibiting the greatest number of coral species (Figure 16).

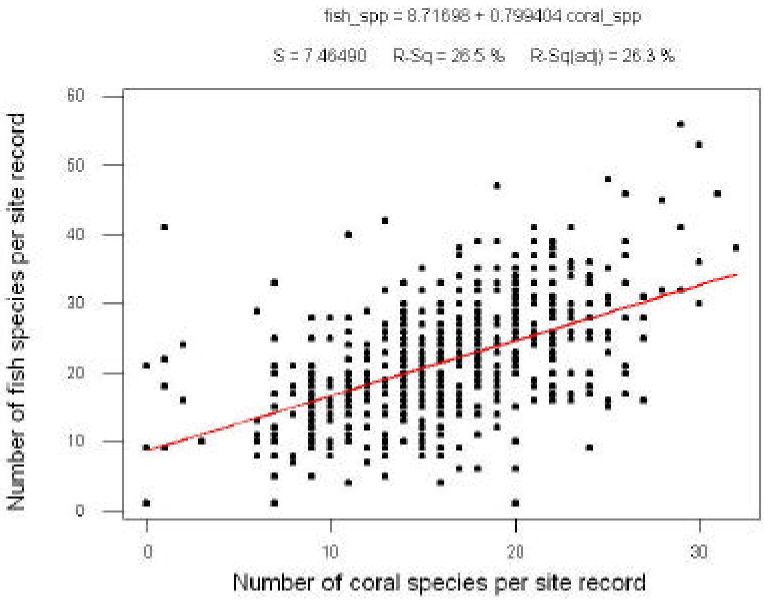

FIGURE 16: REGRESSION PLOT OF NUMBER OF FISH SPECIES AGAINST NUMBER OF CORAL SPECIES

3.3.3 Lobster (*Panulirus* spp)

The displayed maximum value of DAFOR 2 was recorded at only 1% of survey sites in this sector (Figure 17). The maximum value in any sector was DAFOR 2 (6 - 20 lobsters) but this recorded at only 1 survey site in West Bay. The average value recorded in all sectors was zero, indicating a high level of fishing pressure and/or habitat destruction.

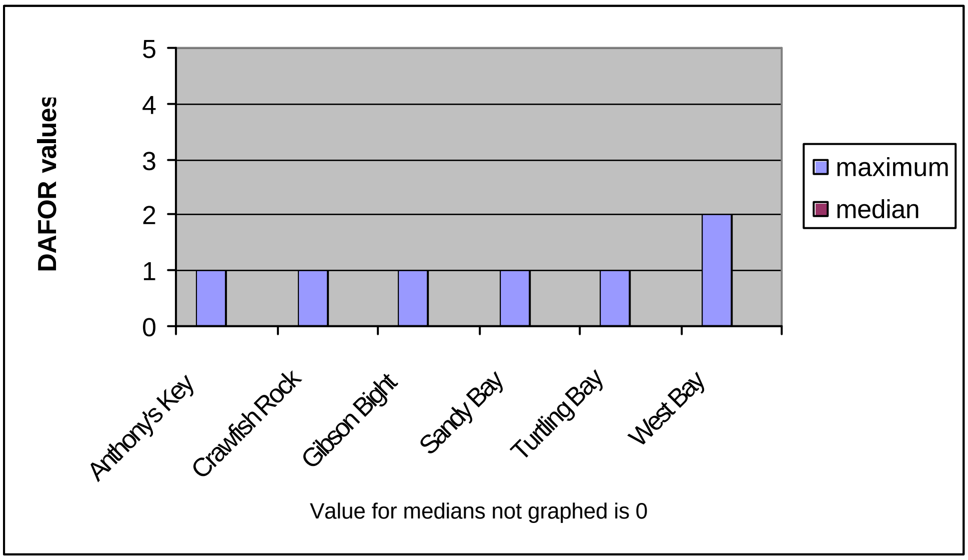

FIGURE 17: LOBSTER (*PANULIRUS SPP*) ABUNDANCE BY SECTOR

3.3.4 Queen Conch (*Strombus gigas*)

The maximum value in all sectors was DAFOR 1 (<6 conch), and the average in all sectors was zero (Figure 18), once again indicating a high level of overfishing.

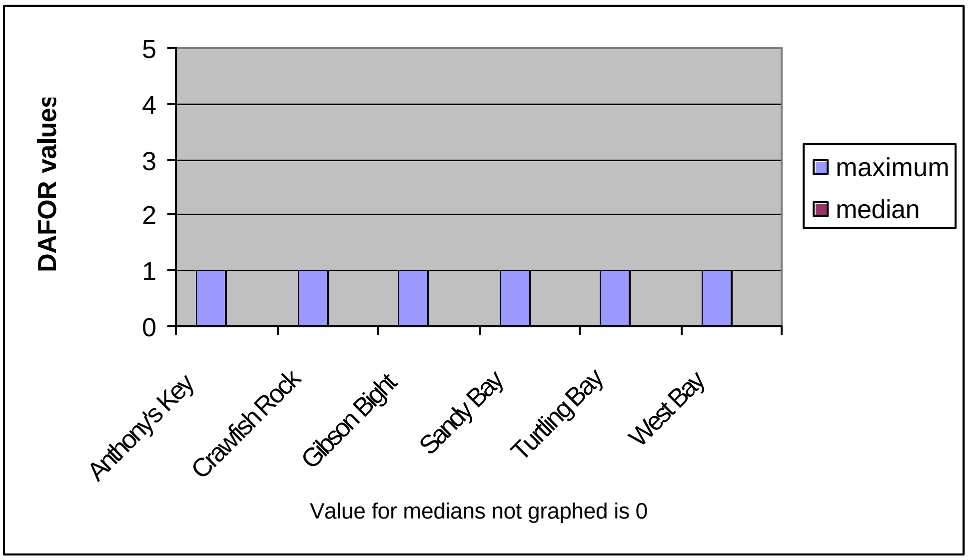

FIGURE 18: QUEEN CONCH (*STROMBUS GIGAS*) ABUNDANCE BY SECTOR

3.3.5 Long Spined Sea Urchins (*Diadema* spp)

The displayed maximum value of DAFOR 3 was recorded at <1% of survey sites (Figure 19), and again the average value across all sectors was zero. This is not surprising, as populations of this species were almost wiped out across the Caribbean in the early 1980s and have yet to recover. This collapse was caused by an as yet unidentified pathogen.

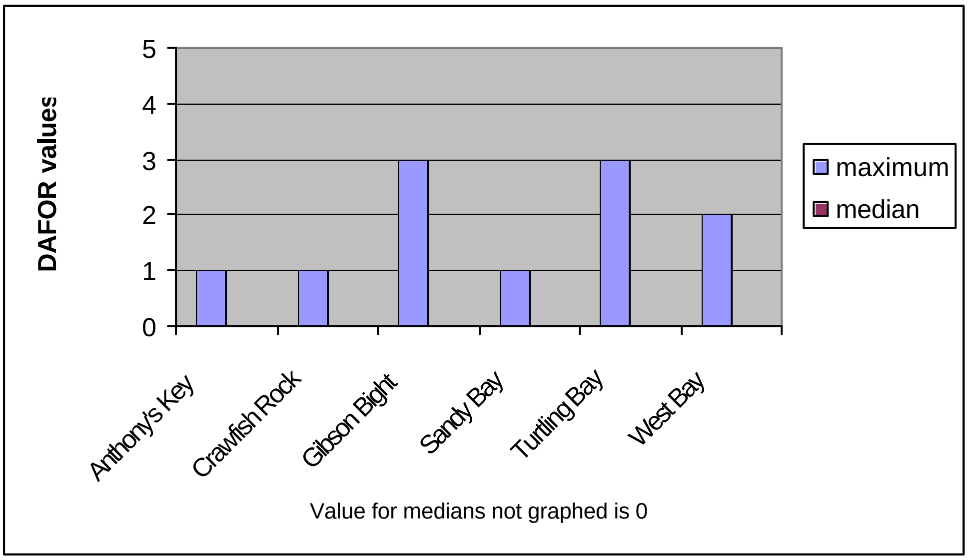

FIGURE 19: LONG-SPINED SEA URCHINS (*DIADEMA* SPP) ABUNDANCE BY SECTOR

3.3.6 Banded Coral Shrimp (*Stenopus hispidus*)

The maximum value in any sector was DAFOR 1 (<5 individuals). Zero banded coral shrimp were recorded in 2 out of the 6 sectors (Figure 20).

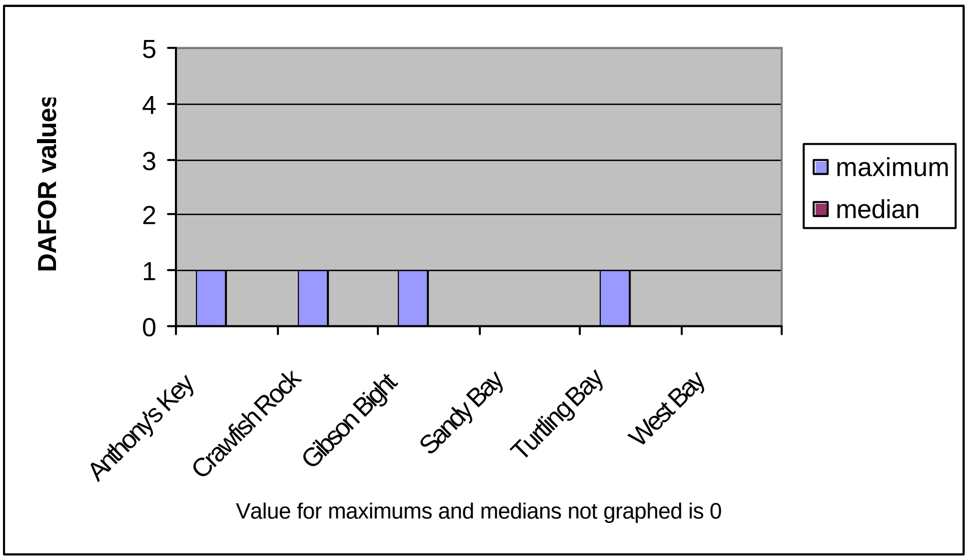

FIGURE 20: BANDED CORAL SHRIMP (*STENOPUS HISPIDUS*) ABUNDANCE BY SECTOR

3.3.7 Pencil Urchin (*Eucidaris* spp)

Zero Pencil Urchins were recorded in 2 out of the 6 sectors (Figure 21) and the average in all sectors was zero.

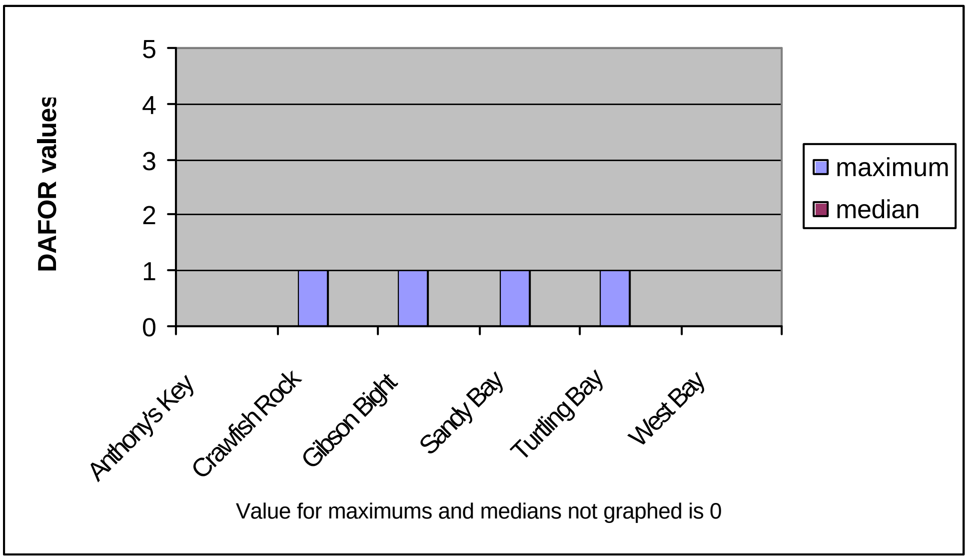

FIGURE 21: PENCIL URCHIN (*EUCIDARIS* SPP) ABUNDANCE BY SECTOR

3.3.8 Flamingo Tongue (*Cyphoma gibbosum*)

Zero Flamingo Tongue were recorded in 2 out of the 6 sectors (Figure 22) and the average in all sectors was zero.

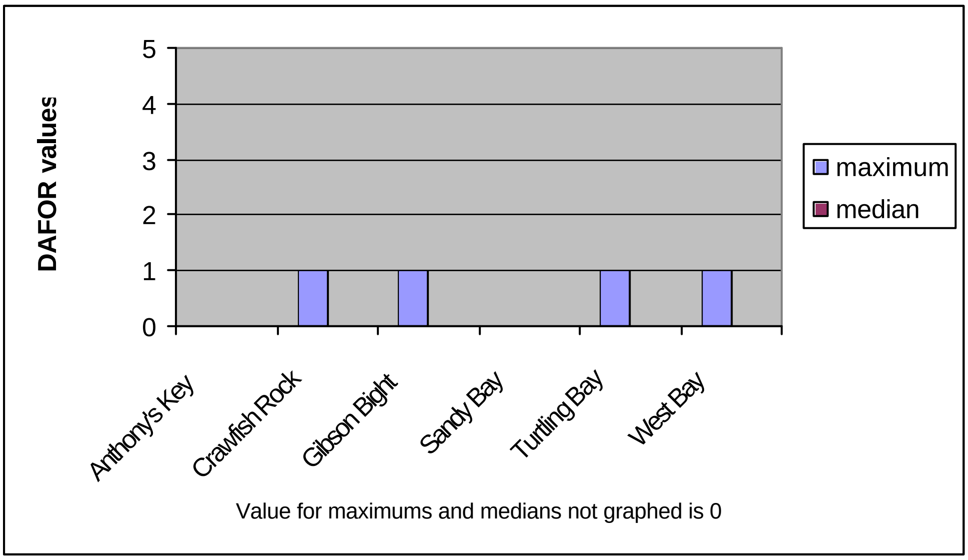

FIGURE 22: FLAMINGO TONGUE (*CYPHOMA GIBBOSUM*) ABUNDANCE BY SECTOR

3.3.9 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, the fish populations will also decline. The average value for butterflyfishes observed in all sectors was zero, although large local groups were found at some sites. As can be seen from Figure 23, Sandy Bay, Turtling Bay and West Bay all had sites with populations of butterflyfishes in the order 21-50 individuals (DAFOR 3).

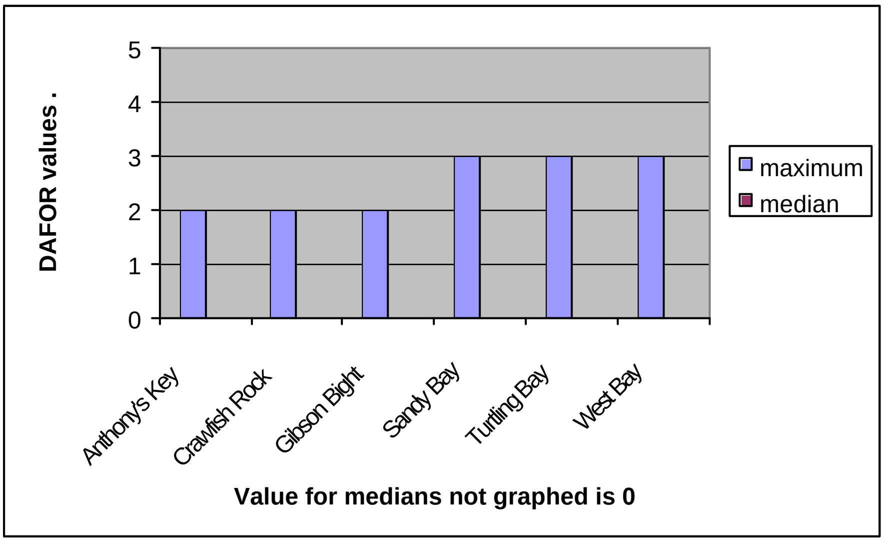

FIGURE 23: TOTAL BUTTERFLYFISH (CHAETODONTIDAE) ABUNDANCE BY SECTOR

3.3.10 Grouper (Serranidae)

The displayed maximum value of DAFOR 3 was recorded at only 2 of 517 surveyed transects (Figure 24). Zero Grouper of any species were observed on 17% of transect. Nassau Grouper (a Reef Check Indicator Species) was not observed on 96% of survey transects.

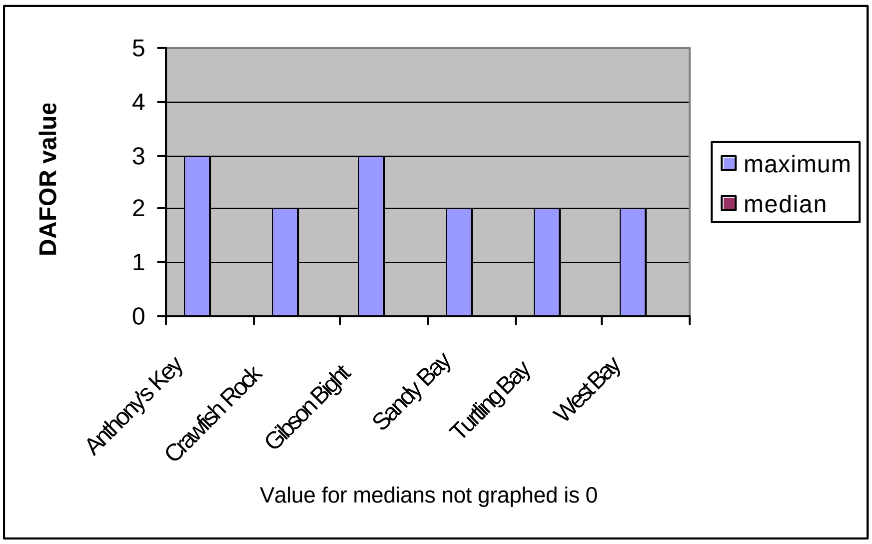

FIGURE 24: TOTAL GROUPER (SERRANIDAE) ABUNDANCE BY SECTOR

3.3.11 Snapper (Lutjanidae)

The displayed maximum value of DAFOR 4 was recorded at only 1 of 517 of surveyed transects (Figure 25). Zero Snapper of any species were observed on 29% of transects.

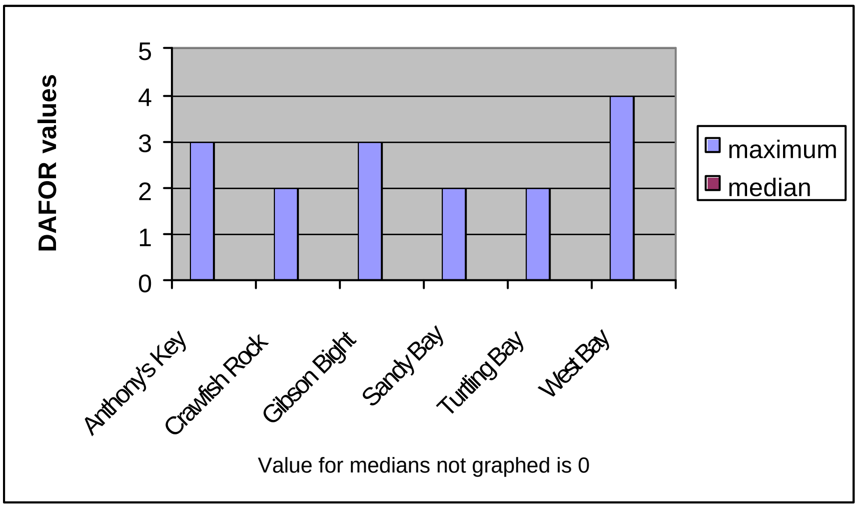

FIGURE 25: TOTAL SNAPPER (LUTJANIDAE) ABUNDANCE BY SECTOR

3.3.12 Parrotfish (Scaridae)

The displayed maximum value of DAFOR 4 was recorded at only 1 of 517 surveyed transects (Figure 26). Zero Parrotfish of any species were observed on 12% of transects.

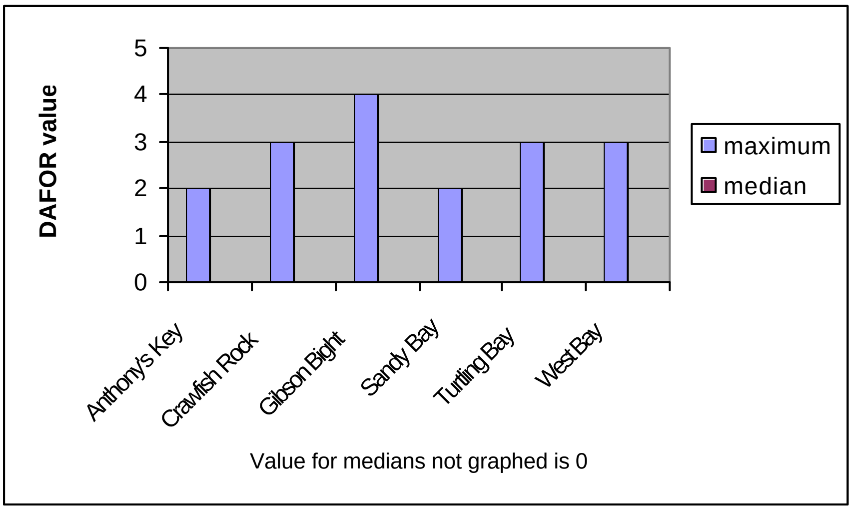

FIGURE 26: TOTAL PARROTFISH (SCARIDAE) ABUNDANCE BY SECTOR

3.3.13 Surgeonfish (Acanthuridae)

The displayed maximum value of DAFOR 4 was recorded at only 9 of 517 surveyed transects (Figure 27), with 3 of these values being recorded in the Turtling Bay sector. Zero Surgeonfish of any species were observed on 11% of transects

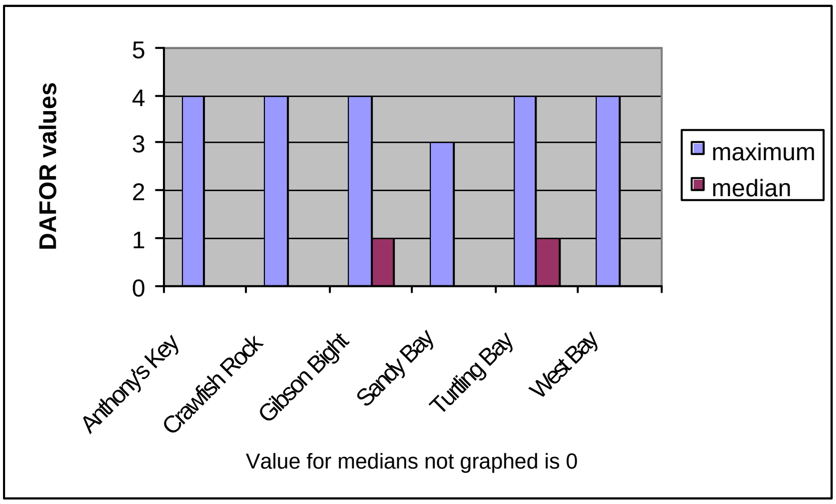

FIGURE 27: TOTAL SURGEONFISH (ACANTHURIDAE) ABUNDANCE BY SECTOR

3.3.14 Macro Algae

The graph for macroalgae shown in Figure 28 was generated from Reef Check data collected from the Northwest region. Please note that West Point has been included in this particular dataset, and Crawfish Rock has been omitted. Macroalgal cover was highest in the Turtling (or Turtle) Bay sector, with a mean value of 39% coverage, with the higher value (42%) being recorded on the 'deeper' transect (~20m).

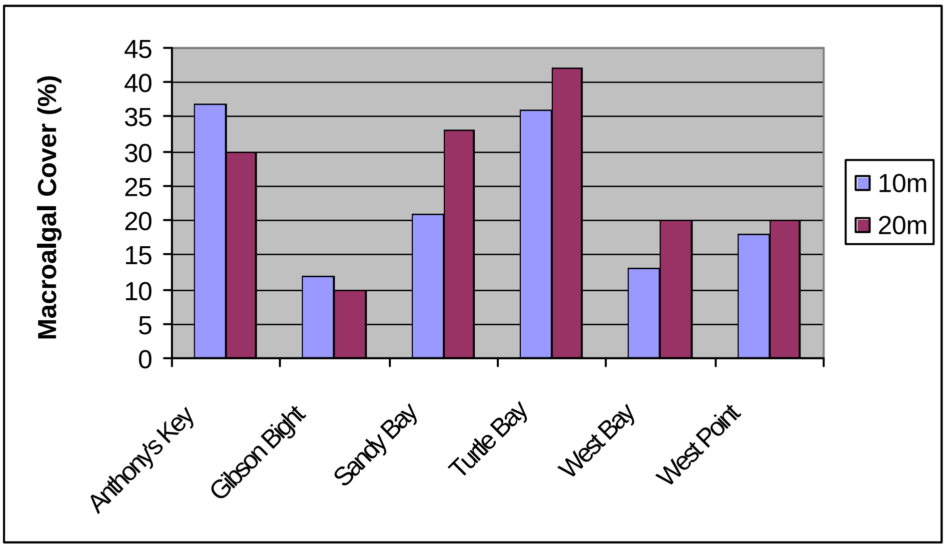

FIGURE 28: MACRO-ALGAL COVER (%) BY SECTOR

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. The SIMPER routine in MiniTab statistical software is then used to define the key characteristics of each cluster. Ultimately, 6 discreet ecological habitats have been defined for the area. A summary of these is presented in Table 7.

TABLE 7: MAJOR CHARACTERISTICS OF THE 6 BENTHIC CLASSES DEFINED from baseline data collected along the north west shore of Roatán. Figures in parentheses indicate median abundances in accordance with DAFOR ratings assigned during surveys. The most characteristic species, lifeforms or substratum categories (greater than 5% contribution to cluster similarity as defined by SIMPER analysis) are highlighted in bold

Habitat	# Surveys	Average Depth (m)	Substratum	Hard Corals	Octocorals	Sponges	Algae / Seagrass
1 – Shallow seagrass dominated lagoon area with green calcified algae	21	3	**Sand (1.5)** with **seagrass (4.0)** and **green algae (1.0)**	Total Hard Coral (0.5)	Total (0)	Total Sponge (0.5)	***Thalassia testudinum* (3.0)** *Syringodium filiforme* (2.0), *Dictyosphaeria cavernosa* (1.0)
2 – Lower reef slope with bedrock and sand patches and mixed hard coral, sponge and algal assemblages	176	25	**Bedrock (2.0)** Sand (1.0) Dead Coral (1.0)	Total (1.5) *Montastrea annularis* (1.5) *Porites astreoides* (1.0) *M. cavernosa* (1.0)	Total (1.0) *Briareum asbestinum* (0.5)	Total (1.0)	***Lobophora variegata* (1.5)** Brown Filamentous **(1.5)** ***Dictyota*** spp.**(1.0)** Red Brown Branching (1.0)
3 – Mid reef slope with diverse hard coral cover, especially massive and encrusting corals and brown algae	141	16	**Bedrock (2.0)** Dead Coral (1.5) Sand (1.0) Rubble (1.0)	Total (1.5) ***Montastrea annularis* (1.0) *M. cavernosa* (1.0) *Porites astreoides* (1.0)**	Total (1.0) *Gorgonia ventalina* (1.0)	Total (1.0)	***Dictyota*** spp. **(1.5)** Brown Filamentous **(1.5)** ***Lobophora variegata* (1.5)** Red Brown Branching (1.0) *Halimeda spp.* (1.0)
4 – Shallow upper reef slope dominated by bedrock with patches of sand and mixed hard coral and algal assemblages	36	7	**Bedrock (2.5)** Sand (1.5) Dead Coral (1.0) Rubble (1.0)	Total (1.5) ***Diploria strigosa* (1.0)** *Porites astreoides* (1.0) *Siderastrea siderea* (1.0) *Millepora* spp (1.0)	Total (1.5) ***Gorgonia ventalina* (1.0)**	Total (1.0)	Brown Filamentous **(1.0)** Red Brown Branching **(1.0)** Green Calcified (1.0) *Dictyota spp*. (1.0)
5 – Upper reef slope with significant hard coral cover dominated by *Montastrea, Porites and Agaricia spp.* and mixed algal communities	137	10	**Bedrock (2.0)** Dead Coral (1.5) Sand (1.0) Rubble (1.0)	Total (1.5) ***Montastrea annularis* (1.5) *Porites astreoides* (1.0) *Montastrea cavernosa* (1.0) *Agaricia agaricites* (1.0)**	Total (1.0) *Gorgonia ventalina* (1.0)	Total (1.0)	*Dictyota* spp **(1.5)** Brown Filamentous **(1.0)** *Lobophora variegata* (1.0) Red Brown Branching (1.0) Green Calcified (1.0)
6 – Shallow upper reef slope and reef crest dominated by *massive and encrusting corals* with abundant algal cover	6	6	**Dead Coral (1.5)** Bedrock (1.0) Sand (1.0) Rubble (1.0)	Total (1.5) ***Montastrea annularis* (1.0) *Diploria strigosa* (1.0) *Millepora*** spp **(1.0)**	Total (1.0) *Gorgonia ventalina* (1.0)	Total (1.0)	*Dictyota* spp **(2.0)** *Lobophora variegata* **(1.5)** Red Brown Branching **(1.5)** *Liagora* spp **(1.5)** Brown Filamentous (1.0) *Sargassum hystrix* (1.0)

3.5 CONSERVATION MANAGEMENT VALUES

Using five ecological indices, comparisons between survey records can now be made in order to highlight key areas of ecological importance. The indices used are live hard coral cover at each site, the number of benthic species recorded (not including algae), the 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.

The average of each of these indices is calculated and then each individual survey record is then compared against the average to determine whether it is above or below average. A survey record that was below average in all five indices would score a Conservation Management Value (CMV) of 0; a survey record that was above average in one index would score a CMV of 1 and so on up to a maximum CMV of 5. 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 29), the colour red represents areas where lower CMVs are dominant; the colour green represents areas where higher CMVs are dominant.

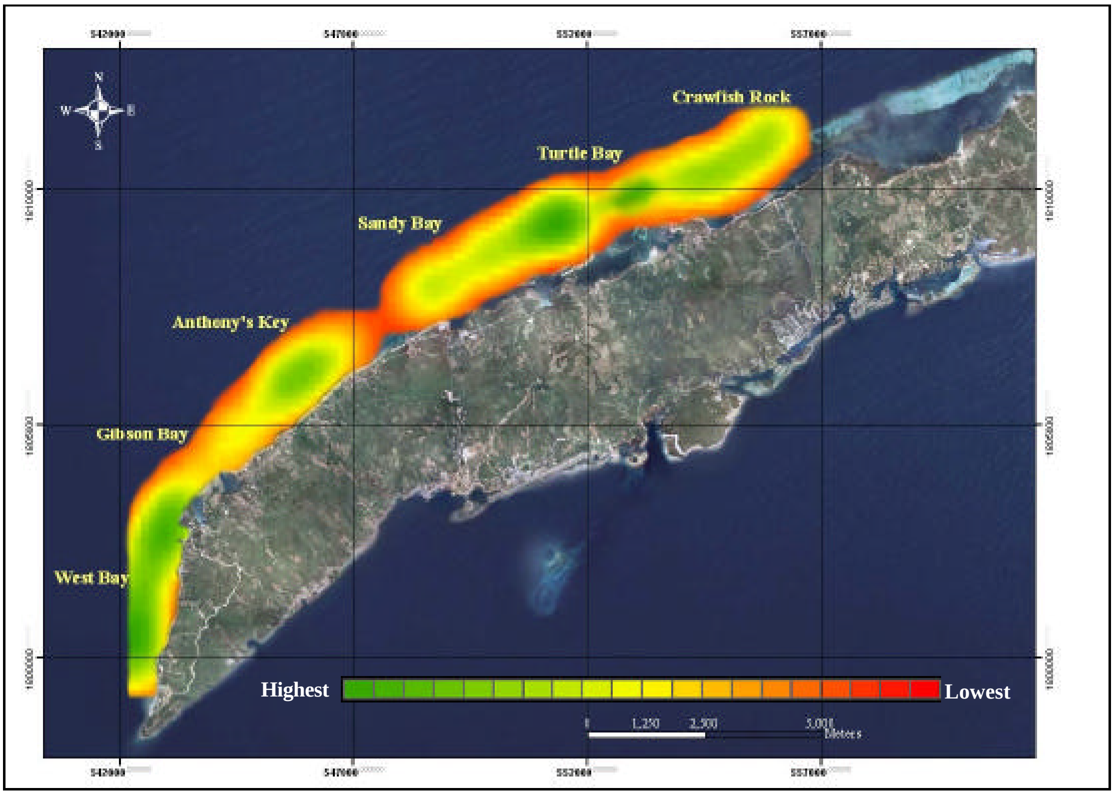

FIGURE 29: CONSERVATION MANAGEMENT VALUE DENSITIES DISPLAYED AS A COLOUR RAMP

4 DISCUSSION

Most scientists agree that the capacity of corals to adapt to changes in environmental conditions will depend on the level of additional 'unnatural' stresses with which they have to contend. As Kinsey (1998) observes, corals can endure chronic (long-term, low level) stress, and even rebuff acute (short-term, high level) stresses over a short period, but that chronically stressed reefs are less likely to be capable of successfully moderating the impacts of acute stresses. It is likely that reefs that are not subject to anthropogenic stresses will be more resistant to (capable of rebuffing) and resilient of (capable of recovering from) 'naturally' occurring acute stresses, such as hurricane damage and coral bleaching events.

Key anthropogenic stresses are known to include unmitigated coastal development, land-based sources of pollution, and overfishing (Burke and Maidens, 2004; Buddemeier et al, 2004). In fact, Burke and Maidens (2004) conclude that the reefs of the Bay Islands of Honduras are amongst the most at risk from unmitigated coastal development within the entire Caribbean region. On the reefs of Northwest Roatán, the data gathered during this research show that, with the exceptions of live hard coral cover and macroalgae, the abundances of all of the key indicator species are extremely low. A number of species such as flamingo tongue and pencil urchins were entirely absent from the site records in two of the six survey sectors. [It should be noted, however, that the paucity of long-term datasets on the species composition of these reefs makes it impossible to say whether the absence of many of these indicators is a recent phenomenon or an historical one].

4.1 BENTHIC COMMUNITIES

Moderate levels of live hard coral were recorded in all sectors, with high levels (DAFOR 4: approximating to 51-75% of the surveyed benthos) being found in two sectors, Turtling Bay and Crawfish Rock (Figure 15). As Turtling Bay also had one of the highest abundances of Staghorn (Figure 14) and Elkhorn corals (which are now rare in the Caribbean), the 'health' of this sector can be considered to be of critical importance to the reefs of Roatán and other down current reef systems that will import the larvae of these corals. High cover of live hard coral may, however, be misleading as to the actual state of reef health: it may also indicate that the reef is undergoing deterioration due to either high mortality or low recruitment. We must therefore be cautious in relying entirely on live coral cover as an indication of 'health' (Birkeland, 1996) without taking into account other considerations such as biodiversity, coral species present and macroalgal distribution.

Despite its high abundance of live hard coral, the Turtling Bay sector can be considered to be severely at risk of imminent degradation, as it also had the highest levels of macroalgal growth. Being an indicator of nutrient enrichment, brown fleshy algae are often associated with sewage pollution (Hodgson 1999), and the local abundance of such algae may be linked to nutrient runoff from the adjacent garbage dump at Mud Hole. Pollution from Mud Hole may take a number of forms other than nutrient enrichment: the disposal of toxic waste, by-products of herbicides and pesticides, and the generation of hydrogen sulphide may all have effect, although they are not referred to in the literature to the same extent as nutrient loading.

Although currently outside the boundaries of the West End Sandy Bay Marine Reserve, the Turtling Bay and Crawfish Rock sectors lie within the boundaries of the proposed extension. However, without the removal of the causative agents of degradation, the incorporation of these sectors to the marine reserve is unlikely to have any significant effect on halting a decline in reef health.

4.2 FISH AND COMMERCIALLY HARVESTED INVERTEBRATE COMMUNITIES

Finfishes are often erroneously thought of as mere 'inhabitants' of a reef, when they are, in fact, intrinsic components of the entire reef system. With particular regard to the Caribbean and its recent history of wide-spread phase-shifts from coral dominated reefs to macroalgal dominated ones, the importance of maintaining viable populations of herbivorous grazers in particular cannot be overstated. The literature reflects a general belief that herbivores are probably more instrumental in influencing macroalgal populations than is eutrophic runoff, although the latter is very likely to exacerbate a potential phase-shift.

The median (average) values recorded for grouper, snapper, lobster and conch in every sector was zero, indicating a very high level of overfishing. Zero grouper or snapper of any species were recorded on 17% and 29% of all surveys respectively. The average value for parrotfishes across all sectors was also zero; the average value for surgeonfishes was zero in 4 out of the 6 sectors, with Gibson Bight and Turtling Bay having averages of DAFOR 1 (1-5 individuals). Large schools of surgeonfishes (DAFOR 4 (51-250 individuals)) were recorded on 9 out of the 517 surveyed transects, with 3 of those being recorded in Turtling Bay.

The Nassau Grouper is a tropical/sub-tropical species, found from the southern USA throughout the Caribbean to Brazil, to depths of 150 metres. This fish is recognized to be one of the most valuable in the Caribbean region, and tends to be consumed as a 'fish of choice' because it is easy to eat with comparatively few bones. The Nassau Grouper is particularly vulnerable to exploitation and is listed as endangered by the International Union for the Conservation of Nature and Natural Resources (IUCN), but is not thus far listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The reason that this species is particularly vulnerable is that the individuals spawn by the age of 7 and then continue to spawn throughout their adult life. Spawning occurs in large aggregations in order to optimise fertilisation, minimise egg predation, facilitate dispersal and maximise recruitment. It is these aggregations that make them susceptible to fishing to the extent that, for the Caribbean as a whole, the spawning stock biomass has now been reduced to 1% of the assumed pre-exploitation levels (Ray and McCormick-Ray, 2004). During this survey campaign, zero of these fish were recorded on 494 out of 517 survey sites.

The effects of fishing tend to reduce the abundance of the target species, lower their average size and modify their species composition (Van't Hof, 2001) by selectively removing larger individuals due to an ever-increasing requirement for local fish catch. Tourist fishing trips in Roatán do not target reef fish species, but rather pelagic coastal species. However, it is likely that the increased demand for seafood on Roatán is influential on the low reef fish populations. Like other areas of the Caribbean, Roatán's restaurants have a popular seafood menu of reef species such as grouper, snapper, spiny lobster and conch. Although there are local restrictions on these reef species such as size limits and closed seasons (Van't Hof, 2001), most tourists are unaware of these restrictions and may be served undersized produce out of season, thus inadvertently supporting unsustainable fishing practices.

4.3 OTHER IMPACTS

Although the data on coral bleaching collected for this report were qualitative (i.e. presence/absence), the prevalence of this phenomenon (recorded on 28% of all survey dives) suggests that quantitative data should be recorded to gain a clearer insight into particular species and/or regions that are most prone to bleaching, and on the effects of (and recovery rates from) such events. As most scientists predict an increase in bleaching events over the coming decades (e.g. Burke and Maidens 2004), data on the nature and effects of these events with specific regard to Roatán may prove invaluable to resource managers in the future. As mentioned previously, reefs experiencing high levels of chronic anthropogenic stress are less likely to be capable of recovering fully from such events, and such stresses will need to be mitigated through management intervention.

The sectors exhibiting the highest levels of dive boat activity were also found to exhibit the most frequent recordings of coral damage. The correlation between these variables across all 6 sectors was statistically significant, and this suggests the need for targeted research to determine the effects of large scale recreational diving on reef integrity and to help develop management plans to ensure the sustainable use of the reef resources for all stakeholders.

5 CONCLUSIONS

In the absence of immediate and decisive management action, there is no reason to suspect that the reefs of northwest Roatán will not continue to degrade. Apart from losses to the ecological value of the reefs, the associated economic losses will also be great to the artisinal fishing and fledgling tourism industries of the island. In the space of a few short years, Roatán is in severe danger of progressing rapidly from being an up-and-coming Caribbean tourism destination to becoming catastrophically degraded. This situation is the case in much of the Caribbean today.

Although Roatán can boast some very impressive tourism resorts, these are not unusual in the Caribbean. Beaches are another major tourist attraction, but again the beaches of the island are far from being exceptional within the region. Furthermore, these beaches rely on the coral reefs to provide their sand and to protect the shoreline from erosion by waves. What is potentially exceptional about Roatán is its coral reefs, and preliminary analysis of recent Coral Cay Conservation survey data indicate that the reefs around the east end of the island (as well as the island of Barbaretta) may be some of the best remaining reefs of their type in the Caribbean. This creates an enormous opportunity for managers.

The oceanographic data recorded by CCC throughout the surveying program around Roatán indicate that the prevailing currents in inshore waters move from the east to the west. As most reefal organisms such as corals and fishes reproduce by spawning in the water, downcurrent areas will obtain much of the benefit of the ecological health in upcurrent ones. The eastern reefs can be considered to be the source of much of the historical biological richness of Roatán's reefs and their immediate protection and management can be considered to be pivotal to the economic and ecological future of the whole island.

Many of the world's leading coral researchers have concluded that if the stressors that have been causative in reef degradation are effectively removed, reef systems that have not been 'fatally' damaged have a high chance of recovery over relatively short timescales. The removal of these stressors, however, requires the political will to do so.

6 RECOMMENDATIONS

The urgent implementation and enforcement of management plans to safeguard the reef resources of the east end of Roatán and the island of Barbareta. This region is currently undeveloped compared to the rest of the island, although it is likely that the degradation of the northwest reefs will cause an increased influx of tourism pressure and economic migration of Hondurans. If the stressors to the reefs of the northwest can be removed, the upcurrent reefs at the east end will be the source of much of the larval stocks required for the reef to 'repair' itself.

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. CCC intends to run such a workshop for the diving professionals of the West End in 2006.

The location and protection of key spawning sites for depleted fish stocks, such as those of grouper and snapper. Anecdotal evidence suggests that many of these sites may be located around the island of Barbaretta. The CCC project scientist is currently working with the fishing communities of the East End to locate these sites geographically and seasonally.

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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