SUMMARY OF CORAL CAY CONSERVATION'S REEF CHECK DATA (1997 AND 1998) FROM TURNEFFE ATOLL, BELIZE

- by -

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This report is part of a series of working documents detailing CCC's science programme on Turneffe Atoll (1994-1998). The series is also available on CD-Rom.

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EXECUTIVE SUMMARY

The coastal waters of Belize consist of a complex set of reefal resources which are economically important for industries such as tourism and fishing. Effective management of these resources can be assisted by data collected by self-financing volunteer divers. This technique has been used in Belize by Coral Cay Conservation (CCC) to provide data to the Department of Fisheries and Coastal Zone Management Project.

Between 1994 and 1998 CCC collected baseline data on the benthic and fish communities of Turneffe Atoll. In addition to this work, CCC undertook Reef Check surveys in 1997 and 1998 to assess the health of the reefs. Reef Check is an international programme to complete a global synoptic survey of the health of the world's reefs by using volunteer divers to record the abundance of key 'indicator' organisms. The Reef Check data collected by CCC at Turneffe Atoll were incorporated into the global database but also provide an opportunity to (1) provide quantitative data on the reefs close to Calabash Cay (2) document any changes occurring from 1997 to 1998 (3) assess differences in reef health between two sites which are thought to have been exposed to different degrees of diver damage and (4) provide a gross comparison of the health of Turneffe Atoll with the rest of the Caribbean.

Reef Check surveys in 1997 and 1998 were carried out close to Calabash Cay since this was convenient for CCC volunteers and any future Reef Check surveys. In 1997 'Site 1' (typical of the atoll) was surveyed by CCC volunteers and field science staff. This site was re-surveyed in 1998 along with 'Site 2' (known to be popular with recreational divers). The Reef Check survey protocol utilises two transects at a depth of approximately 3 and 10 m and five types of data are recorded: a general site description; a fish belt transect (for fish typically targeted by fisherfolk); an invertebrate belt transect (for invertebrate taxa typically targeted as food species or collected as curios); a substratum line transect to assess the benthic community; and a semi-quantitative assessment of anthropogenic impacts. Visual comparisons between years, sites and depths were facilitated via a series of bar-charts and quantitative assessment of these trends was achieved using the t-test.

Both sites were classified as 'Forereef + Dense massive and encrusting coral' but changes were apparent between 1997 and 1998 between Site 1 and Site 2, although further spatio-temporal data are required to support these trends. At the mid-depth transect, hard coral cover increased and fleshy seaweed decreased suggesting an improvement in reef health. The decrease in fleshy seaweed is also in direct contrast to general patterns in the Caribbean, where reefs are shifting from coral dominated to algal dominated. On Turneffe Atoll, the apparent increase in herbivores may be responsible for the fall in algal abundance. In contrast, there were no significant changes in algae or coral cover in the shallow reef, possibly because there is no increase in herbivores. There were no significant changes in abundance of any fish or invertebrate indicator species but an indication that abundances may have increased from 1997 to 1998. However, the absolute abundances of commercially and ecologically important species may have significant effects to local fishermen and reef health.

There is only anecdotal evidence that Site 2 has more divers than Site 1 but this hypothesis is supported by the increased cover of rubble at Site 2, which may be caused by divers. Similarly, a significantly lower abundance of gorgonians was recorded at Site 2 which may be caused by direct breakage by divers but also diseases following diver damage. There were no significant differences between the indicator fish or invertebrate species.

Results from all Turneffe Atoll data indicated that the reef is in better condition than the 'average' Caribbean reef. There was a higher cover of live coral, a lower cover of dead coral and a higher ratio of live : dead coral. In addition, the mean abundance of indicator species in Belize are the same as, or higher, than the modes for the rest of the Caribbean. The comparatively good health of Turneffe Atoll is likely to be caused by the low population density of Belize and relatively low fishing pressure which was reflected by the minimal anthropogenic impacts recorded on the transects.

This study leads to the following recommendations:

?? Agencies in Belize should continue to undertake Reef Check surveys at Sites 1 and 2 at Calabash Cay.

?? Sites 1 and 2 should be marked with a permanent stake or surface buoy to ensure that annual surveys are carried out in the same area.

?? Reef Check surveys on Turneffe Atoll should be extended to include sites in other areas, particularly the western (leeward) reef.

?? Agencies in Belize should establish a programme of recording the number of dives undertaken at Turneffe Atoll and the most popular dive locations.

?? Agencies in Belize should establish a standard environmental awareness briefing for all divers which can be used by dive resorts on Turneffe Atoll and elsewhere.

?? Agencies in Belize should continue to aim to establish a multiple use marine protected area at Turneffe Atoll.

ACKNOWLEDGEMENTS

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ABBREVIATIONS

CCC	Coral Cay Conservation
CZMP	Coastal Zone Management Project
CZMU	Coastal Zone Management Unit
DC	Dead coral
FS	Fleshy seaweed
GEF	Global Environment Facility
GOB	Government of Belize
GPS	Global Positioning System
HC	Hard coral
IUCN	World Conservation Union
MOU	Memorandum of Understanding
MRC	Marine Research Centre
NGO	Non Government Organisation
OT	Other
PADI	Professional Association of Diving Instructors
PS	Project Scientist
RB	Rubble
RC	Rock
SC	Soft coral
SCUBA	Self contained underwater breathing apparatus
SD	Sand
S.D.	Standard deviation
SI	Silt/clay
SO	Science Officer
SP	Sponge
UCB	University Collage Belize
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme

FIGURES, TABLES AND APPENDICES

1. INTRODUCTION

1.1 Belize

The coastal waters of Belize (Central America) consist of a complex set of reefal resources, including the largest barrier reef in the western hemisphere (Figure 1). Belize also has three major Caribbean atolls, numerous patch reefs, lagoons, sand and mangrove cays and mangrove forests. The coastal waters of Belize are economically important for industries such as tourism and fishing. In 1990, aware of a growing conflict between the preservation and human exploitation of the reef environment, Government of Belize (GOB) established a Coastal Zone Management Unit (CZMU) under the Ministry of Agriculture and Fisheries. The CZMU was then superseded by a Coastal Zone Management Project (CZMP), funded by the UNDP Global Environment Facility (GEF). In 1998 a Coastal Zone Management Bill established a Coastal Zone Management Authority and Institute to provide overall management of the coastal zone.

1.2 Coral Cay Conservation

Effective management, including conservation of coral reefs and tropical forests, requires a holistic and multi-sectorial approach. This is often a highly technical and costly process which many developing countries cannot adequately afford. With appropriate training, non-scientifically trained, self-financing volunteer divers have been shown to be able to provide useful data for coastal zone management at little or no cost to the host country. This technique has been pioneered and successfully applied by Coral Cay Conservation (CCC), a British non-profit organisation.

CCC is an international NGO committed to providing resources for the protection and sustainable use of tropical coastal environments. CCC does not charge the host country for the service it provides and is primarily self-financed through a unique volunteer participatory scheme. Within the scheme, members of the public are given the opportunity to join a phase of each project in return for a financial contribution to the CCC programme. At the expedition site, volunteers are provided with suitable training and collect data under the guidance of project scientists. Finances generated from the volunteer programme allow CCC to provide conservation education, technical skills training and capacity building, contributing to a strong policy of collaboration with government and non-government organisations within the host country.

Data and technical assistance have been provided to both the Department of Fisheries and CZMP under the remit of a Memorandum of Understanding (MOU). The MOU was signed in 1990 and updated and extended in both 1994 and 1998. Since 1990, CCC has provided data for six proposed or established marine protected areas at South Water Cay, Bacalar Chico, Sapodilla Cays, Snake Cays, Laughing Bird Cay and Caye Caulker. These projects have generally provided habitat maps, the associated databases and management recommendations to assist reserve planning (for example McCorry et al., 1993; Gill et al., 1995; Gill et al., 1996).

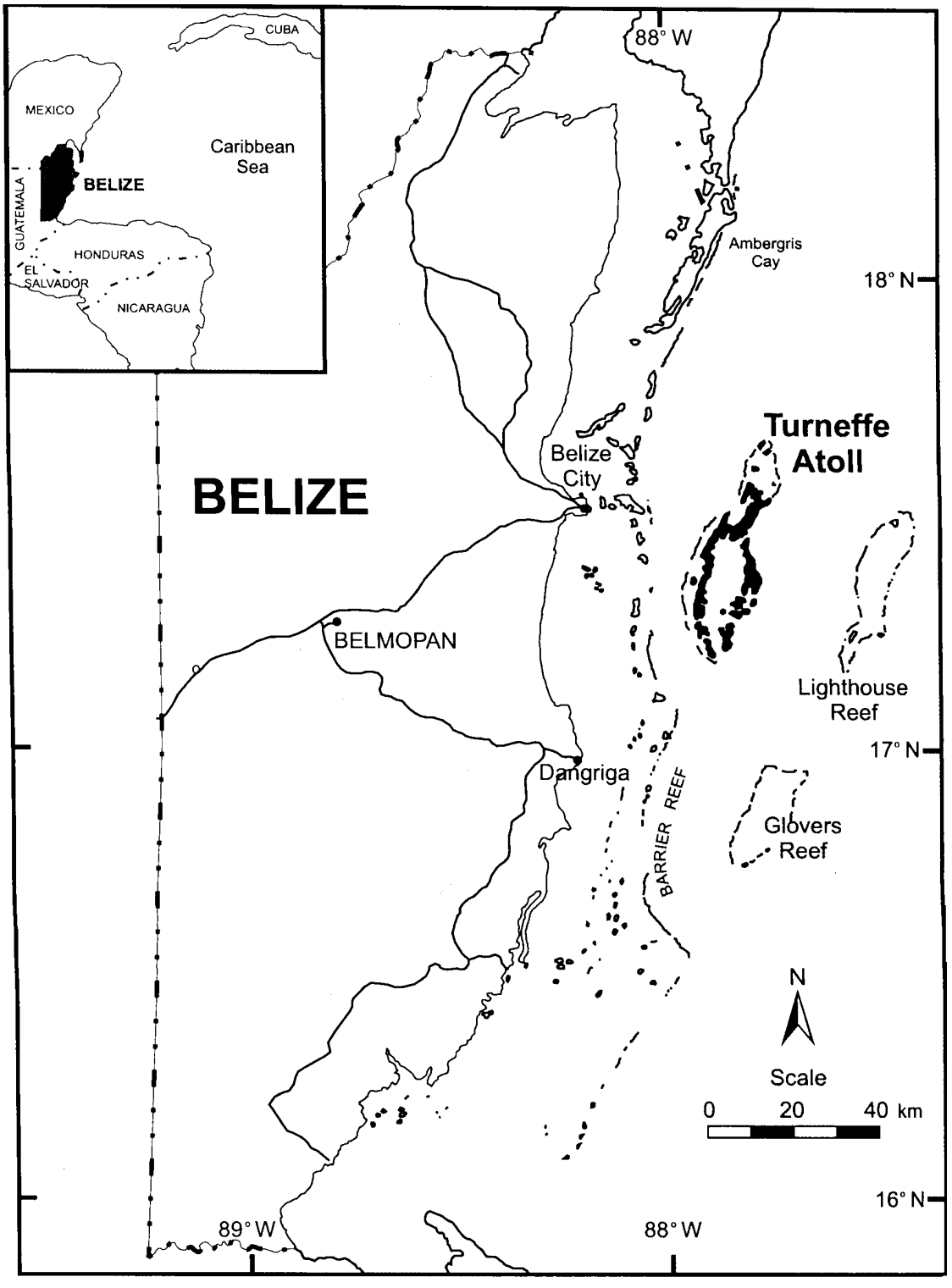

Figure 1. Map of Belize showing the location of Turneffe Atoll. Source: Murray et al. (1999).

1.3 Turneffe Atoll project

In 1993 the University College of Belize (UCB) entered into a working agreement with CCC to collaborate towards the establishment of a permanent, self-financing Marine Research Centre (MRC) of both regional and international standing. The field site was selected as Calabash Cay on Turneffe Atoll (Figure 2), the largest atoll in the Caribbean at approximately 330 km^2 (UNEP/IUCN, 1988). Turneffe Atoll is completely surrounded by an extensive reef system which encompasses a complex central lagoon and extensive mangrove forested cays. The principle objectives of the MRC project were identified as protection of the terrestrial and marine resources of Turneffe Atoll, strengthening the capacity of UCB to undertake coastal marine research and training and providing technical assistance to the Department of Fisheries. In August 1994, the agreement between CCC and UCB was endorsed by the GOB through the signing of a MOU between the three lead agencies. A core component of this MOU was establishing and monitoring a management plan for Turneffe Atoll.

Since 1994 CCC volunteers have been carrying out surveys around the whole atoll which have resulted in an extensive database of baseline information. Analysis of these data and combination with aerial photographs has led to a Turneffe Atoll Habitat Map, the first draft of which was completed in August 1998. Between March 1997 and December 1998 this baseline database has been complemented by on-going surveys to quantitatively document the abundance of commercially important fish species.

CCC's survey work at Turneffe Atoll was designed to obtain sufficient data from which comprehensive habitat and additional resource maps could be created in order to assist the planning of sustainable management initiatives. However, in addition to this primary aim, CCC has also initiated basic assessments of reef health close to Calabash Cay via Reef Check and Atlantic and Gulf Rapid Reef Assessment surveys.

1.4 Reef Check

A serious problem with the traditional approach to monitoring reef health is that there are only a small number of reef scientists who can only carry out periodic surveys. Thus the global database for the health of coral reefs is very patchy and not easily comparable. During the 1997 International Year of the Reef, a global synoptic survey of the health of the world's reefs was undertaken by using volunteer divers to record the abundance of key 'indicator' organisms. Named 'Reef Check', this international programme completed the first global survey of coral reefs and involved over 750 volunteer sport divers (led by 100 volunteer scientists) on more than 300 reefs in 31 countries. Reef Check 1997 was co-ordinated by Dr Gregor Hodgson at the Hong Kong University of Science and Technology[1].

[1] Further details of Reef Check can be found at http://www.ReefCheck.org/

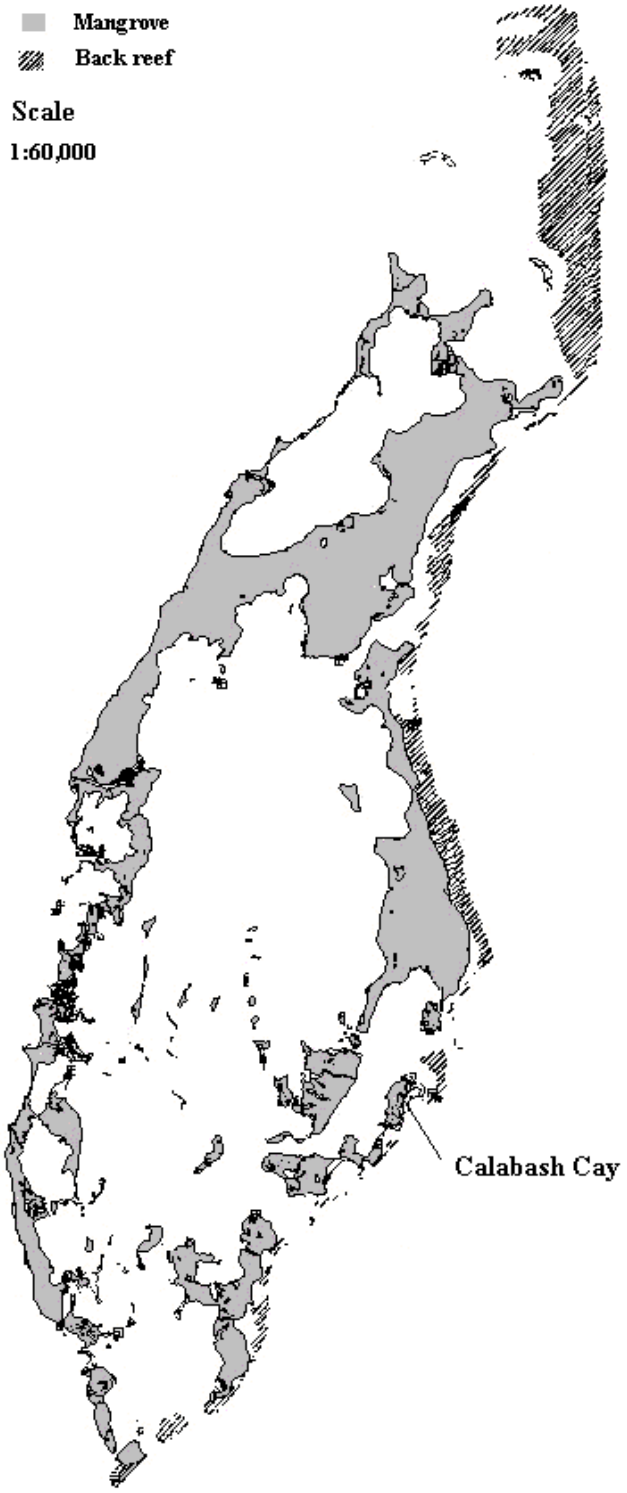

Figure 2. Map of Turneffe Atoll, showing the location of Calabash Cay which is the site of the UCB / GOB / CCC Marine Research Centre.

The results of Reef Check 97 provided the first solid evidence that coral reefs have been damaged on a global scale. In addition to producing valuable scientific results, Reef Check 97 raised the awareness of scientists, governments, politicians and the general public about the value of coral reefs, threats to their health and solutions to coral reef problems. Following the success of Reef Check 97, it was decided to repeat the survey annually.

CCC took part in Reef Check 1997 and 1998 at Turneffe Atoll to provide valuable data to assess global reef health. The data also provided an opportunity for CCC to compare reefs in Belize with other reefs regionally and globally. Furthermore, the Reef Check data provide an indicator of increasing or decreasing reef health and hence the efficacy of reef management programmes. Finally, Reef Check has provided UCB, CCC and the MRC with increased publicity and heightened awareness of the work on Turneffe Atoll.

1.5 Report outline

This report aims to present the results of the Reef Check surveys at Calabash Cay in 1997 and 1998 and provide a gross indication of reef health at Turneffe Atoll. The specific aims of this report are to:

?? Provide quantitative data on the reefs close to Calabash Cay;
?? Document any changes occurring from 1997 to 1998;
?? Assess differences in reef health between two sites which are thought to have been exposed to different degrees of diver damage;
?? Provide a gross comparison of the health of Turneffe Atoll with the rest of the Caribbean.

In addition, this report contains recommendations for continuing Reef Check in 2000 and beyond. The raw data are appended for researchers wishing to compare future surveys with the 1997 and 1998 baselines.

2. METHODS

2.1 Survey location

Reef Check surveys in 1997 and 1998 were carried out as close to the MRC on Calabash Cay (Figure 3). This site was convenient both for CCC volunteers and UCB researchers undertaking any future Reef Check surveys. The site was also known to be in excellent condition, as required by the Reef Check null hypothesis (reefs are not significantly affected by human impacts). In 1997 one site ('Site 1'), known to be typical of the atoll, was selected and surveyed. This site was re-surveyed in 1998 along with a second site ('Site 2') which was known to be popular with recreational divers (Figure 3). Site 1 was 260 m from the shore and the GPS co-ordinates at the start of the transect point were 17°16'44.5" N and 87°48'18.5" W. Site 2 was 300 m from the shore and approximately 700 m south of Site 1. The GPS co-ordinates at the start of the transect point were 17°14'58.6" N and 87°48'23.9" W.

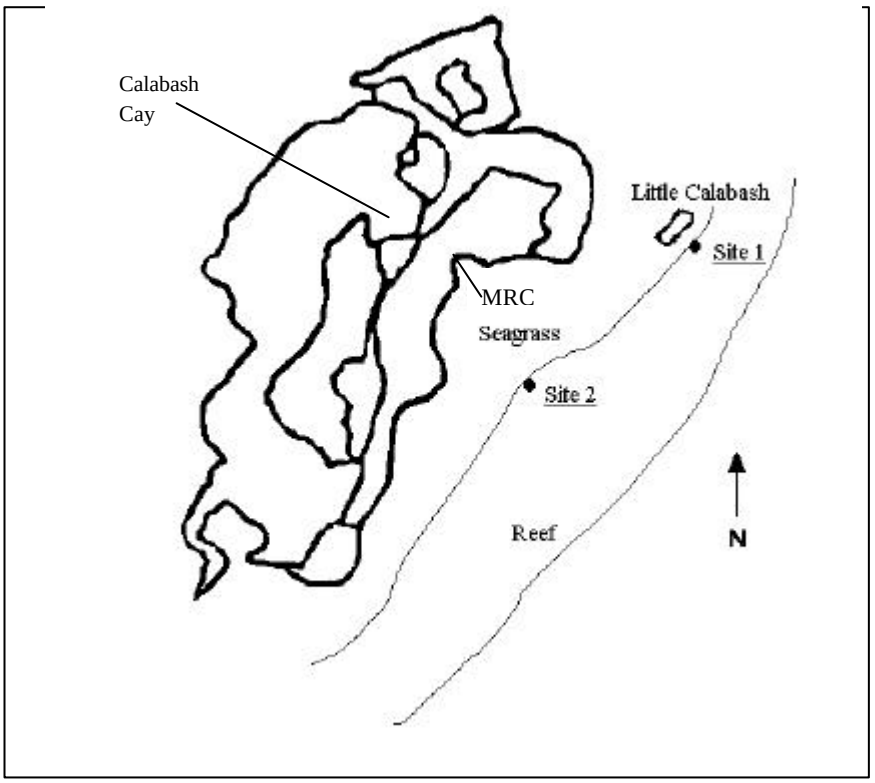

Figure 3. The location of the 1997 and 1998 Reef Check sites.

2.2 Surveyors

Volunteer divers in Belize are co-ordinated by a Project Scientist (PS) and Science Officer (SO). The primary responsibilities of the PS and SO are to train CCC volunteers in marine life identification, survey techniques and other supporting skills. The PS and SO also co-ordinate and supervise subsequent surveys and data collection. Volunteers have a week of intensive science training and testing (see Harborne, 1999)

which enables them to identify species accurately, therefore ensuring precise and consistent data collection (Mumby et al., 1995).

All data collected during Reef Check 1997 and 1998 were recorded by either field science staff or volunteer divers who had successfully undertaken CCC's marine ecology training course.

2.3 Survey protocol

Reef Check's survey methods are specially designed for recreational divers, so that training is rapid and organism identification is accurate. The following sections provide a synopsis of the Reef Check protocol[2]. Full details are given in Appendix 1 and further updates can be found on the website[3].

2.3.1 Laying transects

The Reef Check survey protocol utilises two transects at a depth of approximately 3 and 10 m below chart datum, chosen for practical reasons of time and safety. Along each contour, four 20 m long line transects are deployed and surveyed. The transects follow the designated depth contour in sequence but the start and end points are separated by a 5 m space. The distance between the start of the first transect and end of the last transect is, therefore, 20 + 5 + 20 + 5 + 20 + 5 + 20 = 95 m.

2.3.2 Data collection

Five types of data are recorded via three surveys along the transect line at each depth.

Site description

The Site Description Sheet includes anecdotal, observational, historical, locational and other data. These data are important for interpreting global trends in the data set.

Fish belt transect

Four 5 m wide by 20 m long transects (centred on the transect line) are sampled for fish typically targeted by fisherfolk, aquarium collectors and others. In the Caribbean these species and families are Nassau grouper (*Epinephalus striatus*), any grouper over 30 cm (Serranidae), grunts and margates (Haemulidae), snappers (Lutjanidae), parrotfish over 20 cm (Scaridae), butterflyfish (Chaetodontidae) and barracuda over 1 m (*Sphyraena barracuda*; 1997 only).

[2] Following Reef Check 1997 protocol changes were implemented in 1998. In 1997 surveys were carried out between 14 June and 31 August and in 1998 this was expanded to 1 April to 30 September. The depth ranges for transect placement were expanded in 1998 from strictly 3m and 10m (1997) so that the shallow transect lay between 2m-6m and the mid-depth transect was between 6m-12m. This allowed teams to choose the depth of best reef development. Finally, in the Caribbean, queen and helmet conch and barracuda were removed. Pencil urchin, triton shell, flamingo tongue, gorgonians and the banded coral shrimp were added in 1998. Further modifications have been made for 1999.

[3] http://www.ReefCheck.org/

The diver assigned to count fish swims slowly along the transect and then stops to count target fish every 5 m, and then waits three minutes for target fish to come out of hiding before proceeding to the next stop point. This is a combination timed and area restriction survey of four sections (20 m long x 5 m wide = 400 m^2). At each depth contour there are sixteen 'stop-and-count' points.

Invertebrate belt transect

Four 5 m wide by 20 m long transects (centred on the transect line) are sampled for invertebrate taxa typically targeted as food species or collected as curios. In the Caribbean these taxa are banded coral shrimp (*Stenopus hispidus*), long-spined black sea urchins (*Diadema* spp.), lobster (all edible species), pencil urchin (*Eucidaris* spp.), triton shell (*Charonia variegata*), flamingo tongue (*Cyphoma gibbosum*) and gorgonians (sea fan, sea whip). Quantitative counts are made of each species.

In addition, surveyors note the presence of coral bleaching or unusual conditions (e.g. that might be diseases) along the transects.

Substratum line transect.

Four 20 m long transects are point sampled at 0.5 m intervals to determine the substratum types on the reef. Point sampling was chosen because it is the least ambiguous and fastest method of survey and is easily learned by recreational divers. The diver looks at a series of points where the transect tape touches the reef and notes down what lies under those points. A 5 mm diameter metal object tied onto a 2 m long nylon string is used as a plumb-line in cases where the tape is hanging above the substratum. The object is dropped at each designated point and it touches only one substratum type which can be recorded. The categories recorded under each 50 cm point are: hard coral, soft coral, dead coral, fleshy seaweed, sponge, rock, rubble, sand, silt / clay and 'other'. In order to deal with any ambiguity, the divers are given specific guidance on these categories (Appendix 1).

Anthropogenic data

During each survey anthropogenic impacts are assessed for coral damage via either anchors, dynamite, or 'other' factors and trash from fishing nets or 'other'. Divers rated the damage caused by each factor using a 0-3 scale (0 = none, 1 = low, 2 = medium, 3 = high).

2.4 Data analysis

All data were transferred to field recording sheets and subsequently to standard Microsoft Excel spreadsheets. CCC spreadsheets were submitted to Reef Check for integration into the global data set.

For this study, line transect data were converted to mean percentage cover of each substratum category per depth contour. Belt transect data were used to calculate the

mean abundance of each fish and invertebrate taxa. Anthropogenic data were represented by median abundance ratings.

Visual comparisons between years, sites and depths were facilitated via a series of bar-charts. Quantitative assessment of these trends was achieved using the t-test. The t-test is a parametric test which examines the null hypothesis that the difference between two means is zero (against the alternative hypothesis that the difference is not equal to zero; Toker, 1992). For this study a separate variance t-test was used.

Comparative data, from Reef Check 1997, for the Caribbean region was extracted from Hodgson (1999). Data were extracted as accurately as possible but there was a degree of error since raw data were not available. For example, modes of indicator species (lobster, grouper, Haemulidae, butterfly fish and *Diadema*) were used for the Caribbean region to provide an indication of their abundance.

3. RESULTS

All the raw data from the 1997 and 1998 surveys are appended (Appendix 2).

3.1 Sites

The surveys were carried out on 30th and 31st August 1997 and between the 1st and 3rd September 1998. In 1997 the surveys were carried out under cloudy conditions and in 1998 the weather was sunny.

Sites 1 and 2 are 57.6 km away from the nearest population centre (Belize City: approximately 50,000 people; McField et al., 1996). The sites are regarded as exposed and have been damaged by hurricanes, particularly Hurricane Hattie in 1961 (Stoddart, 1963)[4]. Generally the sites have a low anthropogenic impact since they are moderately affected by tourist diving and are not affected by dynamite fishing, poison fishing, aquarium fish collection, and sewage or industrial pollution (McField et al., 1996). Both sites are on the forereef and are bordered by an eastern, seaward escarpment and a western reef crest (Figure 3).

3.2 Site characteristics

Table 1 summarises the gross characteristics of the 1997 and 1998 sites.

Table 1. Benthic characteristics of Reef Check sites. Shallow transects at approximately 3m and mid-depth transects at approximately 10m. Standard deviation shown in parentheses.

BENTHIC CATEGORIES	SITE 1 1997				SITE 1 1998				SITE 2 1998			
	Shallow		Mid-depth		Shallow		Mid-depth		Shallow		Mid-depth	
Hard coral	29.4	(6.6)	20.6	(4.3)	36.9	(4.7)	33.8	(6.3)	36.9	(15.2)	25.0	(7.4)
Soft coral	18.8	(4.3)	15.6	(3.1)	22.5	(7.4)	24.4	(9.9)	23.1	(4.3)	13.8	(3.2)
Dead coral	1.3	(2.5)	0.0	(0.0)	3.8	(1.4)	4.4	(2.4)	5.0	(2.0)	10.6	(7.5)
Fleshy seaweed	5.6	(5.5)	15.0	(7.1)	3.1	(2.4)	1.3	(2.5)	0.0	(0.0)	2.5	(2.9)
Sponge	0.0	(0.0)	0.0	(0.0)	15.0	(7.4)	12.5	(6.1)	0.0	(0.0)	3.1	(1.3)
Rock	34.4	(7.2)	26.3	(7.8)	3.1	(1.3)	5.0	(6.1)	1.3	(2.5)	5.6	(6.6)
Rubble	4.4	(2.4)	11.3	(7.8)	8.8	(10.9)	10.6	(11.1)	21.9	(21.1)	39.4	(10.1)
Sand	6.3	(9.5)	11.3	(7.5)	6.9	(4.7)	8.1	(5.5)	11.9	(9.0)	0.0	(0.0)
Silt / clay	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Other	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)

All sites have a relatively high cover of hard coral, although there is consistently less cover at mid-depths in comparison with shallow depths. The proportion of dead coral is relatively low at most sites and soft coral cover is relatively high. Fleshy seaweed coverage is high at mid-depth Site 1 (1997) but low at both sites in 1998. There is a notably high sponge cover at Site 1 (1998) but the recorded coverage of rock, rubble and sand varies widely, even within the same site.

[4] Hurricane Mitch affected Turneffe after the 1998 Reef Check surveys.

The benthic data indicate that all the sites and depth zones can be classified as 'Dense massive and encrusting corals' within the classification scheme for marine habitats of the Caribbean (Mumby and Harborne, 1999). The characteristics of this benthic class are a diverse, hard coral cover of greater than 5%. Since both sites are on the forereef, the Reef Check sites can all be classified as being within a 'Forereef + Dense massive and encrusting coral' habitat (Mumby and Harborne, 1999).

3.3 Comparison of 1997 and 1998

Benthic (line transect) and belt transect data collected at Site 1 in 1997 and 1998 are visually compared in Figures 4-7. Shallow (3 m) and mid-depth (10 m) data are displayed separately.

Table 2 summarises the results from the t-tests which statistically compared each parameter, from both line and belt transects, for change between 1997 and 1998. Only those comparisons which highlighted a significant ($P < 0.05$) difference between 1997 and 1998 are shown.

Table 2. Significant t-test results between reef parameters measured at Site 1 in 1997 and 1998. S.D. = Standard deviation.

BENTHIC CATEGORIES	DEPTH	SITE 1 1997		SITE 1 1998		SIGNIFICANCE
		Mean (%)	S.D.	Mean (%)	S.D.	
Sponge	Shallow	0.0	0.0	15.0	7.4	<0.05
Rock	Shallow	34.4	7.2	3.1	1.3	<0.01
Hard Coral	Mid	20.6	4.3	33.8	6.3	<0.05
Dead Coral	Mid	0.0	0.0	4.4	2.4	<0.05
Fleshy Seaweed	Mid	15.0	7.1	1.3	2.5	<0.05
Sponge	Mid	0.0	0.0	12.5	6.1	<0.05
Rock	Mid	26.25	7.8	5.0	6.1	<0.01

The results of the t-tests showed that only a small number (16.7%) of the changes between 1997 and 1998 were significant. Furthermore, there were no significant differences in the abundance of any of the taxa recorded on the belt transects. The changes that were observed consisted of an increase of sponge cover at both shallow and mid-depth sites in 1998. At mid-depth there were also a significant increases in hard coral and dead coral. In contrast, there was a highly significant decrease in rock at both shallow and mid-depths and a decrease of fleshy seaweed at mid-depth from 1997 to 1998.

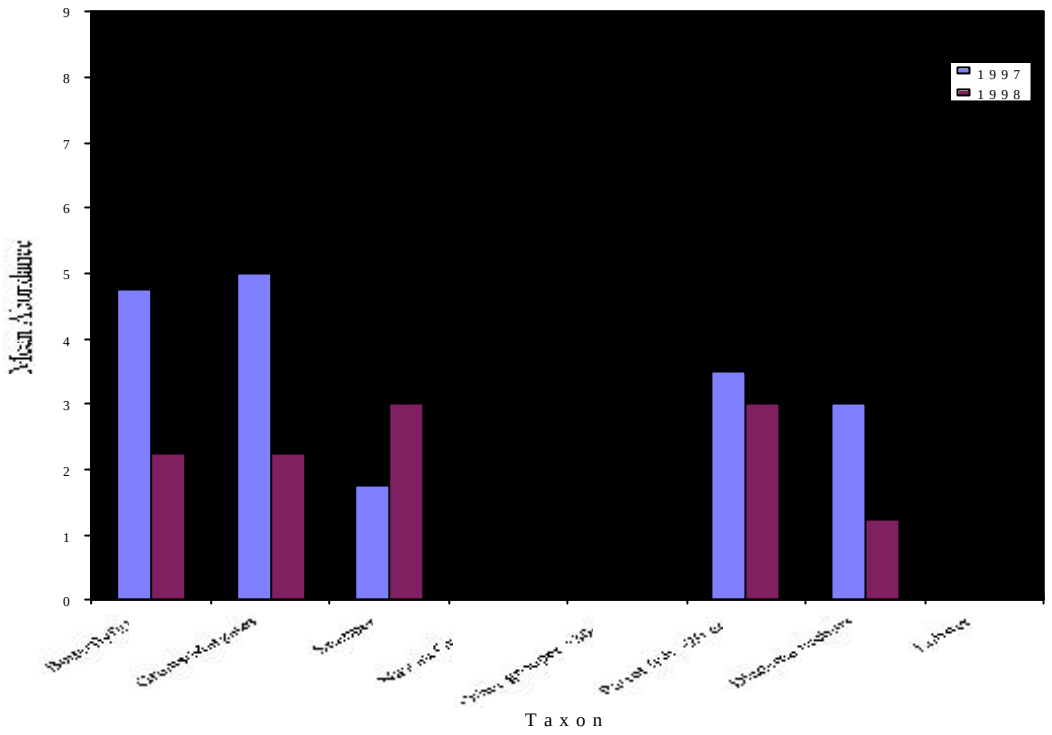

Figure 4. Comparison of 1997 with 1998 shallow belt transect data. Bars represent standard deviation.

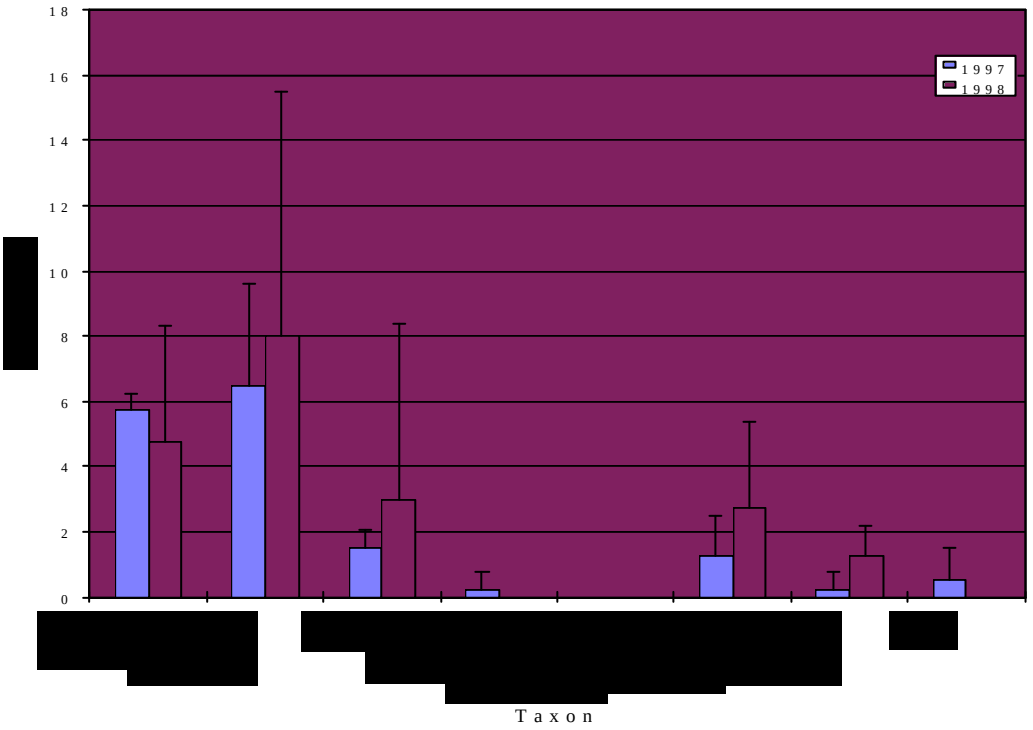

Figure 5. Comparison of 1997 with 1998 mid-depth belt transect data. Bars represent standard deviation.

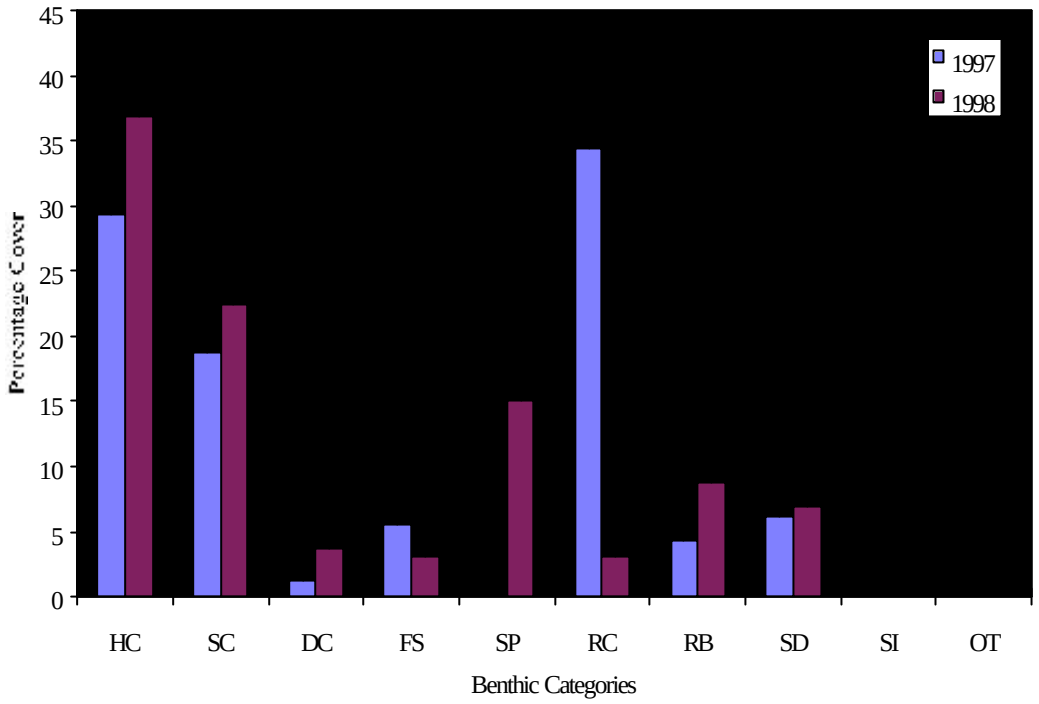

Figure 6. Comparison of 1997 with 1998 shallow line transect data. Bars represent standard deviation.

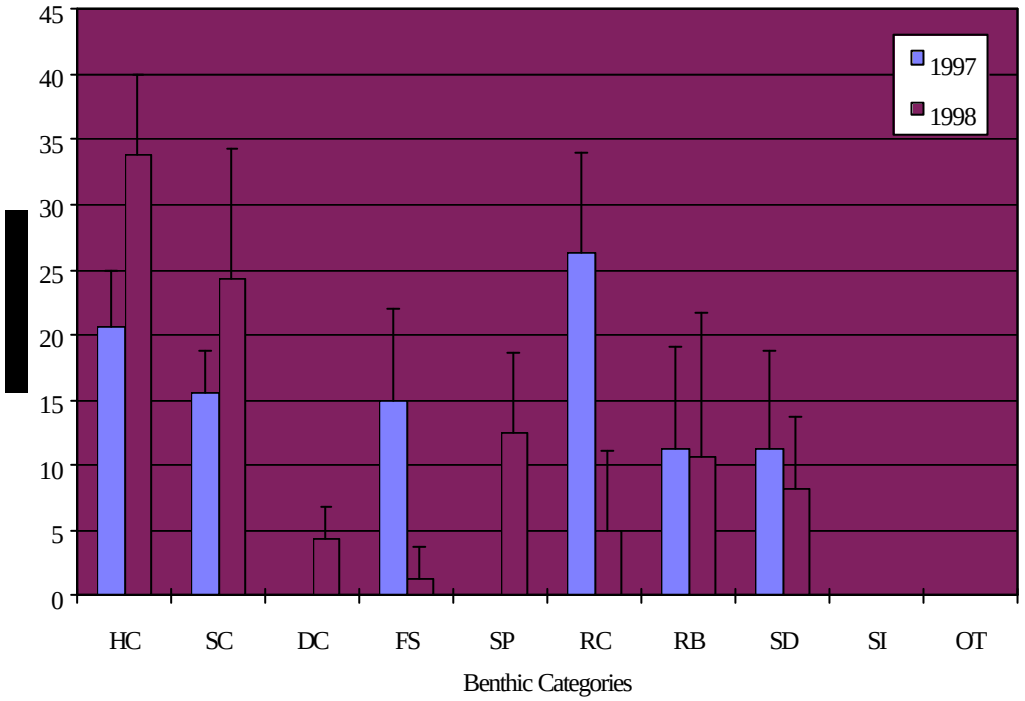

Figure 7. Comparison of 1997 with 1998 mid-depth line transect data. Bars represent standard deviation.

Benthic categories: HC = hard coral; SC = soft coral; DC = dead coral; FS = fleshy seaweed; SP = sponges; RC = rock; RB = rubble; SD = sand; SI = silt; OT = other.

3.4 Comparison of Site 1 and Site 2 in 1998

Benthic (line transect) and belt transect data collected at Site 1 and Site 2 in 1998 are visually compared in Figures 8-11. Shallow (3 m) and mid-depth (10 m) data are displayed separately. It was anticipated that Site 1 is typical of a 'good' site at Turneffe Atoll and that Site 2 may have suffered some damage from increased diving pressure.

Table 3 summarises the results from the t-tests which statistically compared each parameter, from both line and belt transects, for change between Sites 1 and 2. Only those comparisons which highlighted a significant ($P < 0.05$) difference between Sites are shown.

Table 3. Significant t-test results between reef parameters measured at Site 1 and Site 2 in 1998. S.D. = Standard deviation.

BENTHIC CATEGORIES	DEPTH	SITE 1		SITE 2		SIGNIFICANCE
		Mean	S.D.	Mean	S.D.	
Sponge	Shallow	15.0	7.4	0.0	0.0	<0.05
Gorgonians	Shallow	40.5	8.7	9.3	2.1	<0.05
Rubble	Mid	10.6	11.1	39.4	10.1	<0.01

Similarly to the comparison between 1997 and 1998 data, no change of abundance of any commercially or ecologically important fish or invertebrate species was significant. However, Site 2, thought to be the more impacted site, has significantly less gorgonians and sponges on the shallow transect and more rubble on the mid-depth transect than at Site 1. It should be noted that the 'gorgonians' parameter was only introduced for the 1998 surveys and, therefore, it has not been possible to examine any changes in gorgonian numbers at Site 1 between 1997 and 1998.

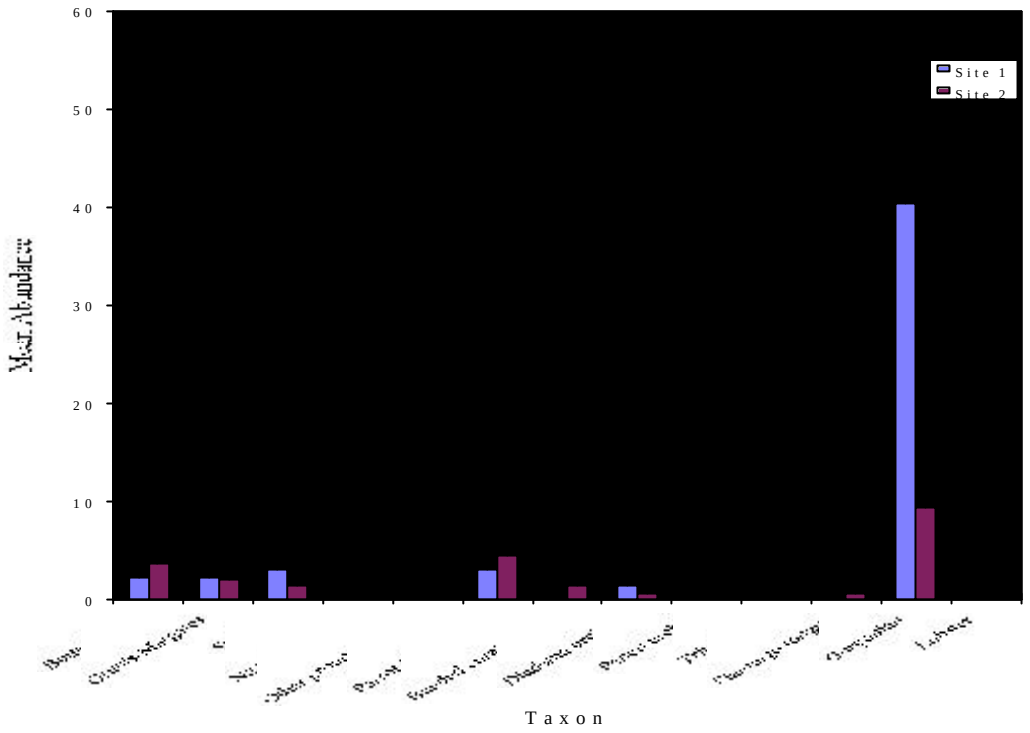

Figure 8. Comparison of shallow belt transect data from Site 1 and Site 2 in 1998. Bars represent standard deviation.

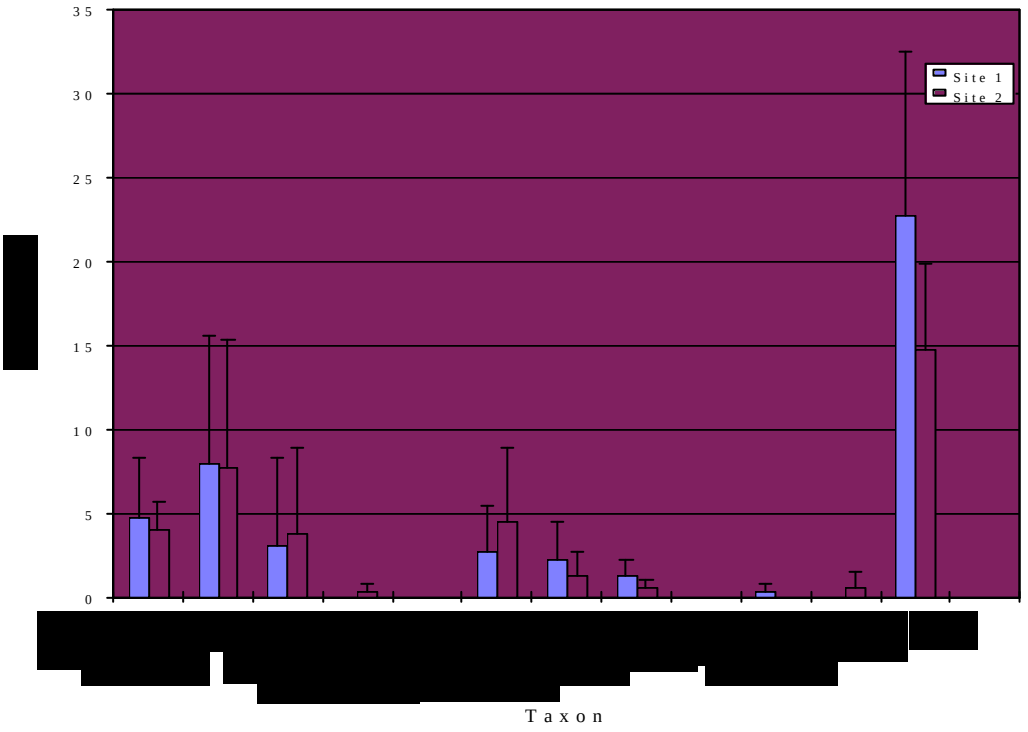

Figure 9. Comparison of mid-depth belt transect data from Site 1 and Site 2 in 1998. Bars represent standard deviation.

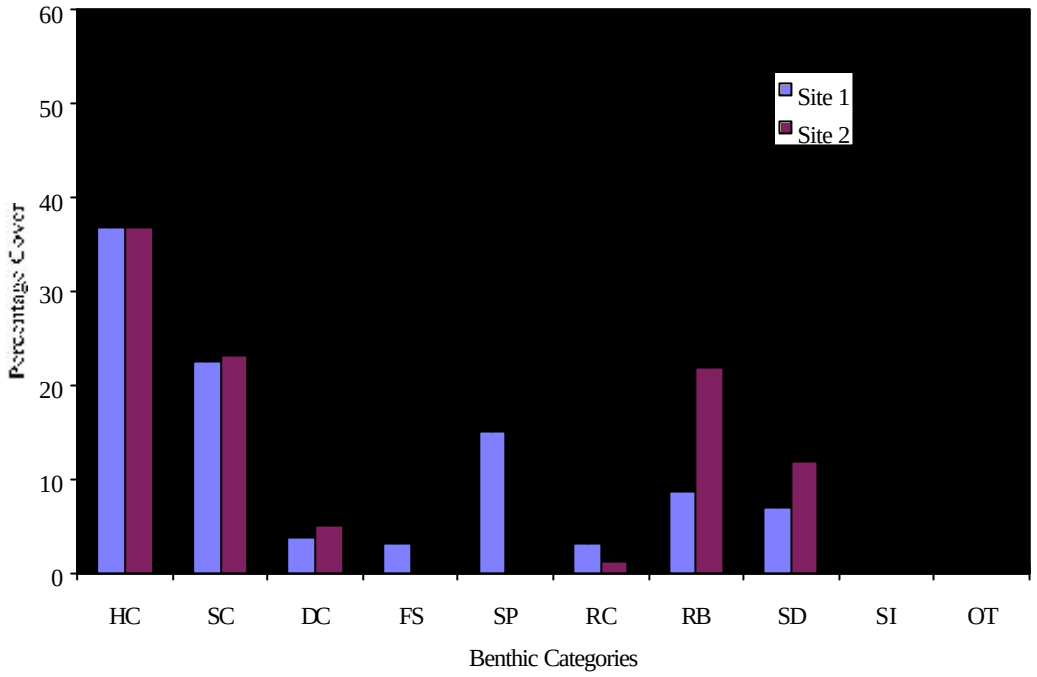

Figure 10. Comparison of shallow line transect data from Site 1 and Site 2 in 1998. Bars represent standard deviation.

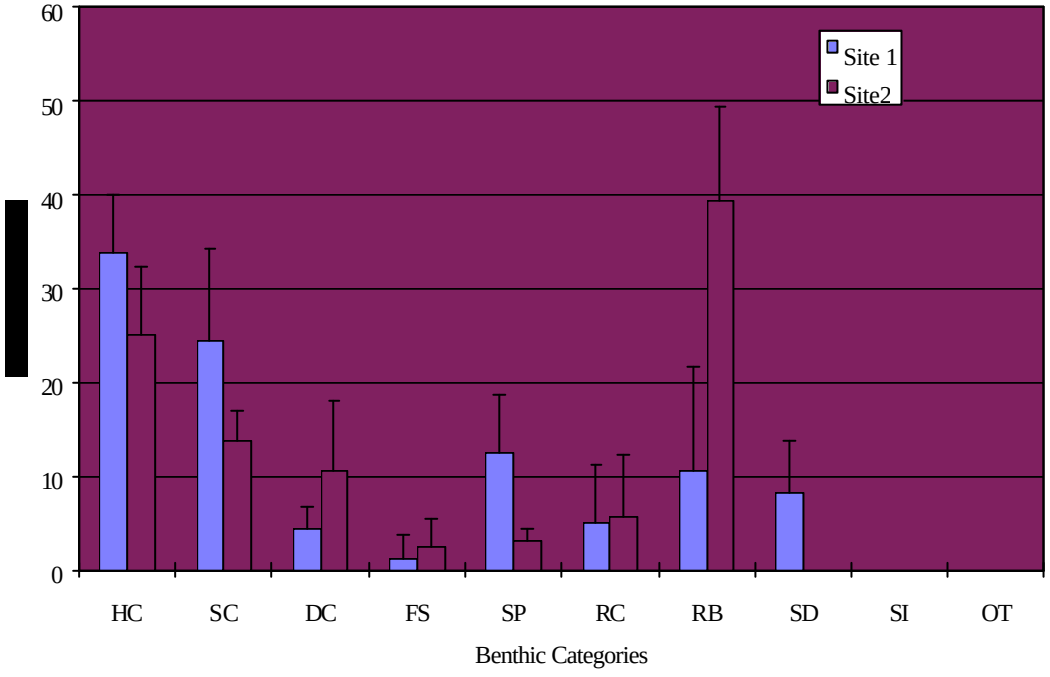

Figure 11. Comparison of mid-depth line transect data from Site 1 and Site 2 in 1998. Bars represent standard deviation.

Benthic categories: HC = hard coral; SC = soft coral; DC = dead coral; FS = fleshy seaweed; SP = sponges; RC = rock; RB = rubble; SD = sand; SI = silt; OT = other.

3.5 Comparisons between Belize and the Caribbean region

To make a comparison between this study and the Caribbean region, data were extracted from the results of the 1997 Reef Check (Hodgson, 1999). No detailed statistical analysis can be undertaken since raw data were not available and, therefore, only trends can be highlighted. The mid-depth and shallow data that CCC collected at Sites 1 and 2 were combined for the comparison. Figure 12 compares the live and dead coral cover from Turneffe Atoll with data from the Caribbean region.

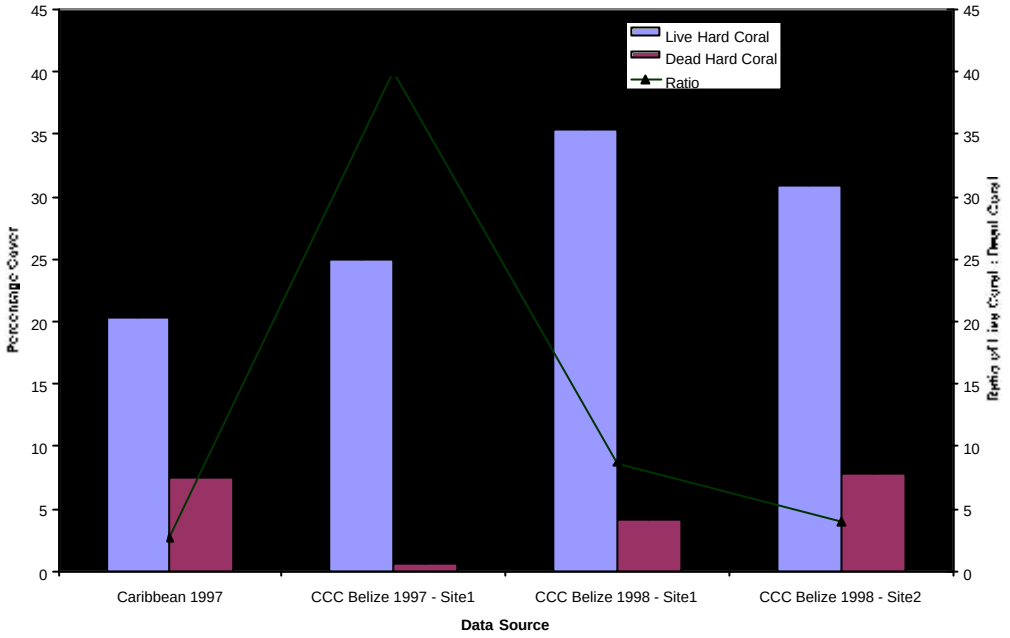

Figure 12. Comparison of live hard coral and dead hard coral coverage in Belize (this study) and the Caribbean region (from Hodgson, 1999).

Figure 12 shows that all three CCC data sets have a higher percentage cover of live coral and, except for Site 2 in 1998, a lower percentage cover of dead coral than the mean for the Caribbean region. CCC sites also have a higher hard coral : dead coral ratio and this is particularly high in 1997.

The abundance of some indicator species at Turneffe Atoll can be compared with their abundance in the rest of the Caribbean to give another indication of reef health. Data for the Caribbean were extracted from Hodgson (1999) and compared to mean values from Belize (Table 4). Regional values are represented as modes since more detailed values are not available. Statistical analysis is not appropriate for comparing Caribbean and Turneffe Atoll data.

Table 4. Comparison of indicator species modes for the Caribbean region (from Hodgson, 1999) and means from Turneffe Atoll (this study).

CATEGORIES	CARIBBEAN	TURNEFFE ATOLL		
	1997 mode	1997 Site 1 mean	1998 Site 1 mean	1998 Site 2 mean
Lobster	0.0	0.25	0.00	0.00
Grouper	0.0	0.13	0.00	0.13
Haemulidae	2-5	5.75	5.13	4.88
Butterflyfish	0-2	5.25	3.50	3.75
Diadema	0.0	1.65	1.25	0.50

Table 4 shows that Turneffe Atoll had a greater or equal abundance of each indicator species than the mode for the Caribbean region. The most prominent of the abundance differences was the high number of butterflyfish found in Belize, particularly in 1997.

3.6 Anthropogenic data

Tables 5 and 6 shows a summary of the semi-quantitative anthropogenic data collected by the Reef Check protocol. Few anthropogenic impacts were observed at Turneffe Atoll and no form of any impact was recorded in 1997. In 1998 the only impacts were unspecified incidents of 'coral damage' at both shallow and mid-depths and at both sites. The low occurrence of anthropogenic impacts limits scope for detailed statistical comparisons.

Table 5. Summary of anthropogenic data recorded at Site 1 in 1997 and 1998.

PARAMETER	SITE 1 1997				SITE 1 1998			
	Shallow depth		Mid depth		Shallow depth		Mid depth	
	Median	Range	Median	Range	Median	Range	Median	Range
Coral damage : Anchor	0.0	-	0.0	-	0.0	-	0.0	-
Coral damage: Dynamite	0.0	-	0.0	-	0.0	-	0.0	-
Coral damage : Other	0.0	-	0.0	-	1.0	0-2	0.5	0-1
Trash : Fish nets	0.0	-	0.0	-	0.0	-	0.0	-
Trash : Other	0.0	-	0.0	-	0.0	-	0.0	-

Table 6. Summary of anthropogenic data recorded at Site 1 and Site 2 in 1998.

PARAMETER	SITE 1 1998				SITE 2 1998			
	Shallow depth		Mid depth		Shallow depth		Mid depth	
	Median	Range	Median	Range	Median	Range	Median	Range
Coral damage : Anchor	0. 0	-	0.0	-	0.0	-	0.0	-
Coral damage: Dynamite	0.0	-	0.0	-	0.0	-	0.0	-
Coral damage : Other	1.0	0-2	0.5	0-1	0.5	0-1	0.5	0-1
Trash : Fish nets	0.0	-	0.0	-	0.0	-	0.0	-
Trash : Other	0.0	-	0.0	-	0.0	-	0.0	-

4. DISCUSSION

Reef Check was originally designed to highlight global patterns in reef health rather than local trends. Increasingly, however, the protocol is being used for site specific monitoring programmes because it is taxonomically simple, flexible and statistically robust. The principle aim of this study was to utilise Reef Check data to provide general information on the health of Turneffe Atoll in order to aid its preservation and sustainable use.

Although statistically robust, the low number of line and belt transects surveyed via the Reef Check protocol limits the conclusions that can be drawn from these data. Similarly, the small spatial and temporal scales of the Turneffe Atoll data set allow only general trends to be identified. However, since the protocols were designed for non-professional divers the data are likely to be accurate and consistent. Furthermore, CCC volunteers have had more training than the average Reef Check surveyor, thus increasing the reliability of the data.

4.1 Comparison of 1997 to 1998

Belize has a relatively small population and a limited number of population centres. Turneffe Atoll is remote from these centres and there is a very low population density, mainly caused by the large areas of mangrove which prevent building. Hence, it can be assumed that anthropogenic impacts are fairly low. There are, however, some changes apparent from 1997 to 1998. Although these differences may be attributable to changes in reef health, it is also important to note that the location of Site 1 in 1998 was achieved via GPS rather than a permanent marker. GPS is accurate to ± 30 m[5] and, therefore, the 1998 transect was unlikely to be in exactly the same place as 1997. Reefs are heterogeneous environments and although both transects were in the same habitat type (Section 3.2) some of the changes may be caused by benthic patchiness. Further spatial and temporal replicates are required to establish whether the trends documented here are actual changes in reef parameters.

The increase in hard coral and a decrease in fleshy seaweed at the mid-depth transect suggests an improvement in reef health and possibly an increase in species diversity. High coral cover is generally regarded as key parameter of reef health (Hatcher et al., 1989). In addition, numerous studies (for example Talbot and Goldman, 1972) have found significant correlations between substratum complexity and fish diversity. An increase in hard coral cover can increase substratum rugosity, vertical relief and coral species richness which are variables linked with patterns (diversity and quantity) of fish communities (for example Risk, 1972). The decreases in bedrock abundance at Site 1 from 1997 to 1998 is consistent with the increase of coral cover since it offers a suitable substratum for larval settlement. A second factor increasing the cover of bedrock is the decrease in fleshy algae which exposes the underlying substratum

A decrease in fleshy seaweed is in direct contrast to general patterns in the Caribbean, where most reefs have experienced a dramatic decrease in coral cover and concomitant increase in macro-algae over the last two decades (for example Hughes,

[5] http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html#SA

1994). Belize has been cited as an undisturbed system but data from Glovers Atoll show algal cover increasing from less than 10% to current levels of over 60% (e.g. McClanahan et al., 1999). This pattern has been attributed to a number of factors, particularly the mortality of *Diadema* urchins in the 1980's (reviewed by Lessios, 1988), removal of herbivorous fish and increased nutrients within the water column. Similar to the increase in coral cover, low algal abundance is regarded as an indication of a balanced reef system (reviewed by Done et al., 1996).

This ecological shift, however, has not been consistent in Belize and suggests a complex set of synergistic factors varying within the coastal zone. For example, on the barrier reef and Glovers Atoll patch reefs the changes paralleled the decimation of *Acropora* from white-band disease and show the role of coral mortality along with putative changes in herbivory and nutrients (McClanahan et al., 1999). The physico-chemical environment must also have an important role since the increased flushing on the forereef at Glovers Atoll seems to have limited disease and the increase in erect macro-algae is less apparent (McClanahan and Muthiga, 1998). In contrast, on the rhomboid reefs close to Carrie Bow Cay the result of *Acropora cervicornis* death is an alternative community state dominated by *Agaricia tenuifolia* (Aronson et al., 1998). Aronson et al. (1998) suggest that this shift seems to have been caused by intense herbivory by the urchin *Echinometra viridis*, reducing macro-algae and facilitating *Agaricia* recruitment.

Although not statistically significant, the increase in herbivores such as parrotfish and *Diadema* observed at the mid-depth transect are likely to be an important factor for the fall in algal abundance. The increased herbivory may have also caused the increase in visible dead coral at the mid depth transect. In contrast, there are no significant changes in algae or coral cover in the shallow reef. This may be because there is no increase in herbivores and there is actually a decrease in parrotfish and *Diadema* abundances.

The significant increase in sponges which occurs on both mid and shallow depth transects is difficult to explain and is likely to be caused by their patchy distribution. Wilkinson (1997) suggested that a high abundance of encrusting sponges may indicate high nutrient levels, but such a significant decrease in water quality seems unlikely on a remote atoll over a short time period. As with all other parameters, additional data is required to establish whether the trends observed between 1997 and 1998 are true indicators of reef health or a function of habitat heterogeneity.

Although there are no *significant* changes in abundance of any indicator species, some of the data indicates a trend of increased abundance from 1997 to 1998. This is particularly true for mid-depth data where populations of grunts/margates, snappers, parrotfish and *Diadema* have increased. Only the commercially important snapper increased on the shallow transect and the decreases in the commercially and ecologically important butterflyfish, grunts/margates, parrotfish and *Diadema* require further monitoring.

Despite the slight increase in the numbers of some indicator species is 1998, the absolute abundances are still low and some species are completely absent. Fishing has caused massive reductions in the density of commercially important fishes, such as groupers, throughout the Caribbean (Roberts, 1995). Therefore, the lack of these fish

species on Reef Check surveys in this study is not surprising. Reduced fish populations have significant economic consequences to local fishermen but the effect to a reef in unclear. Roberts (1995) highlights that linkages among fishes and their echinoderm prey have been striking but the effects of piscivore loss seems to have little influence on the abundance of other species. The low abundance of parrotfish is ecologically more significant since they are a major grazer of algae and play a key role in coral-algal interactions (Choat, 1991). The possible trend of decreasing butterflyfish should also be monitored since they have been proposed as indicators of reef health via their trophic association with hard corals (Reese, 1975). The economic and ecological consequences of reduced fish populations requires management initiatives on Turneffe Atoll.

The lobster fishery in Belize is also extremely important economically and totalled Bz$17.6 million in 1995 (McField et al., 1996). Although there has been no stock assessment of lobster, it is likely that the fishery is above the maximum sustainable yield (McField et al., 1996). The low number of lobsters (only two individuals in total) indicate that the stocks at Turneffe may be fished unsustainably, with significant consequences for local fisherfolk. It is likely that the total absence of lobsters on the shallow transect is caused by fishermen close to Calabash Cay collecting lobster using snorkelling equipment (ARH, pers. obs.).

4.2 Comparison of Site 1 to Site 2 in 1998

There is no quantitative data to confirm that Site 2 has more divers than Site 1 but observations by CCC science staff and the establishment of a permanent mooring buoy provide anecdotal evidence. This hypothesis is supported by the increased cover of rubble at Site 2 (mid-depth) which may be caused by divers. For example, Riegl and Velimirov (1991) found that on reefs with a high frequency of visitors, major tissue loss, algae overgrowth and coral breakage were significantly higher than on reefs with a low frequency of visitors. Similarly, a significant decrease in sponge cover at the shallow depth could be caused by divers and snorkellers knocking over and killing large sponges. A significantly lower abundance of gorgonians was recorded at the shallow transect at Site 2, possibly caused by direct breakage by divers but also diseases. Gorgonians, especially sea fans, are particularly vulnerable to sub-lethal diver damage which may increase their susceptibility to disease.

Although these trends are consistent with diver damage, additional spatial and temporal data are required to confirm the conclusions. For example, the differences may be caused by habitat heterogeneity or different physical regimes. Exposure is an important determining factor of reef communities (Sheppard, 1982) and the increased rubble and reduced sponges may be caused by increased wave action in that part of the bay. However, it is likely this would also affect parameters such as hard coral cover which was similar at the mid-depth transects (33.8% and 25%) and identical at the shallow transects (36.9%).

Similarly to the 1997 and 1998 comparisons (Section 4.1) no significant differences were seen between the indicator fish or invertebrate species but the low numbers of groupers and complete absence of lobsters at both sites is alarming. Over fishing of these species is likely to have significant economic and ecological impacts. Pencil

urchins, triton shells and flamingo tongues also had a low abundance but these species are naturally relatively rare. However, the small numbers of triton shells maybe caused by curios collection (Human, 1992).

4.3 Comparisons between Belize and the Caribbean region

Results from all three sets of CCC data (Site 1 in 1997 and 1998 and Site 2 in 1998) indicates that the reef at Turneffe Atoll is in better condition than the average for the Caribbean region. Although it is not possible to test the differences statistically, there was a higher percentage cover of live coral, lower percentage cover of dead coral and a higher ratio of live : dead coral. In addition, the mean abundance of indicator species in Belize was the same as, or higher, than the modes for the rest of the Caribbean although the absolute values are still lower than expected for an unexploited reef system.

The comparatively good health of Turneffe Atoll is likely to be caused by the low population density of Belize, low fishing pressure (relative to many other areas of the Caribbean), good water quality and coastal zone management and environmental awareness. The apparent lack of severe anthropogenic effects are reflected by the minimal impacts recorded on the transects (generally median values of 0) and the perceived low prevalence of human activities listed on the Site Description form.

5. CONCLUSION AND RECOMMENDATIONS

Analysis of 1997 and 1998 Reef Check data shows that Turneffe reefs are healthy and in good condition compared to the whole Caribbean region. There are also some indications that reef health is improving, such as increasing coral cover. However, there are some concerns, particularly the low numbers of commercially important groupers and lobsters from over fishing.

Reef Check has also been shown to provide a good basis for reef health assessment and data can be collected accurately by non-professional divers. The data presented in this study are limited spatially and temporally, but provide a foundation for more extensive and detailed monitoring surveys to fully assess changes in reef health. Some studies, such as the CARICOMP surveys carried out by UCB, are already started and will be extended by the World Bank-GEF Meso-American Barrier Reef System project (Sale, pers. com.). Furthermore, Reef Check data from Turneffe Atoll and other areas of Belize, contribute to the global database and assist the aims of a synoptic view of global reef health and public awareness.

Recommendation 1: UCB, the Coastal Zone Management Project or the Fisheries Department continue to undertake Reef Check surveys at Sites 1 and 2 at Calabash Cay. These data could form the basis of a long-term monitoring database for the atoll.

Recommendation 2: Sites 1 and 2 could be marked with a permanent stake or surface buoy to ensure that annual surveys are carried out in the same area, reducing the possible effects of reef heterogeneity. Note that although the re-surveys should be carried out in the same *area*, they should be randomly located (i.e. not always starting at the stake) as this reduced statistical power because of spatial autocorrelation.

Recommendation 3: If possible, Reef Check surveys on Turneffe Atoll to be extended to include sites in other areas, particularly the western (leeward) reef. This will improve the spatial scale of the database and provide further evidence for any apparent trends.

There was some evidence that Sites 2, a popular dive site, had suffered damage consistent with diver impacts. These included increased rubble and fewer sponges. The quantity of divers at all sites on Turneffe Atoll should be monitored in order to assist interpretation of monitoring data. Furthermore, Medio et al. (1996) suggest briefing divers to increase their environmental awareness can significantly affect the number of contacts divers make with the benthic community. Such measures would compliment the system of permanent mooring buoys being established.

Recommendation 4: Establish a programme of recording the number of dives undertaken at Turneffe Atoll and the most popular dive locations. These data could be used to help interpret monitoring programmes and assist any future carrying capacity calculations.

Recommendation 5: Establish a standard environmental awareness briefing for all divers which can be used by dive resorts on Turneffe Atoll and elsewhere. Such a briefing could be developed using the PADI AWARE programme.

Turneffe Atoll is more remote than many other reefs in the Caribbean and seems to be in good condition. However, Bryant et al. (1998) estimate the threat to the atoll as 'medium'. Although this threat is lower than many reefs in Central America, there is some cause for concern and pressure from fishing, development and diving, combined with effects from natural events such as coral bleaching, are likely to increase. A marine protected area for Turneffe Atoll has been proposed (Gibson, pers. com.) and this would help to maintain reef health. Such a reserve would also provide additional ecological and economic benefits, such as increased fish catches and income for local communities (Clark, 1996).

Recommendation 6: Continue to aim to establish a multiple use marine protected area at Turneffe Atoll, with an integrated monitoring programme to measure its efficacy.

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