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**An Investigation into the Effects of Tourism on
Buccoo Reef, Tobago.**

Claire Fletcher

**University of Southampton
BSc (Hons) Environmental Sciences
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Supervisor: Professor Stephen Hawkins
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Abstract

A review of the widespread destruction of coral reefs, caused by man's overexploitation of fragile reef environments around the world, is presented and past and present conservation efforts, highlighted. A lack of resources has greatly weakened the conservation efforts made by local authorities to better manage the Buccoo Reef Marine Park in Tobago, and the impacts of tourism which directly threaten the reef's existence are detailed.

Buccoo Reef is subject to heavy tourist and recreational use. Visitors aggregate at two main areas of the Marine Park, so these sites were surveyed to determine the extent of damage that has been caused by snorkellers and guide boats using the reef. Several regions of Buccoo Reef are virtually isolated from tourist activity, so two control sites, with corresponding depths to the impact sites, were chosen from these areas.

The percentage coral cover and coral species diversity were assessed for subsequent analysis of the community structure and to establish a reliable estimate reef health. In addition to this, the diversity of reef fishes and the numbers of *Echinometra lucunter* were determined in an attempt to ascertain the effect of human disturbance on reef inhabitants.

The results indicate that reef walking in the shallow areas is causing considerable degradation of the coral communities and *E. lucunter* populations, while increasing reef fish diversity. Snorkelling and recreational boating in the deeper waters has had negligible impact.

The current management strategy for the Buccoo Reef Marine Park is ineffective and must be modified to ensure sustainable use of this fragile resource. Further work is required to better understand the cause-and-effect relationship between reef fish, urchins and tourist activity, and long-term monitoring programmes are necessary for measuring the rate of reef degradation.

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1. INTRODUCTION

Coral reefs are among the earth's most productive and biologically diverse ecosystems (Laydoo, 1991). Reefs not only provide shelter and food, but they are also breeding and nursery grounds for many important species. About 6,000 to 8,000 fish species as well as sponges, sea anemones, worms, crustaceans, and snails live on coral reefs (Sea World, 1999). In addition to the array of marine life they support, reefs also represent a valuable living resource, providing sand for beaches, protection from coastal erosion, places of recreation, and raw materials with potential medicinal applications (Laydoo, 1991).

Unfortunately, the over exploitation and poor management of these living resources has led to widespread destruction of coral reefs in many parts of the world. Marine scientists report that ten percent of the world's coral reefs are already destroyed, and without appropriate conservation strategies, a further sixty percent could be lost in the next forty years (Hammond, 1999). Coral reefs in the Caribbean have come under fire from a variety of impacts such as over-fishing, collecting, pollution, poor land-use practices, recreation, and tourism (Laydoo, 1991).

In most cases, it is a combination of these stresses, which causes the rapid destruction of reef communities. The focus of this investigation, however, is on the isolated effects of tourism, and more specifically, the direct impacts of tourist activities such as reef-walking and snorkelling. Although the ill-advised behaviour of an individual diver on the reef may only have a minimal impact, the cumulative effect of destruction caused by snorkellers in large numbers can be considerable (Well, 1992). Reef organisms are especially vulnerable because they grow slowly, have limited adult mobility, and are restricted to the reef habitat (Chin, 1998). Even if snorkellers avoid direct physical contact with the coral, and abstain from standing on or kicking it, the action of treading water still creates considerable turbidity which stirs up sediment and disturbs reef creatures (Well, 1992).

Tourism also causes considerable damage to the reef habitat indirectly through the discharge of untreated waste from hotels and increased sedimentation induced by onshore developments. Even though these factors are not considered in this investigation, they should still be recognized as important components.

1.1 Global Conservation Efforts

Concern about the state of the world's reefs inspired scientists and environmental groups to declare 1997 as "The International Year of the Reef (IYOR)" (Frontier, 1999). More than 225 organizations in over 45 countries sponsored the event and the IYOR Public Awareness Campaign was a great success (Coral Reef Alliance, 1999). Scientists and volunteers from the worldwide diving community became involved in diagnosing the condition of representative reefs throughout the tropical seas (Reef Check, 1998). Aquariums, scientists, and conservation organizations collaborated to produce a variety of courses, brochures, and other educational materials and, individual coral reef areas created and revised management plans for their coastal zones (Indiana University, 1999). To continue this momentum, the Reef Conservation UK (RCUK) was formed "to promote conservation, public awareness, and education about coral reefs, as well as to ensure that all reef-related activities were conducted in a responsible manner" (Reef Relief, 1998).

1.2 Regional Conservation Efforts

In the West Indies, the Caribbean Coastal Marine Productivity Programme (CARICOMP) has developed a Coral Reef Monitoring Network (1992), in association with the United Nations Environmental Programme (UNEP) Long-Term Global Monitoring System, to examine representative coral sites for environmental threats and changes in Caribbean Reefs (Reef Relief, 1999). So far the program has established a Level I data collection protocol and issued a manual and standard equipment for coastal ecosystem and coral reef monitoring. However, in the seven years the programme has been operating, little

progress has been made in reef conservation at the local level. Small island states, such as Tobago, often lack the financial resources necessary to conduct long-term monitoring program or to ensure that current management plans are enforced. Without a customized management strategy based on site-specific investigations, the impact of tourist activity on heavily visited coral reefs, like Buccoo Reef, cannot be effectively controlled.

1.3 Local Conservation Efforts

In an attempt to manage and conserve the Buccoo Reef System in the face of intense anthropogenic pressures, the government of Trinidad and Tobago declared the reef a Restricted Area under the Marine Areas (Preservation and Enhancement Act) Act No.1 in 1973. The Buccoo Reef Marine Park currently covers an area of 150ha with a terrestrial area of 300ha (John, 1996), including the major centres of attraction to visitors (see Plate 1). Regulations governing entry into and activities within the Restricted Area prohibit “the removal of fish, coral, and other marine fauna...or interference with the sea bed.” (Act No.1, Chapter 37:02)

In 1976, the Institute of Marine Affairs, an independent research organization, was set up with the assistance of the UNDP in order to conduct research on the marine environment of Tobago, particularly the Buccoo Reef/Bon Accord complex. Preliminary reef studies based on photographic evidence collected during the 1950s and 1960s, indicated extensive coral damage to the reef crests, particularly the Outer Reef (Kenny, 1976). The tourist industry in Tobago at that time was still “undeveloped” in comparison to what it has become today, and only a few boats actually operated in the area. Without the necessary baseline data, Kenny could not prove with any certainty that the damage was caused by humans, especially since Buccoo Reef is exposed to oceanic swells throughout the year and certain amounts of natural damage are expected to occur at all times. Kenny concluded that storm damage was probably the initial factor responsible for damage to the Outer Reef and that subsequent activity on the reef prevented the natural regeneration, which might be expected.

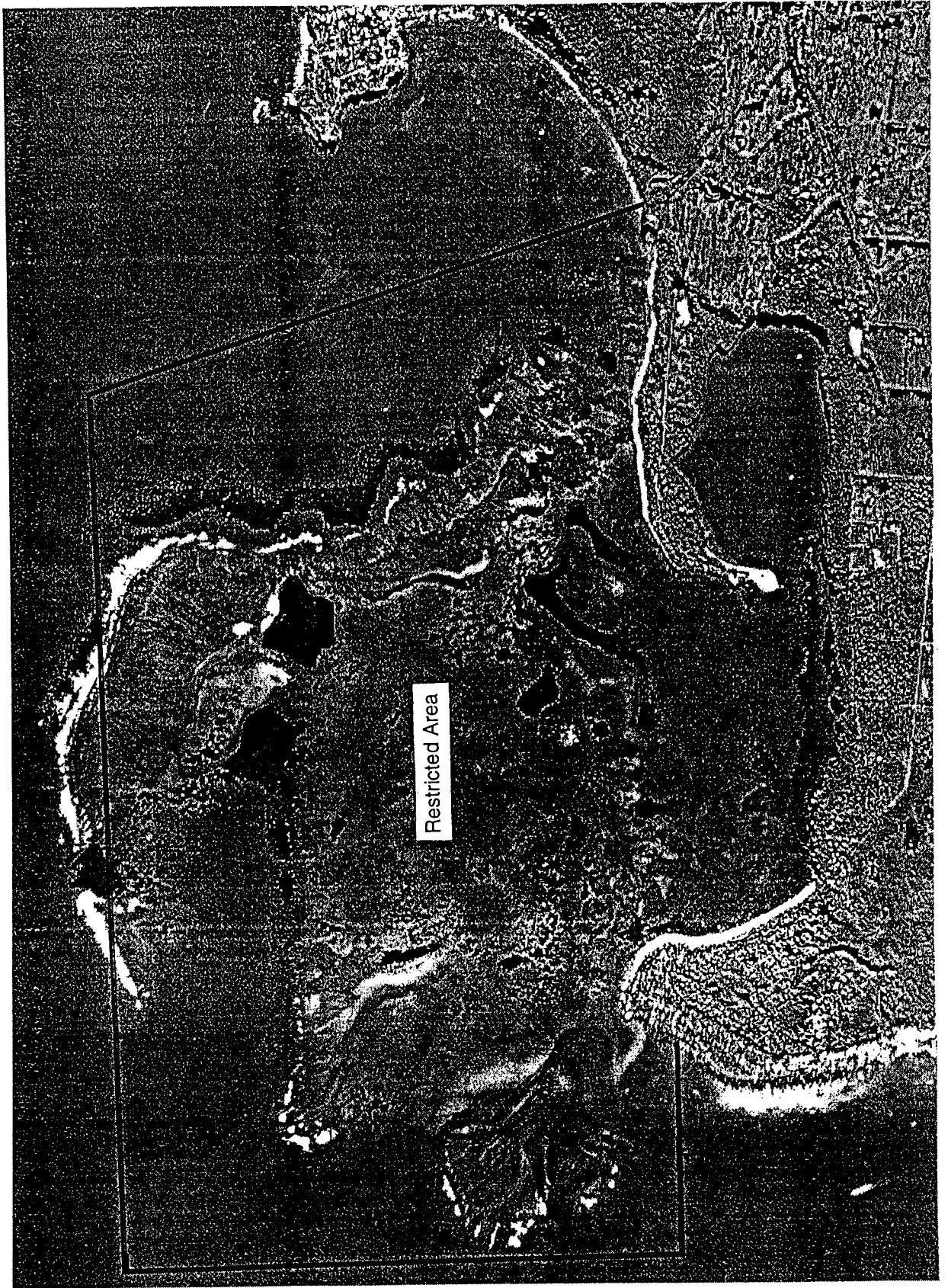


Plate 1 Aerial photograph of the Buccoo Reef Marine Park (1:25000).
(North West Geomatics Ltd 1994)

Since then, coral reef monitoring techniques have become increasingly precise and systematic, but a lack of resources has limited the scope for more detailed research and monitoring of the reef. More recent reef studies co-ordinated by the Institute of Marine Affairs are part of a series being carried out to record the changes in reef structure overtime, including shifts in the relative abundance of plants and animals, and percentage of bottom covered by living organisms (VINP, 1994). Over the last year, the Centre for Social and Economic Research on the Global Environment (CSERGE) has also conducted several basic ecological studies within the Restricted Area in an attempt to assess the present condition of the reef. Primary indicators of coral reef health, such as percentage living coral and water quality, are being used in conjunction with economic and social criteria in order to develop a framework incorporating stakeholder participation, which will lead to more sustainable resource management (CSERGE, 1998).

Stakeholders have been actively involved in the management of the Buccoo Reef Marine Park since local divers set up the Crusoe Reef Society in 1986. Since then, the society has been working in close collaboration with government authorities to improve the management of the Buccoo Reef area by monitoring, preserving, and protecting the marine and coastal environment in Tobago (Well, 1992).

1.4 Objectives of this Study

Overall, the purpose of my study was to define more clearly the relationship between reef health and tourist activity within the Buccoo Reef Marine Park and therefore determine whether the present management strategy is appropriate. By comparing the community structure between degraded (“impact”) and undisturbed (“no impact”) sites, the extent of decline in certain areas of Buccoo Reef resulting from human-caused stresses was estimated. The type and magnitude of stress created by snorkellers differs between specific areas depending on the depth of water. The shallow reef flat is particularly popular for reef walking and is therefore subject to immense trampling pressure, while the deeper coral communities are more likely to be affected by anchor damage. By studying the reef

communities at both depths, I was able to differentiate between the ecological effects caused by each type of disturbance. Specifically, my hypotheses were as follows:

H^0 – Tourist activity has no ecological impact on Buccoo Reef, Tobago.

H^1 – Tourist activity in shallow water (between four and six feet) has a negative ecological impact on Buccoo Reef, Tobago.

H^2 – Tourist activity in deep water (between ten and fifteen feet) has a negative ecological impact on Buccoo Reef, Tobago.

2. OVERVIEW of STUDY AREA

2.1 Tobago

My research was carried out through a case study of tourist impact on Buccoo Reef, Tobago, located at the southern end of the arc of islands of the Lesser Antilles. Tobago's marine environment is ideal for coral development, with surface temperature averaging between 26°C and 28°C, minimal turbidity, and salinity ranging between 32 and 36 ppt throughout the year (Laydoo, 1991). In addition to this, the floodwaters of Venezuela's Orinoco River provide a nourishing supply of plankton and microorganisms necessary to support the numerous coral reefs found along Tobago's coastline (UNEP, 1988).

2.2 Buccoo Reef

By far the largest and best known of all the reefs in Tobago is Buccoo Reef, located on a shallow shelf extending off the northern coast of south-west Tobago (11°10'N, 60°5'S) (UNEP, 1988). It is believed that Buccoo Reef represents more than ten thousand years of coral growth, which explains why the reef system is so extensive, covering an area of approximately 12ha between Buccoo Bay to the East and Pigeon Point to the west (see Fig. 1). Like all coral reefs found around Tobago, Buccoo Reef is a fringing reef consisting of a large, shallow reef lagoon bordered by the Bon Accord Lagoon and mangrove swamp landward, and an arc of five distinct reef flats separated by sand channels. These reef flats are the shallowest areas of the reef extending from depths of less than one meter at the reef crest to about four meters landward of the breaker zone. Seaward of the breaker zone, the fore reef slopes gradually to depths of approximately thirty metres, merging into a sand sea floor.

The Buccoo Reef System is part of an extensive recreation and tourist complex which draws somewhere between 30,000 and 35,000 visitors per year (Shim, 1999). Glass-bottom boats take tourists and locals from Buccoo Bay, Store Bay, and Pigeon Point to reef

areas at low tide where snorkelling and reef walking are popular activities (UNEP, 1988). The increasing importance of tourism to the economy of small developing islands like Tobago, and the easy accessibility of Buccoo Reef has resulted in overexploitation of the reef habitat (Chin, 1998). Experience in the Caribbean and elsewhere shows that such an unregulated use of coral reefs for tourist-oriented activities leads to a reduction in coral cover, due to careless anchoring of boats and trampling over shallow reef areas.

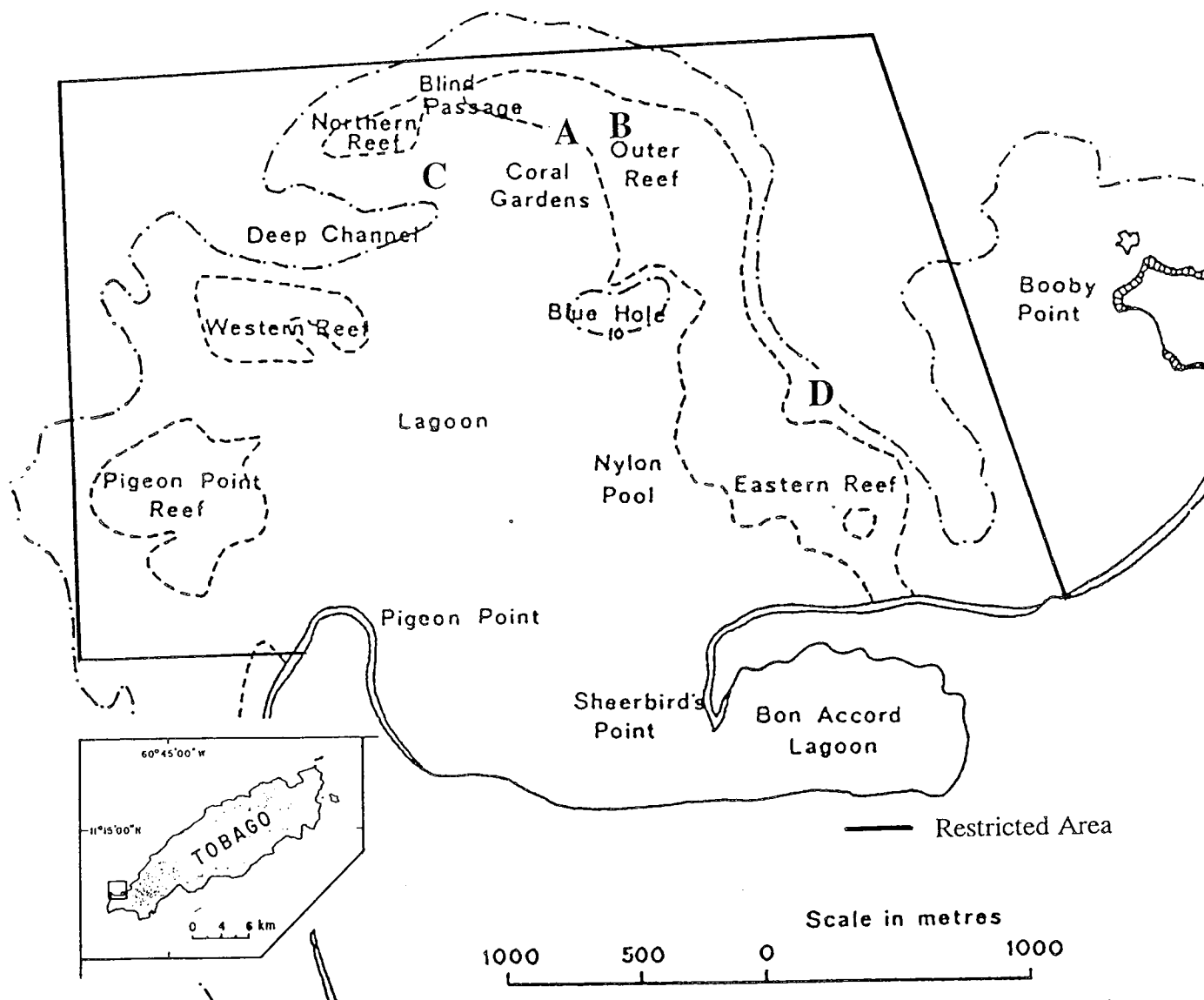


Fig. 1. Configuration of the Buccoo Reef Complex showing the four survey sites (A – D).

A... shallow, impact site

C... deep, impact site

B... shallow, no impact site

D... deep, no impact site

3. MATERIALS AND METHODS

The methodology used in this study was derived from established coral reef monitoring techniques and modified to make the most efficient use of limited time and resources, without compromising data quality. The core indices used were an assessment of coral abundance and diversity of major reef fishes. All of the sampling methods used were simple, low impact techniques that minimized the risk of damaging the reef during data collection. Data was collected over seven consecutive days during the rainy season between the 24th and 31st August 1998, but it was assumed that neither coral condition nor fish populations were affected by changes in climate, or any other environmental variables. It may be unrealistic to assume that tourist activity is the only factor affecting the reef's condition, but studies of isolated effects, such as this, are an essential step towards understanding their contribution to the overall destruction of coral reefs. This information can then be used to plan an appropriate management strategy and hence, ensure the optimum allocation of resources (Laydoo, 1991).

3.1 Pre-dive preparation

Before any research could be conducted within the Buccoo Reef Restricted Area, the Marine Affairs office (a division of the Tobago House of Assembly) had to be provided with a project outline including a comprehensive account of all activities to be undertaken. Following a meeting with the Marine Park Manager, Mr. David Shim, permission was granted on the 7th August 1998.

3.1.1 Diving equipment and training

In addition to basic snorkelling apparatus, adequate SCUBA gear (including depth gauge) was acquired and the necessary training associated with the use of this equipment

was undergone in July 1998. An underwater camera was used to document the transect locations and the extent of reef damage for future comparison.

3.1.2 Species identification

The relevant sources of information were consulted prior to sampling in order to become familiarized with species identification specific to coral reefs in the Caribbean (Reef Check, 1998). Laminated coral and fish species identification cards were used in the field for reference.

3.1.3 Site selection

Coral and fish species were sampled at four sites on the reef identified in Fig. 1. Sites A (shallow, impact) and C (deep, impact) were strategically chosen because of their suspicion to be degraded by heavy tourist activity. Site A was just inshore of the breaker zone where the water is between four to six feet deep and represents an area used heavily by tourists for “walking”. Site C was a deeper part of the reef (10 to 15 feet of water) where most of the snorkelling activity occurs. Sites B (shallow, no impact) and D (deep, no impact) were chosen to represent parts of the reef that were of comparable depths to A and C, respectively, but were not thought to be degraded by human activity. All depths were measured with a depth gauge as part of the location recording.

3.2 Establishing the transects

At each of the four sites, an area was chosen that was representative of the main community expression in that part of the reef. Once selected, a 20m baseline was laid over the reef set to one side of the subjectively chosen area (NOAA, 1998). Random number tables were used to choose four points, no less than one meter apart, along the baseline. At

each of these four points, a 10m transect line made of nylon and marked at 0.5m intervals was set-up perpendicularly to the baseline and held into place by stainless steel stakes (CARICOMP, 1998).

3.2.1 Point Intercept transects

Since the transect lines were suspended above the substratum, a plumbline had to be constructed using a sinker and a 2m cotton string. The sinker was dropped at every 0.5m interval marked along the line and the substrate type it touched was recorded (VINP, 1994). This procedure was repeated for the remaining transect lines until four interval transects were completed at each of the four sites. Species percentage cover was calculated by dividing the number of points scored by a given species by the total number of points (VINP, 1994).

3.2.2 Chain transects

A light brass chain 2m long (1cm link size) was marked every 10 links using plastic-coated copper wire (VINP, 1994). The chain was laid out on the substratum directly below the transect lines, starting from the marking stake nearest the baseline. The chain was adjusted to follow the surface contour of the substrate, taking care to avoid bridging gaps and crevices, and it was checked from above the transect line to help ensure that the chain was precisely positioned below (CARICOMP, 1998). Once the deployment was satisfactory, the position of the last link of the chain was marked and the chain was moved to this new starting point so that the next section of the transect could be covered. This was repeated until the chain touched the second stake fixed to the far end of the transect line and the total number of links required to completely cover the substratum was recorded on an underwater slate.

To determine an index of topographic complexity (McCormick, 1994), the ratio of the reef surface distance to the linear distance was calculated for each transect sampled using the following equation:

$$\text{Structural Complexity} = \frac{\text{Number of transect links} \times \text{centimetres per link}}{\text{Total transect length (cms)}}$$

(VINP, 1994)

From the four values of structural complexity determined at each site, a mean topographic index was calculated and used as a reliable estimate during inter-site comparisons.

3.3 Quadrats

A 1m x 1m quadrat frame was constructed using ½" PVC pipe and elbows. Small holes were drilled into the pipes to decrease buoyancy and reduce water resistance, thus making the frame easier to handle underwater and less likely to damage the substrate (AGRA, 1998). The quadrat was strung with ten vertical and horizontal lines to create a grid of one hundred squares, with each 10cm x 10cm square representing 1% of the total quadrat area.

Percentage cover of identified species was estimated by counting the number of squares (or partial squares) covered by each coral species and recording these numbers on a tabulated underwater slate (VINP, 1994). At the shallow impact, and no impact sites, forty quadrats were assessed by placing the frame every 1m on alternating sides along the length of each transect line (AGRA, 1998). At this depth, the rock-boring sea urchin (*Echinometra lucunter*) is a major component of the reef community so the number of these urchins per quadrat was also recorded. In the deeper waters, the number of quadrats sampled was limited to thirty replicates at each site (impact, and no impact) due to time constraints associated with sub-aqua diving.

3.4 Measurement of species diversity

The Shannon-Weaver index (H'), which combines both the number of species and the relative abundance, was calculated using the formula:

$$\text{Shannon-Weaver Diversity Index } (H') = - \sum p_i \ln p_i$$

(Fowler, 1997)

where $p_i = n_i/N$, in which N = the total number of colonies of all coral species in the quadrat (or total number of centimetres of live coral under the line for a chain transect), and n_i = the number of colonies of each coral species in the quadrat.

3.5 Random Swim Fish Census

All fish counts were conducted between 1000 and 1400 hours when visibility underwater was at a maximum due to overhead sunlight (AGRA, 1998). To minimize the error due to human interference, the random swim fish census was conducted fifteen minutes after the baseline and transects had been deployed. During this time, a special effort was made to prevent any physical disturbance to the immediate aquatic environment; particularly the reef fish being investigated (Reef Check, 1998). At a random location within the selected reef area, a list was made of all the fish species identified within the field of view. The fifteen-minute census period was divided into three five-minute intervals and the name of each fish species was recorded in the interval in which it was first seen (VINP, 1994). This procedure was repeated at each of the four sites.

4. RESULTS

Cumulative means of percentage coral cover confirmed that an adequate number of quadrats had been sampled at each of the 4 sites (Fig. 2- Fig. 5) (Appendix 6), thus providing a useful representation of the reefs condition at these locations. As the sample size increased, the length of the error bars gradually decreased and the mean percentage coral cover approached a constant value. Having established reliable estimates of the coral density, comparisons were made between the 'impact' and 'no impact' sites at both depths.

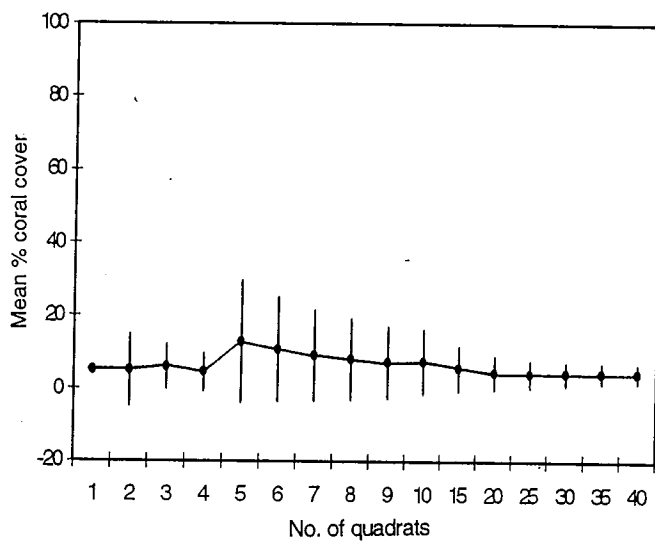


Fig. 2. Estimated coral cover (expressed as mean % coral cover and 95% C.I.) at shallow, impact site with increasing sampling using quadrats. Buccoo Reef, Tobago. (28/08/98)

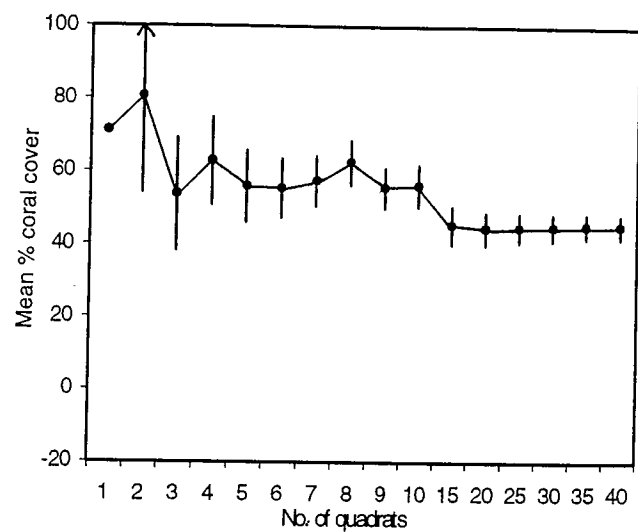


Fig. 3. Estimated coral cover (expressed as mean % cover and 95% confidence intervals) at shallow, no impact site with increasing sampling using quadrats. Buccoo Reef, Tobago. (29/08/98)

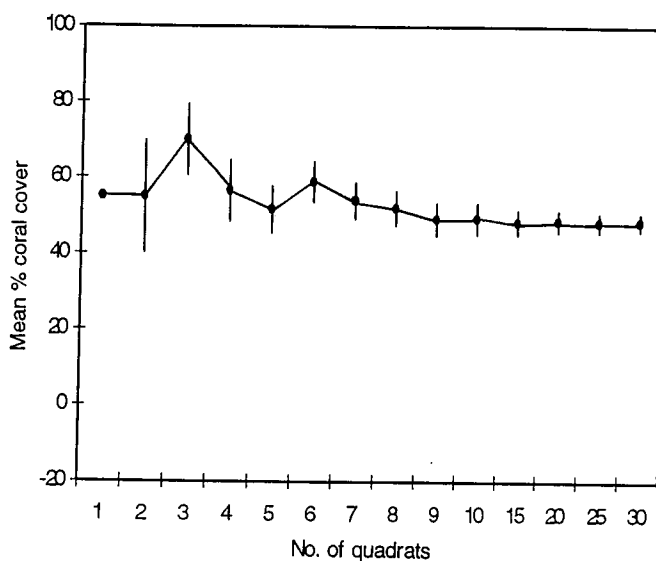


Fig. 4. Estimated % coral cover (expressed as mean % cover and 95% confidence intervals) at deep, impact site with increasing sampling using quadrats. Buccoo Reef, Tobago. (30/08/98)

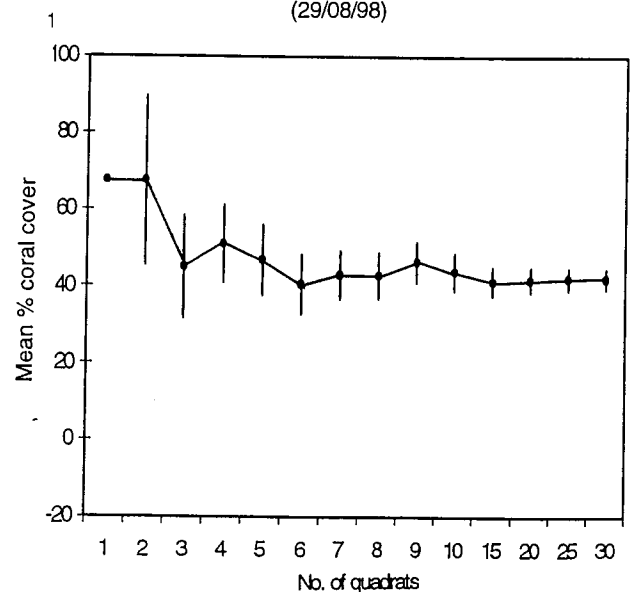


Fig. 5. Estimated coral cover (expressed as mean % cover and 95% confidence intervals) at deep, no impact site with increasing sampling using quadrats. Buccoo Reef, Tobago. (31/08/98)

4.1 Mean percentage coral cover

At the shallow site exposed to intense tourist activity, the mean percentage coral cover was reduced to approximately one tenth of its comparable control site (Fig. 6, Plate 2-4). In contrast, the negligible difference in the mean percentage coral cover between deep, impact and deep, no impact sites suggests that coral density in deeper water was much less affected by direct human interference. One-way analyses of variance (ANOVA) were conducted to test the statistical significance of these differences in coral density using percentage coral cover per quadrat as the dependant variable (Table 8.1, Appendix 8). The results in Fig. 6 confirmed that mean percentage coral cover was significantly lower at the impact site than at the control in shallow waters ($F_{1, 78}=73.8$, $P<0.05$, $n=40$). However, the same test revealed that there was no significant difference in coral cover density between the deep impact and deep, no impact sites ($F_{1, 58}=1.37$, $P>0.05$, $n=30$).

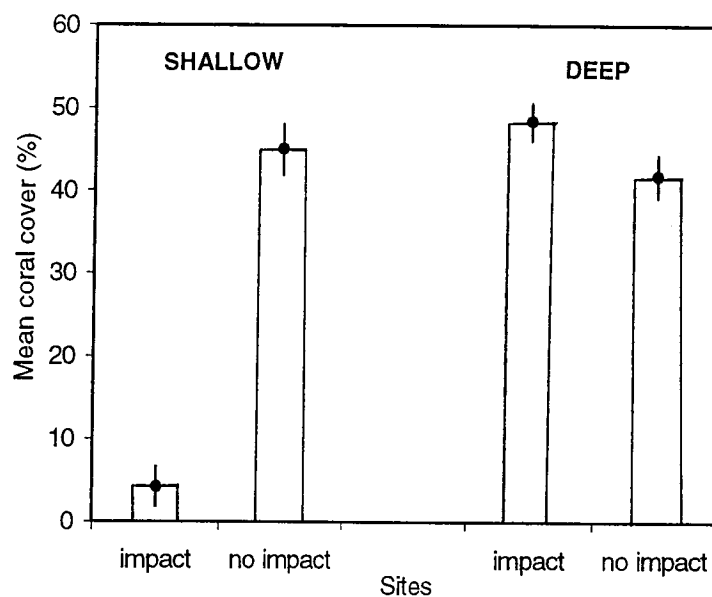


Fig. 6. Mean percentage coral cover at shallow (impact, no impact) and deep (impact, no impact) sites using quadrat data. Buccoo Reef, Tobago. (28/09/98 - 31/08/98)

4.2 Point intercept transects

Cumulative numbers of coral species verified that an appropriate number of transects had been sampled at each of the four study areas (Fig. 7- Fig. 10) (Table 2.6, Appendix 2). After two or three transects, depending on the site, there was a typical levelling off as the number of additional species decreased.

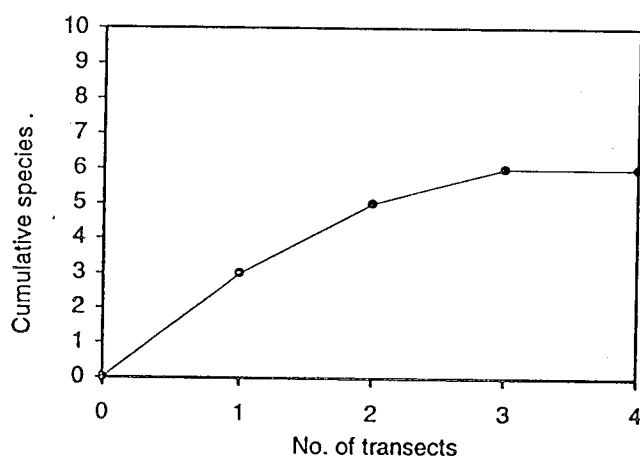


Fig. 7. Cumulative number of coral species identified at shallow, impact site with increasing sampling using point intercept transects. Buccoo Reef, Tobago (24/08/98).

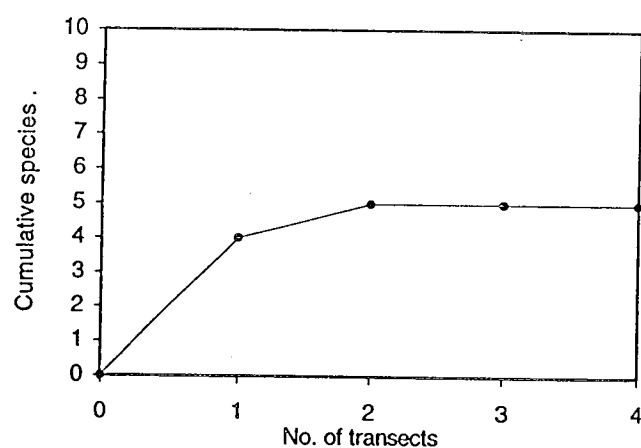


Fig. 8. Cumulative number of coral species identified at shallow, no impact site with increasing sampling using point intercept transects. Buccoo Reef, Tobago (25/08/98).

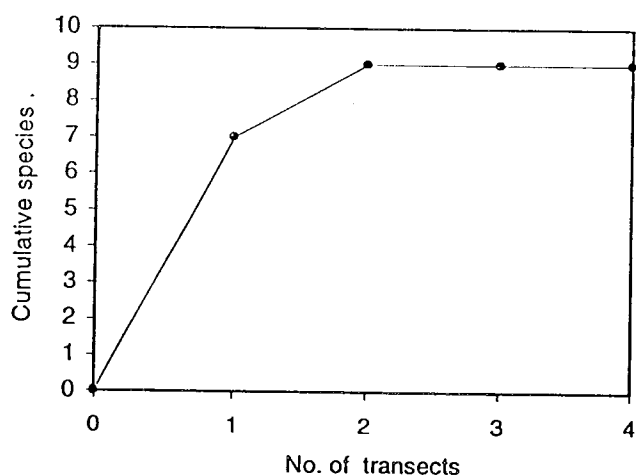


Fig. 9. Cumulative number of coral species identified at deep, impact site with increasing sampling using point intercept transects. Buccoo Reef, Tobago (26/08/98).

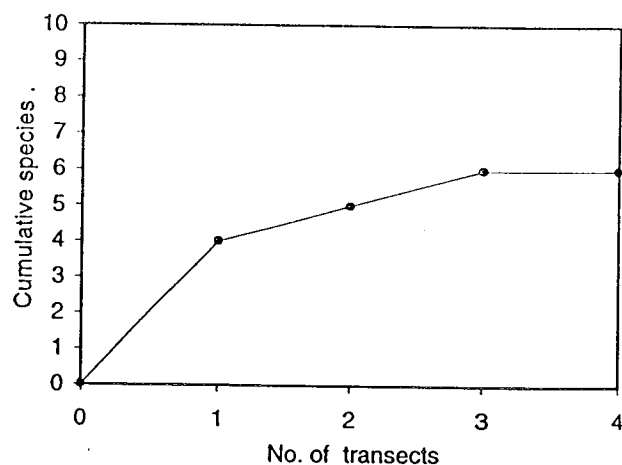


Fig. 10. Cumulative number of coral species identified at deep, no impact site with increasing sampling using point intercept transects. Buccoo Reef, Tobago (27/08/98).

4.3 Shannon-Weaver indices

The species abundance information in the quadrat samples taken at each site was reduced to a single index of diversity, the Shannon-Weaver Index (H'). The mean Shannon index derived from these samples showed the species diversity of the shallow, impact site was slightly less than the shallow, no impact site. In contrast, the species diversity calculations in the deeper water produced the opposite result and H' was actually higher at the impact site than at the control (Fig. 11) (Table 7.1, Appendix 7). The same conclusion was obtained when H' was calculated from the transect data. Even though these values of H' were higher than those derived from the quadrat samples, the relative differences in H' between the sites were consistent and a similar pattern emerged (Fig. 12)(Table 7.2, App 7).

The statistical significance of these differences in H' between sampling sites was formally tested by one-way ANOVA, using the number of species per quadrat as the dependent variable (Table, 8.2, Appendix 8). The results revealed that the mean species diversity at the shallow, impact site was significantly less than the mean at the control ($P < 0.05$), and in the deeper water, the mean species diversity at the impact site was significantly more than the mean at the control ($P < 0.05$).

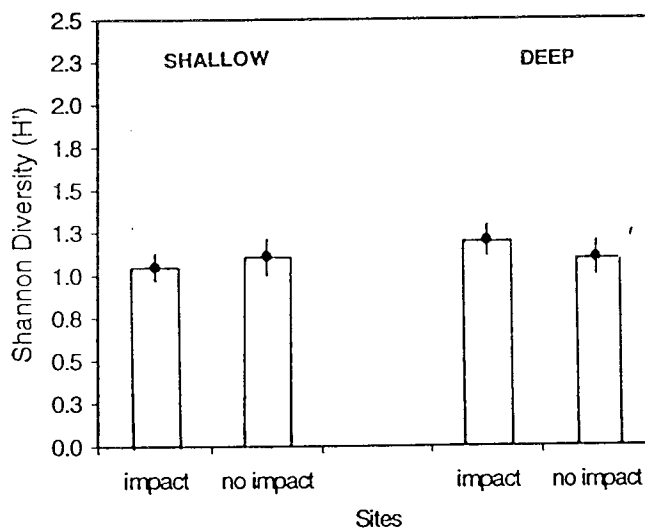


Fig. 11. Mean and 95% confidence intervals of Shannon Diversity at shallow (impact, no impact) and deep (impact, no impact) sites based on coral species cover data within quadrats. Buccoo Reef, Tobago (24/08/98-27/08/98)

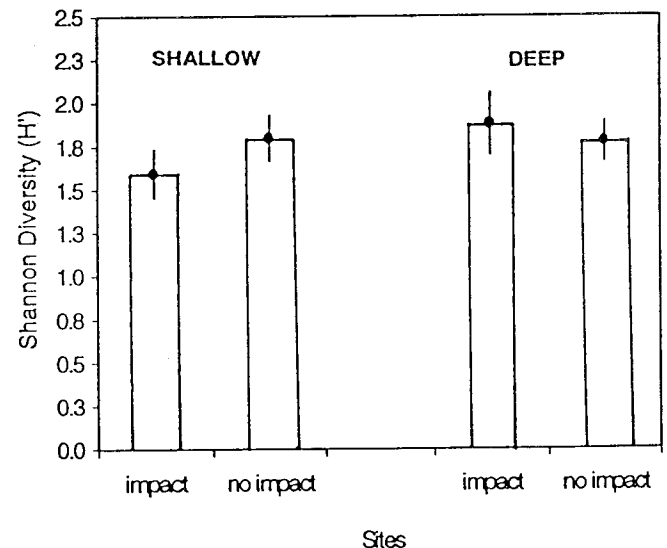


Fig. 12. Mean and 95% confidence intervals of Shannon Diversity at shallow (impact, no impact) and deep (impact, no impact) sites based on coral species cover data along transects. Buccoo Reef, Tobago (24/08/98-27/08/98)

4.4 Multivariate analysis

In the MDS analysis of the quadrat data (Fig. 13) (raw data in Tables 1.1-1.2, Appendix 1), differences between community composition in the shallow, impact (A) and shallow, no impact (B) sites was clearly distinct. However, there was an obvious overlap adjoining replicates from the two locations, indicating that some parts of the control site resembled the typical reef structure at the impact site. Since the stress level of this MDS plot did not exceed 0.1, the ordination provided a good representation of the data with no real prospect of misinterpretation. The slightly higher stress level calculated for the MDS analysis of the quadrats sampled at the deep sites (Fig. 14) (raw data in Tables 1.3-1.4, Appendix 1) suggested that although the plot gave a potentially useful 2-dimensional representation, it should be treated with some degree of scepticism. That aside, the MDS in Fig. 14 showed that the community composition of the impact (C) and control (D) sites on the deeper reef were much more difficult to distinguish. On closer examination of the pattern, the replicates within the control site appeared to form a loose cluster fairly difficult to detect amongst the widely scattered samples from the impact site.

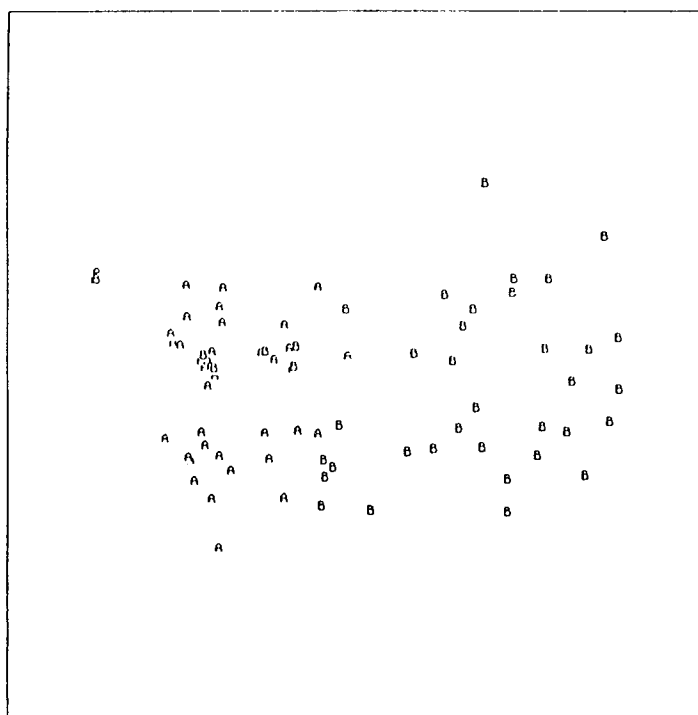


Fig. 13 MDS for coral species percentage cover quadrat data. Buccoo Reef, Tobago.
A = shallow, impact site and B = shallow, no impact site (stress = 0.1).

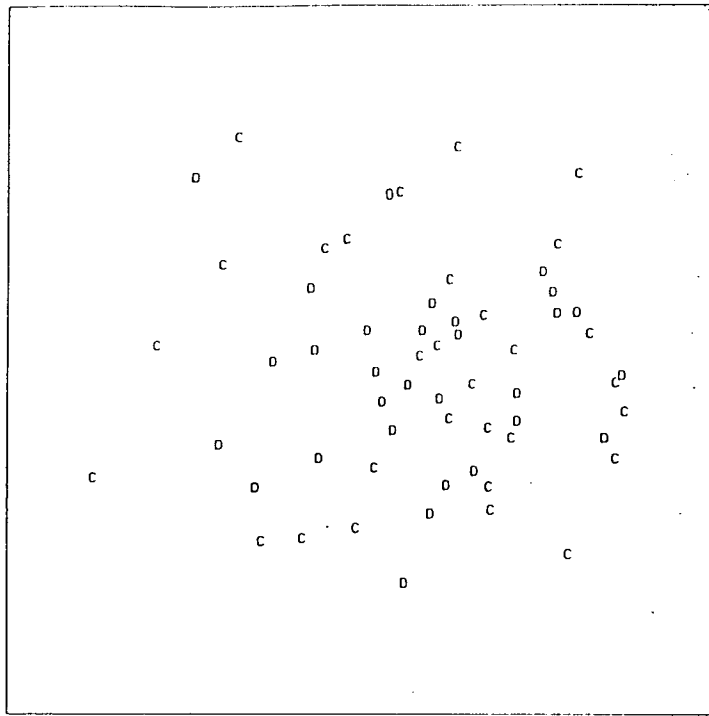


Fig. 14 MDS for coral species percentage cover quadrat data. Buccoo Reef, Tobago,
C = deep, impact site and D = deep, no impact site (stress = 0.2)

The MDS analysis of the transect data (Fig. 15) (raw data in Tables 2.1-2.4, Appendix 2) clarified variation between the deep sites, and illustrated the relative differences in the community structure between all four sites. The results in Fig. 15 were not only consistent with the outcomes of the previous MDS analysis, but the plot also indicated that there were greater similarities between sites of equal depth (A&B, C&D) than there were between sites of comparable impact (A&C, B&D). Hence, the differences in community composition between the shallow and deep of the reef were too large to allow for any realistic comparisons to be made.

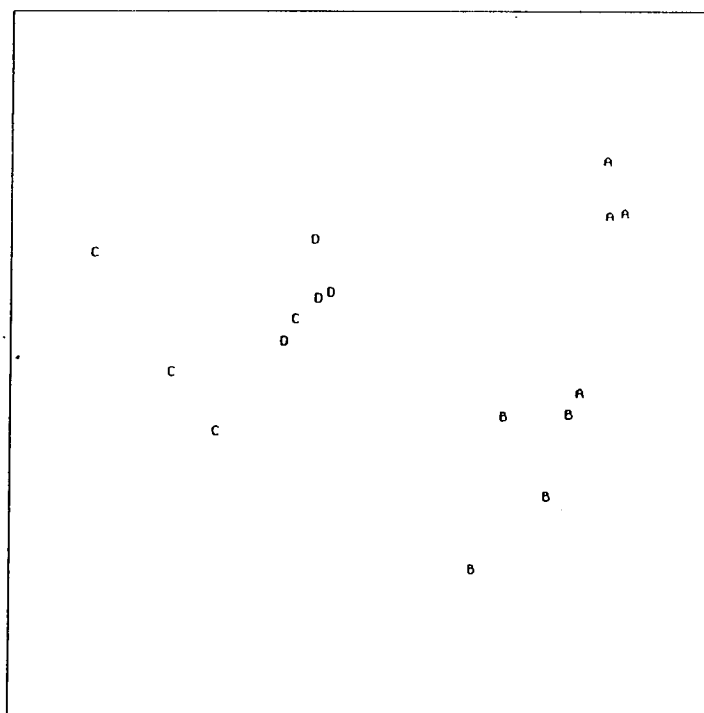


Fig. 15 MDS for coral species percentage cover transect data. Buccoo Reef, Tobago.

4.5 Topographic indices

The difference in community structure between the shallow and deep areas of the reef was further demonstrated by their contrasting mean indices of topographic complexity (Fig. 16) (raw data in Appendix 3). The average topographic indices calculated for both deep sites were considerably greater than those of the shallow sites, regardless of differences in impact. More relevant to this study were the less conspicuous differences in structural complexity between the impact and no impact sites at equivalent depths. As can be seen in Fig. 16, the impact sites at both depths had lower topographic indices than their corresponding control sites. A *t*-test showed a statistically significant difference in topographic complexity between the impact and no impact sites on the shallow reef at $P=0.02$, but also indicated that the corresponding difference on the deeper water was not statistically significant ($P=0.1$).

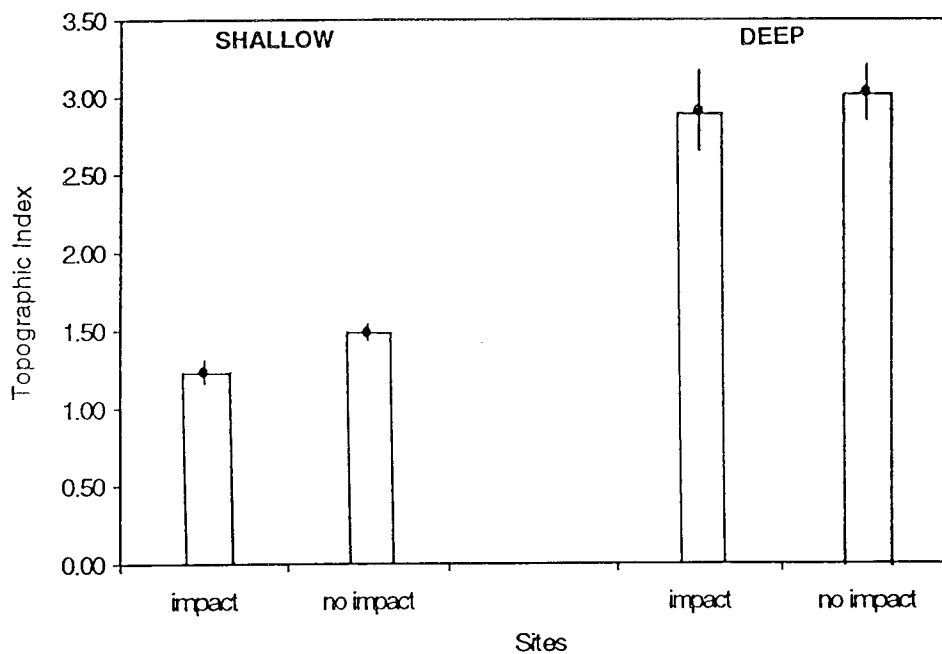


Fig. 16. Average Topographic Indices and 95% confidence intervals for shallow (impact, no impact) and deep (impact, no impact) sites. Buccoo Reef, Tobago. (24/08/98 - 27/08/98)

4.6 Fish Counts

The curves in Fig. 17 (raw data in Appendix 5) display a consistent pattern of results among the fish counts executed at each of the four sites. In each case, the total number of species identified increased, rapidly at first and then gradually slowed down, as the sample effort increased. This uniformity suggests that the results were reliable and could be used confidently in comparing fish diversity. Consistent with previous data, the greatest difference in the total number of fish species was found between the shallow, impact and shallow, no impact sites; while the diversity of fish estimated at both deep sites remained very similar. More surprising was the fact that the species diversity of fish at the shallow, impact site was highest of all four sites.

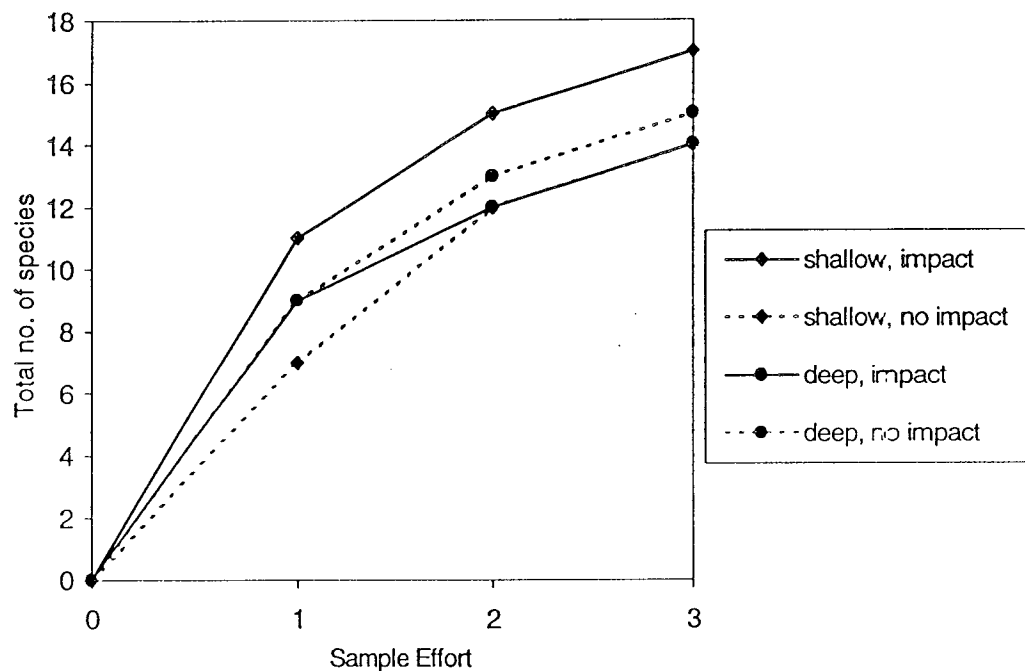


Fig. 17. Species diversity of reef fish at each of the four sites. Buccoo Reef, Tobago. (24/08/98 - 27/08/98); sample effort = length of time (measured in 5 min intervals) during which fish species were first identified.

4.7 Sea urchin (*Echinometra lucunter*) density

The mean density of *E. lucunter* in shallow water (Fig. 18) was much lower at the impact site than at the control (Appendix 4). A *t*-test showed the difference in urchin density between the two sites to be significantly different ($P=0.1$).

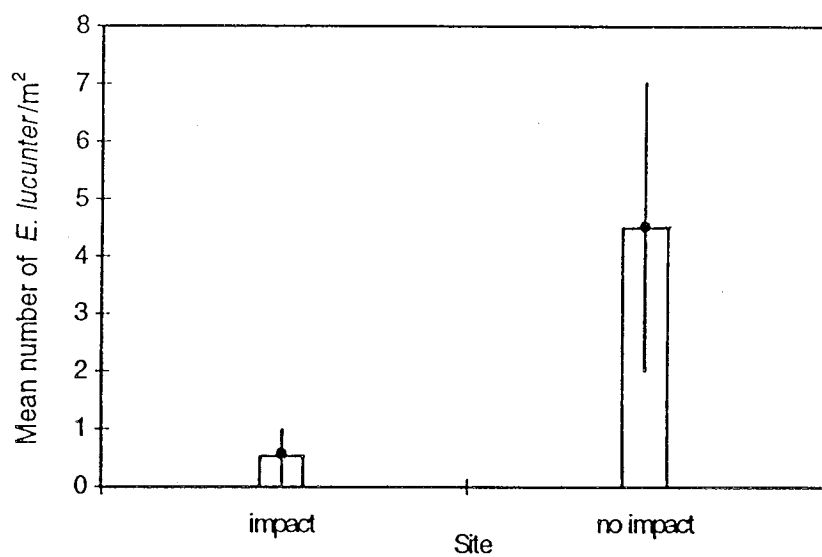


Fig.18. Mean density of sea urchins (*Echinometra lucunter*) at shallow, impact and shallow, no impact sites. Buccoo Reef, Tobago. (28/09/98- 29/08/98)

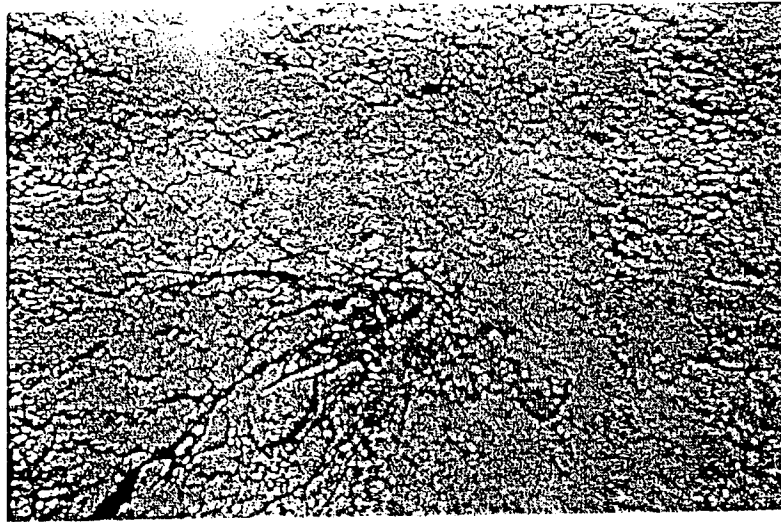


Plate 2 Broken *Gorgonia ventralina* at shallow, impact site.
Buccoo Reef, Tobago (24/08/98).

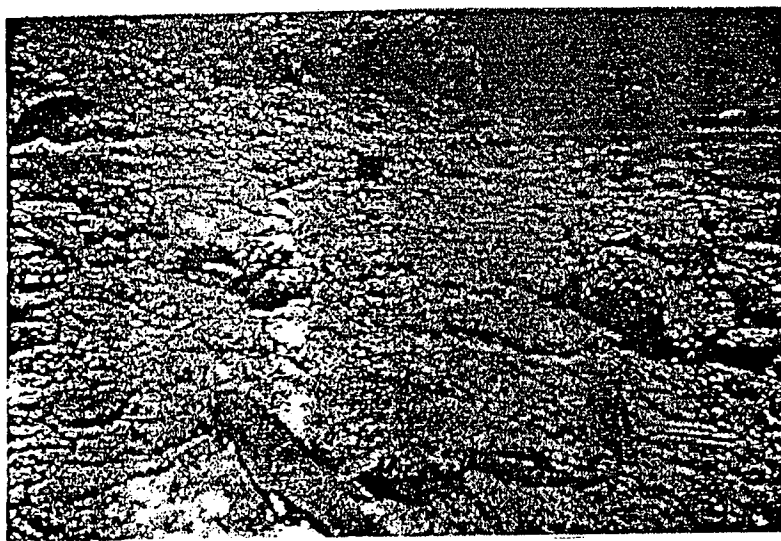


Plate 3 Shallow, impact site: *Bodianus rufus* (left, foreground) and *Ocyurus Chrysurus* (right, foreground) searching for food amongst the rocks and dead coral. Buccoo Reef, Tobago (24/08/98).

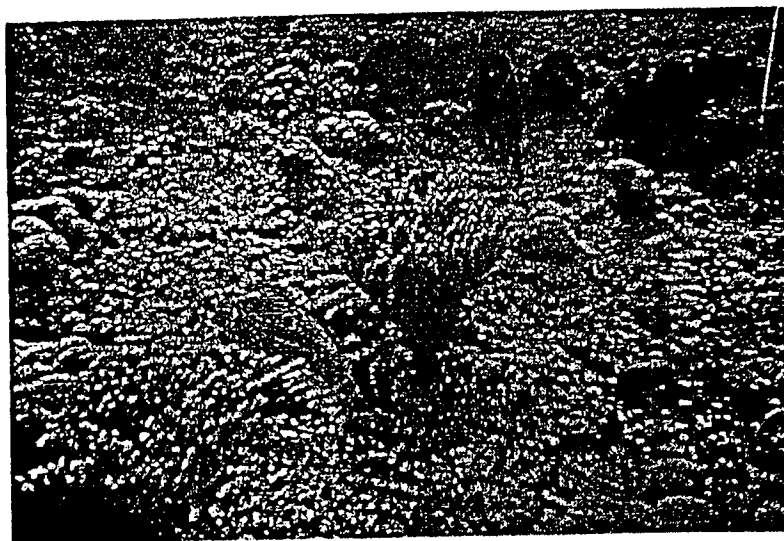


Plate 4 Shallow, no impact site: *Haemulon sciurus* (centre) and *Pomacanthus paru* (top) swimming amongst *Gorgonia flabellum* (top), *Ellisella clongata* (centre), and *Favia fragum* (bottom, right). Buccoo (25/08/98)

5. DISCUSSION

5.1 Effect of tourist activity on coral communities

There are several notable advantages of examining hard-bottom epifauna, e.g. coral, in impact studies such as this. Not only are corals the principle component of all reef ecosystems (Laydoo, 1991), they can also be sampled non-destructively through visual assessment, and their immobility is ideal for local effect studies (Clarke & Warwick, 1994). The majority of coral cover data collected during this study were derived from replicate quadrat samples at each site. Because quadrats provide data only on the horizontal plane and not on spatial relief, their use is inherently problematic on an irregular and highly three-dimensional reef surface. "Taxa with plate-shaped morphologies tend to be over-represented relative to columnar species in census data" (VINP, 1994). In this situation, chain transects may have been a more appropriate and accurate way of gathering information on species diversity and relative abundance. However, chain transects are tedious and time-consuming, and it is difficult to avoid causing some damage to the reef if the chain becomes entangled in branching coral (VINP, 1994). Instead, point sampling was chosen to support the quadrat data because it is "the least ambiguous and fastest method of survey" (Reef Check, 1998).

Despite their limitations, the quadrat and transect results show that there is an obvious cause-and-effect relationship between reef health and tourist activity within the Buccoo Reef Marine Park. As was expected, the physical impacts of snorkellers touching and standing on corals greatly reduced the proportions of living coral and their structural complexity. My findings therefore confirm the earlier work of Kenny on the Outer Reef. Kenny estimated that about 95% of the shallow reef area had been destroyed, but without the necessary baseline data, he could not quantify the proportion of damage that was human-induced (Kenny, 1976). The control sites sampled in this study eliminated this problem since comparisons made with impact sites allowed me to estimate the magnitude of damage, and further suggest that the impact of tourist activity is depth dependent. As the

depth of water increases, the likelihood of accidentally damaging the coral decreases, hence the level of disturbance to the reef system declines. Consequently, at the deeper sites where water is between ten to fifteen feet, the level of physical disturbance was too low to have any significant effect on either coral density or topographic complexity.

By contrast, this low level of disturbance actually increased the species diversity of the deeper reef ecosystem. This can be explained by the intermediate disturbance hypothesis (Connell, 1978) which proposes that diversity is expected to rise at intermediate levels before its strong decline with gross disturbance (Clarke & Warwick, 1994). Hence, the reduced species diversity at the shallow, impact site is likely to be the result of frequent disturbance to the reef community. The MDS plots (Fig.13 – Fig.15) accurately summarized these differences in coral abundance and diversity between impact and control sites in a low-dimensional space.

5.2 Effect of tourist activity on fish populations

Fish population studies are also useful for examining local effects on coral reefs due to the high site fidelity associated with reef species. Furthermore, fish are of immediate commercial and public interest therefore studies of fish communities are more directly related to the needs of environmental managers (Clarke & Warwick, 1994). Fish censusing, however, is particularly difficult with in the coral reef environment because of “the structural complexity of the habitat and the diversity, mobility and abundance of reef fish” (VINP, 1994). The observer must be able to identify fauna quickly and accurately, hence additional data about the fish e.g. number and length, can be difficult for non-specialists to record (VINP, 1994).

The random swim technique adopted in this study provided a useful list of species but produced only limited quantitative data and no density estimates. Visual census methods like this are not free from observer bias since some species are more conspicuous in colouration and behaviour than others (Clarke & Warwick, 1994). This human error is

compounded by the fact that only the "observable portion of the fauna is counted, so cryptic, nocturnal and pelagic species are likely to be underestimated" (Clarke & Warwick, 1994).

Although the appropriate steps were taken to decrease the influence of the diver's presence on the behaviour of fish, replicate fish counts should have been made at each site (at least 10 censuses) to increase the reliability of the data collected. Despite the inadequacy of the sample size, the results of the random swim fish census echoed the previous results derived from the coral studies. Once again, tourist activity in the shallow water had a greater impact on the reef community than in the deeper water, although in this case, frequent disturbance increased the diversity of fish.

A wide variety of reef fish aggregated at the shallow impact site, despite the strong human presence, possibly to feed on the large supply of turf algae growing on dead coral. It is these large fish populations which continue to attract tourists to the area even though most of the living coral has been destroyed.

5.3 Effect of tourist activity on *E. lucunter* populations

Some species of fish, primarily *Ginsburgellus novemlineatus* and *Balistes* sp., also feed on the small, rock-boring sea urchin, *Echinometra lucunter*, found in shallow, wave-swept areas (Colin, 1988). In the West Indies, *E. lucunter* shows peak spawning activity during the summer months but population growth was limited at the shallow impact site possibly due to a higher predatory pressure relative to the control site. However, none of *E. lucunter*'s main predators were identified during the fish counts, hence it is unlikely that predation was intense enough to cause such a significant impact. Alternatively, the urchin population may have been restricted by a limited food resource at the shallow, impact site. At night, *E. lucunter* leaves its rock holes to feed on coralline algae in the surrounding area (Colin, 1988). Coralline algae are not only the main food source of *E. lucunter*, but it is also very important for coral recruit settlement on shallow reefs. It is therefore possible that

tourist activity inhibited the settling of coralline algae in some way, which would have serious repercussions on the coral recruit settlement in the area. To test this hypothesis, quantitative data about the settling of coralline algae and/or coral recruits at the two shallow sites would have to be collected.

It would also be interesting to leave an area of the shallow impact site untouched to test the possibility of natural regeneration and/or experiment with transplants of hardy coral species from other parts of the reef (Kenny, 1976). In addition, long-term monitoring programmes could provide invaluable information about the rates of reef destruction and enable park managers to assess the effectiveness of current and future conservation strategies (Jackson, 1984).

5.4 Recommendations

The Tobago House of Assembly (THA) Management Plan for the BRMP currently proposes to extend the area of the Marine Park, establish new anchor sites on the reef-walking area, and purchase an additional patrol boat, once additional resources are allocated (Shim, 1999). The following is a list of alternative strategies, some of which might prove to be easier and more cost-effective to implement:

- 1) "Much of the damage caused by tourists is accidental; if people understood how the reef functions and how vulnerable it is, they are more likely to try to avoid contributing to the damage" (Well, 1992). Tourists can be educated with brochures or by tour guides about reef conservation, and school courses should teach children how to protect their coral reefs (McAllister, 1996).
- 2) At present, tour guide operators at Buccoo Reef provide tourists with waterproof shoes for standing in shallow water. By adopting a "no shoes" policy, much like the "no gloves" policy in the Cayman Islands (Well, 1992), snorkellers with bare feet would be less likely to stand on the coral.

- 3) The number of people visiting the Marine Park could be restricted by encouraging the use of other reefs on the island, many of which are easily accessible by beach e.g. Pirate's Reef.
- 4) In many parts of the world, the zoning of Marine Parks for tourism has allowed for the sustainable exploitation of fragile reef systems (Hutchings *et al*, 1994). In the same way, snorkeling could be prohibited in vulnerable or damaged areas of Buccoo Reef to reduce the tourist pressure at threatened sites and to allow for reef regeneration.

5.5 Conclusions

In summary, the data collected in my study provide evidence that reef walking and snorkelling have had severe impacts on the coral communities in shallow areas of Buccoo Reef. However, tourist activity had only created moderate disturbance in the deeper water, hence damage to the reef caused by the deployment of anchors by reef-guide boats was negligible. It is therefore possible to reject the initial null hypothesis and conclude that tourist activity in the shallow areas of Buccoo Reef has a negative ecological impact on the reef system, while the less aggressive conduct at the deeper sites does not have any detrimental effects.

The effects of tourist impact on reef fish diversity and *E. lucunter* population size remain largely inconclusive and require further experimental study. Even though several assumptions were made during this investigation and all other anthropogenic impacts were ignored, the findings will make it easier to document the need for management action and to distinguish the consequence of human activities from the changes due to natural processes (VINP, 1994). Unfortunately, without the accurate GPS co-ordinates for each sample site, the data collected during this study cannot be used in conjunction with any future investigations.

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Appendices

Appendix 1: Quadrat data

Table 1.1 Percentage cover of each reef species (or substrate component) per quadrat at shallow, impact site. Buccoo Reef, Tobago (28/08/98). "dca" = dead coral with turf algae.

Species	Quadrat number									
	1	2	3	4	5	6	7	8	9	10
<i>Diplora strigosa</i>	0.5	1	0	0	0	0	0	0	2	1
<i>Diplora clivosa</i>	0	2	0	1	2	0	0	0	0	0
<i>Ellisella elongata</i>	2	0	0	0	0	0	0	0	0	0
<i>Favia fragum</i>	0	0	0	1.5	0	0	0	0	0	0
<i>Porites astreoides</i>	0	0	0	0	0	1	0	1	0	1
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	0	0	0	0	0	0	0	0	0	0
<i>Madracis decactis</i>	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	6	0	0.5	5	0	0	2	0
Orange wall sponge	0.5	0	0	0	0	0	0	0	0	0
rock	40	20	70	75	65	29	50	49	76	63
rubble	10	50	4	10	20	15	0	0	0	0
sand	20	15	5	10	10	20	25	45	5	5
dca	27	12	15	2.5	2.5	30	25	5	15	30

Table 1.1 (cont.)

Species	Quadrat number									
	11	12	13	14	15	16	17	18	19	20
<i>Diplora strigosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	0	0	0	0	6	0	0	0	0	0
<i>Favia fragum</i>	0	0	15	10	40	1	0	2	2	0
<i>Porites astreoides</i>	0	0	0	0	0	0	0	3	0	3
<i>Gorgonia ventalina</i>	0	0	0	0	0	5	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	0	0	0	0	0	0	0	0	0	0
<i>Madracis decactis</i>	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	0	0	0	2	0	0	0	0
Orange wall sponge	0	0	0	0	0	0	0	0	0	0
rock	10	50	70	40	34	72	45	70	43	47
rubble	5	0	0	5	5	0	20	0	0	0
sand	5	25	5	5	10	15	5	10	45	10
dca	80	25	10	40	5	5	30	15	10	40

Appendix 1 (cont.)

Table 1.1 (cont.) Percentage cover of each reef species per quadrat at shallow, impact site. Buccoo Reef, Tobago (28/08/98). "dca" = dead coral with turf algae.

Species	Quadrat number									
	21	22	23	24	25	26	27	28	29	30
<i>Diplora strigosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	0	1	0	0	0	0	0	0	0	0
<i>Favia fragum</i>	5	0	12	0	5	0	0	0	0	0
<i>Porites astreoides</i>	0	1	0	0.5	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	0	0	0	0	0	0	0	0	0	0
<i>Madracis decactis</i>	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	1	0	0	0	3	0	0	0	0	0
Orange wall sponge	0	0	0	0	0	0	0	0	0	0
rock	44	43	23	55	27	15	10	75	40	40
rubble	10	10	10	15	5	10	20	0	5	0
sand	0	40	5	10	5	30	45	20	25	5
dca	40	5	50	20	55	45	25	5	30	55

Table 1.1 (cont.)

Species	Quadrat number									
	31	32	33	34	35	36	37	38	39	40
<i>Diplora strigosa</i>	0	0	0	1	0	0	0	0	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	0	0	0	0	0	0	0	0	0	0
<i>Favia fragum</i>	10	5	0	0	0	0	0	0	0	0
<i>Porites astreoides</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	0	0	0	0	0	0	0	0	0	0
<i>Madracis decactis</i>	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	0	0	0	0	0	0	0	0
Orange wall sponge	0	0	0	0	0	0	0	0	0	0
rock	60	25	0	25	80	0	60	45	90	55
rubble	0	10	20	0	0	10	5	10	0	10
sand	10	40	65	55	20	75	30	35	5	20
dca	20	20	15	19	0	15	5	10	5	15

Appendix 1 (cont.)

Table 1.2 Percentage cover of each reef species (or substrate component) per quadrat at shallow, no impact site. Buccoo Reef, Tobago (29/08/98). "dca" = dead coral with turf algae.

Species	Quadrat number									
	1	2	3	4	5	6	7	8	9	10
<i>Diplora strigosa</i>	0	4	0	0	0	0	0	0	0	0
<i>Diplora clivosa</i>	4	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	6	2	0	0	0	0	0	10	1	0
<i>Favia fragum</i>	30	5	50	57	75	45	50	55	45	30
<i>Porites astreoides</i>	10	0	0	0	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	0	3	0
<i>Gorgonia flabellum</i>	6	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	2	0	0	0	0	5	0	0	0
<i>Millepora complanata</i>	1	0	0	3	15	1	1	0	0	4
<i>Madracis decactis</i>	0	0	0	0	0	0	3	0	0	0
<i>Dictyota ciliolata</i>	0	0	0	0	0	1	0	2	1	0
<i>Agelus</i> sp.	0	0	0	0	0	0	0	0	0	0
<i>Chlorophyta</i>	0	0	0	0	0	0	0	0	0	0
Orange wall sponge	0	0	0	0	0	0	0	0	0	0
rock	20	70	35	35	10	50	40	33	48	56
rubble	23	0	0	0	0	2	0	0	0	5
sand	0	10	5	0	0	1	0	0	0	0
dca	0	7	10	5	0	0	1	0	2	5

Table 1.2 (cont.)

Species	Quadrat number									
	11	12	13	14	15	16	17	18	19	20
<i>Diplora strigosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	0	0	1	10	6	2	5	1	10	5
<i>Favia fragum</i>	40	15	35	35	31	50	25	90	27	20
<i>Porites astreoides</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	6	0	0	50	0	8	0	0	15
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	30	2	10	2	3	17	8	1	7	3
<i>Madracis decactis</i>	0	5	5	8	0	0	10	1	53	10
<i>Dictyota ciliolata</i>	1	0	0	0	0	0	5	0	0	0
<i>Agelus</i> sp.	0	0	1	0	0	0	0	0	1	0
<i>Chlorophyta</i>	0	0	0	0	0	0	0	0	0	1
Orange wall sponge	0	0	0	0	0	0	0	0	0	0
rock	19	67	42	45	10	24	34	7	1	44
rubble	5	5	4	0	0	5	4	0	1	0
sand	0	0	0	0	0	0	0	0	0	0
dca	5	0	2	0	0	2	1	0	0	2

Appendix 1 (cont.)

Table 1.2 (cont.) Percentage cover of each reef species (or substrate component) per quadrat at shallow, no impact site. Buccoo Reef, Tobago (29/08/98). "dca" = dead coral with turf algae.

Species	Quadrat number									
	21	22	23	24	25	26	27	28	29	30
<i>Diplora strigosa</i>	1	0	0	0	0	0	0	0	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	0	5	15	35	0	0	0	0	0	0
<i>Favia fragum</i>	30	55	50	10	10	5	0	15	0	0
<i>Porites astreoides</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	4	0	0	0	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	1	4	10	15	0	0	0	0	0	0
<i>Madracis decactis</i>	0	5	0	2	0	0	0	0	0	0
<i>Dictyota ciliolata</i>	0	1	1	1	0	0	0	0	0	0
<i>Agelus</i> sp.	0	1	7	0	0	0	0	0	0	0
<i>Chlorophyta</i>	0	0	0	0	0	0	0	0	0	0
Orange wall sponge	0	0	0	0	0	0	0	0	0	0
rock	68	29	13	35	55	30	40	80	0	60
rubble	0	0	0	2	20	20	15	0	15	10
sand	0	0	0	0	5	20	35	5	60	25
dca	0	0	0	0	10	25	10	0	25	5

Table 1.2 (cont.)

Species	Quadrat number									
	31	32	33	34	35	36	37	38	39	40
<i>Diplora strigosa</i>	1	0	0	0	0	0	0	0	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	0	2	2	0	2	0	1	1	35	0
<i>Favia fragum</i>	15	2	3	20	55	20	5	50	15	55
<i>Porites astreoides</i>	0	0	0	0	0	0	2	0	0	0
<i>Gorgonia ventalina</i>	0	1	0	0	0	5	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	0	0	0	1	3	5	0	4	0	5
<i>Madracis decactis</i>	0	0	0	0	0	0	0	0	0	0
<i>Dictyota ciliolata</i>	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	0	0	0	0	0	0	2	0
<i>Chlorophyta</i>	0	0	0	0	0	0	0	0	0	0
Orange wall sponge	0	0	0	0	0	0	0	0	0	0
rock	75	85	50	75	35	65	80	45	30	40
rubble	0	0	20	0	0	0	0	0	8	0
sand	5	5	5	0	0	3	10	0	5	0
dca	4	5	20	4	5	2	2	0	5	0

Appendix 1 (cont.)

Table 1.3 Percentage cover of each reef species (or substrate component) per quadrat at deep, impact site. Buccoo Reef, Tobago (30/08/98). "dca" = dead coral with turf algae.

Species	Quadrat number									
	1	2	3	4	5	6	7	8	9	10
<i>Diplora strigosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	0	15	0	6	2	0	5	43	0	35
<i>Porites asteroides</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	1	0	25	40	0	30	0
<i>Millepora complanata</i>	0	0	30	0	0	5	25	0	0	0
<i>Montastraea annularis</i>	25	0	25	15	50	10	0	25	6	15
<i>Plexaura flexuosa</i>	1	4	0	0	0	1	0	2	2	0
<i>Pseudopterogorgia</i> sp.	0	75	0	0	0	0	0	0	0	0
<i>Dictyota ciliolata</i>	0	0	0	0	0	0	0	0	0	0
<i>Halimeda opuntia</i>	0	0	0	0	0	0	0	5	0	0
Sea cucumber	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	0	1	0	0	0	0	0	0
rock	64	0	45	72	48	59	30	0	10	0
rubble	0	0	0	0	0	0	0	0	0	0
sand	10	6	0	5	0	0	0	25	52	50
dca	0	0	0	0	0	0	0	0	0	0

Table 1.3 (cont.)

Species	Quadrat number									
	11	12	13	14	15	16	17	18	19	20
<i>Diplora strigosa</i>	0	25	0	0	0	0	2	4	0	0
<i>Diplora clivosa</i>	0	25	0	0	0	0	2	0	0	0
<i>Ellisella elongata</i>	25	1	0	5	0	0	0	20	3	10
<i>Porites asteroides</i>	0	0	0	0	0	10	1	0	1	0
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	5	0	1	40	0	0	0	0	1	0
<i>Millepora complanata</i>	15	0	2	0	0	1	7	0	8	0
<i>Montastraea annularis</i>	0	12	20	0	40	0	10	0	7	10
<i>Plexaura flexuosa</i>	6	1	3	0	10	0	7	0	4	5
<i>Pseudopterogorgia</i> sp.	0	0	0	0	0	0	0	0	0	0
<i>Dictyota ciliolata</i>	0	0	0	0	0	1	0	0	0	0
<i>Halimeda opuntia</i>	0	0	0	10	0	0	15	0	45	1
Sea cucumber	0	0	0	2	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	6	2	3	3	0	0	0	0
rock	0	58	60	36	47	0	48	0	21	54
rubble	0	0	0	0	0	0	0	0	0	0
sand	45	3	8	5	0	55	10	51	10	20
dca	4	0	0	0	0	30	0	25	0	0

Appendix 1 (cont.)

Table 1.3 (cont.) Percentage cover of each reef species (or substrate component) per quadrat at deep, impact site. Buccoo Reef, Tobago (30/08/98). "dca" = dead coral with turf algae.

Species	Quadrat number									
	21	22	23	24	25	26	27	28	29	30
<i>Diplora strigosa</i>	0	0	2	20	25	0	10	0	20	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	1	2	0	5	0	3	0	30	0	70
<i>Porites asteroides</i>	0	1	5	0	8	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	15	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	8
<i>Millepora complanata</i>	25	0	0	0	0	15	0	5	0	2
<i>Montastraea annularis</i>	10	25	10	40	8	30	0	40	0	15
<i>Plexaura flexuosa</i>	0	4	5	2	2	2	0	0	0	0
<i>Pseudopterogorgia</i> sp.	0	0	0	0	0	0	0	0	0	0
<i>Dictyota ciliolata</i>	0	0	15	0	0	0	0	0	0	0
<i>Halimeda opuntia</i>	2	5	0	5	5	0	0	0	0	0
Sea cucumber	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	1	0	0	0	0	0	0	5	0
rock	60	47	5	23	52	10	10	10	10	0
rubble	0	0	0	0	0	0	0	0	0	0
sand	2	15	58	5	0	40	80	0	60	5
dca	0	0	0	0	0	0	0	0	5	0

Appendix 1 (cont.)

Table 1.4 Percentage cover of each reef species (or substrate component) per quadrat at deep, no impact site. Buccoo Reef, Tobago (31/08/98). "dca" = dead coral with turf algae.

Species	Quadrat number									
	1	2	3	4	5	6	7	8	9	10
<i>Diplora strigosa</i>	0	9	35	0	0	0	10	20	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	0	0	0	10	50	0	6	0	0	25
<i>Porites asteroides</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	0	0	0	1	4	5	3	10	0	0
<i>Montastraea annularis</i>	45	20	10	20	4	4	8	10	15	25
<i>Plexaura flexuosa</i>	3	2	0	0	0	0	3	2	0	0
<i>Pseudopterogorgia</i> sp.	0	0	0	0	0	0	0	0	0	0
<i>Dictyota ciliolata</i>	0	0	0	0	0	0	0	0	0	0
<i>Halimeda opuntia</i>	0	0	0	0	0	0	0	0	0	0
Sea cucumber	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	0	0	0	0	0	0	0	0
rock	52	64	45	69	27	15	25	49	80	50
rubble	0	0	0	0	0	0	0	0	0	0
sand	0	5	5	0	15	76	45	5	5	0
dca	0	0	5	0	0	0	0	4	0	0

Table 1.4 (cont.)

Species	Quadrat number									
	11	12	13	14	15	16	17	18	19	20
<i>Diplora strigosa</i>	0	0	5	0	0	50	0	0	0	7
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	25	5	5	75	25	10	40	0	0	2
<i>Porites asteroides</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	0	0	0	0	0	0	0	5
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	0	0	0	0	0	0	0	0
<i>Millepora complanata</i>	0	10	25	0	10	15	0	15	4	0
<i>Montastraea annularis</i>	30	5	0	0	20	0	35	30	65	30
<i>Plexaura flexuosa</i>	0	0	10	0	0	1	0	0	0	0
<i>Pseudopterogorgia</i> sp.	0	0	0	0	0	0	0	0	0	0
<i>Dictyota ciliolata</i>	0	0	0	10	0	0	0	0	0	0
<i>Halimeda opuntia</i>	0	0	0	0	0	0	0	0	0	0
Sea cucumber	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	0	0	0	0	0	0	0	0
rock	45	80	45	0	35	5	25	50	31	16
rubble	0	0	0	0	0	0	0	0	0	0
sand	0	0	10	15	10	19	0	5	0	40
dca	0	0	0	0	0	0	0	0	0	0

Appendix 1 (cont.)

Table 1.4 (cont.) Percentage cover of each reef species (or substrate component) per quadrat at deep, no impact site. Buccoo Reef, Tobago (31/08/98). "dca" = dead coral with turf algae.

Species	Quadrat number									
	21	22	23	24	25	26	27	28	29	30
<i>Diplora strigosa</i>	0	0	10	1	0	0	0	0	0	0
<i>Diplora clivosa</i>	0	0	0	0	0	0	0	0	0	0
<i>Ellisella elongata</i>	5	2	0	25	25	0	0	10	0	0
<i>Porites asteroides</i>	0	0	0	0	0	0	0	0	0	0
<i>Gorgonia ventalina</i>	0	0	0	1	0	0	0	0	0	0
<i>Gorgonia flabellum</i>	0	0	0	0	0	0	0	0	0	0
<i>Agaricia lamarcki</i>	0	0	2	0	0	0	0	0	0	0
<i>Millepora complanata</i>	5	0	25	0	0	0	0	0	10	0
<i>Montastraea annularis</i>	50	30	0	10	0	10	0	40	20	20
<i>Plexaura flexuosa</i>	0	5	0	0	0	0	0	0	0	0
<i>Pseudopterogorgia</i> sp.	0	0	15	0	0	0	0	0	0	0
<i>Dictyota ciliolata</i>	0	0	0	0	0	0	0	0	0	0
<i>Halimeda opuntia</i>	0	0	0	0	0	0	0	0	0	0
Sea cucumber	0	0	0	0	0	0	0	0	0	0
<i>Agelus</i> sp.	0	0	0	0	0	0	0	0	0	0
rock	25	0	33	10	10	5	25	20	25	0
rubble	0	0	0	0	0	0	0	0	0	0
sand	15	60	15	53	65	80	55	30	45	70
dca	0	3	0	0	0	5	20	0	0	10

Appendix 2: Transect data

Table 2.1 Reef species (or substrate component) identified at 0.5m intervals along 4 x 10m transect lines at shallow, impact site. Buccoo Reef, Tobago (24/08/98). "dca" = dead coral with turf algae.

Metres	Transect number			
	1	2	3	4
0.0	sand	sand	rock	sand
0.5	rock	rubble	rubble	rubble
1.0	dca	rock	rubble	dca
1.5	rock	sand	dca	dca
2.0	rubble	dca	rock	rock
2.5	sand	rubble	sand	<i>Favia fragum</i>
3.0	dca	dca	rock	<i>Favia fragum</i>
3.5	dca	dca	dca	<i>Favia fragum</i>
4.0	sand	rubble	dca	rock
4.5	<i>Diplora strigosa</i>	rock	rock	rock
5.0	dca	dca	dca	dca
5.5	<i>Diplora clivosa</i>	sand	tube sponge	rock
6.0	rubble	rock	sand	sand
6.5	rock	dca	dca	rock
7.0	sand	dca	sponge	sand
7.5	dca	rock	dca	rubble
8.0	rock	sand	rock	sand
8.5	dca	dca	rock	dca
9.0	dca	tube sponge	rubble	<i>Gorgonia flabellum</i>
9.5	rock	tube sponge	rock	<i>Millepora complanata</i>

Appendix 2 (cont.)

Table 2.2 Reef species (or substrate component) identified at 0.5m intervals along 4 x 10m transect lines at shallow, no impact site. Buccoo Reef, Tobago (25/08/98). "dca" = dead coral with turf algae.

Metres	Transect number			
	1	2	3	4
0.0	<i>Favia fragum</i>	<i>Favia fragum</i>	sand	<i>Favia fragum</i>
0.5	<i>Favia fragum</i>	Green Cactus	<i>Millepora complanata</i>	rock
1.0	dca	<i>Ellisella elongata</i>	rock	rock
1.5	<i>Gorgonia flabellum</i>	rock	<i>Millepora complanata</i>	<i>Favia fragum</i>
2.0	<i>Favia fragum</i>	<i>Favia fragum</i>	Green Cactus	<i>Favia fragum</i>
2.5	rock	<i>Favia fragum</i>	<i>Favia fragum</i>	<i>Millepora complanata</i>
3.0	<i>Millepora complanata</i>	<i>Gorgonia flabellum</i>	sand	Green Cactus
3.5	rock	sand	rock	<i>Ellisella elongata</i>
4.0	<i>Favia fragum</i>	sand	<i>Millepora complanata</i>	<i>Ellisella elongata</i>
4.5	dca	Green Cactus	<i>Favia fragum</i>	rock
5.0	<i>Favia fragum</i>	<i>Favia fragum</i>	rock	dca
5.5	dca	<i>Favia fragum</i>	<i>Millepora complanata</i>	Green Cactus
6.0	<i>Ellisella elongata</i>	rock	<i>Favia fragum</i>	<i>Millepora complanata</i>
6.5	rock	dca	<i>Favia fragum</i>	<i>Millepora complanata</i>
7.0	sand	rubble	<i>Favia fragum</i>	<i>Ellisella elongata</i>
7.5	<i>Millepora complanata</i>	rubble	<i>Millepora complanata</i>	rock
8.0	<i>Favia fragum</i>	rock	dca	<i>Favia fragum</i>
8.5	rubble	<i>Favia fragum</i>	<i>Ellisella elongata</i>	rock
9.0	rubble	sand	<i>Millepora complanata</i>	rubble
9.5	sand	rock	<i>Ellisella elongata</i>	rock

Appendix 2 (cont.)

Table 2.3 Reef species (or substrate component) identified at 0.5m intervals along 4 x 10m transect lines at deep, impact site. Buccoo Reef, Tobago (26/08/98). "dca" = dead coral with turf algae.

Metres	Transect number			
	1	2	3	4
0.0	sand	sand	<i>Gorgonia flabellum</i>	rock
0.5	<i>Montastraea annularis</i>	sand	<i>Montastraea annularis</i>	<i>Montastraea annularis</i>
1.0	dca	sand	rock	<i>Montastraea annularis</i>
1.5	<i>Montastraea annularis</i>	rock	<i>Montastraea annularis</i>	<i>Ellisella elongata</i>
2.0	<i>Ellisella elongata</i>	<i>Montastraea annularis</i>	<i>Ellisella elongata</i>	rock
2.5	<i>Halimeda opuntia</i>	<i>Ellisella elongata</i>	sand	<i>Ellisella elongata</i>
3.0	<i>Halimeda opuntia</i>	<i>Ellisella elongata</i>	rock	Tube sponge
3.5	<i>Ellisella elongata</i>	<i>Ellisella elongata</i>	sand	<i>Plexaura flexuosa</i>
4.0	<i>Millepora complanata</i>	<i>Halimeda opuntia</i>	<i>Plexaura flexuosa</i>	<i>Millepora complanata</i>
4.5	<i>Millepora complanata</i>	<i>Montastraea annularis</i>	<i>Pseudopterogorgia</i> sp.	rock
5.0	<i>Montastraea annularis</i>	<i>Ellisella elongata</i>	<i>Pseudopterogorgia</i> sp.	<i>Favia fragum</i>
5.5	<i>Ellisella elongata</i>	<i>Ellisella elongata</i>	rock	<i>Halimeda opuntia</i>
6.0	<i>Halimeda opuntia</i>	<i>Ellisella elongata</i>	rock	<i>Favia fragum</i>
6.5	rock	<i>Millepora complanata</i>	rock	<i>Favia fragum</i>
7.0	rock	Tube sponge	<i>Montastraea annularis</i>	sand
7.5	sand	sand	sand	sand
8.0	rock	sand	<i>Ellisella elongata</i>	sand
8.5	dca	sand	sand	<i>Montastraea annularis</i>
9.0	dca	<i>Montastraea annularis</i>	<i>Halimeda opuntia</i>	<i>Montastraea annularis</i>
9.5	sand	sand	<i>Ellisella elongata</i>	sand

Appendix 2 (cont.)

Table 2.4 Reef species (or substrate component) identified at 0.5m intervals along 4 x 10m transect lines at deep, no impact site. Buccoo Reef, Tobago (27/08/98). "dca" = dead coral with turf algae.

Metres	Transect number			
	1	2	3	4
0.0	sand	<i>Montastraea annularis</i>	dca	sand
0.5	<i>Montastraea annularis</i>	<i>Montastraea annularis</i>	<i>Montastraea annularis</i>	sand
1.0	rock	rock	sand	<i>Montastraea annularis</i>
1.5	sand	<i>Millepora complanata</i>	dca	<i>Montastraea annularis</i>
2.0	<i>Ellisella elongata</i>	<i>Montastraea annularis</i>	rock	rock
2.5	<i>Plexaura flexuosa</i>	<i>Ellisella elongata</i>	<i>Ellisella elongata</i>	sand
3.0	dca	dca	<i>Ellisella elongata</i>	<i>Ellisella elongata</i>
3.5	<i>Montastraea annularis</i>	rock	<i>Montastraea annularis</i>	<i>Ellisella elongata</i>
4.0	<i>Ellisella elongata</i>	<i>Montastraea annularis</i>	<i>Montastraea annularis</i>	dca
4.5	<i>Millepora complanata</i>	<i>Montastraea annularis</i>	dca	<i>Millepora complanata</i>
5.0	<i>Millepora complanata</i>	<i>Montastraea annularis</i>	<i>Montastraea annularis</i>	<i>Millepora complanata</i>
5.5	<i>Millepora complanata</i>	rock	<i>Millepora complanata</i>	rock
6.0	<i>Millepora complanata</i>	dca	<i>Millepora complanata</i>	sand
6.5	<i>Millepora complanata</i>	<i>Montastraea annularis</i>	sand	rock
7.0	sand	rock	rock	<i>Montastraea annularis</i>
7.5	<i>Montastraea annularis</i>	dca	dca	<i>Montastraea annularis</i>
8.0	<i>Montastraea annularis</i>	sand	<i>Diplora strigosa</i>	<i>Montastraea annularis</i>
8.5	sand	rock	<i>Diplora strigosa</i>	<i>Diplora strigosa</i>
9.0	rock	rock	sand	<i>Ellisella elongata</i>
9.5	<i>Ellisella elongata</i>	<i>Pseudopterogorgia</i> sp.	<i>Ellisella elongata</i>	sand

Appendix 2 (cont.)

Table 2.5 Percentage cover of each reef species (or substrate component) per transect (n=4) at:
(i) shallow, impact (ii) shallow, no impact (iii) deep, impact site (iv) deep, no impact sites.
Buccoo Reef, Tobago (August, 1998). "dca" = dead coral with turf algae.

(i) shallow, impact site

Species	% cover/transect				
	1	2	3	4	Ave.
<i>Diplora strigosa</i>	5	0	0	0	1.3
<i>Diplora clivosa</i>	5	0	0	0	1.3
Tube sponge	0	10	10	0	5.0
<i>Favia fragum</i>	0	0	0	15	3.8
<i>Gorgonia flabellum</i>	0	0	0	5	1.3
sand	20	20	10	20	17.5
rock	25	20	35	25	26.3
dca	35	35	30	20	30.0
rubble	10	15	15	10	12.5

(ii) shallow, no impact site

Species	% cover/transect				
	1	2	3	4	Ave.
<i>Millepora complanata</i>	30	0	35	15	20.0
<i>Ellisella elongata</i>	5	5	0	15	6.3
<i>Favia fragum</i>	10	30	25	20	21.3
Green Cactus	0	10	0	10	5.0
<i>Gorgonia flabellum</i>	5	5	0	0	2.5
sand	10	15	10	30	16.3
rock	15	20	15	0	12.5
dca	15	5	5	5	7.5
rubble	10	10	10	5	8.8

(iii) deep, impact site

Species	% cover/transect				
	1	2	3	4	Ave.
<i>Montastraea annularis</i>	15	15	15	20	16.3
<i>Millepora complanata</i>	10	5	0	5	5.0
<i>Ellisella elongata</i>	15	30	15	10	17.5
<i>Halimeda opuntia</i>	15	5	5	5	7.5
Tube sponge	0	5	0	5	2.5
<i>Gorgonia ventalina</i>	0	0	5	0	1.3
<i>Plexaura flexuosa</i>	0	0	5	5	2.5
<i>Pseudopterogorgia</i> sp.	0	0	10	0	2.5
<i>Favia fragum</i>	0	0	0	15	3.8
sand	15	35	20	15	21.3
rock	15	5	25	20	16.3
dca	15	0	0	0	3.8

(iv) deep, no impact site

Species	% cover/transect				
	1	2	3	4	Ave.
<i>Montastraea annularis</i>	20	35	20	25	25.0
<i>Millepora complanata</i>	25	5	10	10	12.5
<i>Ellisella elongata</i>	15	5	15	15	12.5
<i>Plexaura flexuosa</i>	5	0	0	0	1.3
<i>Diplora strigosa</i>	0	0	10	5	3.8
<i>Pseudopterogorgia</i> sp.	0	5	0	0	1.3
sand	20	5	15	25	16.3
rock	10	30	10	15	16.3
dca	5	15	20	5	10.0

Appendix 2 (cont.)

Table 2.6 Cumulative number of species recorded at shallow (impact, no impact) and deep (impact, no impact) sites with increasing number of transects surveyed ($n=4$).
Buccoo Reef, Tobago (24/08/98 - 27/08/98).

No. of transects	Cumulative number of species at site			
	shallow, impact	shallow, no impact	deep, impact	deep, no impact
0	0	0	0	0
1	3	4	7	4
2	5	5	9	5
3	6	5	9	6
4	6	5	9	6

Appendix 3: Chain transect data

Table 3.1 Topographic indices calculated for each transect surveyed ($n=4$) at shallow (impact, no impact) and deep (impact, no impact) sites. Buccoo Reef, Tobago (24/08/98 - 27/08/98). The average topographic index, standard deviation, and 95% confidence intervals at each site are also shown. "Topographic index" = ratio of reef surface contour distance to linear distance (see eq. [1] in *Method*).

Chain number	Topographic index			
	shallow, impact	shallow, no impact	deep, impact	deep, no impact
1	1.14	1.47	3.06	3.07
2	1.21	1.44	2.65	3.25
3	1.32	1.57	2.72	2.99
4	1.28	1.48	3.21	2.80
Ave. topographic index	1.24	1.49	2.91	3.03
Standard deviation	0.079	0.056	0.269	0.187
95% confidence interval	0.078	0.055	0.263	0.183

Appendix 4: Sea urchin (*Echinometra lucunter*) density

Table 4.1 Number of sea urchins (*E. lucunter*) per quadrat at shallow, impact and shallow, no impact sites. Buccoo Reef, Tobago (28/08/98 - 29/08/98).

Quadrat no.	No. of <i>E. lucunter</i> /quadrat	
	shallow, impact	shallow, no impact
1	0	0
2	0	0
3	0	2
4	0	6
5	0	5
6	0	4
7	0	2
8	6	6
9	1	8
10	0	14
11	0	37
12	0	4
13	7	8
14	0	7
15	0	2
16	0	35
17	0	3
18	0	4
19	2	10
20	0	1
21	2	5
22	1	2
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0
31	2	0
32	0	0
33	0	0
34	0	1
35	0	8
36	0	0
37	0	0
38	0	0
39	0	3
40	0	4
Mean	0.53	4.53
S.D.	1.50	8.06
95% C.I.	0.47	2.50

Appendix 5: Random stationary fish count

Table 5.1 Reef fish species identified at shallow, impact site during 3 consecutive 5-minute intervals. Buccoo Reef, Tobago (24/08/98).

No.	Time Interval		
	0-5 mins	6-10 mins	11-15 mins
1	<i>Sparisoma viride</i>	<i>Bodianus rufus</i>	<i>Haemulon sciurus</i>
2	<i>sarcus coeruleus</i>	<i>Dasyatis americana</i>	<i>Sarcus vetula</i>
3	<i>Mulloidichthys martinicus</i>	<i>Abudefduf saxatilis</i>	
4	<i>Holacanthus bermudensis</i>	<i>Hypoplectrus unicolor</i>	
5	<i>Pomacanthus paru</i>		
6	<i>Microspathodon chrysurus</i>		
7	<i>Chaetodon ocellatus</i>		
8	<i>Halichoeres garnoti</i>		
9	<i>Acanthurus chirurgus</i>		
10	<i>Acanthurus bahianus</i>		
11	<i>Holocentrus ascensionis</i>		

Table 5.2 Reef fish species identified at shallow, no impact site during 3 consecutive 5-minute intervals. Buccoo Reef, Tobago (25/08/98).

No.	Time Interval		
	0-5 mins	6-10 mins	11-15 mins
1	<i>Pomacanthus paru</i>	<i>Acanthurus chirurgus</i>	<i>Haemulon sciurus</i>
2	<i>Thalassoma bifasciatum</i>	<i>Acanthurus coeruleus</i>	<i>Sarcus coeruleus</i>
3	<i>Microspathodon chrysurus</i>	<i>Scarus criocensis</i>	
4	<i>Pomacentrus fuscus</i>	<i>Chaetodon capistratus</i>	
5	<i>Sparisoma viride</i>	<i>Scarus vetula</i>	
6	<i>Mulloidichthys martinicus</i>		

Table 5.3 Reef fish species identified at deep, impact site during 3 consecutive 5-minute intervals. Buccoo Reef, Tobago (26/08/98).

No.	Time Interval		
	0-5 mins	6-10 mins	11-15 mins
1	<i>Microspathodon chrysurus</i>	<i>Balistes vetula</i>	<i>Acanthurus chirurgus</i>
2	<i>Thalassoma bifasciatum</i>	<i>Acanthurus coeruleus</i>	<i>Chaetodon capistratus</i>
3	<i>Sparisoma aurofrenatum</i>	<i>Chaetodon striatus</i>	
4	<i>Acanthurus bahianus</i>		
5	<i>Scarus vetula</i>		
6	<i>Scarus croicensis</i>		
7	<i>Haemulon chrysargyreum</i>		
8	<i>Sparisoma viride</i>		
9	<i>Ocyurus chrysurus</i>		

Appendix 5 (cont.)

Table 5.4 Reef fish species identified at deep, no impact site during 3 consecutive 5-minute intervals. Buccoo Reef, Tobago (27/08/98).

No.	Time Interval		
	0-5 mins	6-10 mins	11-15 mins
1	<i>Acanthurus chirurgus</i>	<i>Scarus vetula</i>	<i>Acanthurus coeruleus</i>
2	<i>Thalassoma bifasciatum</i>	<i>Haemulon chrysargyreum</i>	<i>Abundefduf saxatilis</i>
3	<i>Microspathodon chrysurus</i>	<i>Balistes vetula</i>	
4	<i>Sparisoma viride</i>	<i>Chaetodon capistratus</i>	
5	<i>Halichoeres garanoti</i>		
6	<i>Acanthurus bahianus</i>		
7	<i>Haemulon flavolineatum</i>		
8	<i>Ocyurus chrysurus</i>		
9	<i>Scarus croicensis</i>		

Appendix 6: Mean percentage coral cover

Table 6.1 Changes in the estimated mean percentage coral cover (including standard deviation and 95% confidence intervals) at shallow, impact site with number of quadrats sampled. Buccoo Reef, Tobago (28/08/98).

No. of quadrats	Mean % coral cover	Standard deviation	95 % confidence interval
2	5.0	7.07	9.84
3	6.0	5.29	6.00
4	4.5	5.26	5.15
5	12.8	19.11	16.75
6	10.7	17.87	14.30
7	9.1	16.81	12.45
8	8.0	15.89	11.01
9	7.1	15.10	9.87
10	7.4	14.27	8.84
15	5.5	11.83	5.99
20	4.3	10.41	4.56
25	4.0	9.32	3.65
30	4.1	8.56	3.08
35	4.2	8.19	2.72
40	4.2	7.81	2.42

Table 6.2 Changes in the estimated mean percentage coral cover (including standard deviation and 95% confidence intervals) at shallow, no impact site with number of quadrats sampled. Buccoo Reef, Tobago (29/08/98).

No. of quadrats	Mean % coral cover	Standard deviation	95 % confidence interval
2	80.5	18.97	26.29
3	53.7	13.65	15.45
4	62.8	12.18	11.94
5	55.8	11.12	9.75
6	55.3	10.10	8.08
7	57.3	9.24	6.84
8	62.4	8.78	6.08
9	55.4	8.34	5.45
10	56.0	9.14	5.66
15	45.2	9.94	5.03
20	44.3	9.94	4.36
25	44.5	9.94	3.90
30	44.6	9.94	3.56
35	45.1	9.94	3.29
40	45.0	9.94	3.08

Appendix 6 (cont.)

Table 6.3 Changes in the estimated mean percentage coral cover (including standard deviation and 95% confidence intervals) at deep, impact site with number of quadrats sampled. Buccoo Reef, Tobago (30/08/98).

No. of quadrats	Mean % coral cover	Standard deviation	95 % confidence interval
2	55.0	10.61	14.69
3	70.0	8.26	9.35
4	56.5	8.08	7.92
5	51.6	7.00	6.14
6	58.8	6.53	5.22
7	53.9	6.33	4.69
8	52.0	6.46	4.48
9	49.1	6.44	4.21
10	49.2	6.46	4.00
15	48.2	6.19	3.13
20	48.5	6.19	2.71
25	48.2	6.19	2.43
30	48.4	6.19	2.22

Table 6.4 Changes in the estimated mean percentage coral cover (including standard deviation and 95% confidence intervals) at deep, no impact site with number of quadrats sampled. Buccoo Reef, Tobago (31/08/98).

No. of quadrats	Mean % coral cover	Standard deviation	95 % confidence interval
2	67.5	22.04	15.91
3	45.0	13.18	11.65
4	51.0	10.05	10.26
5	46.8	9.12	10.40
6	40.5	7.80	9.75
7	43.0	6.81	9.19
8	42.9	5.91	8.53
9	46.4	5.29	8.10
10	43.8	4.88	7.88
15	41.2	3.64	7.19
20	41.5	3.15	7.19
25	41.8	2.82	7.19
30	41.8	2.57	7.19

Appendix 7: Shannon-Weaver index

Table 7.1 Mean Shannon diversity (H'), including standard deviation and 95% confidence intervals, for shallow (impact, no impact) and deep (impact, no impact) sites using quadrat data. The formula for the Shannon-Weaver index is given in eq. [2] of the *Method*. Buccoo Reef, Tobago (24/08/98 - 27/08/98)

	Site			
	shallow, impact	shallow, no impact	deep, impact	deep, no impact
Mean Shannon index	1.05	1.11	1.20	1.10
Standard Deviation	0.25	0.32	0.25	0.29
95% confidence interval	0.08	0.10	0.09	0.10

Table 7.2 Mean Shannon diversity (H'), including standard deviation and 95% confidence intervals, for shallow (impact, no impact) and deep (impact, no impact) sites using transect data. The formula for the Shannon-Weaver index is given in eq. [2] of the *Method*. Buccoo Reef, Tobago (24/08/98 - 27/08/98)

	Site			
	shallow, impact	shallow, no impact	deep, impact	deep, no impact
Mean Shannon index	1.59	1.8	1.88	1.78
Standard Deviation	0.14	0.14	0.19	0.12
95% confidence interval	0.14	0.14	0.18	0.12

Appendix 8: One-way analysis of variance (ANOVA) summary tables
(calculated using Microsoft Excel)

Table 8.1 One-way ANOVA of coral density at shallow, impact and shallow, no impact sites using percentage coral cover per quadrat as the dependent variable. Buccoo Reef, Tobago (August, 1998).

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
shallow, impact	40	166.5	4.16	61.04
shallow, no impact	40	1798	44.95	838.97

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>F crit</i>
Between Groups	33272.4	1	33272.4	73.94	3.96
Within Groups	35100.59	78	450.01		
Total	68373	79			

Table 8.2 One-way ANOVA of coral density at deep, impact and deep, no impact sites using percentage coral cover per quadrat as the dependent variable. Buccoo Reef, Tobago (August, 1998).

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
deep, impact	30	1453	48.43	541.56
deep, no impact	30	1254	41.8	423.54

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>F crit</i>
Between Groups	660.02	1	660.02	1.37	4.01
Within Groups	27988.17	58	482.55		
Total	28648.18	59			

Appendix 8 (cont.)

Table 8.3 One-way ANOVA of species diversity at shallow, impact and shallow, no impact sites using number of species per quadrat as the dependent variable. Buccoo Reef, Tobago (August, 1998).

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
shallow, impact	40	46	1.15	1.21
shallow, no impact	40	147	3.68	3.81

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>F crit</i>
Between Groups	127.51	1	127.51	50.78	3.96
Within Groups	195.88	78	2.51		
Total	323.39	79			

Table 8.4 One-way ANOVA of species diversity at deep, impact and deep, no impact sites using number of species per quadrat as the dependent variable. Buccoo Reef, Tobago (August, 1998).

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
deep, impact	30	110	3.67	2.51
deep, no impact	30	79	2.63	1.55

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>F crit</i>
Between Groups	16.02	1	16.02	7.90	4.01
Within Groups	117.63	58	2.03		
Total	133.65	59			

Appendix 9: Summary Tables

Table 9.1 Summary of biomass (expressed as percentage coral cover per quadrat) at shallow (impact, no impact) and deep (impact, no impact) sites. Buccoo Reef, Tobago (August, 1998).

Quadrat no.	% coral cover/quadrat			
	shallow, impact	shallow, no impact	deep, impact	deep, no impact
1	10	71	26	50
2	0	90	84	85
3	8	0	100	0
4	0	90	16	69
5	46	28	32	30
6	0	53	95	9
7	0	69	24	58
8	0	98	39	42
9	0	0	26	75
10	10	61	50	20
11	0	93	59	10
12	0	0	38	25
13	3	5	41	45
14	0.5	5	38	45
15	5	15	55	55
16	2.5	55	52	76
17	0	43	51	15
18	0	50	23	45
19	0	10	70	31
20	0	50	50	44
21	4	57	38	31
22	3	54	72	37
23	0	20	69	52
24	2	63	10	37
25	6	32	48	60
26	3	71	53	55
27	3	34	42	48
28	8	59	90	50
29	8	47	25	30
30	2	16	37	25
31	1	8		
32	5	87		
33	0	60		
34	1	21		
35	15	63		
36	0	30		
37	12	60		
38	6	67		
39	3	5		
40	0	58		
Ave. % coral cover	4.2	45.0	48.4	41.8
Standard Deviation	7.8	9.9	6.2	2.6

Appendix 9 (cont.)

Table 9.2 Summary of diversity (expressed as number of species per quadrat) at shallow (impact, no impact) and deep (impact, no impact) sites. Buccoo Reef, Tobago (August, 1998)

Quadrat no.	No. of species/quadrat			
	shallow, impact	shallow, no impact	deep, impact	deep, no impact
1	3	6	2	2
2	2	4	3	3
3	1	2	2	2
4	2	3	4	3
5	2	3	2	3
6	2	4	3	2
7	0	5	3	5
8	2	4	3	4
9	3	5	3	1
10	2	3	2	2
11	0	4	4	2
12	0	5	5	3
13	2	6	5	4
14	1	5	5	2
15	2	5	3	3
16	3	4	4	4
17	0	7	7	2
18	2	4	2	2
19	2	6	7	2
20	1	7	1	4
21	3	4	4	3
22	3	7	6	3
23	1	7	5	4
24	1	5	5	4
25	2	1	5	1
26	0	1	4	1
27	0	0	1	0
28	0	1	4	2
29	0	0	2	1
30	0	0	4	5
31	2	2		
32	1	3		
33	0	2		
34	1	2		
35	0	4		
36	0	4		
37	0	3		
38	0	3		
39	0	3		
40	0	3		
Ave. species no./quadrat	1.2	3.7	1.4	3.9
Standard Deviation	1.1	2.0	1.1	2.2

Appendix 9 (cont.)

Table 9.3 Percentage frequency of occurrence of each species (i) per quadrat, and (ii) per transect at shallow (impact, no impact) and deep (impact, no impact) sites. Buccoo Reef, Tobago (August, 1998).

Species	Percentage frequency of occurrence							
	shallow, impact		shallow, no impact		deep, impact		deep, no impact	
	Quadrat (n=40)	Transect (n=4)	Quadrat (n=40)	Transect (n=4)	Quadrat (n=30)	Transect (n=4)	Quadrat (n=30)	Transect (n=4)
<i>Diplora strigosa</i>	12.5	25.0	7.5	0.0	26.7	0.0	30.0	50.0
<i>Diplora clivosa</i>	7.5	25.0	2.5	0.0	6.7	0.0	0.0	0.0
<i>Ellisella elongata</i>	5.0	0.0	52.5	100.0	60.0	100.0	56.7	100.0
<i>Favia fragum</i>	30.0	25.0	92.5	100.0	0.0	25.0	0.0	0.0
<i>Porites astreoides</i>	17.5	0.0	5.0	0.0	20.0	0.0	0.0	0.0
<i>Gorgonia ventalina</i>	2.5	0.0	20.0	0.0	3.3	25.0	6.7	0.0
<i>Gorgonia flabellum</i>	0.0	25.0	5.0	50.0	0.0	0.0	0.0	0.0
<i>Agaricia lamarcki</i>	0.0	0.0	5.0	0.0	30.0	0.0	3.3	0.0
<i>Millepora complanata</i>	0.0	25.0	62.5	75.0	40.0	75.0	46.7	100.0
<i>Madracis decactis</i>	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0
<i>Montastraea annularis</i>	0.0	0.0	0.0	0.0	73.3	100.0	80.0	100.0
<i>Plexaura flexuosa</i>	0.0	0.0	0.0	0.0	56.7	25.0	23.3	0.0
<i>Pseudopterogorgia</i> sp.	0.0	0.0	0.0	0.0	3.3	0.0	3.3	25.0
<i>Dictyota ciliolata</i>	0.0	0.0	20.0	0.0	6.7	25.0	3.3	0.0
<i>Halimeda opuntia</i>	0.0	0.0	0.0	0.0	30.0	100.0	3.3	0.0
Sea cucumber	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0
<i>Agelus</i> sp.	15.0	50.0	12.5	0.0	23.3	50.0	0.0	0.0
<i>Chlorophyta</i>	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0
Orange wall sponge	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Echinometra lucunter</i>	17.5	0.0	57.5	0.0	0.0	0.0	0.0	0.0