Anthropogenic physical damage to coral reefs in Tobago

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ABSTRACT: Coral reefs are subject to natural and anthropogenic disturbances. As human activity upon reefs in Tobago increases as a result of tourism, managing the impact of physical damage caused by recreational activities becomes increasingly important. This study estimated anthropogenic pressures on four reefs in Tobago, assessed physical damage at each site using two separate indicators and gathered information about stakeholder perceptions of reef condition and the causes of degradation based on questionnaires. Anthropogenic pressure varied greatly at each site with highest yachting activity at Pirates Bay (Eastern Reef) followed by Store Bay (Kariwak Reef) then Mount Irvine Bay (Mt. Irvine Reef). SCUBA diving activity on Kariwak and Mt Irvine Reef were similar but not observed on Eastern Reef. Little evidence of anthropogenic activity upon Booby Reef was recorded and levels of damage were considered predominantly natural. Density of coral rubble (CR) at Booby Reef was nearly half that of Kariwak and Mt. Irvine Reef though densities of broken coral colonies that were still living (BCC) were similar. Densities of both CR and BCC at Eastern Reef were over five times higher than at any other site with ca. 65 % of the reef being damaged. Increasing Coral damage correlated significantly with increasing yachting pressure but there was no correlation between diving pressure and coral damage. Perceptions of the overall condition of Tobago's reefs were similar between stakeholders but there were differences between yacht users, divers and fishermen in their perceptions of reef condition and the causes of degradation. Current anchor damage management in the form of reef demarcation buoys (RDBs) at Store Bay and Mt. Irvine Bay may be sufficient at reducing yachting impacts and current diving pressure is unlikely to cause considerable impact, but continued monitoring is essential to evaluate their success - this study provides baseline data for this. At Pirates Bay there is currently no reef management but installation of RDBs alone may exacerbate current conflicts between yacht users and fishermen and a compulsory mooring system for visiting yachts is recommended.

KEY WORDS: Coral damage · Anchors · Yacht · Divers · Stakeholder perception · Tobago · Management

INTRODUCTION

Coral reefs are important both ecologically and economically but world-wide decline in coral reef ecosystems is accelerating (Glynn 1994). Natural causes of reef degradation, such as hurricanes, disease, predation, bleaching and the El Niño phenomenon have received considerable attention (Bythell et al. 2000, Glynn 1985, Lessios et al. 1984, Rogers et al. 1991), but it is the intensity and frequency of anthropogenic impacts, and how these interact with natural events that is of increasing concern. Sedimentation and eutrophication are often considered the most pervasive chronic stresses leading to global reef decline but localized physical damage to reefs associated with

recreational activities is of rapidly increasing concern because of growing interest in reef based tourism and yachting (Rogers & Garrison 2001).

Physical damage can impact a reef in several ways generally resulting in higher mortality, lower growth rates and less reproduction (Ward 1995). Large damage events will reduce the topographic complexity of a reef which can have implications for wave attenuation properties and both coral and fish community composition (Hawkins et al. 1999, McIlwain & Jones 1997). The scale of impact is dependant on the cause and frequency of the stressor; one boat grounding incident may decimate large areas of coral reef while an individual SCUBA diver may just graze a few coral colonies. However the cumulative impact of heavy diving pressure could eventually outweigh the impact of one boat grounding. This study will focus on hard coral damage as corals are the primary reef builders and are often the slowest organism to recover from a damage event. Different species of coral vary in their ability to resist damage or breakage from mechanical force (Marshall 2000) and recovery rates are also subject to several variables such as rates of coral reproduction, polyp survivorship and growth. Because natural processes such as wave action can cause physical damage to corals, certain species have evolved tolerance and resistance to mechanical breakage. It has also been suggested that coral fragmentation through physical disturbance may be an adaptive form of asexual reproduction in coral (Highsmith 1982) although high mortality rates and low fecundity suggest the costs may outweigh the advantages (Smith & Hughes 1999).

Tobago is a small island (300 km^2) located at the southern end of the Lesser Antilles chain in the Caribbean archipelago. It is a popular destination for yachts as it does not suffer the hurricanes of many other Caribbean Islands, and therefore provides safe anchorage. Between 1990 and 2000 the number of yacht arrivals to Trinidad and Tobago has increased 5 fold and 55,532 arrivals from cruise ships were recorded in 2003. Tourist pressures specific to Tobago are not easy to quantify, available figures refer to both Trinidad & Tobago, but big events such as the Angostura Tobago Sail Week, the carnival, the Great Race and its position as a stop off point to Trinidad, Grenada and the rest of the Caribbean make Tobago a popular anchorage for many yachts (Blommestein 2004). Specific information on dive tourism for Trinidad and Tobago is not available but tourism as a whole has risen to over 400,000 tourist arrivals in 2003 with ca. 100,000 estimated to visit Tobago alone in 2004 (TIDCO 2004). It is not clear however if this estimate records arrivals from Trinidad as many Trinidadians visit Tobago for recreational purposes.

Physical damage events to corals may be sporadic and highly localized but on a small island such as Tobago that is aiming to develop eco tourism the increasing number of visitors to its reefs is likely to exacerbate reef degradation unless management and enforcement is successful. Already extensive areas of coral rubble attributed to storm events, anchor damage and reef walking have been observed within the Buccoo Reef complex, South West Tobago (Laydoo 1991). Damage from anchors has been identified in Tobago as a management problem (O.Day pers comm 2003). Currently a programme to install reef demarcation buoys (RDBs) at Tobago's most popular anchorages, in order to protect fringing reefs from anchor damage, has been initiated between the Buccoo Reef Trust, the Department of Marine Resources and Fisheries of the Tobago House of Assembly and the Tobago Diving Association. Durable markers indicating a no-anchor zone will be anchored 10 m seaward of the

reef edge. Consultation with fishermen and tour boat operators was aimed to reduce potential conflict and identify suitable placement of the buoys

Although diver damage (Rouphael & Inglis 1997, Hawkins et al. 1999, Schleyer & Tomalin 2000, Zakai & Chadwick-Furman 2002, Zubillaga et al. 2003), ship groundings (Ebersole 2001, Riegl 2001), and to some extent reef walking (Kay & Liddle, 1989, Liddle & Kay 1987, Rogers & Cox 2003, Woodland & Hooper 1977) have been quantified, relatively little is known quantitatively about anchor damage on coral reefs. This is the first study to quantify physical damage to reefs in Tobago and suggest the principle causes of that damage. The study had three main objectives, firstly to assess yachting and diving pressure levels upon several reefs in Tobago. Little information is available on annual scuba diver, yacht or snorkeller numbers for the whole of Tobago, making accurate estimates for specific bays or reefs even harder. Because finding a reliable estimate of anthropogenic pressures for each site is important when comparing to physical damage at that site, this study will use several methods, including daily observations, interviews with relevant organisations and review local literature to form an aggregate estimate incorporating factors such as high and low tourist seasons. The second objective is to provide a rapid assessment of coral damage at each site. Two indicators of damage will be recorded to strengthen results. The null hypothesis is that physical damage will not vary with changes in yachting and diving pressures. Ideally a study similar to this would have been conducted before the start of the existing RDB programme to better guide deployment of the buoys to areas in most need. The third objective will gauge relevant stakeholder perceptions of reef condition in Tobago, the main causes of degradation, and how physical damage is caused. If certain stakeholder groups do not consider physical damage an issue in Tobago, or perhaps blame certain factors for reef degradation, it will help identify potential conflicts that can then be addressed and also indicate the perceived importance of the RDB project. For example, if physical damage is not perceived a major cause of reef degradation while sedimentation is, then money spent on RDBs may appear better spent on improving land-based runoff. Stakeholder participation and consensus is essential for coastal management to be successful (Suman et al. 1999) and combining stakeholder opinions with ongoing monitoring of physical damage will enable the success of current management objectives to be evaluated.

MATERIALS AND METHODS

Study Sites. Field work was carried out at four sites in Tobago (Figure 1). Three of the sites are included in the current reef demarcation buoy (RDB) programme. Site 4 is not included in the RDB programme but has been included in this study as it represents the closest example to a control site as little human activity upon the reef occurs (O.Day pers comm. 2004).

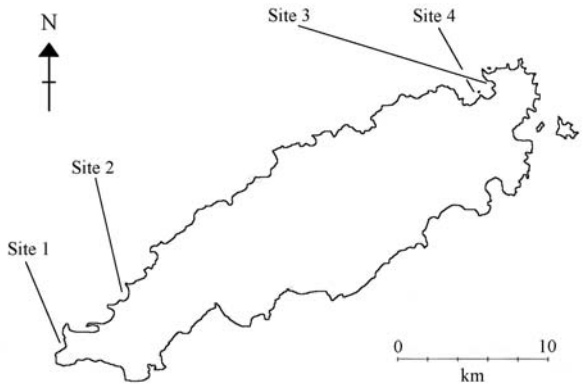

Figure 1. Outline map of Tobago showing the location of each study site. Sites 1, 2 & 3 are included in a reef demarcation programme.

Site 1: Kariwak Reef (11°9'25''N, 60°50'50''W) is a gently-sloping fringing reef within Store Bay with a maximum depth of ca. 12 m. Brain coral (*Diplora* spp*)* and Star coral (*Montastrea* spp) dominate the reef slope with fire corals (*Millapora* spp), elkhorn (*Acropora palmata*) and various soft corals also present. Store Bay is one of Tobago's most popular beaches and is also host to several large events throughout the year, such as the Angostura Tobago Sail Week, the Carib Great Race and the Carib International Fishing Tournament. Beach seining is also still practised within the Bay and 6 RDBs have recently (2nd May 2004) been placed along the outer reef edge.

Site 2: Mount Irvine Reef (11°11'70''N, 60°47'90''W) lies between 4 m and 8 m depth towards the Mount Irvine Bay. *Montstrea* spp and *Diplora* spp colonies dominate the benthic community, however soft corals such as sea fans (*Gorgonia* spp*)*, feathers (*Psuedopterogorgonia* spp*)* and whips (*Ellisella* spp*)* seem more common here than the other sites within the survey. The Bay is the third largest fishing port in Tobago after Scarborough and Charlottesville and is increasingly popular with tourists, predominantly for the surfing conditions. Three RDBs are placed along the outer edge with 3 more scheduled to be installed before September 2004

Site 3: Eastern Reef (11°33'15''N, 60°55'30''W) is a gently-sloping fringing reef within Pirates Bay dominated by large colonies of *Diplora* spp, *Montastrea* spp and finger coral (*Porites porites*). In deeper areas gorgonians such as *Psuedopterogorgonia* spp and the sausage coral (*Plexauralia* spp) are common (Laydoo 1991). Corals occur to a maximum depth of ca. 15 m (Laydoo 1991) though most are found much shallower than this. Well sheltered from wave action, the Bay is an important anchorage for yachts. Fishing is an important industry within nearby Charlottesville, with beach seining practised within Pirates Bay. There is a low level of tourism within the area (NETMP 2003). Seven RDBs are scheduled to be installed along the outer reef edge by September 2004.

Site 4: Booby reef (11°32'80''N, 60°55'11''W) is a large reef formation between Booby Island and the Tobago mainland and has distinct habitat zones (Laydoo 1985). The south-western area included in the study lies between 4 m and 7 m depth and is characterised by *Diplora* spp and *Montastrea* spp colonies. The reef cannot be reached from land and the surrounding shallow reef tops (often exposed at low tides) makes approach by boat hazardous. For these reasons human activity upon the reef is considered very low and no RDBs are currently planned for the site (O.Day pers comm 2004).

Anthropogenic pressure. At each site daily observations were taken at 0900 – 1500 hours local time on three separate occasions between 4th May 2004 and 10th June 2004. Within each bay the type and number of anchored boats were recorded. Numbers of SCUBA divers and snorkellers on the reef were noted along with any fishing activity operating within the sites from which a mean average could be taken. Informal interviews were arranged to gain broader knowledge about human activities within the four sites. Interviewees were selected based on their involvement in regular activity on the study sites including; 3 Angostura Tobago Sail Week Organisers, 4 Local dive shops (Manta Dive, R & Sea Divers, Undersea Tobago and Sublime), 4 Life guards and 3 local fishermen. The following 'grey' literature also provided further local information on anthropogenic pressures affecting the study sites: North East Tobago Management Plan, custom & Excise International Arrivals data, TIDCO (Tourism and Industry Development Company of Trinidad and Tobago) tourism statistics 2003 and a UNECLAC (United Nations Economic Commission for Latin America and the Caribbean) report titled, 'Yachting in Eastern Caribbean Development'. By combining information from all these sources it was possible to estimate levels of human activity, for high and low tourist seasons and large annual events, to estimate annual anthropogenic pressures for each reef given that:

$$P = L_n + H_n + E_n \qquad \text{(Equation 1)}$$

where P is the annual anthropogenic pressure, L is the mean estimate of low season anthropogenic pressure, H is the mean estimate of high season anthropogenic pressure, E is the mean estimate of anthropogenic pressure during large events and n is the number of days at that level of pressure per year

To standardise the estimates of anthropogenic pressure with respect to the area of each site, the reef and bay areas were measured. Coordinates were taken using a Garmin "etrex" handheld GPS (Global Positioning System) every 10 m using a small boat which followed the reef edge directed by a towed diver. Estimates of area using GPS coordinates were carried out using ArcView GIS 3.1, when calculating bay area a straight line from headland to headland was used. Yachting pressure will be expressed as yachts per year per km^2, while diving pressure, which is concentrated specifically over the reef, will be expressed as divers per year per m^2.

Coral damage. There are many different indicators of physical damage on a reef including densities of overturned colonies, coral rubble and broken fragments but for this study densities of coral rubble (CR) and broken coral colonies (BCC) were used to reflect all possible forms of damage. CR, expressed in centimetres per metre, was defined as unconsolidated dead coral fragments including dead overturned colonies. BCC (centimetre per metre) was defined as broken (any part) or overturned live coral colony with no extensive regeneration or callus formation. Non-attached but otherwise live colonies were classified as broken if there was visible evidence that the stem had been broken off. Visible white scrape marks or gouges on live coral were also classified as BCC. CR represented past physical damage while BCC indicated recent damage. At each site 5 x 20 m line intercept transects were carried out at ca. 5m depth, using Global Coral Reef Monitoring Network protocols (English et al. 1997). The start point for each transect was chosen haphazardly within the depth constraints and area available at each site, and the

tape measure was then laid in a straight line at a random orientation. The density of broken coral colonies and coral rubble directly under the line was recorded using underwater slates and pencils.

Values of CR and BCC were transformed using Log_{10} transformation to improve homogeneity of variances however BCC values were not normally distributed. Differences in CR between sites were compared using one-way ANOVA and Kruskal-Wallis analysis used for BCC values. Associations between anthropogenic activity (Diving and yachting pressure) and coral damage were assessed using Regression analysis for CR values and Spearman's Rank correlation analysis for BCC values.

Stakeholder perceptions of reef condition, physical damage and its causes. A brief pilot study interviewing two yacht owners and one fisherman selected at random enabled relevant stakeholder groups to be identified and allowed questions to be adapted to promote productive responses. Divers, fishermen, yacht owners and their crew appeared to be the three main stakeholders within the four sites and thus were interviewed. Glass bottom-boat operators and their customers were not included as initial observations showed they did not operate on any of the reefs within the study area. Structured questionnaires were given to stakeholders at each site. Individuals were approached and after a brief introduction the questions concerning reef condition and causes of degradation were presented and read out. Interviewee responses were marked by crossing or circling the equivalent response on the questionnaire (Appendix a). Finally the interviewees were asked to comment on the existing management programme and their responses were recorded in note form. Numbers interviewed within each stakeholder group varied dependant on availability and time constraints.

RESULTS

Anthropogenic pressure. The tourist high season can be considered as ca. 6 months of the year with peaks around February and March, between mid-June and August and in December (TIDCO 2004), while peak yachting season, also 6 months, is from November to April (NETMP 2003). Store Bay was the only site to host large annual events; information from TIDCO and the NETMP and Angostura event organisers suggest large events cover ca. 16 days per year. Average annual yacht and diver numbers at each site for low season, high season and occasional events were estimated for each site (Table 1).

Table 1. Estimated yachting and diving pressure for each site. Booby Reef has not been included as no human activity was observed upon the site and interviews with local fishermen suggest activity on the reef is extremely low. Snorkelling, fishing and glass-bottom boat activity is also not included as they are unlikely to have cause impact at the study sites. It was not possible to calculate error for the estimates owing to the range of sources they were derived from. For complete data set see Appendix b.

Site	Yachts $year^{-1}$	Yachts $year^{-1}$ $km^{2\,-1}$	Divers $year^{-1}$	Divers $year^{-1}m^{2-1}$
Store Bay (Kariwak Reef)	7005	3254	3013	0.13496296
Mt Irvine (Mt. Irvine Reef)	2509	952	2346	0.3680095
Pirates Bay (Eastern Reef)	8276	9227	0	0

Although yachting, diving, glass-bottom boat and snorkelling activity were all observed in Store Bay, only snorkelling and diving were recorded over Kariwak reef within the study period. Because the reef is ≥4 m in depth snorkelling is ruled out as a major cause of damage. Observations of yacht numbers fluctuated greatly up to a maximum of 66 per day, owing to an influx of yachts for the Angostura Tobago Sail week. Diving and yacht anchoring appeared the only potential anthropogenic impacts on Mt Irvine reef (Table 1). Although Mt Irvine Bay was the only site where fishing boats were observed operating they did not catch fish in the Bay but traded on the shore and all boats had fixed moorings some distance from the reef. No snorkelling activity was observed over Mt Irvine reef most likely because it is ca. 150 m from shore and over 4 m deep. Relatively low values for yachting pressure were found at Mt Irvine although diving pressure was similar compared to Store Bay. Fishing activity in Pirates Bay was restricted to seine netting from the beach and is not considered to directly damage the coral as the net was not passed over areas of reef. Snorkelling levels were also very low and concentrated close to the shore amongst shallow reef based on rocky substrate. Yachting activity within Pirates Bay was higher than all other sites, especially when the smaller area within Pirates Bay is considered. Diving activity on Booby and Eastern reefs was estimated to be negligible although occasional diving is likely. None of the activities under observation were recorded on or around Booby Reef. Pirates Bay was the only site where anchor drops on the reef were actually observed (Figure 2) with 4 separate incidents recorded in just three daily observations.

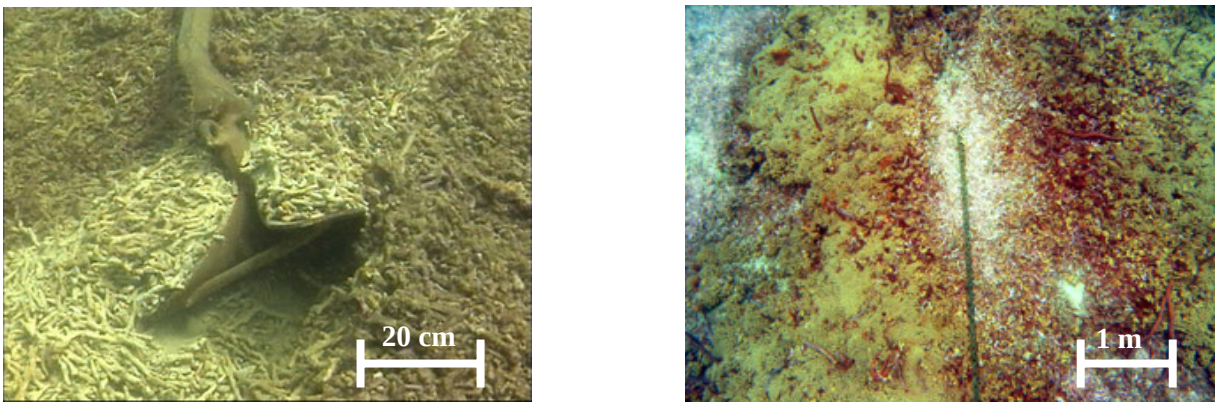

Figure 2. Two separate anchor damage incidents on Eastern Reef. a) Plough anchor digging into finger coral (*Porites porites*). b) Shows damage caused from an anchor chain on *Porites porites* colony. (Photographs by R.Langton 2004)

Coral damage. Density of coral rubble differed significantly between sites ($F=9.24$, $P\leq0.001$) with Eastern Reef at Pirates Bay having the highest BCC values, over 6 times greater than the other sites with coral rubble accounting for nearly 60% of all benthic cover. Densities of BCC also differed significantly between sites with BCC at Kariwak and Booby Reefs lower than Eastern Reef ($Z=2.29$, $P\leq0.05$; $Z=2.21$, $P\leq0.05$ respectively). Booby Reef showed the lowest BCC and CR values (0.4 and 5.7 cm^{-m} respectively). Mt Irvine Reef and Kariwak Reef had only slightly higher levels of BCC than Booby Reef despite greater diving pressures and yachting activity. However, CR values, indicative of past damage were nearly double at Mt Irvine and Kariwak that at Booby Reef (Figure 3).

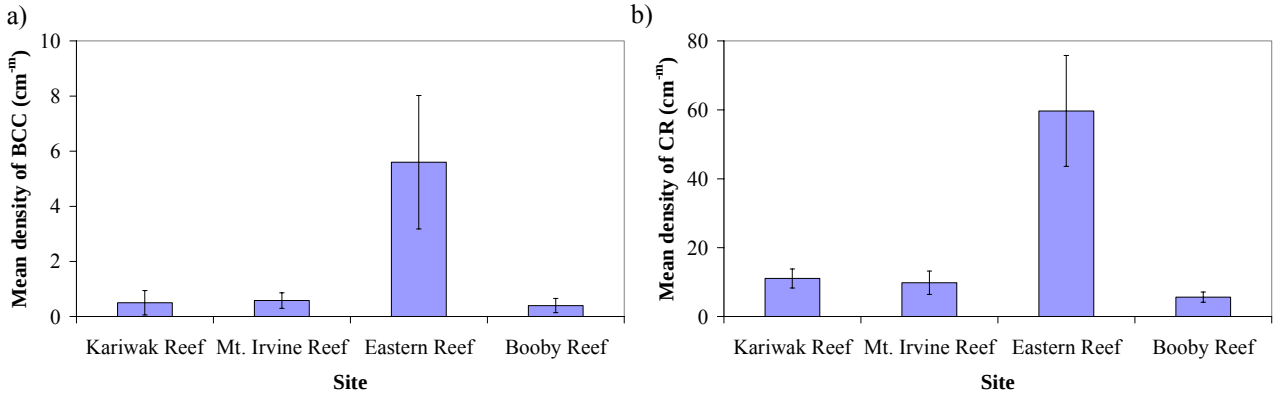

Figure 3. Mean densities of coral damage at each reef site with standard error bars. a) Mean density of broken coral colonies (BCC) at each site (cm^{-m}). b) Mean density of coral rubble (CR) at each site (cm^{-m}).

The positive correlation between increasing CR with increasing yachting pressure was highly significant ($F = 30.03$, $P \leq 0.001$) but there was no significant correlation between diving pressure and CR ($F = 1.45$, $P \geq 0.05$), see Figure 4. Results from Spearman's Rank analysis of BCC data supports the CR data with increasing BCC correlating significantly with higher yachting pressure ($r_s = 0.45$, $P = \leq 0.05$) and no significant correlation between diving pressure and BCC ($r_s = -0.28$, $P = \geq 0.05$).

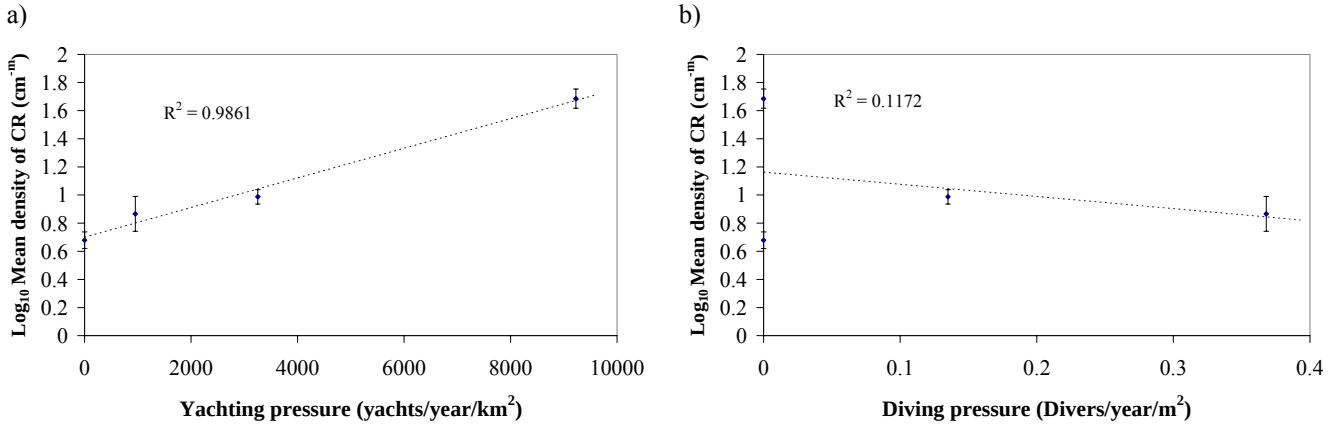

Figure 4. Relationship between anthropogenic pressures and coral rubble. a). Mean CR with error bars plotted against yachting pressure. b). Mean CR with error bars plotted against diving pressure.

Stakeholder perceptions of reef condition, physical damage and its causes. Mean ratings on the overall condition of Tobago's reefs did not indicate any great difference of opinion between the three stakeholder groups, with mean ratings of all groups between 2.5 and 3 (Figure 5a). There were differences of opinion on individual reef condition between sites and stakeholder groups. However, at Store Bay both divers and yacht users on average considered Kariwak Reef less degraded than stakeholders considered the reef at Mt Irvine Bay to be (Figure 5b). The condition of Eastern Reef at Pirates Bay was perceived very differently by the two stakeholder groups present. Fishermen gave Eastern Reef a mean condition rating of 1.33 (1 = Whole reef heavily degraded) while yacht users perceived the reef to be in much healthier condition with a mean condition rating approximately 3.5 (Figure 5b).

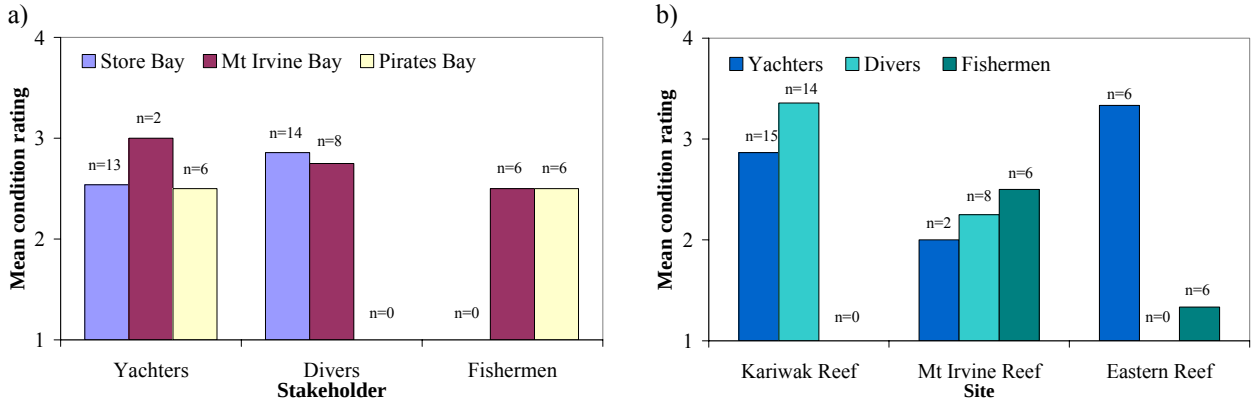

Figure 5. Mean perceived condition of reefs in Tobago. a) Stakeholder perceptions of overall condition of Tobago's reefs with location of participants shown. b) Stakeholder perceptions of the condition of individual study sites.

Although one of the initial intentions of the questionnaire was to ask participants to rate all causes of reef degradation in Tobago in order of importance from 1 to 10 from a list presented to them (1 being considered the greatest cause of degradation), most participants only provided one or two answers. Physical damage was not considered by any stakeholder group as the main cause of reef degradation; divers saw eutrophication as having the most detrimental impact (over 55% indicated this response) and untreated waste from hotels and settlements was commonly blamed. Yacht users (50%) considered disease a major cause of degradation while fishermen (ca. 60%) saw sedimentation as the biggest threat. Interestingly there appears to be considerable difference in opinion between fishermen and the other two stakeholder groups. Yacht users and divers on average consider over-fishing the second largest cause of degradation and sedimentation having the least impact even though most fishing is pelagic and not conducted over the reef (Figure 6a). Yacht owners and crew did not show any clear preference in responses concerning the causes of physical damage but fishermen and divers both identified yachts as the main factor responsible for physical damage on the reefs with the survey. Glass bottom boat operators were blamed by ca. 30% and ca. 18% of yacht users and divers respectively even though the tours did not actually operate over any of the reef sites in this investigation (Figure 6b).

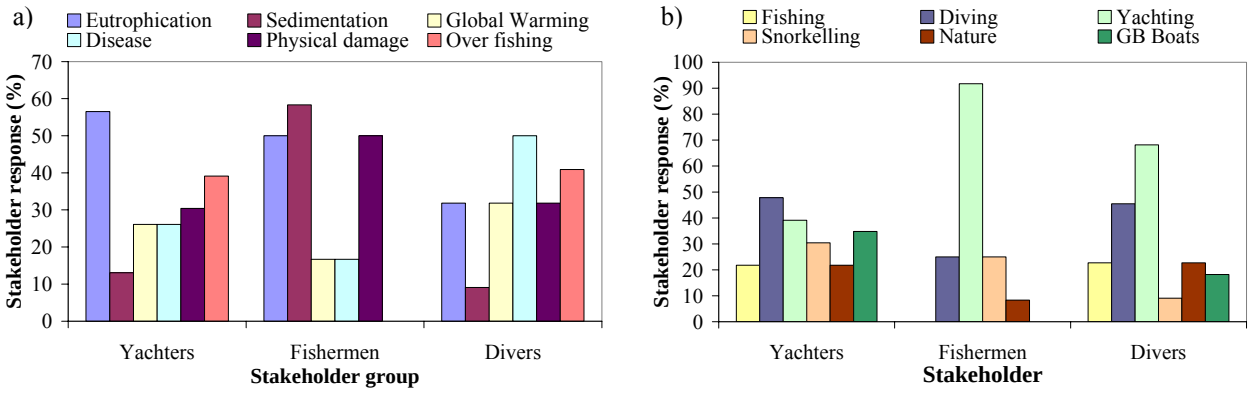

Figure 6. a) Perceived major causes of reef degradation as a percentage of each stakeholder group identifying each factor as a major cause of reef degradation. b) Stakeholder perception of major causes of physical damage upon all site reefs. The percentage of stakeholders identifying each cause of physical damage is shown.

Overall yachts were considered the major cause of physical damage with over 55% of all participants at each site blaming that activity. Diving was considered the second most damaging activity overall, however at Pirates Bay snorkelling was perceived as the second major cause of physical damage. At both Store Bay and Mt. Irvine Bay most participants considered current management adequate to ensure protection of the reef although concerns over enforcement of the no-anchor zones were raised. At Pirates Bay all fishermen interviewed were unhappy with the current lack of reef management and several believed that the proposed RDB programme would not be sufficient in protecting the reef from all anchor damage. Several yacht owners in Pirates Bay were opposed to the RDB programme suggesting it would spoil the aesthetic beauty of the bay and reduce available space for anchorage.

DISCUSSION

Yachting and SCUBA diving were the two main anthropogenic physical pressures on the reefs. Stakeholder perception reflected this apart from at Pirates Bay where SCUBA diving was not regularly carried out. Fishing was not practised over the study reefs but does operate out of the bays in the survey. Although snorkelling was observed at two sites the potential for this to cause damage at ca. 5 m depth, where sampling occurred, is considered minimal as skin divers are unlikely to accidentally damage or stand on corals at these depths. Yacht numbers were similar between Pirates and Store Bay (8276 and 7005 respectively) and if anchor damage is the major cause of coral damage similar damage would have been expected however, this was clearly not the case. Pirates Bay is a smaller area than Store Bay, therefore there is much less space for yachts to find mooring sites that will not damage the reef, yachting pressure on Eastern Reef is nearly 3 times that on Kariwak Reef (Table 1). Yachting pressure on Eastern Reef is further exacerbated by conflict between local fishermen and yacht users over space for seine netting and anchoring.

Yachting pressure was positively related to both indicators of coral damage. As Pirates Bay is well sheltered from wave action and the reef is not currently used for dive tourism, anchors are most likely to have caused the high levels of damage but numbers of yachts alone cannot account for the massive levels of damage compared to the other sites. Yacht pressure was highest within Pirates Bay yet at the time of this study did not have RDBs; however it is not possible to conclude that placing RDBs at Store Bay and Mt Irvine have resulted in the difference because they have only just been installed. If yachting pressure were the only factor in physical coral damage, high levels of past damage would have been expected at Kariwak Reef, where yachting pressure is also high. At ca. 5 m depth on Eastern Reef there was a very large colony of *Porites porites* finger coral covering ca. 30 m^2; some of the transects, by chance, were on or near this colony and recorded high levels of coral damage (up to 93 % coral rubble) meaning at an undamaged state nearly 100 % live coral cover. This may not be representative of the entire reef system where hard coral cover is lower, indeed transects not over the *P. porites* colony showed much lower levels of damage.

High levels of coral cover will increase the potential for coral damage especially considering the delicate finger-like structure of *Porites porites*. The structural strength of corals may be an adapted response to hydraulic stress and fine, branched corals are commonly restricted to sheltered areas (Rogers et al. 2003). As Pirates Bay is

protected from wave action it is possible that the finger coral form of *Porites porites* on Eastern reef are especially susceptible to mechanical disturbance. Marshall (2000) showed experimentally however that *Porites spp* showed high resistance to mechanical stress but at Eastern Reef anchors and their chains were evidently responsible for the majority of damage (Figure 2). Asexual reproduction through fragmentation has been suggested to be a selective adaptation, favouring fragile growth forms to evolve (Highsmith 1982), but the small fragment size of broken *Porites porites* observed (less than ca. 10 cm), will greatly reduce the potential for re-attachment or survival of the fragments (Smith & Hughes 1999). When regression analysis was performed on CR data without values from transects on the *P. porites* colony the correlation between yachting pressure and CR was still significant ($F = 7.01$, $P = \leq 0.05$) suggesting that damage on Eastern reef would be highest as a result of anchor damage even if the fragile *P. porites* colony were not present.

The number of divers per year was higher on Kariwak Reef than Mt. Irvine Reef although per area of reef, diving pressure at Mt. Irvine is higher, 0.37 compared with 0.14 divers $year^{-1}$ $m^{2\ -1}$ at Kariwak Reef. Diving pressure upon Kariwak and Mt. Irvine Reef is ca. half of recommended carrying capacity estimates of 5000-6000 divers per dive site per year (Hawkins & Roberts 1997) suggesting that it will not be a major cause of coral damage and results showed no correlation between diving pressure and coral damage. However, it would be unwise not to consider the potential impacts of diving on these reefs as both reef sites regularly dived upon tend to be used as training sites for in-experienced divers and experiments have shown that untrained divers cause greater damage to corals (Medio et al. 1997). Considerable changes in reef structure may also occur with the initial use of a dive site. Fragile species may be disturbed at very low levels of diving activity, with increases in dive pressure not necessarily corresponding with cumulative deterioration as more hardy coral species remain (Rouphael & Inglis 2002). Studies have shown that diver behaviour can have considerable impact upon rates of coral damage (Medio et al. 1997; Rouphael & Inglis 2001) and it is equally as plausible that yacht user behaviour may impact rates of coral damage through anchoring events. At Store Bay, yachting pressure peaks during large occasional events such as the Angostura Sail Week, with so many yachts in an organised event a self regulatory process may exist whereby individuals found anchoring too close to the reef would lead to reprimands by fellow yacht owners or event organisers. In Pirates Bay there are no such events and individual yachts are responsible only for their own actions and no penalty for anchoring on the reef is enforced.

Obtaining representative views from each stakeholder group were difficult because numbers of participants were low as the study was carried out during the low tourist season and any conclusions should be treated with caution. Fishermen considered sedimentation the greatest cause of reef degradation while the remaining stakeholder groups rarely considered this as a major factor. This difference may be explained by the fishermen's better understanding of local issues; visiting yachters and divers may not be aware of recent controversy concerning sediment runoff from new road developments (O. Day pers comm, 2004). This lack of local knowledge would also explain why glass-bottom boat tours were identified as a cause of physical damage on study sites by diving and yachting participants even though glass-bottom boat tours do not actually operate upon the reefs in this study. Mt. Irvine Reef was considered more degraded than Kariwak Reef even though recorded levels of coral rubble density were lower at Mt. Irvine. Many of the divers interviewed were inexperienced and as a result are likely to have

followed a route determined by an experienced instructor, highlighting the most interesting and aesthetically pleasing aspects of the reef, as a result opinions provided by such divers may not represent each reef as a whole. The largest difference in opinion was at Pirates Bay between yachters and fishermen. Yachters considered Eastern Reef to be in good to excellent condition while fishermen believed the reef to be virtually destroyed, often blaming anchors for the majority of damage. These differences of opinion could explain why current and proposed management options for protecting the reef in Pirates Bay were not seen as adequate by either stakeholder.

Finding a control site for any coral reef investigation is extremely difficult owing to the complexity of the habitat. Booby reef was chosen because human activity upon it was considered extremely low. Physical damage at Booby Reef was considered natural damage and the study assumed that similar levels of natural damage would occur at the other study sites. Different reef sites are subjected to varying hydrological pressures which may influence levels of natural damage; however because the bays in the study are suitable for anchorage, protected from high wave energy, the variation between natural damage at each site may be considered low. Transects were restricted to ca. 5 m which immediately excludes certain areas of reef which may be impacted or respond differently to physical disturbances. Shallower areas are likely to be affected less by anchors and scuba divers and possibly more by snorkellers and finding accurate figures on snorkelling pressure would require substantial monitoring. The area of each study reef varied which lead to a difference in sample density when measuring coral damage, with prior knowledge of reef areas it would have been possible to adjust sample sizes to accommodate variations in reef size.

Anchor, diver or natural damage can be very varied but also difficult to distinguish between (Figure 7), which is why two general indicators were used. Measuring numbers of over-turned colonies has been suggested as best indicator of anchor damage (Dinsdale & Harriott, 2004), however this alone would not be suitable as this study assessed the impacts of all anthropogenic damage, not just anchors. Although this study shows a positive correlation between yachting pressure and coral damage and no correlation between diving pressure and coral damage, these results can not be directly applied to all reef habitats. Different reefs will resist and react differently to physical damage. The topography of a reef and individual colony morphology can play important roles in impacts of mechanical disturbance (Bries 2004, Rouphael & Inglis 1997). However, by measuring coral variables such as skeletal density, branch thickness, branch spacing, branch length, colony height and colony area it may be possible to predict a coral species susceptibility to breakage (Marshall, 2000) and if reef community structure is known then the impacts of anchors or divers can be predicted and appropriate management measures taken (Riegl & Riegl 1996, Rouphael & Inglis 1997). Although this study concentrates on physical damage to corals, it is essential that this is not considered in isolation, because of the complexity of reef habitats. Interactions with other impacts such as disease, nutrient enrichment and climate changes, will affect the impacts of physical damage (Glynn 1994). Studying these interactions is an area for future work and managing their impacts is an increasing challenge for coastal managers.

Figure 7. The types of damage an anchor can cause will vary greatly depending on anchor and chain type, coral type, topography, wave action and currents.

Different damage events will be identifiable for different lengths of time and must be considered if long term monitoring is to be carried out. Coral scrapes and scars may rapidly be covered in macroalgae within days (C. Bentley pers comm 2004) and would be missed from transect measurements even though coral recovery from the event may take much longer. If a reef has high densities of large over-turned colonies the reef will appear damaged for many years. Even if a management strategy prevented any further anthropogenic damage to corals may seem unsuccessful in the short term as recovery may take decades.

Future work & management recommendations. The strong correlation between yachting pressure and coral damage suggests that action to reduce anchor damage to reefs within popular anchorages in Tobago should be an ecological priority. Although current diving pressures upon the study reefs do not appear to be having a significant detrimental impact, dive operators should be encouraged to teach customers good environmental practises when diving near corals. The economic benefits of protecting the study reefs from physical damage are not easy to quantify but would be useful in evaluating the success of management strategies, the only direct use of the reefs observed was for tourist activities as the fishing industry in Tobago is primarily pelagic (O. Day pers comm. 2004). The current RDB programme, which results in no-anchor zones, is likely to benefit Kariwak and Mt. Irvine Reef where competition for space within the bays is less compared to Pirates Bay. A no-anchor zone over Eastern Reef may reduce further coral damage but the social and economic costs must also be considered. By restricting available areas for anchoring, yachters are more likely to encroach upon areas used by fishermen for seine netting therefore increasing the potential for conflict. As tourism is set to increase around Pirates Bay, the future potential revenue from reef-based activities may be high however it can be difficult to justify expensive reef protection programmes when the economic benefits are not quickly realised. This report recommends that fixed mooring buoys be placed in Pirates Bay. Manta Ray^{tm} and helical anchored mooring buoys often used in soft substrate and rubble can provide heavy duty long term anchorage for yachts, whilst protecting the reef from further anchor damage (Halas 1997). They can be placed directly on the reef or coral rubble which will reduce competition for space by fishermen and yachters as the seine nets are not placed over the reef. By charging a fee to use the

moorings it could be possible to cover the costs of maintenance and even employ a member of staff to enforce any regulations in place. Similar mooring buoy projects have been successful at many popular reef sites around the world in reducing anchor damage (Halas, 1997) and continued monitoring of coral damage will allow evaluation of the success of any management strategy implemented. Anthropogenic physical pressures, such as yachting and diving, should also be monitored to enable management strategies to adapt to changes in human activity.

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