SCUBA DIVING AS A SIGNIFICANT CONTROL ON CORAL DIVERSITY.

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ABSTRACT: With the SCUBA diving industry growing at a rate of 7% per annum and a major qualifying agency having just certified its 10 millionth diver, an increasing amount of direct pressure is being placed on marine organisms. In many tropical areas, diving tourism is concentrated in a small area and is often seen to be having an impact on benthic organisms. Due to levels of experience, poor practice, lack of education and negligence, many divers make contact with the substrate, both voluntarily and involuntarily. Bonaire in the Netherlands Antilles offers an ideal site for studying the effects of divers on corals since the marine park legislates for many anthropogenic disturbances. This includes fishing, tourism and development. For 40 sites around Bonaire and Klein Bonaire, diver numbers were compared with data for species diversity. Data was also collected on past wave events, 'healthy' coral cover and the abundance of *Diadema antillarum* and *Echinometra lucunter*. There is a significant relationship between the number of divers and the number of coral species per site. Those sites with up to 4000 dives per year were found to have the highest diversity and species richness. The results exhibited a remarkable similarity when compared to the model for the Intermediate Disturbance Hypothesis. There is also a significant relationship between the distance from development and Shannon Weiner diversity (H'). This study looks in detail at the role of SCUBA activity in coral diversity maintenance, and assesses its significance as a disturbance to the reefs of Bonaire.

INTRODUCTION

The diversity of organisms on coral reefs has been studied in relation to levels of mortality and disturbance on a number of occasions (Aronson and Precht 1995; Edinger *et al.* 1998; Lugo *et al.* 2000; Mackey and Currie 2000; Richmond 1993; Rogers 1993; Wood 1998; Wootton 2001). Various hypotheses have been put forward in an attempt to illustrate the role of disturbance in maintaining diversity on coral reefs, notably the Intermediate Disturbance Hypothesis (Figure 1)(Connell 1978).

Figure 1.

It is suggested that an increase in disturbance is likely to increase the diversity at that site through the colonisation of disturbed areas by opportunistic species. At an intermediate level of disturbance (in terms of frequency or magnitude), a high diversity would be expected. Beyond a given threshold, any further increase in disturbance is likely to decrease diversity by preventing the establishment of less hardy species. This hypothesis has been investigated a number of times in relation to various disturbances and at number of scales (Aronson and Precht 1995; Bythell *et al.* 2000; Dial and Roughgarden 1998; Jones and Syms 1998; Rogers 1993).

The effects of SCUBA diving and snorkeling on coral reefs and diversity have been studied at length (Davis and Tisdell 1995; Davis and Tisdell 1996; Hawkins and Roberts 1993; Hawkins *et al.* 1999; Medio *et al.* 1997; Ohman *et al.* 1993; Rouphael and Inglis 1997; Rouphael and Inglis 1995). It has been shown that even relatively low levels of diving can have pronounced effects on marine communities, manifested in shifts in community structure rather than loss of overall coral cover (Hawkins *et al.*

1999). Divers have been observed having a number of different interactions with the substrate (Table 1).

Table 1.

Such interactions do not necessarily lead to coral mortality, but may cause breakages to those corals with relatively weak morphologies, such as aboescent species(Hall 1997; Marshall 2000).

The most likely groups to be in contact with the substrate are photographers (likely to cause twice as many breakages than non-photographers) or learner divers and others with poor buoyancy skills (Rouphael and Inglis 1995). For those involved in macro photography, certain cameras require the subject to be within 1-4 mm of a framing device. This has a two-fold effect; direct contact of the camera on the subject, also divers tend to become absorbed in the task at hand and through negligence or ignorance kick or damage the coral in the locality of the chosen subject. Others who chose to operate bulky camera rigs often have buoyancy problems and thus come into contact with the substrate with their fins or other equipment (Personal observations).

Learner divers take time to develop buoyancy skills and thus are likely to come into contact with the substrate until they build up enough experience (Rouphael and Inglis 1995). One further group observed coming into contact with the substrate are technical divers or those with a twin tank set – up. This is likely to be due to the difficulty with achieving balanced, neutral buoyancy above the reef when wearing bulky equipment (personal observations). Such observations conflict with findings that more experienced divers are less likely to contact the substrata (Rouphael and Inglis 1995).

Bonaire in the Netherlands Antilles offers an ideal situation for studying the effects of divers on corals (Figure 2).

Figure 2.

Bonaire is situated in the southern Caribbean (12°10'N, 68°15'W) approximately 100 km north of Venezuela. It is approximately 40 km long by 11 km at its widest point, with a land area of 288 km². The small, uninhabited island of Klein Bonaire is located 750 m off the western shore of Bonaire. (De Mayer 1998)

Since 1969, nearly 20% of the total land area of Bonaire has been protected as a national park. Since 1979, the waters around Bonaire, from the high water mark to the 60 metre depth contour, have been designated a marine park and are protected by law (De Mayer 1998). Activities within the marine park are managed to protect the reef, seagrass and mangrove systems.

Most of the controls lie in the tourism and fishing sectors since there is very little primary or secondary industry on the Island. A salt production enterprise in the south if the Island is not deemed to pose a threat to the environment. Oil storage in the north of the Island is a potential threat that has to date been unrealised. There is a small aquaculture venture on the east coast of the Island, which operates as a completely closed system (Personal observations). Bonaire thus offers a unique environment for research because of the controls on destructive fishing and boating practices, little pollution and the promotion of responsible diving. The majority of the dive sites are on the leeward (West) side of the Island, which is sheltered and allows year-round visitation and ideal diving conditions (Figure 3).

Figure 3.

Bonaire depends on diving tourism for much of its foreign income (as much as $23.2 million in 1991 (Dixon *et al.* 1993). It is therefore a priority of the government to maintain the marine environment in a healthy state.

In order to investigate the effect of SCUBA divers on reefs around Bonaire, a study was carried out comparing the number of divers that visit 40 of the 52 dive sites and the coral diversity at those sites.

METHODS

SITE SELECTION

All the sites on the west coast share a similar topography. The reef flat slopes gently to the drop – off between 8 and 14 metres. The slope then becomes steeper to a depth of 50 metres where the reef joins a sandy seabed. Some areas in the North Slope down to depths in excess of 100m. The mooring buoys are placed in around 8 metres of water, close to the edge of the drop-off.

In some areas the reef above 7 metres had been considerably damaged by a wave event after hurricane Lenny in 1999 (Figure 4).

Figure 4.

10 of the 40 sites surveyed were close to beachfront developments (see Figure 2) hence could be affected by non-point source pollution from development and wastewater.

DIVER NUMBERS

It is a legal requirement for dive operators in Bonaire to record data on the number of divers visiting each dive site by boat. To assess which sites were most popular, figures from the top five busiest dive centres were collated (January – June 2001). These centres account for 61% of tag sales (Tag sales being Bonaire Marine Parks source of revenue and entry fee charge). The results were proportional visit figures.

In order to take account of the shore dives, a number of assumptions were made. Having discussed the shore dives with the 5 dive operators it was reasonable to double the numbers of dives by boat for those sites that could be reached by shore. This was a relatively accurate method of taking shore dives into account (not considered in previous studies) and is supported by factors such as the size of car parks near to the dive site. More complex assumptions were made for the sites in front of the resorts. From interviews it was ascertained that the hotels had on average 50% occupancy rates, with an average of 1 diver per room. That diver was likely to do 1.5 resort shore dives per day for an average of 6 days.

These calculations gave a figure for the number of dives per site from January to June and ultimately a projected figure for the number of dives per year per site. Then it was possible to apply the percent of divers visiting each site figure to the number of tag sales for the same period. When the total number of dives calculated manually was compared with the likely number of dives considering the tag sales, the former was 17% less than the latter – accounting for the remaining dive operators not considered in the calculations.

The final figures for the number of divers per site were calculated using the percent figures from the first calculation and the likely number of dives given the expected tag sales for 2001.

CORAL SURVEYS.

Divers most frequently disturb the area around the mooring buoys at each dive site. This is the area they descend to at the start of the dive, it is also the area where safety stops are carried out, divers wait for their buddies and where photographers finish rolls of film. In the marine reserves, where there are no mooring buoys, areas were sampled at random using the same geometry as described below.

A tape measure was run out parallel with the shore to a distance of 20m with the mooring buoy on the 10m point. $1m^2$ quadrats were placed randomly in the area between a depth of 7 and 12 metres (as measured by dive computers and gauges). A power analysis was carried out where n = 45 on three different sites. 30 quadrats per site was sufficient to detect 98% of the species. Identification by the observers was not significantly different ($p = 0.001$). Information was recorded onto slates and immediately entered into a spreadsheet. Each quadrat was divided into a $10cm^2$ grid so percent cover could be estimated with ease. The percent cover of each hard coral species was recorded to an accuracy of 0.1%. The percent cover of soft coral life forms was also recorded to an accuracy of 0.1%.

An estimate was made for each quadrat of the percent of diseased and bleached coral. *Diadema antillarum* and *Echinometra lucunter* individuals were also recorded to account for any outbreaks. These extra factors were taken into account in order to investigate any influence they may have been having on reef diversity.

Regression analysis, plots in 'Axum' and Primer MDS were used to explore the data. For each site the species richness was calculated (number of species per m^2). The Shannon diversity statistic was also calculated (H').

$$H' = -\sum p_i \ln p_i$$

Where p_i (the proportional abundance of the ith species)$=\left(\frac{n_i}{N}\right)$.

RESULTS

Having calculated the figures for the number of divers visiting each site, the resorts surveyed were omitted from the study because of the uncertainty involved with the amount of divers visiting (due to ease of access) and the number of assumptions made. Not including the resorts, the visitation rates for 2001 are likely to range form around 50 people per year in the Marine reserve, and 13100 people per year at the popular wreck dive the Hilma Hooker (Table 2).

Table 2.

The Hilma Hooker was often observed with a boat on the mooring and 5-8 cars parked in the closest car park. Second to the Hilma Hooker is Bonadventure, the most popular boat dive that is situated on the south side of Klein Bonaire, with 10900 divers expected during the year.

The Marine reserve is not open to the public but is open to research divers under the supervision of a ranger, hence a few divers are likely to visit over the course of a year. Lighthouse point is very close to some coastal development and has a problem with algae on the reef flat. This is possibly due to nutrient rich water being released from septic tanks that are used by Bonairians for waste water treatment (Montanas 2001).

The busiest sites do not match up with (Hawkins and Roberts 1993) figures. The most popular site in 1993 were Carls Hill and Jerrys Jam, both located to the north of Klein Bonaire. During the time of survey, Carls Hill was one of the least popular sites

and Jerrys Jam was closed with no mooring or possibility of shore dives. This discrepancy can be accounted for by the effects of the Hurricane Lenny wave event in 1998 when sites to the North of Klein Bonaire were destroyed to a depth between 7 – 8 metres.

The coral surveys produced results for diversity ranging from 2.67 (Margate Bay) to 1.34 (Lighthouse point). The species richness ranged from 8.77 species per m^2 at Sampler to 5.23 at the Hilma Hooker. There was an average of 35% live coral cover, with Angel city having 50% live coral cover, and Jerrys reef with 15% live coral cover (being a spur and groove reef with sandy substrate in the groove).

Thorough searches were carried out for *Diadema antillarum* and *Echinometra lucunter* but no significant numbers were found. It is unlikely that the apparent lack of grazing invertebrates is a control on the coral diversity, since there are a large number of grazing fish around the West coast. In particular, parrot fish (*Spaisoma viride* and *Scarus coelestinus*), which are not targeted by fishermen.

When plotted in alongside a locally weighted regression (LOWESS), two key observations can be made. Firstly, there is a negative relationship between the number of divers visiting a site and the species richness at that site (Figure 5).

Figure 5.

Those sites that have up to 4000 dives per annum have the highest species richness. The most heavily dived sites, Hilma Hooker and Bonadventure have the lowest species richness.

The relationship between the number of divers a site receives and Shannon/Weiner diversity is more complex, (Figure 6).

Figure 6.

There is an overall increase in the diversity between those sites that receive 0 – 4000 divers per year, then the diversity decreases in a linear fashion. Lighthouse point with the lowest diversity was dominated by filamentous green algae to a depth of 10 metres. Margate Bay, located a relatively long way south has an intermediate number of divers visit, as do Mi Dushi and Sampler which are both boat dives only. All three of these sites show high diversity, considerably higher than the marine reserves, which have no public access.

Montastrea annularis dominates the reefs around Bonaire, and accounts for 62% of the coral cover within the Marine Reserve. Other species frequently encountered were *Colopophyllias natanas, Madracis miribalis* and *Agaracia agaracities*. Those species less frequently observed include *Scolymia spp, Leptoseris cucullata, Rhizosmilia maculata, Millepora squarrosa, Rhizopsammia goesi* and *Isophyllia sinuosa.* Such species may less robust than others and hence occupy a more specialised niche (e.g. *Leptoseris cucullata,* commonly known as Fragile Lettuce Coral). There were no significant dissimilarities between the coral community structure at the sites surveyed.

DISCUSSION

Coral reef diversity is maintained by a number of factors operating at a number of different scales (ChadwickFurman 1996; Chesson 2000; Connell 1978; Dial and Roughgarden 1998; Gordon 2000; Huston 1995; Karlson and Hurd 1993; Van Woesik 2000). The result is a dynamic system in a state of constant flux, capable of withstanding minor disturbances.

This study has presented an opportunity to examine the effects of Scuba diving on coral reef diversity in a relatively stable environment. Other studies on diving and coral reefs have concentrated on the damage caused by divers to coral and the nature of the contact (Davis and Tisdell 1995; Jameson *et al.* 1999; Medio *et al.* 1997). Few studies have investigated the rate of coral mortality caused by the diving, or the ecological significance of disturbance from recreational diving.

The results presented here pose a number of more complex issues than have been previously considered in relation to the effect of SCUBA diving. There is a remarkable similarity between the LOWESS plot (Figure 6) and the Intermediate Disturbance Hypothesis of Connell (1978)(Figure 1), suggesting that the range of diving pressure found on Bonaire exacts a control on species diversity, with maximum diversity observed at an intermediate diving pressure.

By interpreting these results conservatively it is possible to suggest that species diversity decreases when diver pressure exceeds a threshold of 4500 visits per year (as suggested by (Dixon *et al.* 1993; Hawkins *et al.* 1999)). Sites with between 0 and 4000 visits per year show an increase in diversity beyond the natural level. The dive sites should therefore be managed to have no more than 4500 visitors per year, to maximise the benefits of diving tourism whilst limiting environmental impact.

Further investigations of the data show that the Marine Reserve sites have Shannon Weiner diversities ranging from 1.56 to 1.91. Only 4 of the sites surveyed (all close to development) have diversities lower than the marine reserve. Personal observations suggest that these sites have been degraded by human influences; therefore the conservative argument seems somewhat futile. Sites that have between 8000 and 10000 visits per year have similar diversities to the Marine Reserve sites and the community structure is not significantly different (after Primer Multiple Dimensional Scaling analysis). Accordingly previous estimates of carrying capacity

(4500 – 5000 divers per year (Dixon *et al.* 1993; Hawkins *et al.* 1999)) can be doubled without having an adverse effect on coral diversity.

Since coral reefs are dynamic systems, it is apparent that they are able to withstand a considerable amount of disturbance before they no longer exist in a 'natural' state. In the long term the effect of divers on coral reefs may not be as significant as originally perceived. Breakages that do occur are traditionally perceived as detrimental to the reef, the reasons for this (e.g. that the reef looks bad) seem somewhat tenuous from an ecological standpoint.

Coral reefs in their 'natural' state are seldom pristine, due to environmental disturbances. The environment in which a coral reef exists provides copious sources of disturbance and a reef is unlikely to exist in a 'pristine' state. Further to this, the reefs around Bonaire are products of a system that has changed considerable amount over the last 500 years (Jackson 1997). Therefore the existence of a 'pristine' reef can be seen as a 'red herring'. Divers act to increase the diversity of the reefs around Bonaire, along with numerous other factors such as parrot fish grazing, turtle grazing, wave events and so on. The argument that any extra damage caused by SCUBA divers is detrimental to the system is difficult to substantiate, since rates of coral mortality caused by diver activity have not been studied to any length. One key study found that weekly touching of corals did not have any effect on the structure, morphology or overall health of the colonies (physiology was not considered) (Talge 1992).

Having SCUBA divers on reefs increases diversity, which is beneficial to biotic and abiotic components of the system (Adey 2000). Indeed, divers may act as substitutes (in terms of contact damage) for the megafauna that has been removed through centuries of overfishing and coastal degradation (Jackson 1997). SCUBA diving can thus be seen as a significant control on coral diversity around Bonaire, but

not necessarily a detrimental one since it does not cause mortality and community decline unless diving pressure is exceptionally high.

There was no relationship between live coral cover and diver numbers; neither was there a relationship between the percent of healthy coral and diver numbers (Table 3).

Table 3.

Diver damage was possibly observed at some sites in the form of coral breakage (although this could have been turtle or parrot fish damage). Hurricane damage had a significant relationship with live coral cover but no relationship with diversity or species number, as would be expected.

Other significant controls on diversity should be management priorities in Marine Parks, such as pollution and development, which are more likely to cause coral mortality. On Bonaire a significant relationship exists between diversity and proximity to development as well as the number of divers. Environmental variables were established to test for any relationship between the proximity of a site to development (to account for any non-point source pollution) and the effect of the hurricane Lenny wave event (Table). Hence pollution may have an influence on reef diversity around Bonaire. In an attempt to manage damage to the reefs through non-point source pollution, the department of the environment is still pursuing the installation of a secondary waste water treatment plant. This may prove to be the most important step in maintaining the diversity of Bonaire's reefs in the future.

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REFERENCES

Adey, W. H. (2000) Coral reef ecosystems and human health: Biodiversity counts! Ecosystem Health 6, 227-236.

Aronson, R. B. and Precht, W. F. (1995) Landscape Patterns of Reef Coral Diversity - a Test of the Intermediate Disturbance Hypothesis. Journal of Experimental Marine Biology and Ecology 192, 1-14.

Bythell, J. C., Hillis-Starr, Z. M. and Rogers, C. S. (2000) Local variability but landscape stability in coral reef communities following repeated hurricane impacts. Marine Ecology-Progress Series 204, 93-100.

ChadwickFurman, N. E. (1996) Reef coral diversity and global change. Global Change Biology 2, 559-568.

Chesson, P. (2000) Mechanisms of maintenance of species diversity. Annual Review of Ecology and Systematics 31, 343-354.

Connell, J. H. (1978) Diversity in rainforests and coral reefs. Science 199, 1302-1310.

Davis, D. and Tisdell, C. (1995) Recreational Scuba Diving and Carrying-Capacity in Marine Protected Areas. Ocean & Coastal Management 26, 19-40.

Davis, D. and Tisdell, C. (1996) Economic management of recreational scuba diving and the environment. Journal of Environmental Management 48, 229-248.

De Mayer, K. (1998) Coastal Region and small Island papers 3: Bonaire, Netherlands Antilles. In Environment and development in coastal regions and small Islands.

Dial, R. and Roughgarden, J. (1998) Theory of marine communities: The intermediate disturbance hypothesis. Ecology 79, 1412-1424.

Dixon, J. A., Scura, L. F. and Vanthof, T. (1993) Meeting Ecological and Economic Goals - Marine Parks in the Caribbean. Ambio 22, 117-125.

Edinger, E. N., Jompa, J., Limmon, G. V., Widjatmoko, W. and Risk, M. J. (1998) Reef degradation and coral biodiversity in Indonesia: Effects of land-based pollution, destructive fishing practices and changes over time. Marine Pollution Bulletin 36, 617-630.

Gordon, C. E. (2000) The coexistence of species. Revista Chilena De Historia Natural 73, 175-198.

Hall, V. R. (1997) Interspecific differences in the regeneration of artificial injuries on scleractinian corals. Journal of Experimental Marine Biology and Ecology 212, 9-23.

Hawkins, J. P. and Roberts, C. M. (1993) Effects of Recreational Scuba Diving On Coral Reefs - Trampling On Reef-Flat Communities. Journal of Applied Ecology 30, 25-30.

Hawkins, J. P., Roberts, C. M., Van't Hof, T., de Meyer, K., Tratalos, J. and Aldam, C. (1999) Effects of recreational scuba diving on Caribbean coral and fish communities. Conservation Biology 13, 888-897.

Huston, M. A. (1995). Biological diversity: The coexistence of species on changing landscapes. Cambridge: Cambridge University Press.

Jackson, J. B. C. (1997) Reefs since Columbus. Coral Reefs 16, S23-S22.

Jameson, S. C., Ammar, M. S. A., Saadalla, E., Mostafa, H. M. and Riegl, B. (1999) A coral damage index and its application to diving sites in the Egyptian Red Sea. Coral Reefs 18, 333-339.

Jones, G. P. and Syms, C. (1998) Disturbance, habitat structure and the ecology of fishes on coral reefs. Australian Journal of Ecology 23, 287-297.

Karlson, R. H. and Hurd, L. E. (1993) Disturbance, Coral-Reef Communities, and Changing Ecological Paradigms. Coral Reefs 12, 117-125.

Lugo, A. E., Rogers, C. and Nixon, S. (2000) Hurricanes, coral reefs and rainforests: Resistance, ruin and recovery in the Caribbean. Ambio 29, 106-114.

Mackey, R. L. and Currie, D. J. (2000) A re-examination of the expected effects of disturbance on diversity. Oikos 88, 483-493.

Marshall, P. A. (2000) Skeletal damage in reef corals: relating resistance to colony morphology. Marine Ecology-Progress Series 200, 177-189.

Medio, D., Ormond, R. F. G. and Pearson, M. (1997) Effect of briefings on rates of damage to corals by scuba divers. Biological Conservation 79, 91-95.

Montanas, P. (2001). Personal communication: Department of the environment, Bonaire.

Ohman, M. C., Rajasuriya, A. and Linden, O. (1993) Human Disturbances On Coral-Reefs in Sri-Lanka - a Case-Study. Ambio 22, 474-480.

Richmond, R. H. (1993) Coral-Reefs - Present Problems and Future Concerns Resulting From Anthropogenic Disturbance. American Zoologist 33, 524-536.

Rogers, C. S. (1993) Hurricanes and Coral-Reefs - the Intermediate Disturbance Hypothesis Revisited. Coral Reefs 12, 127-137.

Rouphael, A. B. and Inglis, G. J. (1997) Impacts of recreational scuba diving at sites with different reef topographies. Biological Conservation 82, 329-336.

Rouphael, T. and Inglis, G. (1995). The effects of qualified recreational SCUBA divers on coral reefs. North Queensland: James Cook University.

Talge, H. (1990). The impact of recreational divers on coral reefs in the Florida Keys. In Proceedings of the American Academy of underwater sciences. Tenth annual scientific diving symposium., pp. 365- 373.

Talge, H. (1992). Impact of recreational divers on Scleratinian corals at Looe Key, Florida. In Proceedings of the seventh International Coral Reef Symposium, vol. 2. Guam.

Van Woesik, R. (2000) Modelling processes that generate and maintain coral community diversity. Biodiversity and Conservation 9, 1219-1233.

Wood, R. (1998) The ecological evolution of reefs. Annual Review of Ecology and Systematics 29, 179-206.

Wootton, J. T. (2001) Causes of species diversity differences: a comparative analysis of Markov models. Ecology Letters 4, 46-56.

Figure 1. The Intermediate Disturbance Hypothesis where intermediate frequencies and magnitudes of disturbance can result in a higher species diversity (Connell 1978). A suggested mechanism for this is that diversity is highest where neither population failure to recover from mortality or competitive displacement dominate (Huston 1995).

Figure 2. Bonaire within the Caribbean (inset). Bonaire is 40km long by approximately 11km wide, with most of its dive sites on the leeward side of the island. Those dive sites marked with a hairline are those surveyed for this study. The shaded areas show the main centres of coastal development.

Figure 3. Healthy stands of *Acropora palmata*, other marine animals and clear waters attract many divers to Bonaire.

Figure 4. The location of some of the key dive sites surveyed and areas effected by hurricane Lenny wave event (the bold lines indicate the areas most significantly damaged).

Figure 5. Species richness and the number of dives per site per annum. The fitted line is a LOWESS (locally-weighted regression) estimate.

Figure 6. Shannon – Weiner diversity (H') and the number of dives per site per annum, with some of the key sites marked on. The fitted line is a LOWESS (locally-weighted regression) estimate.

Figure 1.

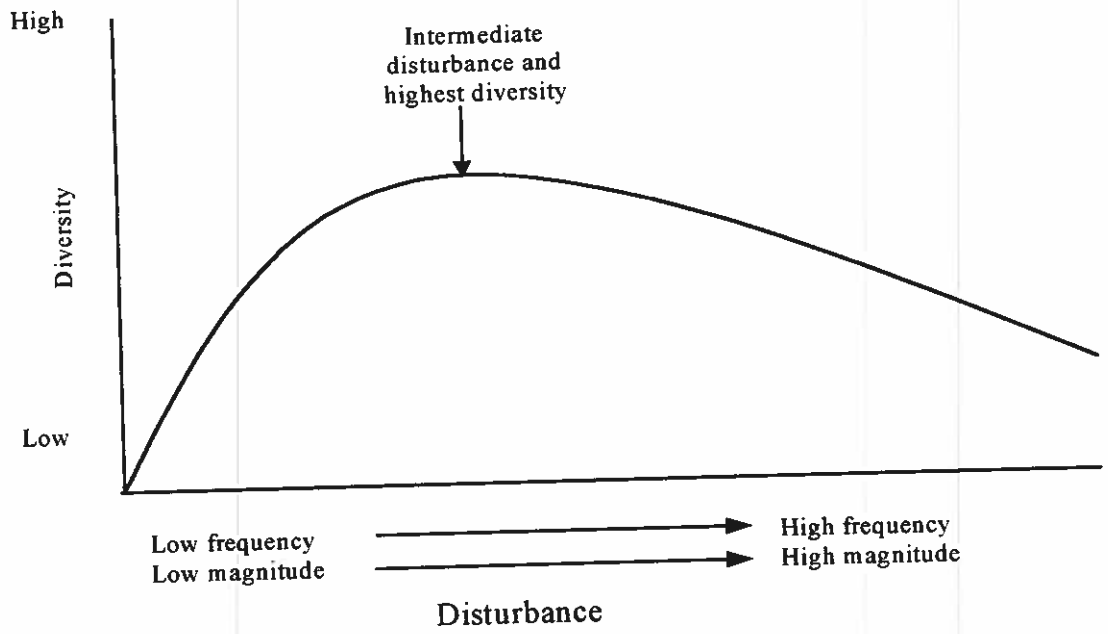

High
Intermediate
disturbance and
highest diversity
Diversity
Low
Low frequency
Low magnitude
High frequency
High magnitude
Disturbance

Figure 2.

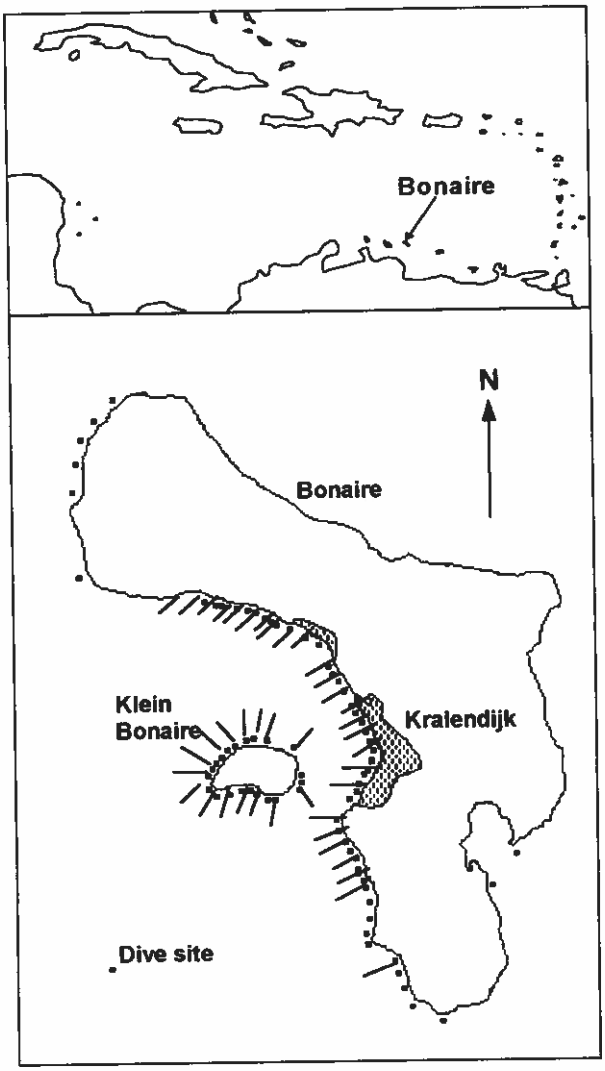


Figure 3.

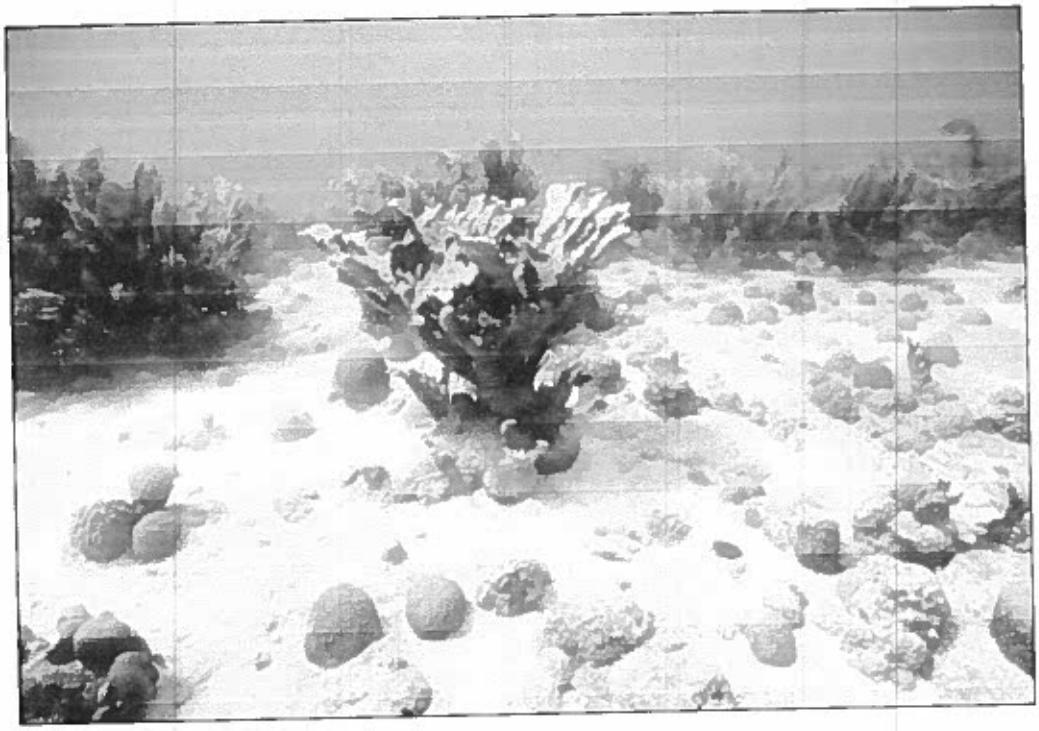


Figure 4.

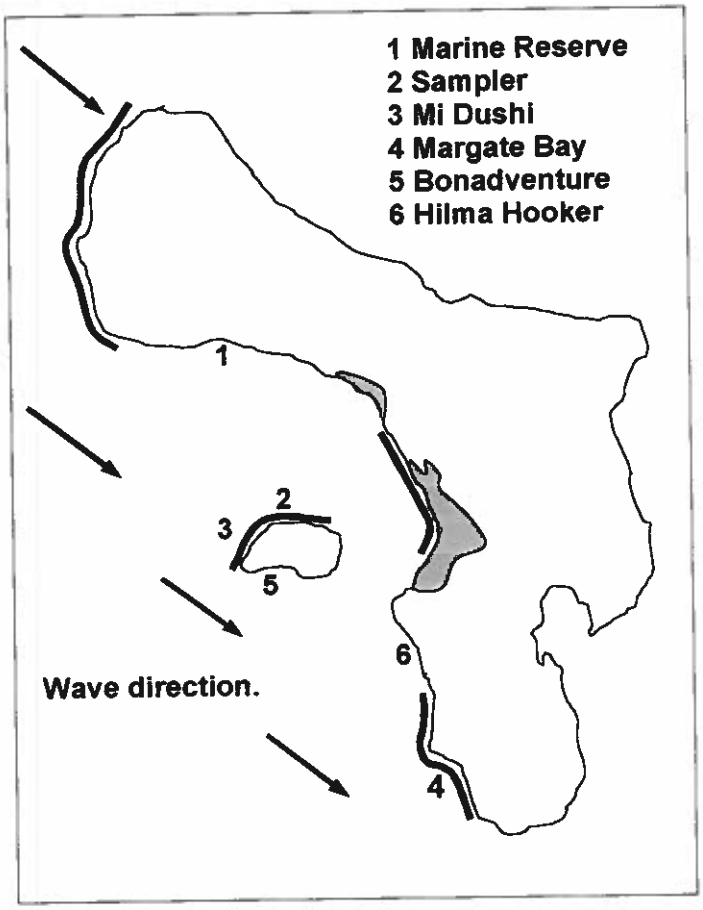
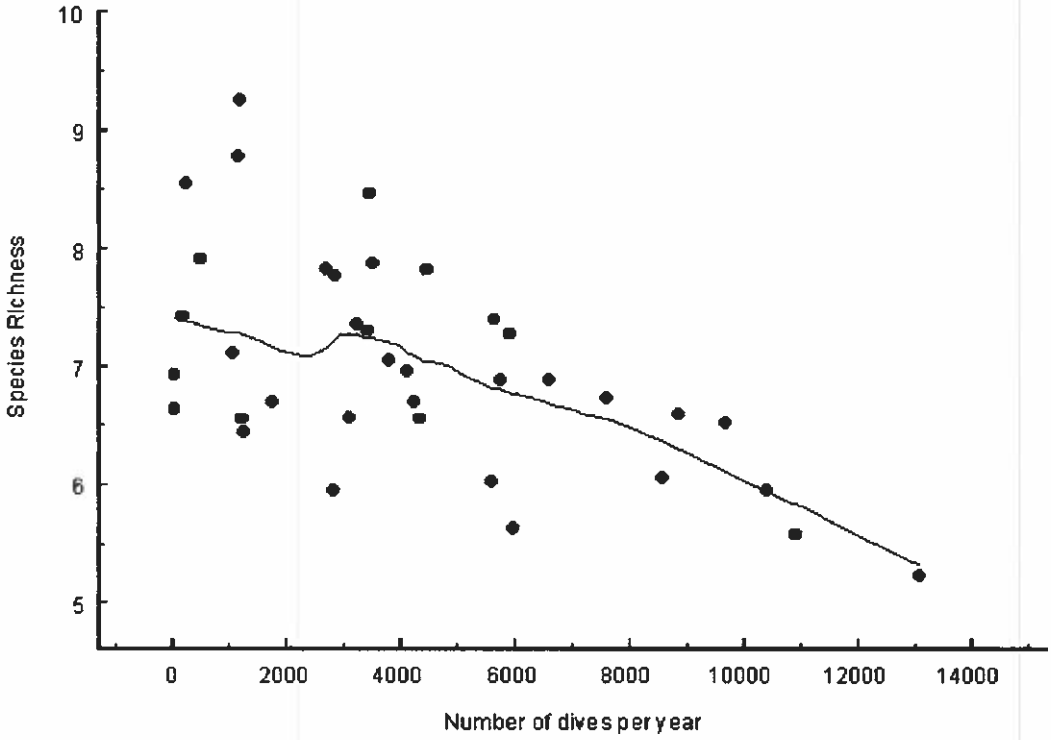

1 Marine Reserve
2 Sampler
3 Mi Dushi
4 Margate Bay
5 Bonadventure
6 Hilma Hooker
1
2
3
5
6
4
Wave direction.

Figure 5.


10
9
8
7
6
5
Species Richness
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2000
4000
6000
8000
10000
12000
14000
Number of dives per year

Figure 6.

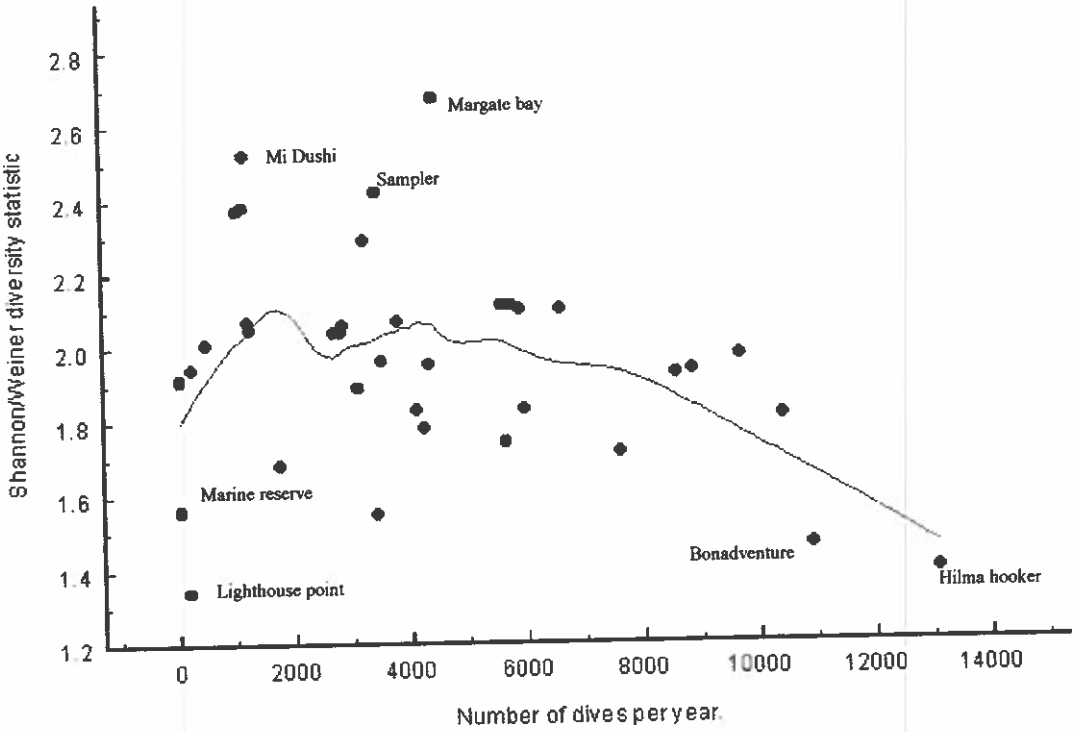
Shannon/Weiner diversity statistic
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
0
2000
4000
6000
8000
10000
12000
14000
Number of dives per year
Margate bay
Mi Dushi
Sampler
Marine reserve
Lighthouse point
Bonadventure
Hilma hooker

Table 1. Key interactions between SCUBA divers and coral reef substrate(Talge 1990). Most contacts are unlikely to cause mortality directly but can be considered a constant disturbance.

1. Placement of hand on the coral to steady the diver or help regain control
2. Kicking or brushing with fins
3. Standing on coral (mainly snorkellers)
4. Grabbing corals to pull themselves through the water
5. Rubbing against stoney coral with part of the body
6. Hitting the coral with SCUBA tank or other pieces of equipment
7. Creating sediment clouds.

Table 2. Projected dive site visitation figures (for 2001) and coral diversity figures for dive sites on the West coast of Bonaire. The sites in italics are resorts. Species richness is given in number of species per m^2. *H'* is the Shannon Weiner diversity statistic.

	Number of dives per year	Species richness	(*H'*).
Eighteen Palms	*125046*	*6.31*	*1.39*
Reef Scientifico	*57295*	*6.63*	*1.74*
Bari Reef	*47954*	*7.02*	*2.44*
Hilma Hooker	13097	5.23	1.39
Bonaventure	10908	5.57	1.46
Angel City	10417	5.95	1.81
Thousand Steps	9688	6.51	1.97
Andrea I	8870	6.59	1.93
Weber's Joy	8593	6.05	1.92
Calabas Reef	7618	6.73	1.71
Karpata	6618	6.88	2.1
Monte's Divi (Tree)	5982	5.62	1.83
South Bay	5901	7.27	2.1
Rock Pile	5769	6.88	2.11
Andrea Ii	5649	7.39	1.74
Something Special	5586	6.02	2.11
Margate Bay	4466	7.82	2.67
Rappel	4341	6.55	1.95
La Dania's Leap	4240	6.69	1.78
Oil Slick Leap	4120	6.95	1.83
Barcadera	3806	7.05	2.07
Joanna's Sunchi	3510	7.87	1.96
Jerry's Reef	3472	8.46	2.42
Small Wall	3428	7.3	1.55
Country Garden	3246	7.35	2.29
A. In Wonderland	3120	6.56	1.89
Jeff Davis	2862	7.77	2.06
Forest	2818	5.94	2.04
North Belnam	2718	7.83	2.04
Bachelors Beach	1761	6.7	1.68
Windsock Steep	1271	6.43	2.05
Punt Vierkant	1233	6.55	2.07
Mi Dushi	1189	9.25	2.52
Sampler	1164	8.77	2.38
Invisibles	1069	7.11	2.37
Carl's Hill	491	7.91	2.01
Sharon's Serenity	258	8.54	1.94
Lighthouse Point	189	7.42	1.34
Marine Reserve 1	47	6.64	1.91
Marine Reserve 2	47	6.92	1.56

Table 3. Significance (p values) of regression between species richness, Shannon diversity (H') and selected environmental variables. Figures in bold are where the relationship is statistically significant.

Environmental variable	Species richness.	H'	% helathy coral.	% living coral.
Proximity to development (Km)	0.414	**0.010**	0.511	0.625
Hurricane impact factor (/5)	0.109	0.813	0.141	**0.000**
% healthy coral	0.021	0.193	-	-
% live coral cover	0.021	0.193	-	-
Number of dives per site.	**0.010**	0.108	0.551	0.145