Effects of SCUBA diving on coral reef invertebrates in the U.S. Virgin Islands: implications for the management of diving tourism

N.E. Chadwick-Furman

Chadwick-Furman, N.E. Effects of SCUBA diving on coral reef invertebrates in the U.S. Virgin Islands: implications for the management of diving tourism. Proceedings of the 6th International Conference on Coelenterate Biology, 1995: 91-100, figs 1-5. Nanette E. Chadwick-Furman, Interuniversity Institute for Marine Science, P.O. Box 469, Eilat, Israel, Fax: 7-6374329, E-mail: furman@brosh.cc.biu.ac.il

Key words: Coral reef; damage; SCUBA diving; tourism management; scleractinian stony coral; alcyonarian soft coral; hydrocoral; sea fan; sponge; St. John; U.S. Virgin Islands.

Abstract: The number of visitors to coral reefs worldwide has increased greatly in recent years. The negative impacts of snorkelers, reef walkers and SCUBA divers on corals are only beginning to be understood. Especially needed is information on critical limits of visitor use, above which damage to reefs may sharply rise. To quantify the effects of SCUBA diving on coral reef invertebrates, I examined seven sites in the U.S. Virgin Islands. The frequency of SCUBA dives per site was determined from log books, and varied greatly from 20 to over 400 dives in 6 months. The amount of damage at each site was assessed by counting all damaged and undamaged individuals of each of 6 major types of invertebrates in a 100 m² area at 4-7 m depth. Levels of water motion also were measured, and did not correlate significantly with damage to any of the reef organisms. Massive stony corals exhibited low levels of damage (up to 1.5% of individuals), which did not correlate with diving frequency. Erect sponges, and branching stony and soft corals exhibited intermediate levels of damage (up to 21.2%). In both types of branching corals, damage correlated significantly with diving activity on the reefs. Sea fans and branching hydrocorals (Millepora spp.) had very high levels of damage on all reefs (up to 70.0%), which did not correlate with diving activity. The results show that sessile invertebrates vary in their vulnerability to damage, and that groups with intermediate vulnerability are the most likely to reveal impacts of SCUBA diving. The data indicate a critical level of about 500 dives per year at each reef site, above which damage to some reef taxa increased greatly. This critical level is lower than those estimated for other coral reefs, and may reflect the fragility of the reefs studied here. Such information concerning the upper critical limits of SCUBA diving and other tourist activities is necessary for the effective management of coral reefs.

Introduction

Tourism associated with coral reefs is rising exponentially world wide, as documented for reef areas in the Caribbean (Tilmant, 1987: 198; Rogers et al., 1988: 405; Dixon, 1993: 39), Australia (Tilmant, 1987: 198; Neil, 1990: 221), and Red Sea (Hawkins & Roberts, 1992a: 1007; 1993: 25; Mashi & Ortal, 1995: 30). Recently, studies have shown significant damage to coral reefs from high levels of recreational SCUBA diving (Riegli & Velimirov, 1991: 249; Hawkins & Roberts, 1992b: 175; Dixon, 1993: 38), reef walking on shallow coral reef flats (Woodland & Hooper, 1977: 2; Neil, 1990: 226; Hawkins & Roberts, 1993: 28), and boat groundings and anchor scars (Rogers et al., 1988: 407). Some studies indicate that there may be a threshold or critical level of visitation on reefs, above which damage rises sharply. Estimates of critical levels of SCUBA diving on coral reefs vary from 4,000-6,000 dives/site/year for Bonaire in the
Caribbean (Dixon, 1993: 38) to 5,000-6,000 dives/site/year for Sharm-El-Sheikh in the Red Sea (Hawkins & Roberts, in press). Determination of carrying capacity or critical visitation level is a first and necessary step for the effective management of popular coral reef areas as viable, sustainable ecosystems.

I present here data from a field study in the U.S. Virgin Islands, which show that: (1) damage to certain reef organisms rises rapidly above a critical level of diving frequency, and (2) reef invertebrates vary widely in their vulnerability to structural damage.

Methods

The present study was conducted during summer 1988 on the south side of St. John, U.S. Virgin Islands, in the area around Greater Lameshur Bay. This area is in a remote location inside Virgin Islands National Park, and contains pristine fringing coral communities (Rogers et al., 1991: 190; Witman, 1992: 643). Few divers were observed to visit the area, except those directly involved in the present study (N. E. Chadwick-Furman, pers. obs.). To measure effects of SCUBA diving, I selected 6 discrete reef sites in the Greater Lameshur Bay area: Coral Gardens and Donkey Bight (protected inner bay sites), Tektite Cove and Yawzi Point (intermediate-exposure sites, described in detail by Edmunds & Witman, 1991: 201; Rogers et al., 1991: 190), and White Point and Cabrite Point (exposed sites; Cabrite Point described in detail by Witman, 1992: 643). I also examined a site at Lesser St. James Island, a small unmarked islet between St. John and St. Thomas Islands, which appeared to receive low frequencies of SCUBA dives due to its remote location.

Data on 3 parameters were collected at each site: numbers of SCUBA dives during the 6 months immediately preceding the study, frequency of damage to coral reef invertebrates, and levels of water motion. To determine SCUBA diving levels, I used log books maintained for each site by students at the Virgin Islands Ecological Research Station (VIERS) during February to July 1988. As explained above, these dives likely represent most if not all diving activity in the Greater Lameshur Bay area during this period.

To assess levels of damage to reefs at each site, I collected data on 6 major types of sessile reef invertebrates likely to incur structural damage (species examined in each group are given in parentheses): (1) massive stony (scleractinian) corals (Colpophyllia natans, Diploria clivosa, D. labyrinthiformes, D. strigosa, Favia fragum, Montastrea annularis, M. cavernosa, Porites astreoides, Siderastrea radians, S. siderea), (2) branching stony (scleractinian) corals (Porites porites), (3) branching soft (alcyonacean) corals (Briareum asbestinum, Eunicea spp., Muricea spp., Plexaura spp., Plexaurella spp., Pseudopterogorgia spp.), (4) gorgonian sea fans (Gorgonia ventalina), (5) branching hydrocorals (Millepora spp.), and (6) erect sponges (Ectoplasia ferox, Haliclonia rubens, H. viridis, Ircinia campana, I. strobilina, Niphates digitalis, N. erecta, Spathespongia vesparium, Xestospongia muta). All damaged and undamaged individuals in each group were counted in belt transects laid parallel to shore at 4-7 m depth at each site. Each belt transect measured 50 x 2 meters, thus 100 square meters of reef area were examined at each site. A damaged individual was defined as one with broken or bent branches, abraded skeleton, or tissue loss which exposed the underlying skeleton (after Riegl &

I also determined water motion levels at each site, as this physical factor may cause extensive structural damage to shallow reef organisms (Edmunds & Witman, 1991: 201; Rogers et al., 1991: 189; Witman, 1992: 649). Relative levels of water motion were determined using the clod-card method of Doty (1971: 32). This method provides only relative values, but allows rapid and easy quantification of water motion levels, and was adequate for the purposes of the present study. Clod cards of plaster of Paris (calcium sulfate) were placed at each site at 4 meters depth, and retrieved after 24 hours. The mass lost due to motion-enhanced diffusion was calculated for each clod, yielding an index of water motion (see Doty, 1971: 33, for method of calculation).

Results

Levels of diving activity varied greatly among the sites, from only 20 dives/6 months at Lesser St. James to 400 dives/6 months at Coral Gardens (fig. 1). Frequently-dived areas included both protected (Coral Gardens) and intermediate-exposure
Fig. 2. Variation in frequency of skeletal damage to sessile invertebrates with levels of water motion at reef sites on St. John, U.S. Virgin Islands. Note that there was no significant correlation between the 2 factors in any of the 6 invertebrate groups examined.

Sites (Tektite Cove), while areas with relatively low numbers of dives also were in both protected (Donkey Bight) and exposed (White Point) locations (fig. 1). Thus, the amount of diving activity did not correlate significantly with water motion levels at the sites examined ($r^2 = 0.35$, $p>0.05$).

Frequency of damage varied widely among the 6 invertebrate groups, and did not correlate significantly with water motion level in any group (range of $r^2 = 0.003-0.45$, $p>0.05$ for all) (fig. 2). Massive stony corals were the most abundant sessile invertebrates at all sites examined (range = 135-625 individuals/100 m$^2$). Massive corals had low levels of damage (range = 0-1.5% of individuals examined), which did not correlate with levels of diving activity ($r^2 = 0.48$, $p>0.05$). Damage to massive corals was observed in the form of abrasion, crushed scleractin, and tissue loss.

Only one species of branching stony coral (*Porites porites*) was common on the
reefs examined here (range = 31-69 individuals/100 m²). P. porites had intermediate 
levels of damage (0-12.5% of individuals), observed in the form of broken branches 
and tissue loss. Damage to these branching stony corals correlated significantly with 
SCUBA diving activity (fig. 3).

Branching soft corals were abundant members of the reef community (range = 
45-220 individuals/100 m²). They also exhibited intermediate levels of damage (0-
21.2% of individuals), which correlated significantly with diving activity (fig. 3). The 
type of damage varied with species; in soft corals with thick rigid skeletons (Briareum 
asbestinum), branches were severed and lying on the surrounding substratum. In spe-
cies with more flexible skeletons (Plexaura spp., Pseudopterogorgia spp.), the branches 
were bent or polyps were missing near the branch tips. In one case, a colony of Plex-
aurella spp. was observed to be almost completely detached from the substratum.

One species of sea fan (Gorgonia ventailina) was fairly abundant at the study sites 
(range = 10-49 individuals/100 m²). Sea fans had relatively high levels of damage at 
all sites (9.4-70.0% of individuals), which did not correlate significantly with levels of 
diving activity ($r^2 = 0.05$, p>0.05). Much damage was observed on sea fans in the

![Graph showing the relationship between branching stony corals and branching soft corals](image)

**Fig. 3.** Variation in skeletal damage to branching stony (Scleractinia) and soft corals (Alcyonacea) with levels of SCUBA diving activity on reefs in the U.S. Virgin Islands.
Fig. 4. Variation in damage to erect sponges with levels of SCUBA diving activity on reefs in the U.S. Virgin Islands.

Form of rips, tissue loss, bent skeletal elements, and holes in which skeleton was completely removed from the fan.

Branching hydrocorals (*Millepora* spp.) varied widely in their abundance, and at some sites were dominant members of the reef community (range = 17-154 individuals/100 m²). They also exhibited high frequencies of damage (2.9-52.2% of individuals), mostly in the form of broken branches, the brittle tips of which were scattered around the base of colonies. The high levels of damage to hydrocorals did not correlate significantly with diving activity ($r^2 = 0.006, p > 0.05$).

The last group of sessile invertebrates examined, the erect sponges, were common and conspicuous members of the reef community at all sites (range = 46-171 individuals/100 m²). Sponges had low to intermediate levels of damage (0-6.3% of individuals), in the form of torn skeletal elements in vase-shaped species such as *Ircinia campiana*, and broken branches in branching species such as *Haliclona* spp.

Damage to sponges increased directly with frequency of SCUBA diving (fig. 4),
but the correlation was not significant ($r^2 = 0.65$, 0.05<p<0.10), possibly due to the absence of data from one site (see Methods).

Discussion

This study shows that damage to branching soft and stony corals varies directly with levels of SCUBA diving activity on fringing reefs in the U.S. Virgin Islands. At SCUBA diving frequencies higher than about 250 dives/6 months/site (=500 dives/year/site), damage to both types of corals rises substantially (fig. 3), indicating a critical level of diving activity on these reefs. The same phenomenon is observed for sponges, in that damage rises steeply above a critical level of about 200 dives/6 months (fig. 4). Thus, data for 3 different types of reef invertebrates with branching morphologies indicate a common trend of increases in structural damage with levels of human visitation.

These findings have important implications for the management of tourism on coral reefs. They indicate that reef organisms may be able to withstand low levels of diving activity with minimal damage. If, however, high frequencies of SCUBA diving are allowed to occur on reefs, as when unlimited diving access is allowed at popular sites, the more fragile and erect reef organisms may suffer substantial skeletal damage. The only way to reduce such damage is to limit the amount of physical contact between diver and reef, in the form of setting upper visitation limits on numbers of dives per site per unit time, and/or in education to change diving behaviour (Hawkins & Roberts, in press; Dixon, 1993: 39).

The critical level of diving frequency indicated for reefs here (about 500 dives/site/year) is much lower than those estimated for reef areas in Bonaire of 4,000-6,000 dives/site/year (Dixon, 1993: 38) and in Egypt of 5,000-6,000 dives/site/year (Hawkins & Roberts, in press), possibly due to the high abundance here of delicate organisms such as branching soft corals and sponges. According to the above data, levels of diving on several of the world’s most popular coral reefs currently far exceed minimal-damage levels, and are likely causing major damage to reef organisms. About 2 km of fringing reef at Elat, in Israel on the Red Sea, currently receive at least 200,000 dives per year (Meshi and Ortal, 1995: 30). Popular reefs at Sharm-el-Sheikh have up to 50,000 dives/site/year, and the Egyptian Government plans to increase this number 10-fold in the next 20 years (Hawkins & Roberts, 1992b: 1007).

Damaged or broken scleractinian corals divert energy from normal growth and reproduction into repairing lost parts (Chadwick & Loya, 1990: 227; Rinkevich & Loya, 1989: 260). Thus, structural damage to live reef corals (and most likely to other reef organisms) may reduce the sexual production of new individuals, and greatly affect the replenishment of organisms to the reef. Some branching corals, in contrast, may disperse colony fragments through breakage (Highsmith, 1982). Nevertheless, the implications of unlimited diving access to coral reefs are serious, as the recovery rate of reefs heavily damaged by human interference is on the scale of decades or longer (Loya, 1990; 373). Limitation of recreational access to reefs may be viewed as an investment in the resource base that supports diving tourism (Dixon, 1993: 37).

The second major finding of the present study is that sessile reef invertebrates may be ranked according to their levels of vulnerability to structural damage (fig. 5).
Sea fans and branching hydrocorals were the most vulnerable organisms on the reefs examined here. High damage levels to sea fans and hydrocorals on reefs with low diving activity indicate that such damage may be due to natural causes, including water motion or predation (Harvell & Suchanek, 1987: 41; Lewis, 1991: 101). The 3 invertebrate groups with intermediate levels of vulnerability (branching soft and stony corals, and erect sponges) (fig. 5) all showed a positive relationship between damage and diving activity. Thus, intermediate-vulnerability organisms are the most likely to reveal the effects of SCUBA diving and other human activities that physically impact the reef. Massive stony corals were the least vulnerable to damage of the groups examined here (fig. 5), probably due to their dense skeletons and lack of protruding structures. They are thus less likely to reveal structural effects of human activities, except under conditions of severe reef damage. Other studies have also shown variation in vulnerability to damage among sessile reef invertebrates, and in general have found that branching organisms are much more susceptible to damage than are massive organisms (Woodland & Hooper, 1977: 2; Liddle & Kay, 1987: 1; Rogers et al., 1991: 192; Hawkins & Roberts, 1992b: 176).

The present study has several weaknesses. Firstly, no attempt was made to differ-
entiate human-caused from natural damage to reef organisms. All damage observed was recorded, and if levels covaried with SCUBA diving activity, the damage was assumed to be of human origin. Thus, the data are correlative, and cause and effect may be only inferred. This is a general problem with diver-impact studies on coral reefs, due to difficulties in monitoring and manipulating the number of SCUBA dives. Small-scale field experiments, however, have directly shown negative impacts of human visitation on reef corals (Liddle & Kay, 1987: 17; Woodland & Hooper, 1977: 2). Secondly, studies conducted recently at some of the sites in Greater Lameshur Bay have revealed that, since the present survey was completed in 1988, major hurricanes have caused far greater damage to the reefs than that recorded here, and likely have obliterated most evidence of diver-related damage in the area (Edmunds & Witman, 1991: 202; Rogers et al., 1991: 192; Witman, 1992: 649). Although major marine storms obviously may cause far greater damage than SCUBA divers to reefs, the effects of divers are not benign. Reefs may be weakened by human impacts, and thus less able to withstand or recover from storms or other natural disturbances which follow (Loya, 1990: 372). A third weakness of the present study is that only a small number of sites was examined due to limitation in the SCUBA diving records available. Thus, the findings represent only a small subset of reefs, and may not be applicable to other reef areas with widely different invertebrate communities or ecological conditions. Because of ecological variation between reef communities worldwide, it is important that carrying capacity estimates of reefs for diving be viewed as elastic rather than fixed (Hawkins & Roberts, in press).

In conclusion, the present study clearly indicates that high levels of SCUBA diving activity may cause substantial damage to certain reef organisms, with implications for the structure of the reef community and the health and sustainability of the ecosystem as a whole. It is to be hoped that this type of information will be used by resource managers and environmental planners to set realistic limits of recreational use on coral reefs. Without implementation of such limits, the most popular reef areas are likely to continue to deteriorate, leading eventually to erosion of the natural resource upon which much tourism is based.

Acknowledgements

I thank the staff of the Virgin Islands Ecological Field Station (VIERS) for logistical support. Diving surveys and data analysis were carried out with the assistance of G. de la Paz, R. Fischer, G. Harvey, A. Hazelton, R. Neumann, S. Paquelet, R. Stewart, and D. Snyder. The Virgin Islands National Park graciously allowed the operation of programs of the School for Field Studies at VIERS during 1988, which made this study possible.

References


