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Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs

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This study investigated the effects of recreational SCUBA diving on the fore-reef slopes of coral reefs near Sharm-el-Sheikh, a popular resort in Egypt. Benthic communities were compared using randomly placed 1-m^2 quadrats at three sites subdivided into heavily and little dived areas. There were significantly more damaged coral colonies, loose fragments of live coral, fragments of coral re-attached to the substratum, partially dead and abraded corals in areas heavily used by divers than in control areas. Damage to corals varied with growth form, branching forms being most vulnerable to breakage.

Changes to communities at heavily and little dived sites were studied over 12 months using 3 × 3 m permanent quadrats. No significant increases in damage attributable to diving were detected for the three sites combined. However, when considered individually, the site which had experienced the greatest increase in diving appeared to have accumulated damage (broken coral) whereas the two others did not.

For management purposes the results show that some reefs can sustain heavy levels of diving without apparent continued degradation. New dive sites can accumulate damage very rapidly. However, at the levels of diver use encountered during this study this may be more of an aesthetic than a biological problem.

INTRODUCTION

Coral reefs are very popular with SCUBA divers due to the great variety of life they support and their immense visual appeal. Until recently diving on reefs was generally perceived as a non-destructive activity, a means by which countries might derive benefit from their reefs without harming them (Tilmant, 1987). However, excessive diving pressure has since been implicated in reef degradation, leading to widespread concern (Ward, 1990).

Recreational diving can damage reefs both directly and indirectly. Several studies have looked at the adverse effects of heavy boating pressure (Bright, 1985; Rogers, 1988) and the provision of facilities for tourists (Brown & Dunne, 1988; Bell *et al.*, 1989), but the direct impact of divers on reefs has received very little investigation. Divers damage reefs in a number of ways. This is usually accidental and can result from kicking, trampling, holding, kneeling or standing on benthic organisms. Resuspension of sediment may also stress organisms (Rogers, 1990). Most work to date has concentrated on effects of trampling on coral reef-flats (Woodland & Hooper, 1977; Kay & Liddle, 1987, 1989; Hawkins & Roberts, in press).

This study was designed to look at the effects of recreational diving on the fore-reef slope communities of reefs around Sharm-el-Sheikh on the Egyptian Red Sea coast. These reefs have attracted large numbers of divers for over 20 years. After a temporary lull in tourism between 1982 and 1986, the number of visitors has risen sharply, reaching a peak during the 1989–90 season, when this study was performed. (Numbers dropped dramatically in 1990–91 due to the Gulf War.) Diving impact was assessed by direct comparison of benthic communities between paired heavily dived

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and little dived areas. In addition a monitoring study was performed to look for change in benthic communities arising from diving activity.

METHODS

Sharm-el-Sheikh provided an ideal location for the study because the strong site-fidelity of divers meant that some areas were heavily dived, whilst similar areas close by were used very little. Boat-diving was predominantly carried out at sites which had permanent mooring buoys, and shore-diving was concentrated in places where access by vehicle, and entry to the water, was easy. In both situations diving activities were confined to within a few hundred metres either side of the mooring buoy or entry point. The most heavily dived areas occurred where the ranges of shore-divers and boat-divers overlapped.

Three sites were studied: Ras Umm Sidd, The Tower and Ras Nasrani (Fig. 1). In a separate survey they ranked among the most heavily used dive sites (Hawkins, 1991). Each site was subdivided into a 'heavily dived' and a 'little dived' area (hereafter termed 'dived' and 'undived' for brevity). These areas were as closely matched in physical characteristics as the constraint of diving pressure allowed and are described below.

Ras Umm Sidd. The fore-reef slope had the same general structure and supported well-developed coral communities in both dived and undived areas (Fig. 2). The dived area faced south and was sheltered from prevailing wind and waves. The undived area faced east and was more exposed, being situated about 1 km away around the adjacent headland.

The Tower. Reef structure was similar within both areas (Fig. 2), although the coral community appeared somewhat less well-developed in the undived area. Both areas faced southeast, but the undivided site was slightly more turbulent due to refraction of waves around a nearby headland.

Ras Nasrani. The fore-reef in the dived area fell away abruptly in the first 2–3 m and then sloped gently for the next 10 m or so (Fig. 2). After this it became steeper again, dropping to about 50 m. In the undived area it dropped steeply for about 15 m and then sloped more gradually. There was a rich coral community in both areas. The dived area was sheltered (facing south-southwest) while the undived area was relatively exposed (facing east-southeast).

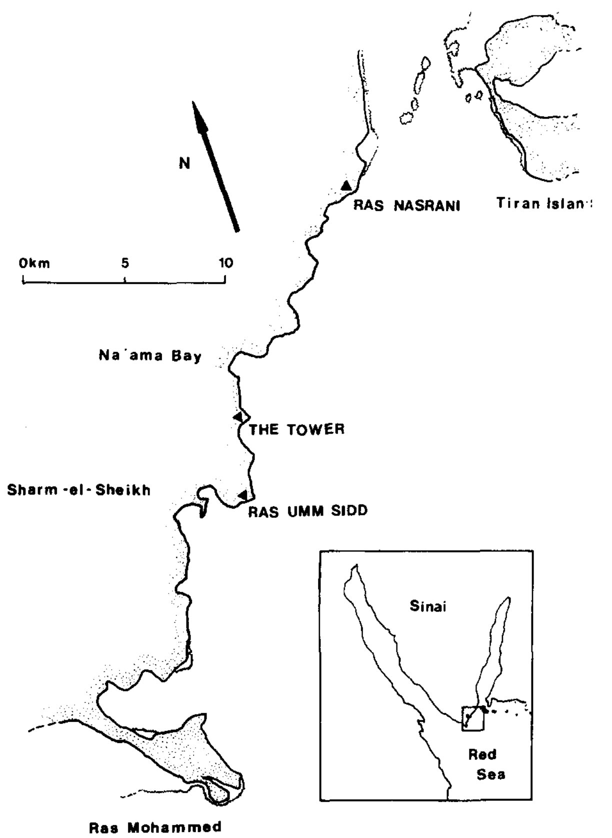

Fig. 1. Location of the study area and sites.

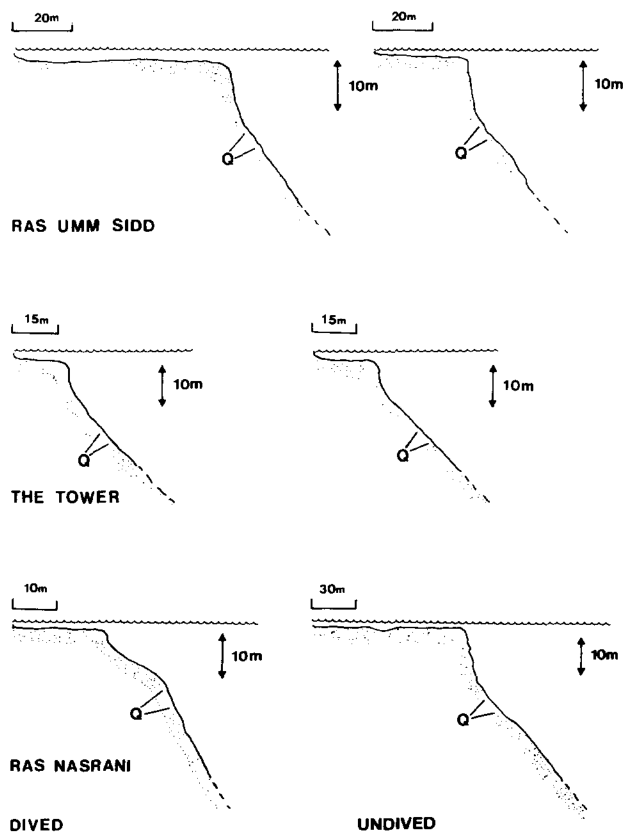

Fig. 2. Reef profiles at each of the study sites. 'Q' marks the position of the permanent quadrats on the fore-reef slope.

Direct comparison between dived and undived areas

Benthic communities were sampled using a 1-m² quadrat, and 20 replicates were taken at random from between 10 and 15 m deep in dived and undived areas of each site. Randomisation was approximated by the observer dropping the first quadrat from 5 m above the bottom over the sampling stratum. Following this, subsequent points were located by the observers closing their eyes and swimming in a haphazardly chosen direction for a variable distance before placing the quadrat. The following attributes were recorded: numbers of hard coral colonies, species, colonies partially dead, colonies recently broken, colonies abraded, loose fragments of live coral, and fragments reattached to substratum. The hydrozoans *Millepora platygyra* and *M. dichotoma* were included with Scleractinia in the hard coral category. Percentage covers of hard coral, soft coral and sponges were also estimated.

A substantial amount of time was taken learning to distinguish abrasion to corals by divers from that caused by natural sources, such as fishes and molluscs. Consequently, numbers of abraded colonies on the fore-reef were only satisfactorily recorded for Ras Nasrani and The Tower. Human abrasion of corals was characterised by irregular areas of broken tissue, often associated with some crushing of delicate structures of corallites. Crushed areas contrasted with the relatively clean removal of surface skeletal material which was characteristic of fish feeding. There was often also some bleaching of tissue around areas of damage by humans. These signs appeared to be good indicators of recent diver abrasion (<1 month old) but if damaged areas became colonised by algae or other organisms they could not usually be distinguished from natural abrasion. Areas so colonised were thus not included in analyses.

Data were analysed using ANOVA, having first been tested for normality using the Kolmogorov–Smirnov one sample test. Percentage data were arcsin square-root transformed to achieve normality.

Monitoring study

Four permanent quadrats were established within each study site, two in the dived and two in the undived areas. Each measured 3 × 3 m and was marked by four small pieces of steel bar driven into the reef. The quadrats were placed on the fore-reef between 10 and 15 m deep, and their locations subjectively selected to be representative of the reef community within this depth range. Figures 2 and 3 show the position of the quadrats within each site. Over one year the quadrats were censused three times at six-monthly intervals. At each census a wire grid consisting of nine 1-m² squares was laid out over the permanent quadrat. The attributes recorded were as listed above, with the exception of hard coral species, abraded colonies, and percentage cover of sponges. In addition the percentage cover for each of the following coral growth forms was recorded: branching, massive, encrusting, foliaceous and plate. During the first census the growth forms of any broken colonies present were recorded. Visual estimates of coral cover within the quadrats were obtained following Weinburg (1981), who considered this to be 'the most practical, versatile and reliable method' for recording benthic reef data.

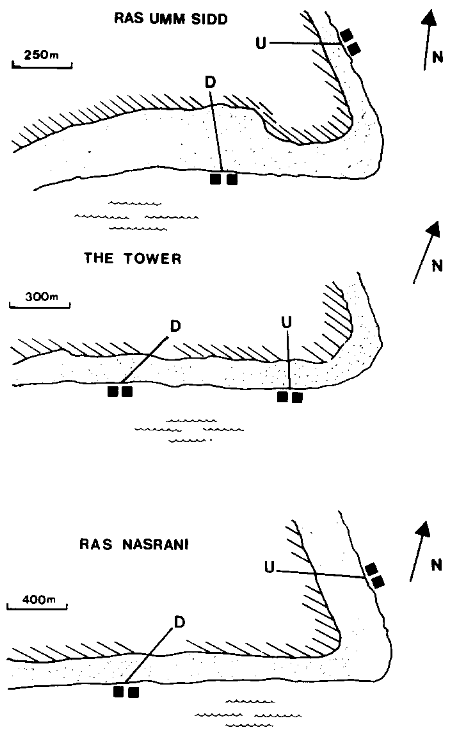

Fig. 3. Sites for the fore-reef monitoring study showing locations of permanent quadrats (■) in heavily dived (D) and undived (U) areas. Hatched areas are land and stippled areas the reef-flat.

A permanent quadrat took one dive to census, with two divers collecting the data. Each diver collected data on the same attributes on every dive.

Sampling consistency was estimated by repeat sampling of four quadrats a few days after the initial census. Little actual change within the quadrat would be likely over this short period, but

Table 1. Spearman's rank correlation coefficients (corrected for ties) showing precision of repeated visual estimates for attributes recorded within four 3 × 3 m quadrats (nine replicate 1-m² samples within each)

	1 m² (*n* = 36)	9 m² (*n* = 4)
Hard coral	0·95	1·00
Soft coral	0·92	1·00
Branching coral	0·78	0·95
Massive coral	0·95	1·00
Encrusting coral	0·48	0·40
Plate coral	1·00	1·00
Foliaceous coral	0·48	1·00
Broken hard coral	0·83	0·95
Fragments hard coral	0·75	0·80
Reattached fragments hard coral	0·39	0·40
Part-dead hard corals	0·63	1·00
Bare substrate	0·46	1·00
Rubble	0·89	1·00
Colonies hard coral	0·83	0·80
Species hard coral	0·59	1·00
Clams	1·00	1·00

$p < 0{\cdot}01$ for all attributes except reattached fragments of hard coral, where $p < 0{\cdot}05$.

sufficient time would have passed to forget previous estimates. Spearman's rank correlation coefficients were calculated for repeated estimates.

Data were analysed using repeated measures ANOVA, having first been tested for normality and transformed where necessary as above. The values used in the analyses were mean values for nine subquadrats within each quadrat. This was because, being adjacent to each other, the nine subquadrats could not be treated as independent replicates. Repeated measures ANOVA technically requires samples to be taken at random from within a treatment at each sampling interval. The treatment areas should be large enough to ensure a low probability of any particular quadrat being resampled during the study. This was not the case in the present study where the same quadrats were resampled. Generalising the results to the rest of the reef should therefore be done with caution (A. J. Underwood, pers. comm.).

Table 2. Results of 2-way ANOVAs on data collected on the fore-reef slope using randomly placed 1-m² quadrats

Parameter	Factor		
	Diving	Site	Interaction
Broken coral	0·000 1	NS	NS
Abraded coral	0·000 1	NS	NS
Fragments coral	0·000 1	0·03	0·05
Reattached coral	0·001	0·02	0·04
Part-dead colonies	0·000 5	NS	0·02
Number of colonies	NS	0·02	0·001
Number of species	NS	0·000 1	NS
% Hard coral	NS	0·02	0·000 9
% Soft coral	0·004	0·000 1	0·000 1
% Sponge	0·02	NS	0·002

Figures show levels of significance, *p*; NS, not significant.

RESULTS

Sampling precision

Correlation coefficients between repeated estimates of benthic attributes within nine 1-m² subquadrats in each of four 3 × 3 m quadrats are shown in Table 1. In general, visual estimates proved reasonably precise since over 60% of the attributes had a Spearman's correlation coefficient >0·75. Only four

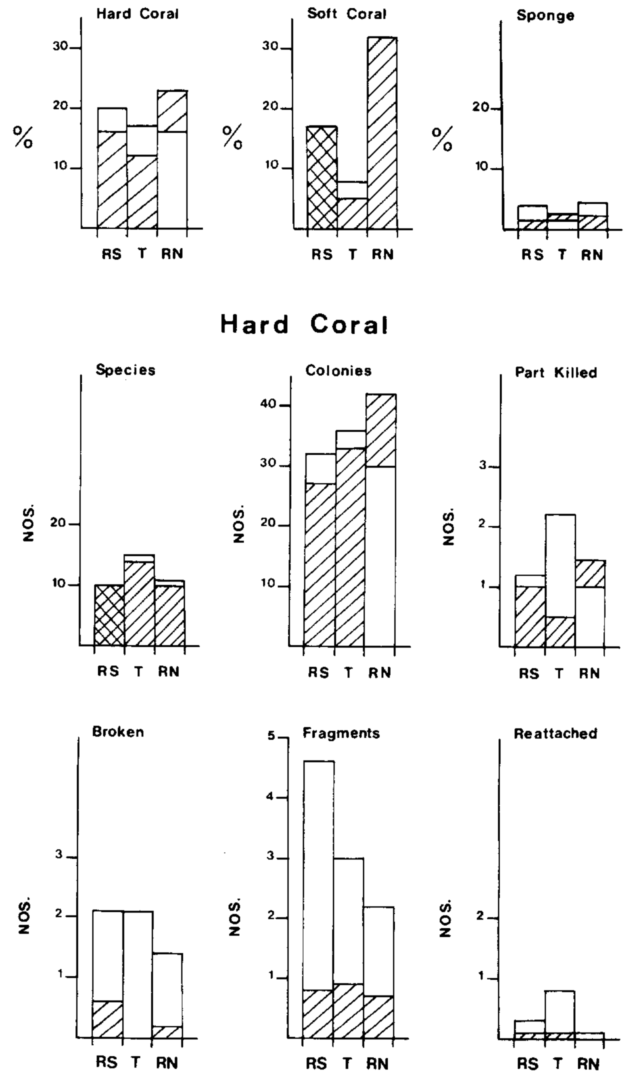

Fig. 4. Mean values ($n = 20 \times$ 1-m² quadrats) for each of the attributes recorded in the direct comparison of heavily dived and undived areas on the fore-reef slope. Opens bars show values for heavily dived areas, hatched bars show undived areas, and cross-hatched bars indicate no difference between areas. RS, Ras Umm Sidd; T, The Tower; RN, Ras Nasrani. Species, Colonies, Part-Killed, Broken, Fragments and Reattached all refer to hard corals.

Table 3. Results of 2-way repeated measures ANOVAs on data collected in the fore-reef monitoring study

Parameter	Factor				
	Diving	Site	Diving × site interaction	Repeated measure	Diving × repeated measure interaction
Broken coral	0·000 1	0·01	0·02	NS	NS
Fragments coral	0·000 1	0·02	0·01	NS	NS
Reattached coral	0·000 1	0·002	0·005	NS	NS
Part-dead colonies	0·001	NS	NS	0·000 5	NS
Number of colonies	NS	0·000 1	0·01	NS	NS
% Hard coral cover	0·002	0·000 1	0·000 7	NS	NS
% Soft coral cover	0·006	0·000 1	0·000 6	NS	NS

Figures show levels of significance, p; NS, not significant.

attributes—% encrusting coral, % foliaceous coral, number of reattached coral fragments, and % bare substrate—had correlation coefficients <0·5. It was sometimes difficult to decide whether a hard coral colony should be termed foliaceous or encrusting since it might combine both growth forms. Inconsistency in deciding which of the two growth forms prevailed would explain the low correlation coefficients for these attributes. Reattached fragments and % bare substrate were also evidently difficult to record precisely.

For the monitoring study, use in ANOVAs of mean values for the nine subquadrats within each 3 × 3 m quadrat reduced the variance, thus increasing precision of the repeated estimates (Table 1).

Direct comparison of heavily dived and undived areas

Table 2 shows the results of comparisons between areas using randomly placed quadrats. There were significant differences between dived and undived areas for seven of the attributes measured. Levels of damage, measured in terms of numbers of hard coral colonies broken, live loose coral fragments, reattached fragments and part-dead colonies, were higher in dived areas at all three sites (Fig. 4, Table 2). There were significantly more abraded colonies in dived than in undived areas at the two sites where this was recorded (Table 2; $\bar{x}$ = 0·8 colonies abraded m^{-2} vs 0·1 m^{-2} at The Tower and 0·5 m^{-2} vs 0·1 m^{-2} at Ras Nasrani). Differences in % soft coral cover and % sponge cover, although significant (Table 2), did not show consistent patterns among sites (Fig. 4).

Significant site effects were found for several attributes, for example number of hard coral species and colonies (Table 2). This was expected since the sites were subject to differing environmental influences such as wave exposure. There were also several significant interactions between diving pressure and site revealed by the analyses (Table 2). In such cases interpretation of the results is not straightforward, indicating instead that the effects of diving pressure differed among sites.

The monitoring study

Table 3 shows the results of repeated measures ANOVAs for 3 × 3 m monitoring quadrats and Fig. 5 the differences between dived and undived areas. All measures of damage were significantly greater in dived than undived areas, confirming the patterns identified using randomly placed quadrats (Table 2, Fig. 4).

A significant diving × repeated measure interaction term would indicate that temporal changes in communities in dived areas differed from changes in undived areas over the one-year course of the study. There were no such significant interactions. However, taking sites individually, it was

Table 4. Mean numbers of broken coral colonies (per m²) in monitored quadrats over the 12-month study period

Site	Dived			Undived		
	March 1989	September 1989	March 1990	March 1989	September 1989	March 1990
Ras Umm Sidd	4·7	3·7	4·7	0·3	0·5	0·4
The Tower	2·5	2·5	1·6	0·3	0·3	0·2
Ras Nasrani	1·7	2·6	2·9	0·0	0·2	0·4

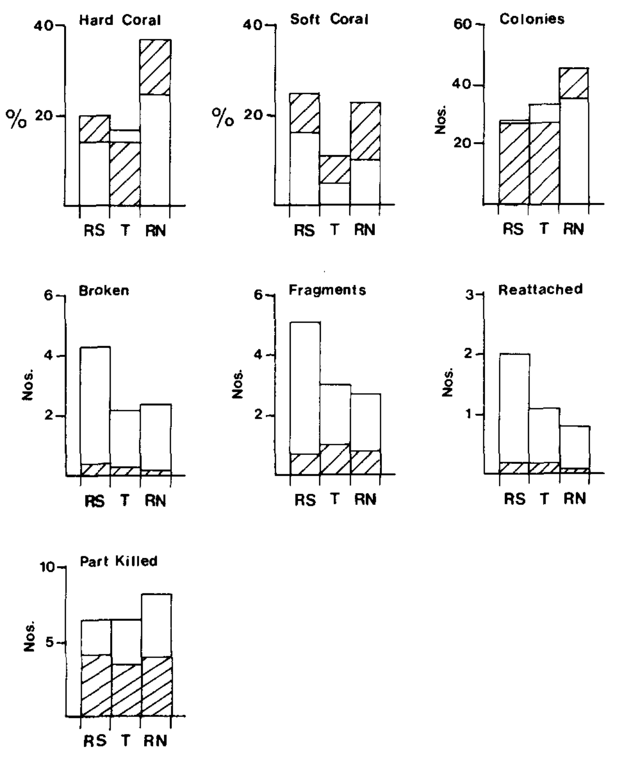

Fig. 5. Mean values for attributes recorded in the monitoring study (means are for two 3 × 3 m quadrats in each treatment, for each of which values were derived from nine 1-m^2 subsamples). Open bars show values for heavily dived areas and hatched bars undived areas. RS, Ras Umm Sidd; T, The Tower; RN, Ras Nasrani. Species, Colonies, Part-Killed, Broken, Fragments and Reattached all refer to hard corals.

notable that numbers of broken corals nearly doubled in the heavily dived area at Ras Nasrani during the study (Table 4).

Only one attribute, number of part-dead coral colonies, changed significantly over the course of the study (significant repeated measure effect). This attribute increased in both dived and undived areas, so the change could have been due to a difference in perception of what constituted a part-dead colony; there was no noticeable dying-off of corals over the year, which should have happened if the increase had been a real one. The monitoring study also showed a marked seasonal decrease in % soft coral cover during the summer

Table 5. Mean percentage soft coral cover (per m^2) in monitored quadrats over the 12-month study period (for dived and undived areas combined)

	% soft coral		
	March 1989	September 1989	March 1990
Ras Umm Sidd	22·5	19·7	19·5
The Tower	8·7	5·0	9·7
Ras Nasrani	17·9	13·9	18·0

(Table 5). At Ras Umm Sidd a corresponding late winter/early spring rise, not indicated by the data, was qualitatively apparent.

Influence of growth form on vulnerability to damage

Of 171 broken hard coral colonies recorded within 108 1-m^2 quadrats, 168 were branching, one foliose, one plate and one massive. The proportions of different growth forms present within those quadrats are shown in Fig. 6. These data, summarised in Table 6, show that susceptibility to diver damage clearly varied with growth form. Branching corals received a greater amount of damage relative to their abundance than any other growth form. Massive and encrusting corals were, however, often abraded by divers. Figure 6 also shows that patterns of abundance of different growth forms were similar between dived and undived areas within each site, although the relative proportions of the growth forms present differed among sites.

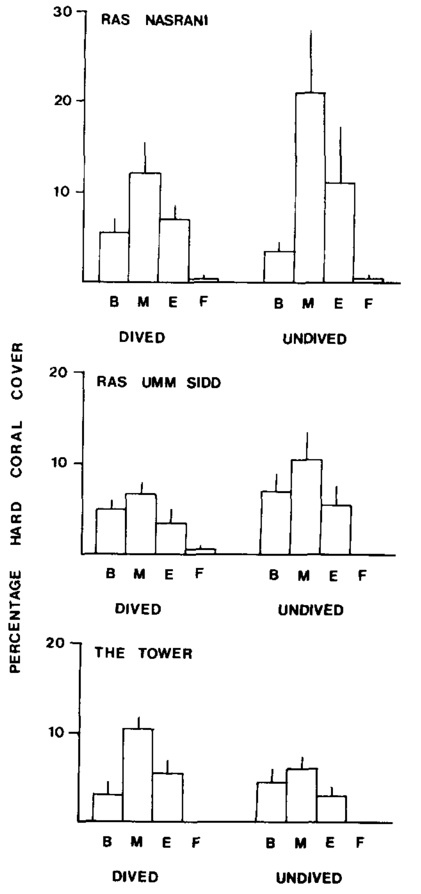

Fig. 6. Mean percentage covers (± 95% Confidence Interval; n = 18 × 1-m^2 samples) of different coral growth forms in 3 × 3 m monitoring quadrats in heavily dived and undived areas. B, branching; M, massive; E, encrusting; F, foliaceous.

Table 6. Colony breakage in relation to growth form (n = 171 broken colonies) compared with mean percentage cover of each growth form within the 108 × 1-m² quadrats sampled

Growth form	% Broken colonies	% Total coral cover
Branching	98·2	21·7
Massive	0·6	51·1
Encrusting	0·0	26·2
Foliaceous	0·6	0·9
Plate	0·6	0·1

DISCUSSION

The findings indicate that divers cause significant damage to benthic communities on the fore-reef slope. In attributing the effects detected to diving, it is important to consider the possible roles of other differences between areas sampled. The only consistent difference was that all three undived sites were slightly more exposed than adjacent dived areas. Wave energy affects reefs in numerous ways, producing differences in coral community structure and reef zonation (Bradbury & Young, 1981). Recent research suggests that corals in exposed areas can have denser skeletons and hence may be more resistant to breakage than those in more sheltered areas (Brown *et al.*, 1985). However, this effect would be most pronounced in shallow water, such as on the reef-flat where wave action is most intense. Being an enclosed body of water, levels of turbulence within the Red Sea are generally low. At the depths sampled (10–15 m) there was very little wave action and so differences between dived and undived areas were slight.

Perhaps the most important criterion for comparability is the relative proportions of different coral growth forms, given that diver damage was found to vary depending on growth form. Since proportions of growth forms were similar between dived and undived areas within each site, then treatment and controls were likely to be similarly susceptible to the effects of divers. For these reasons we consider that undived areas served as adequate controls. Nevertheless, the results should be interpreted with caution.

Given the clear differences in damage between dived and undived areas, and the intensity of diving the sites received, it is perhaps surprising that damage did not increase significantly during the study. If there were changes and these went undetected then possible explanations might be: (1) recovery of a broken coral might mask its detection at the next sampling; (2) live loose coral fragments could become dead coral rubble during the six-month intervals between samples; (3) reattached colonies were few in number and difficult to detect and so estimates were rather variable; (4) colonies which were recorded as broken during one sampling period might have been recorded as part-dead in the next if algae had become established around the point of damage, obscuring the breakage; (5) small sample size. All these may have resulted in some real changes in the attributes going undetected. Particular care was taken during sampling to avoid problems (1) and (4) above.

However, perhaps damage did not accumulate during the study because, for the number of divers using the reefs, deterioration had stabilised. While this may have been the case for Ras Umm Sidd and The Tower, Table 4 shows that at Ras Nasrani the number of broken corals nearly doubled over the course of the study. This increase was masked in the statistical analysis above through combining it with the other two sites for reasons of sample size. A month after the first sampling had been completed, a permanent campsite was established on the beach in front of this site, serving on average about 15 divers a week (30+ dives per day) over a period of six months, in addition to use by local diving centres. This was the first time that such a campsite had been set up at Ras Nasrani, and so the increase in diving pressure over the course of the study was greater than at Ras Umm Sidd or The Tower. The latter sites had been dived intensively for much longer.

This finding suggests that if the observed levels of diving at Ras Nasrani were maintained it could deteriorate to a state already reached at Ras Umm Sidd and The Tower. At the beginning of the study Ras Nasrani subjectively appeared in the best condition of the three sites, but during the next 12 months it was noticeable that rapid degradation was occurring. These findings qualitatively support those made on reef-flats of the Great Barrier Reef by Kay and Liddle (1989) and Woodland and Hooper (1977), who showed that initial phases of trampling impact were the most damaging. The most vulnerable corals were broken first and thereafter damage accumulated less rapidly.

Diving appeared to increase coral abrasion. However, the most damaging effect of abrasion might occur some time later. Broken, abraded tissue is likely to be more susceptible to invasion by pathogens, possibly increasing mortality. Kay and Liddle (1987) showed that tissue of the massive coral *Porites lutea* was damaged by trampling even though its skeleton was not broken. They noted that four months after the damage tissue lesions were still present but that 100% of the colonies affected had survived.

On the fore-reef, although average densities of reattached fragments were fairly low, the significantly higher levels within dived areas appear to indicate that some damage caused by divers is reparable. Highsmith (1982) suggested that reproduction through fragmentation could be the most important form for many major reef-building corals. Furthermore it has been claimed to be the primary factor promoting rapid recovery from storm damage (Shinn, 1976; Highsmith, 1982). This does not mean to say that divers breaking coral should be considered at all beneficial to the reef. However, the process of fragment regeneration may help to mitigate some of their effects.

Although the levels of damage differed significantly between dived and undived areas, absolute levels were relatively low. For example, only about 10% of hard coral colonies in the dived areas were broken. It is conceivable that such differences are relatively unimportant biologically but aesthetically the differences were striking. Heavily dived areas look badly degraded compared with undived areas and so are less appealing to divers. Thus management of reefs for the purposes of recreational diving may require stricter controls than management based on biological criteria alone. However, Tabata (1989) concluded that pristine conditions are not an essential component for a popular dive site if other attractions such as wrecks and tame fish are present. The present study also suggests that although levels of damage can stabilise, conversion from pristine to 'diver-damaged' reef can occur very quickly where diving tourism develops without any regulation.

In brief, this study suggests that heavy diving pressure may be sustainable on Red Sea reefs without serious degradation. However, it is not possible to say whether further increases in diving pressure could be accommodated, nor whether diving has left the reefs more susceptible to other forms of stress, such as disease or temperature extremes. In order to address these questions longer term studies will be necessary.

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REFERENCES

Bell, P. R. F., Greenfield, P. F., Hawker, D. & Connell, D. (1989). The impact of waste discharges on coral reef regions. *Wat. Sci. Technol.*, **21**, 121–30.

Bradbury, R. H. & Young, P. C. (1981). The effects of a major forcing function, wave energy, on a coral reef ecosystem. *Mar. Ecol. Progr. Ser.*, **5**, 229–41.

Bright, T. (1985). Mechanical damage to reef communities in the northwestern Gulf of Mexico. *Proc. 6th Annual Gulf of Mexico Information Transfer Meetings*, New Orleans, USA.

Brown, B. E. & Dunne, R. P. (1988). The environmental impact of coral mining on coral reefs in the Maldives. *Environ. Conserv.*, **15**, 159–66.

Brown, B. E., Sya'rani, L. & Le Tissier, M. (1985). Skeletal form and growth in *Acropora aspera* (Dana) from the Pulau Seribu, Indonesia. *J. Exp. Mar. Biol. Ecol.*, **86**, 139–50.

Hawkins, J. P. (1991). The effects of recreational diving on coral reefs of southern Sinai. MSc thesis, University of Liverpool.

Hawkins, J. P. & Roberts, C. M. (in press). Effects of recreational SCUBA diving of coral reefs: Trampling on reef-flat communities. *J. Appl. Ecol.*

Highsmith, R. C. (1982). Reproduction by fragmentation in corals. *Mar. Ecol. Progr. Ser.*, **7**, 207–26.

Kay, A. M. & Liddle, M. J. (1989). Impact of human trampling in different zones of a coral reef flat. *Environ. Manage.*, **4**, 509–20.

Liddle, M. J. & Kay, A. M. (1987). Resistance, survival and recovery of trampled corals on the Great Barrier Reef. *Biol. Conserv.*, **42**, 1–18.

Rogers, C. S. (1988). Damage to coral reefs in Virgin Islands National Park and Biosphere Reserve from recreational activities. *Proc. Int. Coral Reef Symp., 6th, Townsville*, **2**, 405–10.

Rogers, C. S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Mar. Ecol. Progr. Ser.*, **62**, 185–202.

Shinn, E. A. (1976). Coral reef recovery in Florida and the Persian Gulf. *Environ. Geol.*, **1**, 241–54.

Tabata, R. S. (1989). The use of nearshore dive sites by recreational dive operations in Hawaii. *Coastal Zone*, **3**, 2865–74.

Tilmant, J. T. (1987). Impacts of recreational activities on coral reefs. In *Human Impacts on Coral Reefs: Facts and Recommendations*, ed. B. Salvat. Antenne Museum EPHE, French Polynesia, pp. 195–214.

Ward, F. (1990). Florida's coral reefs are imperiled. *Nat. Geogr.*, July, 115–32.

Weinburg, S. (1981). A comparison of coral reef survey methods. *Bijdragen tot de Dierkunde*, **51**, 199–218.

Woodland, D. J. & Hooper, N. A. (1977). The effect of human trampling on coral reefs. *Biol. Conserv.*, **11**, 1–4.