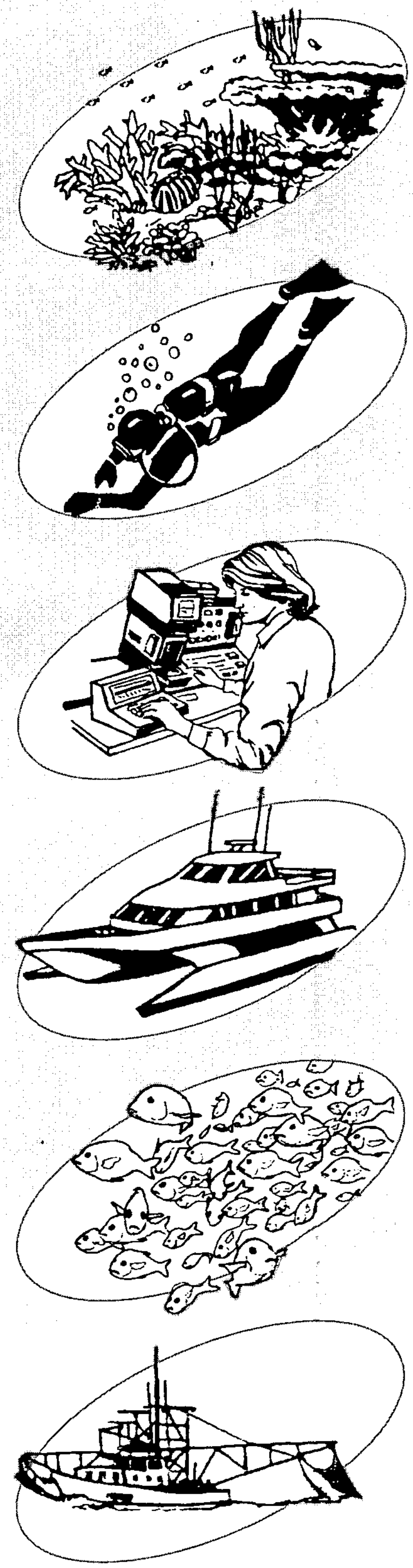
No. 4

CRC REEF RESEARCH

TECHNICAL REPORT



The effects of qualified recreational scuba divers on coral reefs

Tony Rouphael and Graeme Inglis

Department of Tropical Environment Studies & Geography,
James Cook University of North Queensland

CRC Reef Research Centre

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Tony Rouphael and Graeme Inglis
Department of Tropical Environment Studies & Geography,
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The Centre, established in 1993, undertakes an integrated program of applied research and development, training and education, aimed at increasing opportunities for ecologically sustainable development of the Great Barrier Reef and providing an improved scientific basis for Reef management and regulatory decision making.

CRC Reef Research Centre
c/- James Cook University
TOWNSVILLE QLD 4811
Phone: (077) 81 4976
Fax: (077) 81 4099
Email: crc.reef@jcu.edu.au

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1. SUMMARY

The primary objectives of this study were to:

* determine the type and amount of damage done to coral reef habitats by qualified SCUBA divers;
* develop an effective technique for assessing diver damage that can be used to survey dive sites and categorise them according to degree of damage; and
* provide preliminary recommendations to the diving industry on how best to minimise diver related damage on coral reefs.

A study on the behaviour of SCUBA divers was carried out to determine the effects of divers on corals and to examine if the topography of coral reef dive sites influences the type and amount of damage caused by divers. Direct observations were made on 214 qualified SCUBA divers at Agincourt Reef, in the Cairns section of the Great Barrier Reef Marine Park. Most subjects (70%) had completed fewer than 40 dives since gaining their diving certification.

Eighty-five per cent of divers caused no discernible damage to reef benthos. Damage caused by the remaining divers normally consisted of the loss of one or two small fragments per coral colony. Kicks by divers' fins were the major cause of coral injury. With the exception of two soft corals, all damage was sustained by branching hard corals (including the hydrozoan *Millepora sp.*). A small number of divers (4%) were responsible for more than seventy per cent of damage observed during this study. Most of these were underwater photographers, but more research is needed to determine more conclusively if divers with cameras cause more damage than those without. Our limited data from this study show that there was no significant difference in the mean number of damaging incidents caused by divers with cameras compared to divers without cameras. There was no relationship between the rate at which divers caused damage to, or came into contact with corals and the experience of the diver (number of logged dives). Topography of the dive site did not influence the rate of contact SCUBA divers had with the substratum. There was evidence, however, to suggest that the amount of damage caused by divers is related to the relative abundance of branching coral found at the site.

We suggest two strategies that may reduce impacts of SCUBA divers on coral reefs. These include managing the behaviour of divers to minimise contact with the substratum and

managing impacts through appropriate selection of dive sites. Dive tourism operators can promote 'environmentally friendly' diver behaviour at their sites by; (i) presenting a short commentary to visiting divers about the vulnerability of corals to physical stress, (ii) encouraging divers to stay at least 1 metre above or away from corals, and (iii) encouraging underwater photographers to be more aware of their actions when taking photographs. Operators can also minimise diver impacts by selecting dive sites that have minimal cover of branching corals. We also highlight a number of issues, such as the selection of appropriate control sites and damage indicator variables, which should be considered in any monitoring studies. An experiment is currently underway to investigate the long-term effects of divers on corals at sites that had not previously been used as dive sites.

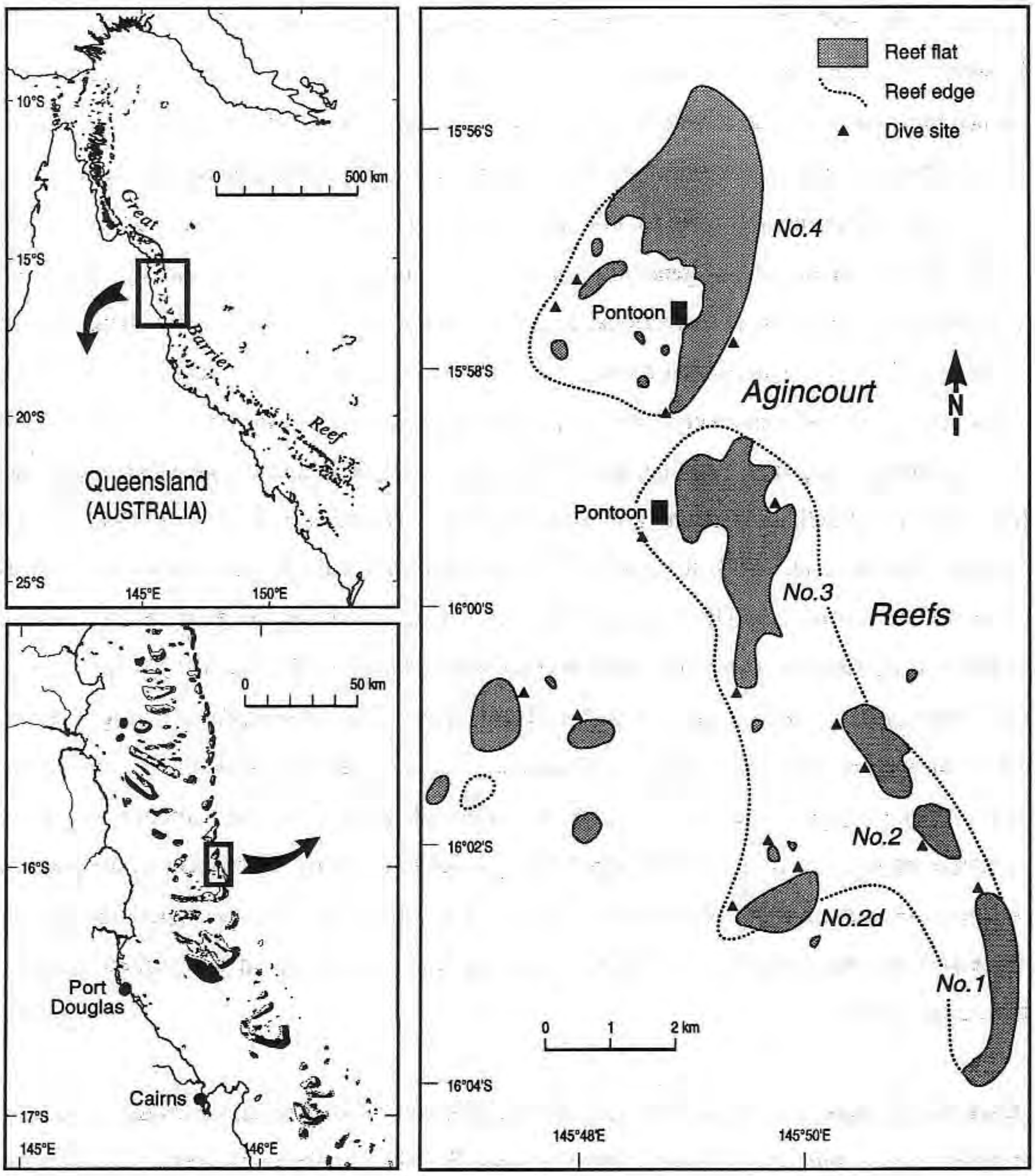


Figure 1: *Location map of the Great Barrier Reef and Agincourt Reefs. The main map shows the most commonly used dive sites and the location of the tourist pontoons.*

2. TECHNICAL REPORT

2.1 *Introduction*

The tourism industry in the Great Barrier Reef Region is growing at an estimated 10% per annum (Craik 1993). Associated with this increase is heightened concern for the impact tourist activities may have on coral reefs. Woodley (1992) describes two types of environmental impact that can occur as a result of reef based tourism: 'once-off' effects and 'recurrent' effects. Once-off effects relate to impacts associated with the initial installation or construction of tourism infrastructure such as marinas, moorings and pontoons. Disturbances directly attributable to these effects generally cease at the completion of the activity. Recurrent disturbance, associated with recreational activities, such as snorkelling or reef walking, are on-going and, therefore, may inhibit recovery of impacted reef organisms (Hatcher et al. 1989). While the impacts of some recreational activities on reef benthos have received attention from marine scientists (e.g. reef walking, Kay and Liddle, 1983, Kay and Liddle 1984, Liddle and Kay, 1987; snorkelling, Tilmant and Schmahl 1981, Hawkins and Roberts 1993; anchor damage, Rogers et al. 1988, Rogers et al 1990), there is relatively little information on the effects of recreational SCUBA diving. SCUBA diving is one of the four major activities undertaken by tourists within the Great Barrier Reef Marine Park (GBRMP) (Craik, 1994). Dive Queensland (unpub.) estimate that 120,000 divers visited Queensland during 1992/93. The total numbers of dives conducted within the GBRMP is thought to be over 1 million per annum (Dive Queensland, unpub.). With continued growth in the number of people participating in this activity, reef management agencies have expressed concern at the potential for increases in the number of damaged corals at some dive sites. Dive tour operators are also concerned that impacts associated with diving may lead to a decline in the aesthetic value of frequently visited sites.

Hawkins and Roberts (1992a) reported that the numbers of broken and partially dead coral colonies were significantly greater at three popular dive sites at Sharm-el-Shekh, Egyptian Red Sea, than at three infrequently used sites. They concluded that the aesthetic value of the heavily used sites had declined considerably in comparison with the infrequently used sites. In Bonaire Marine Park, Bonaire, Scura and Van't Hof (1993) compared estimates of percent cover of coral at frequently used dive sites with infrequently used dive sites and with estimates of the percent coral cover obtained from the same sites 10 years earlier. They suggested that the cover of coral at the heavily used sites had declined significantly over the 10 year period, while that at the infrequently used sites had changed little. The significance of these findings is, however, questionable, given that Scura and Van't Hof (1993) estimated coral cover using techniques that differed from those used in the original study and by their own admission, at least one of the control sites had been 'visited on a regular basis' by divers.

No comprehensive research on the effects of SCUBA diving has previously been carried out within the GBRMP. The aim of this project was to determine the effects of divers on reef benthos and to examine if the topography of coral reef dive sites influences the type and amount of damage caused by divers. More specifically the objectives of the project were to:

* determine the type and amount of damage done to coral reef habitats by qualified SCUBA divers;
* develop an effective technique for assessing diver damage that can be used to survey dive sites and categorise them according to degree of damage, and
* provide preliminary recommendations to the diving industry on how best to minimise diver related damage to coral reefs.

To address these objectives the study was divided into two broad components. The first was a study of the behaviour of SCUBA divers that sought to identify how they interacted with coral reef benthos and whether the topography of the dive site influenced the rate at which divers made contact with the substratum. The findings of this study are summarised in sections 3 and 4. Section 5 is a general discussion highlighting the significance to Reef management agencies of these results, and issues relating to the requirements of a technique for assessing and monitoring the impact of divers on coral reef dive sites. The second component of the study is an experiment designed to assess changes in the benthic assemblages of coral reef dive sites associated with increased rates of visitation by SCUBA divers. Two dive sites have been established on previously un-dived reefs and the coral assemblages at these sites will be monitored over a 12 month period. This experiment is still in progress and findings from it will be published in a future report.

2.2 *Scope Of Study*

It is important to clarify that this study deals exclusively with divers who have completed a recognised SCUBA diving course and have received formal qualifications. It does not address environmental issues concerning introductory or 'resort' SCUBA diving. Furthermore, this study focuses on off-shore dive sites with moorings and does not consider shore based diving activities.

2.3 *Study Site*

The study was undertaken on the Agincourt Reef complex (116° 30'S, 145° 25'E), in the Cairns Section of the Great Barrier Reef Marine Park, Australia (Figure 1). This complex consists of six main reefs situated along the Australian continental shelf, approximately 40 kilometres east of Cape Tribulation, North Queensland. Small patches of coral reef ('bommies') are common on the leeward side of the main reefs. Two large, permanently moored tourist pontoons are serviced by high speed catamarans that visit the reef daily from Port Douglas. Qualified SCUBA divers are taken from the pontoon by a small dive tender to 16 or more dive sites within the reef complex. Most of these sites possess moorings placed exclusively for the use of the dive tender. On average, 8 qualified SCUBA divers visit two dive sites each day (personal observations). Agincourt Reef was chosen as the study site because it offered a variety of dive sites with different reefal features.

3. QUALIFIED SCUBA DIVER BEHAVIOUR; THE TYPE AND FREQUENCY OF CONTACTS WITH CORAL REEF BENTHOS

3.1 *Introduction*

Suitable dive sites which are attractive, and safe, for divers are becoming increasingly difficult to find on reefs close to some major tourist destinations on the North Queensland coast (Carey 1993). Maintaining the ecological and aesthetic values of existing dive sites is, therefore, one of the primary goals of dive tourism operators. Research from the Red Sea and Caribbean suggests that intensive diving pressure at some dive sites can lead to increased numbers of physically damaged coral colonies (Hawkins and Roberts 1992a) or even a reduction in the cover of hard corals (Scura and Van't Hof 1993). The primary aim of these studies was to assess the long-term consequences of this activity on coral reef benthos. This was a reactive management response in which the focus of the investigation was placed on the effects of the disturbance after the event. From a marine park manager's perspective, it is desirable to take a more pro-active approach and investigate how this damage is caused. By assessing how divers interact with reef benthos, reef managers and tour operators can develop more informed management strategies designed to minimise future impacts. Such strategies may include new training procedures for dive instructors that introduce beginner SCUBA divers to appropriate or 'environmentally friendly' dive behaviour in coral reef environments.

Monitoring dive sites for early signs of coral reef deterioration is another potential pro-active management response. An important question relating to this is 'what variables or indicators of damage should be measured when assessing dive site impacts?'. In previous studies researchers such as Riegl and Veliminov (1991) and Hawkins and Roberts (1992), adopted a variety of indicators to quantify the impact of recreational users on coral reefs. These ranged from the mean number of coral lesions per sampling unit to changes in coral species abundance. Green (1979) argues the importance of selecting the correct indicators that 'really measure what we want to know'. By directly observing divers and identifying the types of injuries they inflict on corals, appropriate indicators of damage may be determined.

This section summarises the findings of a behavioural study carried out to determine 1) how divers cause damage to reef benthos, 2) the type of injury caused, 3) the situations that lead to additional damage, and 4) whether the amount of damage caused by divers varies within a 30 minute dive.

3.2 *Methodology*

Independent observations were made on the behaviour of 214 SCUBA divers at nine dive sites within the Agincourt Reef complex, between February and July, 1994. Daily selection of dive sites by the local dive staff was based on a number of criteria, including weather and sea conditions, popularity of the site (i.e. whether it was requested by visiting divers), time constraints, the size of the dive party and the relative experience of visiting divers. Three sites were visited only once during the course of the study, whereas the remaining six sites were visited at least four times. Six to nine divers were randomly selected from the dive party every day to be observed. Randomization was achieved by assigning a number to the names of each visiting diver (obtained from the dive supervisor) and using a random number chart to make the selection. Reef topography at the nine sites ranged from near vertical substrata 'wall sites' to shallow-water, patch reefs of variable topography. At most sites, diving was restricted to a maximum depth of 13 metres. As part of their pre-dive briefing the dive staff would describe the location of 'points of interest' within the dive area, such as giant clams, and remind divers to be careful not to bump into or break corals.

Quantitative observations were made on: (i) the number of times individual divers came into contact with the substratum[1] and whether these contacts resulted in mechanical damage to corals or resuspension of sediments, (ii) the type of damage done, (iii) the growth form of the damaged coral colony, and (iv) the number and size of fragments of coral that resulted from any damage. Each subject was observed for 10 minutes of a thirty minute dive. Pilot studies showed that this time period was the optimum, given a desired level of precision in estimating variables such as contact rates, and limited field time (see appendix I). In addition, this time period allowed an analysis to determine when in a 30 minute dive most damage and sediment resuspension was occurring. The number of logged dives each diver had completed since receiving their diving qualification was obtained from the supervising dive master. A record was also maintained of the number of divers who used underwater cameras to determine if divers with cameras caused more damage than those without.

Observers remained four to six metres behind the subjects so as not to influence their behaviour. Most divers remained in small groups while exploring dive sites and few showed any signs of being aware of the observer. If it was perceived that a subject had modified his or her behaviour due to the presence of the observer (e.g. frequently looking back at the observer) these observations were discarded. This only occurred on five occasions and when interviewed later, only one of the divers stated that it was due to the presence of the observer. The remaining four divers insisted that they were not aware of the observer's purpose.

Several observers participated in this study and, therefore, it was important to minimise any bias that may have arisen due to variability between observers. Comprehensive training procedures were undertaken at the beginning of each field trip. Training procedures included identification tests and practice surveys. During the identification tests, the chief investigator would demonstrate specific types of behaviour and how they should be classified. Decisions rules were developed to help observers correctly classify specific types of behaviour. These are described in Table 1:

[1] In this report the term substratum refers to both the sessile biotic and abiotic components of the reef.

Table 1: *Description of specific behaviour types recorded for each subject.*

I)	**The type of interaction**
a.	Contacts resulting in damage: Any contact (i.e. fin kick) with reef benthos that resulted in structural or mechanical damage. The number of coral fragments generated by each interaction were tallied separately.
b.	Contacts which did not cause any obvious damage: Any contact which did not result in mechanical damage.
II)	**How the interaction occurred.**
a.	Holding: Any contact made with hands.
b.	Fin: Any contact made with the diver's fins.
c.	Kneeling: Divers kneeling on the substratum.
d.	Gauge: any contact made by the gauges of the divers.
e.	Other: Any contacts not included in the above categories eg. by cameras or other equipment etc.
III)	**Type of substratum involved in the interaction.**
a.	Bare rock: Bare substratum and coral rubble.
b.	Soft corals: Gorgonian fans, whip corals and sea whips are also included in this category.
c.	Sponges.
d.	Branching coral growth forms: Including scleractinian and non-scleractinian corals, such as the Family *Milleporidae*. This category includes clustered branchlets, high corymbose and the open arborescent forms described by Liddle (1991).
e.	The remaining categories were based on Veron's (1986) broad coral growth form classification: massive, columnar, encrusting, foliaceous and laminar or plate corals. Digitate to low corymbose were categorised as massive morphologies.

3.3 *Statistical Analysis*

One-way ANOVA's were used to compare both the mean number of diver interactions which resulted in coral damage and diver fin kicks (resulting in sediment resuspension) in either the first, second or third 10 minutes of a dive. A fourth 10 minute period was not included in the analysis because most divers were near the surface within 35 minutes of starting their dive and none were observed to damage corals after 30 minutes. Post-hoc multiple comparisons were performed using Tukey honestly significant difference (Tukey HSD) tests. The proportion of divers who damaged corals within each 10 minute time period were also compared. A t-test for independent samples was used to assess whether the mean number of damaging contacts, attributable to divers with cameras, differed from those without. Chi-squared tests of independence were used to determine if the proportion of divers who damaged corals differed among photographers and non-photographers. Spearman's rank correlation coefficient was used to quantify the strength of association between the experience of individual divers (number of logged dives completed per diver) and the number of divers who damaged or made contact with corals in a 10 minute interval. Data were transformed to comply with the assumption of normality and equal variance required by parametric statistical test. If transforming failed to stabilise the variances the analysis was done using the raw data. Failure to comply with this assumption increases the risk of rejecting the null hypothesis when it should not be (Type I error), but balanced ANOVA is relatively robust to moderate departures from homogeneity (Underwood 1981). For all statistical tests α (type I error rate) was set at 0·05.

3.4 *Results*

Experience amongst visiting divers varied widely. The number of logged dives per diver ranged from 1 to 3,000. Seventy per cent of divers had logged fewer than 40 dives since gaining their dive qualifications. One hundred and fifty of the divers (70%) made some contact with the substrata during the 10 minute observation period. On average, divers made contact with the substrata 5·4 ± 0·63 (mean ± SE) times per 10 minutes. Fin kicks (58%) and holding (32%) were the most common methods of contact (Figure 2). Thirty-two (15%) of the 214 divers caused some damage to corals. Fin kicks were the major cause of coral damage (Figure 3). The mean number of contacts per diver which resulted in damage was small (0·4 ± 0·14 / per 10 minutes) (mean ± SE). Of those divers who damaged corals most only damaged a single coral colony during the observation period.

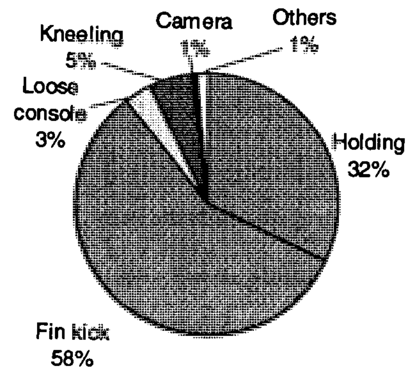


Figure 2: *How SCUBA divers (n=150) made contact with reef benthos or bare substratum.*

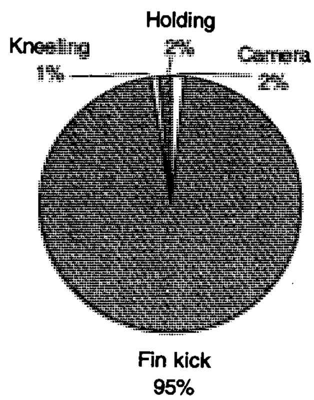


Figure 3: *How SCUBA divers (n=32) damaged corals.*

Eight divers were responsible for over 70% of all damage observed during this study (Table 2). All were male and had dive 'experience' ranging between 5 and 151 logged dives. Five of these divers used underwater cameras during their dive while a sixth was a model for a photographer. Further, all five divers with cameras were relatively inexperienced (the number of logged dives ranged between 5 and 20 dives).

Table 2: *Profile of the eight most destructive divers listing the number of interactions which resulted in damage per diver during a 10 minute observation period, the number of dives each had completed since gaining their dive qualifications, whether they possessed a camera and their gender.*

	Number of damage interactions	Number of logged dives	Camera?	Sex
1	30	12	yes	male
2	16	5	yes	male
3	9	5	yes	male
4	7	101	no	male
5	6	20	yes	male
6	6	20	yes	male
7	6	101	no	male
8	4	151	no	male

With the exception of two soft corals, all damage was sustained by branching hard corals (including the hydrozoan genus *Millepora*). Of the 116 incidents in which coral colonies were damaged, most received only minor physical damage that usually consisted of the loss of one or two tips (fragments) of branches per colony. One hundred and nineteen (80%) of the broken fragments were smaller than 10 cm length (Figure 4) and 53% less than 5 cm length.

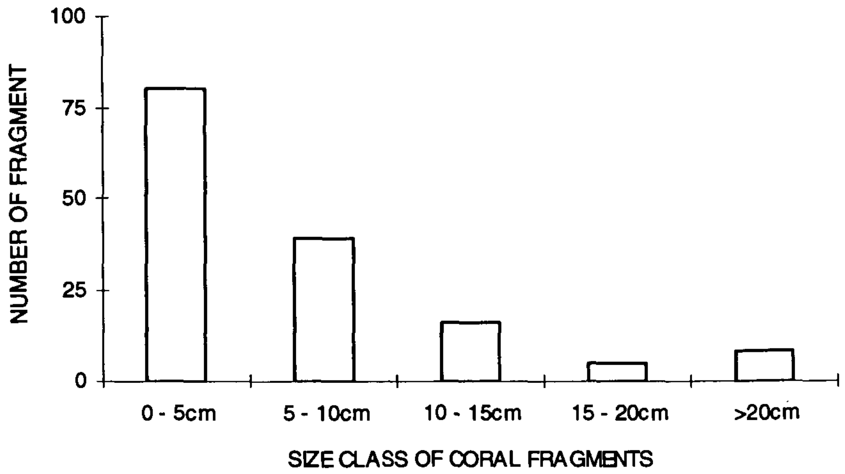


Figure 4: *Distribution of size classes of coral fragments (n=144) caused by divers who damaged corals.*

Eight of the 44 divers (18%) in the study who used underwater cameras broke corals. In contrast, 20 non-photographers (14%) also caused damage. Figure 5 compares the mean number of contacts resulting in coral damage for divers with cameras versus those without. No statistical difference was detected between these two groups (t-value = 1·82, df = 86, $P > 0{\cdot}05$). A Levene's test for homogeneity of variance, however, suggested that the variances in damage rates were significantly greater among photographers than non-photographers (F= 12·63, $P < 0{\cdot}05$). Six photographers caused five or more breakages during the 10 minute observation period, whereas no non-photographers damaged more than one coral. The relative proportion of underwater photographers who damaged corals also did not differ significantly from non-photographers ($\chi^2 = 0.32$, df 1, $P > 0.05$).

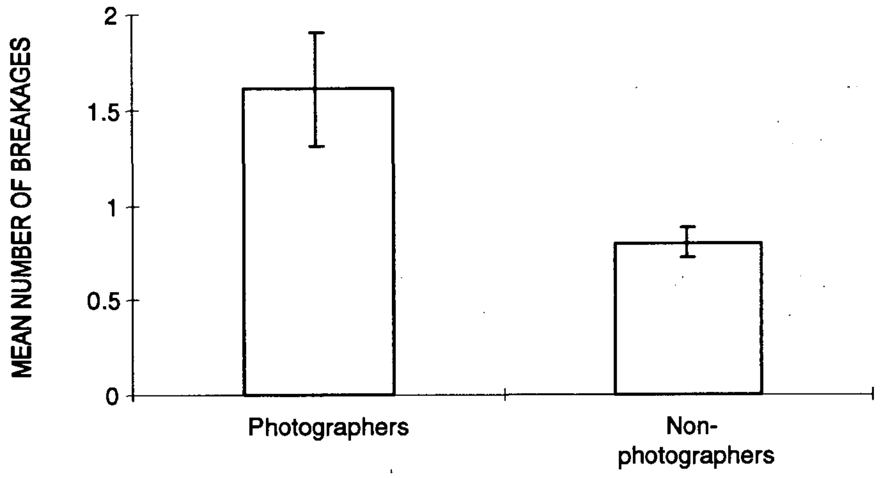


Figure 5: *The mean (± SE) number of breakages caused by underwater photographers (n = 44) versus non-photographers (n = 137).*

There was no correlation between the level of experience and the number of times divers came into contact with or damaged corals ($r = 0{\cdot}05$, $n = 180$, $P > 0{\cdot}05$ and $r = -0{\cdot}03$, $n = 180$, $P > 0{\cdot}05$ respectively). There was, however, some suggestion that the maximum upper limit of contacts divers made with the substratum decreases with increasing level of dive experience (Figure 6). In addition, there was no significant difference for the rate of contact ($F_{2,150} = 0{\cdot}32$, $P > 0{\cdot}05$) and damage ($F_{2,150} = 1{\cdot}05$, $P > 0{\cdot}05$) recorded for the first, second and third 10 minutes of a 30 minute dive.

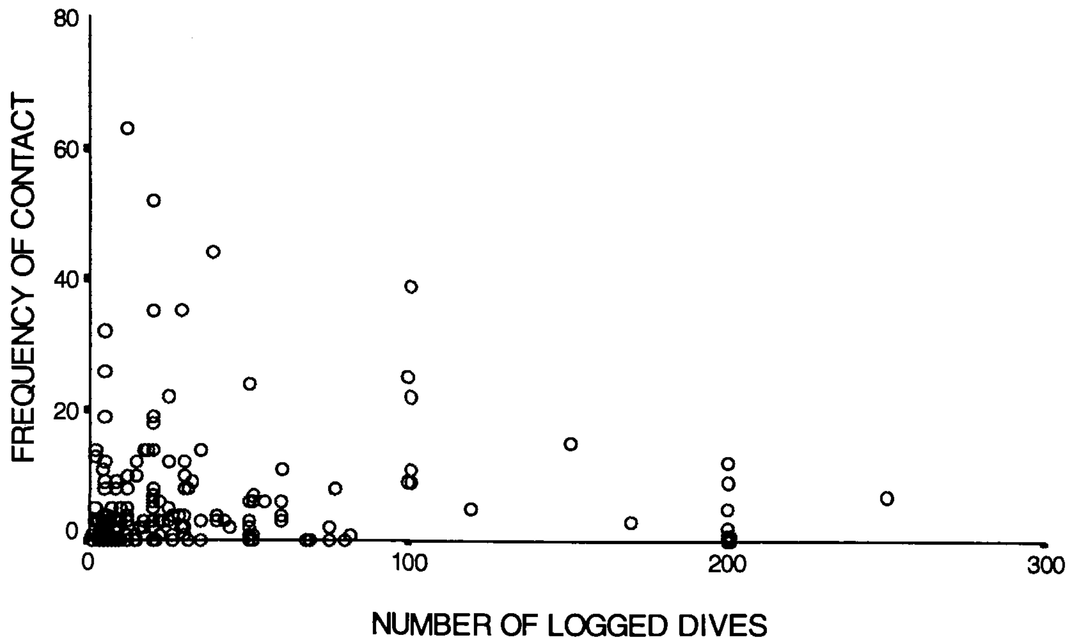


Figure 6: *The relationship between the frequency of contact made per diver per 10 minutes versus the total number of logged dives completed since gaining SCUBA qualifications.*

Thirty-three per cent of the divers resuspended sediments when swimming near the bottom. In 345 incidences in which fin kicks resuspended sediments, 92 (26%) resulted in sediments falling onto living corals. Approximately 50% of divers observed in the first 10 minute period of each dive created sediment clouds, whereas 33% and 20% kicked up sediments in the second and third 10 minute periods respectively. There was a significant difference in the mean number of fin kicks that resuspended sediments in the first, second and third 10 minutes period of each dive ($F_{2,177} = 5.21$ $P < 0{\cdot}05$). A Tukey HSD test showed that more sediment was kicked up in the first 10 minute period (2·28 ± 0·4) (mean ± SE) than in the third (0·7 ± 0·23) (mean ± SE).

3.5 *Discussion*

The results of this study demonstrate that SCUBA divers frequently come into contact with corals and other substrata during a dive but incidents that damage corals are uncommon. In a study of the behaviour of divers in Florida Keys, Talge (1990), reported that 90% of SCUBA divers had one or more interactions with reef benthos, while less than 2% of divers caused any discernible damage to corals. In common with the findings of Talge (1990) most divers in this study made contact with the substratum with their fins. Fin kicks accounted for 95% of all contacts that resulted in damage suggesting that poor buoyancy skills may be at fault. In a similar study of divers at Julian Rocks, New South Wales, Davis et al. (1995) found that most divers were surprised to learn that they had kicked corals during their dive. Anecdotal observations suggested several other factors may influenced the number of contacts divers made with the substratum. During fish feeding activities (dive staff feeding large reef fish) a number of divers were observed to lose concentration and drift onto corals.

Most of the damage we observed was restricted to branching coral growth forms. This parallels Hawkins and Roberts (1992a) findings that branching corals are less resistant to diver impacts than other coral growth forms. Soft corals and sea whips (*Juncellia sp.*) were also observed to be kicked on numerous occasions, but the flexibility of these organisms generally prevented any discernible physical damage. Damage to branching corals was restricted to the loss of one or two small fragments (<10 cm) from the tips of branches. Talge (1990) also reported that the impacts of divers usually resulted in small fragments being broken from the tips of branching corals.

Fragmentation (asexual reproduction) is a "natural" propagation mechanism for many species of corals (Highsmith 1982). Survivorship of a coral fragment is dependent on the species involved and the reef habitat in which the fragment is deposited (Highsmith 1980, Smith 1992). Survivorship of fragments is also highly dependent on size, with small fragments (< 10 cm) less likely to survive than larger fragments (Smith 1992, Harriot and Fisk 1995). Small wounds or fractures, associated with the loss of branch tips are unlikely to lead to total mortality in the fixed or 'mother' colony. Studies that have investigated the survivorship of 'once-off' physically damaged corals suggest that some coral species are not only able to survive severe physical damage (Liddle and Kay 1987) but rapidly repair and regenerate (Loya 1976). Less is known, however, of the survivorship of coral colonies that suffer from frequent, repeated mechanical damage. Hatcher et al. (1989) suggest that chronic disturbance, commonly associated with marine based recreational activities, may have greater implications to reef management than uncommon and highly destructive events because it does not permit sufficient time for some marine organisms to repair and regenerate.

It is unclear from our results if the use of underwater cameras causes divers to break corals more frequently. There was no difference in the mean number of incidents of damage caused by photographers and non-photographers. Nevertheless, five divers with cameras caused almost 60% of the coral damage observed during this study. Cheap underwater cameras which are simple to operate are now becoming readily available to SCUBA divers and snorkellers.

Additional research is required to determine more conclusively if divers with cameras cause more damage than those without.

A commonly held assumption among reef managers and dive tourist operators is that the relative 'experience' of a diver will influence the amount of coral damage they cause during a dive. In this study, the rate of damage per diver was not related to the number of dives the subject had completed since gaining their dive qualifications. This differs from the findings of Davis et. al (1995) who found 'experienced divers' (those with more than 100 logged dives) made significantly fewer 'uncontrolled contacts' with reef benthos than did inexperienced divers. They defined uncontrolled contacts as interactions with corals in which the diver did not purposely touch or kick the substrata (i.e., divers did not look before touching or kicking benthos). The relationship between the maximum upper limits of contact divers make with the substratum and diver experience is inconclusive. The trend towards decreasing maximum upper limits of contact with increasing experience may only be the result of uneven replication along the level of experience gradient. Additional observations of divers with more than 100 logged dives will be required to determine more conclusively if this relationship exists. Furthermore, additional research may be required to determine what influence other measures of diver experience, such as the level of dive qualification and the time of the last dive, have on the rate of contact or the frequency of impacts divers have with reef benthos.

Scura and Van't Hof (1993) noted that in heavily used dive sites in Bonaire, Netherlands Antilles, most coral damage attributable to SCUBA divers was concentrated around the dive boat moorings. They suggested that more damage occurred here because many divers stayed within the immediate vicinity of the mooring. Dive staff on the Agincourt Reef also suggested that more damage was likely to occur around the mooring because less experienced divers practice their buoyancy control skills close to the mooring before embarking on a dive. No evidence was found in this study to suggest that divers caused more physical damage in the first 10 minutes of a dive. There was, however, a greater proportion of divers who kicked up sediments during the first 10 minutes compared with later periods. Additional stress to reef benthos can occur as a result of divers resuspending sediments which eventually settle and accumulate on some organisms (Talge 1990). The mean frequency with which sediments were resuspended by divers in this study was small and sediment plumes caused by divers did not drift far (usually < 2 m).

4. THE INFLUENCE OF REEF TOPOGRAPHY ON THE NUMBER OF INTERACTIONS DIVERS HAVE WITH CORAL REEF BENTHOS

4.1 *Introduction*

Dive sites vary markedly in topography and attractiveness to divers. Hawkins and Roberts (1992b) suggested that the topography of a reef may either reduce or enhance the vulnerability of benthic organisms to the impacts of SCUBA divers depending on the slope or depth of the substratum. For example, sessile benthic organisms attached to vertical faced reefs may be less vulnerable to disturbance because experienced divers are able to swim off and away from the wall. Conversely, weak or novice divers, experiencing strong current flow at these sites, may be compelled to hold onto benthic organisms for added stability.

In this section of the report we compared the rate of contact and coral damage made by SCUBA divers at six sites on the Great Barrier Reef that were characterised by three different reef topographies. Specifically, the study examined the influence of dive site topography on the number of times divers damaged corals. This work takes an important first step towards identifying dive sites that are resistant to frequent use by SCUBA divers.

4.2 *Methodology*

Between February and May 1994, 150 SCUBA divers were observed at six dive sites in the Agincourt Reef. Two sites were chosen to represent one of three different types of reef topography: vertical reef face (hereinafter referred to as Pinnacle Sites), sloping reef face (Shoulder Sites) and patch reef areas of variable topography (Garden Sites). Subjects were selected at random from visiting groups of divers and observed for 10 minute intervals. Twenty-five divers were observed at each site. The number of observations per site was determined from pilot studies to be the most cost-effective given limited field time (see appendix I). The type of information recorded for each diver was described in detail in section 3.2, 'Methodology'. Qualitative observations made on each subject included the number of times they made contact with the substratum and whether the contact resulted in damage to corals, the type of damage caused and the type of coral growth form damaged.

The type of contacts that divers made with the substratum were categorised as:

i) The total **number of contacts** per diver / site / 10 minutes.

ii) The total **number of touches** per diver / site / 10 minutes (i.e., hand touches).

iii) The total **number of fin kicks** per diver / site / 10 minutes. This rate refers only to contacts that involved fin kicks. It includes both fin kicks that did result in damage and those which did not cause obvious injury.

iv) The total **number of damaging contacts** per diver / site / 10 minutes. This rate relates only to contacts between divers and corals which resulted in physical damage to corals.

To assess whether some types of substrata received a greater proportion of contacts or damage relative to its areal extent, estimates of percent cover were obtained for different types of substratum at each of the six sites using quantitative video sampling techniques. Seven 20 metre long line transects were randomly placed within each of the six dive sites. A dive site was defined as the area of reef where most of the diving activity took place. For the Shoulder and Garden Sites this was usually limited to an area approximately 100 m from the mooring. Depths at these sites rarely exceeded 14 metres. At the Pinnacle Sites, the dive area included all sides of the pinnacle. Divers would swim to the base of the reef and swim slowly around it while ascending. At the Shoulder Sites, divers would begin their dive near the mooring block and follow the reef slope for approximately 15 minutes before retracing their path. Divers visiting the Garden Sites were not constrained by a reef slope and could swim in most directions away from the mooring block.

Video recordings of the substratum were made along each transect line using a Hi-8 video-camcorder in a Sony underwater housing. To film each 'belt transect' the camera was held perpendicular to and 40 cm above the substratum. The speed of the filming was approximately 2 minutes per 20 m transect. Estimates of the relative cover of each type of substratum were obtained from the video recording in the laboratory using a random point intercept method (Foster et al. 1991, Carleton and Done 1995). Ten randomly distributed points were fixed to a clear perspex sheet temporarily placed in front of the viewing screen (NEC 50 x 40 cm television screen connected to a NV-SD 10 VHS Panasonic cassette recorder). Twenty randomly selected video frames from each transect were 'frozen' on the viewing screen and the substratum types beneath each point were identified and recorded. The choice of 10 points per frame and 20 video frames per transect for the analysis of the substratum was determined by a pilot study (see appendix I). The per cent cover of each type of substratum for each transect was calculated as:

$$\% \text{ cover of A} = \sum_{i}^{20} \frac{\#\text{ points classified as A}}{2} \quad ; \; i = \text{the number of frames per transect.}$$

The substratum was categorised into nine major groups including bare rock, sand, soft corals and others (algae, mushroom corals, clams etc). The remaining five categories consisted of hard coral growth forms; branching, plate, foliaceous, encrusting and massive corals.

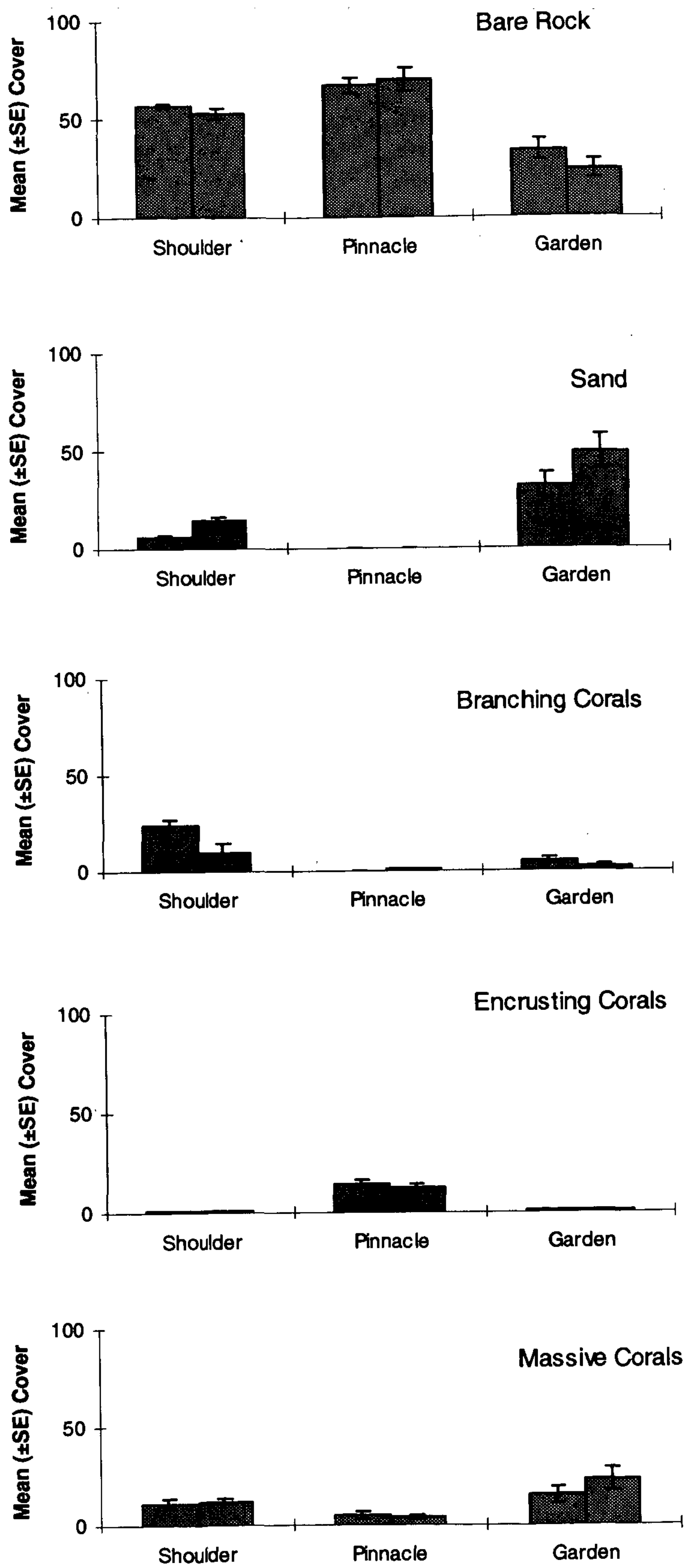
4.3 *Statistical Analysis*

Nested two-factor ANOVA's, with sites (n=2) nested within each reef type (n = 3) were used to compare rates at which divers came into contact with, or broke, corals among the sites and reef topographies. A similar design was used to compare the mean per cent cover of different substratum types among sites and reef topographies. A Tukey HSD test was used to make post hoc multiple comparisons between treatment means. The statistical software package SPSS was used to analyse all data (Norusis 1993). Data were transformed to comply with assumptions of normality and equal variance required by parametric statistical tests. Log (x + 1) transformations were used when observed values in some data sets equalled zero and arcsine transformations were used when analysing proportional data (Underwood 1981). In some instances where transformation failed to stabilise the variances the analysis was done using the raw data.

4.4 *Results*

4.4.1 Biological Differences Between Sites and Reef Topography Types

Dive sites of similar reef topography generally shared similarities in the relative coverage of coral and abiotic substrata (Figure 7). Mean cover of bare rock was significantly more abundant at the Pinnacle Sites compared with the other reef topography sites ($F_{2,3} = 2{\cdot}99$, $P < 0{\cdot}05$). Garden Sites were characterised by large areas of sand (> 35% mean cover), which were totally absent from the Pinnacle Sites and a relatively minor component at the Shoulder



REEF TOPOGRAPHY

Figure 7: *Mean (±SE) percent cover of dominant substratum types found at each of the six study sites and 3 reef topographies.*

Sites (< 15% mean cover). The mean cover of hard coral (combining all hard coral growth forms) ranged from 20% ± 4% (mean ± 1 SE) at one of the Pinnacle Sites through to 37% ± 3% at one of the Shoulder Sites. Cover of hard coral did not differ significantly across topography types or sites (Table 3). Similarly, per cent cover of massive growth forms did not differ between topography types or sites whereas cover of encrusting corals differed significantly between topography types (Table 3). A Tukey HSD test suggested that mean per cent cover of encrusting corals for the Pinnacle topography type (13% ± 2%) was significantly greater than encrusting cover for the other two topography types (< 1%). Cover of branching corals ranged from 24% ± 4% at one of the Shoulder Sites to 2% ± 1% at one of the Pinnacle Sites (Figure 7). The mean percent cover of branching coral varied significantly among sites, but was not related to reef topography (Table 3). A Tukey HSD test suggested that Shoulder Site 1 was significantly different from Shoulder Site 2, whereas the other sites nested within each topography type, did not differ from each other.

Table 3: *Analysis of mean (a) % cover of bare rock, (b) % cover of sand, (c) % cover of total hard coral (combined all hard coral growth forms including plates and foliaceous forms not analysed individually), (d) % cover of massive coral growth forms, (e) % cover of encrusting coral growth forms (f) % cover of branching coral growth forms at two sites nested in 3 topography types.*

SOURCE	df	MS	F	P
(a) Bare rock cover				
Topography	2	0·24	16·2	$P < 0{\cdot}05$
Site (topography)	3	0·01	0·97	$P > 0{\cdot}05$
Residual	36	0·02		
(b) Sand cover				
Topography	2	0·18	4·14	$P > 0{\cdot}05$
Site (topography)	3	0·04	2·99	$P < 0{\cdot}05$
Residual	36	0·01		
(c) Total hard coral cover				
Topography	2	0·01	0·34	$P > 0{\cdot}05$
Site (topography)	3	0·02	1·06	$P > 0{\cdot}05$
Residual	36	0·02		
(d) Massive coral cover				
Topography	2	0·02	3·04	$P > 0{\cdot}05$
Site (topography)	3	0·01	0·86	$P > 0{\cdot}05$
Residual	36	0·01		
(e) Encrusting coral cover				
Topography	2	0·03	52·90	$P < 0{\cdot}05$
Site (topography)	3	0·001	0·46	$P > 0{\cdot}05$
Residual	36	0·001		
(f) Branching coral cover				
Topography	2	0·01	0·55	$P > 0{\cdot}05$
Site (topography)	3	0·03	4·80	$P < 0{\cdot}05$
Residual	36	0·01		

4.4.2 Difference In Diver Behaviour Between Sites and Reef Topography Types

Divers frequently came into contact with the substratum at all six dive sites. The mean number of contacts per 10 minute interval ranged between 3·2 and 7·4 contacts per diver (Figure 8). A nested two-factor ANOVA showed no significant difference in the mean number of contacts amongst sites or amongst topography types (Table 4). There were also no differences amongst sites in the mean number of contacts made by hands or fins (Table 4).

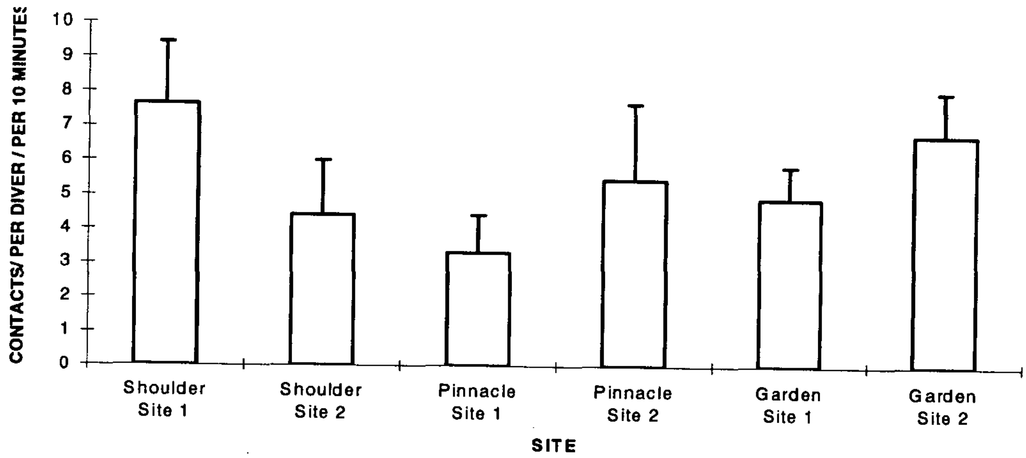


Figure 8: *Mean (±SE) number of total contacts made per diver with the substratum in a 10 minute interval at the six dive sites.*

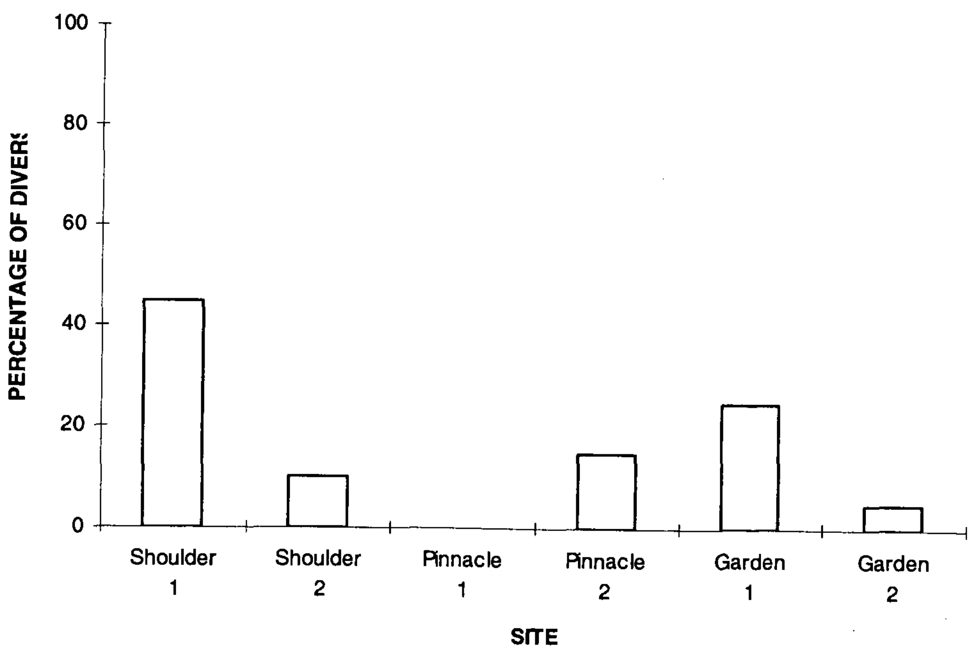


Figure 9: *Percentage of divers observed at each of the six sites who caused damage to corals.*

Table 4: *Analysis of mean (a) number of contacts with the substratum, (b) number of touches by hands, (c) number of contacts by fins and (d) number of contacts that resulted in damage to corals at two sites nested in 3 reef topography types.*

SOURCE	df	MS	F	P
(a) Contact				
Topography	2	0·6	0·35	$P > 0{\cdot}05$
Site (topography)	3	1·75	1·63	$P > 0{\cdot}05$
Residual	144	1·07		
(b) Touch				
Topography	2	0·86	0·99	$P > 0{\cdot}05$
Site (topography)	3	0·87	1·38	$P > 0{\cdot}05$
Residual	144	0·63		
(c) Fin kick				
Topography	2	0·29	0·83	$P > 0{\cdot}05$
Site (topography)	3	0·35	2·16	$P > 0{\cdot}05$
Residual	144	0·16		
(d) Breakage				
Topography	2	0·00	0·01	$P > 0{\cdot}05$
Site (topography)	3	0·17	4·87	$P < 0{\cdot}05$
Residual	144	0·04		

None of the divers observed at Pinnacle Site 1 broke corals, whereas, 12 (45%) divers at Shoulder Site 1 caused some damage (Figure 9). The total number of contacts that resulted in damage ranged from 47 at Shoulder Site 1 to 0 at Pinnacle Site 1 (Figure 10). The mean number of contacts that resulted in damage per diver was markedly larger at one of the Shoulder Sites (1·8 ± 0·77 / mean ± 1 SE) than at the other five sites (0 to 0·28 ± 0·24) (Figure 11, Table 4). Rates of damage differed significantly between sites but not amongst topographic types (Table 4). The rate of damage at Shoulder Site 1 was significantly greater than that at Shoulder Site 2 but the remaining site pairs were not significantly different from each other (Tukey HSD tests).

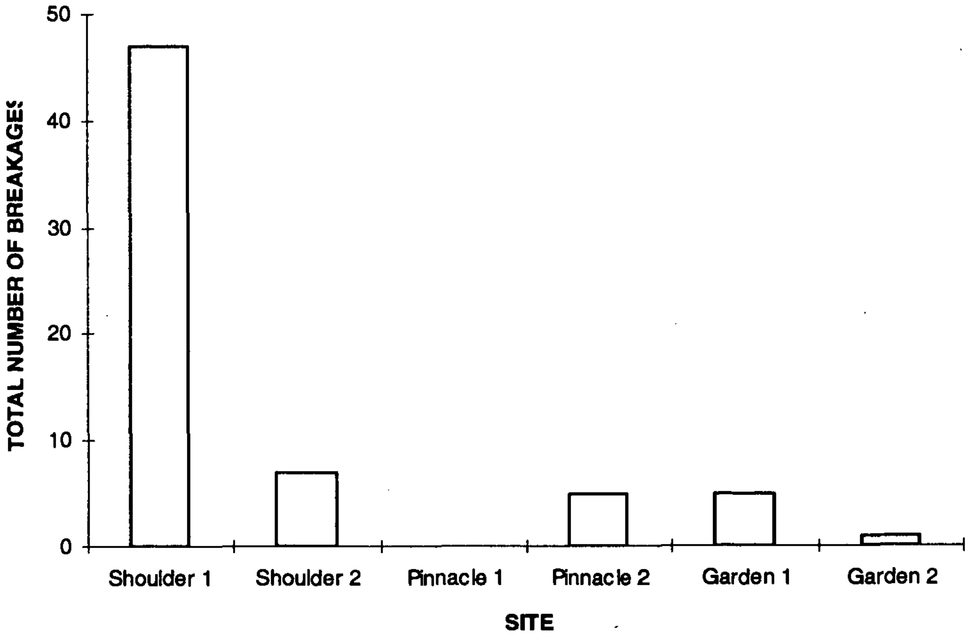


Figure 10: *Total number of incidences in which divers were observed to damage corals for each of the six dive sites.*

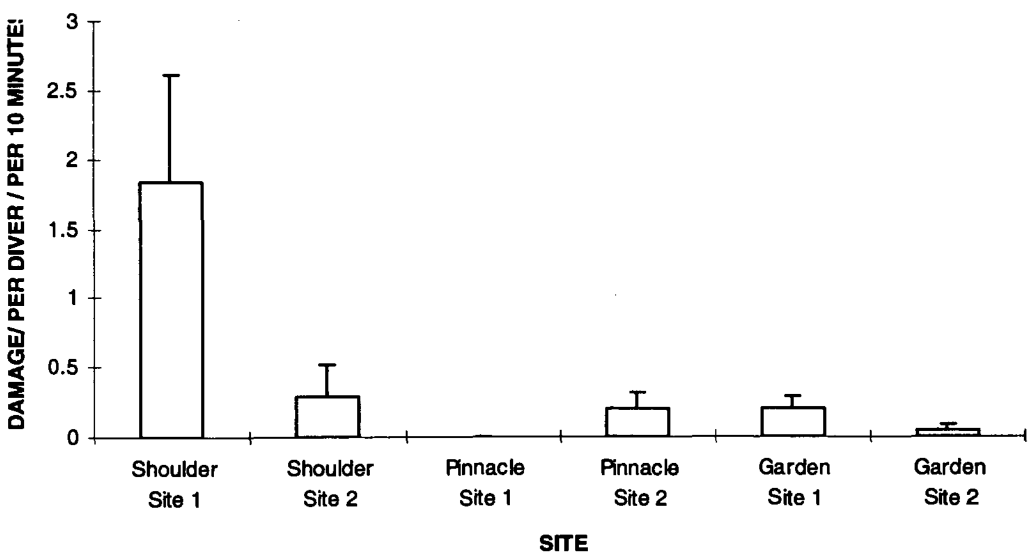


Figure 11: *Rate of damage (mean ± SE) per diver in a 10 minute interval at the six study sites.*

Plots of the rates of diver damage and the mean percentage cover of branching coral at the six sites suggest that the amount of damage done at a coral reef dive site was related to the abundance of branching coral at the site (Figure 12). Ninety-five percent of damage caused by divers was to branching coral growth forms. The largest number of breakages was recorded at Shoulder Site 1 which also had the greatest per cent cover of branching corals. Conversely, the remaining five sites, which had a sparse cover of branching corals, had significantly smaller rates of damage.

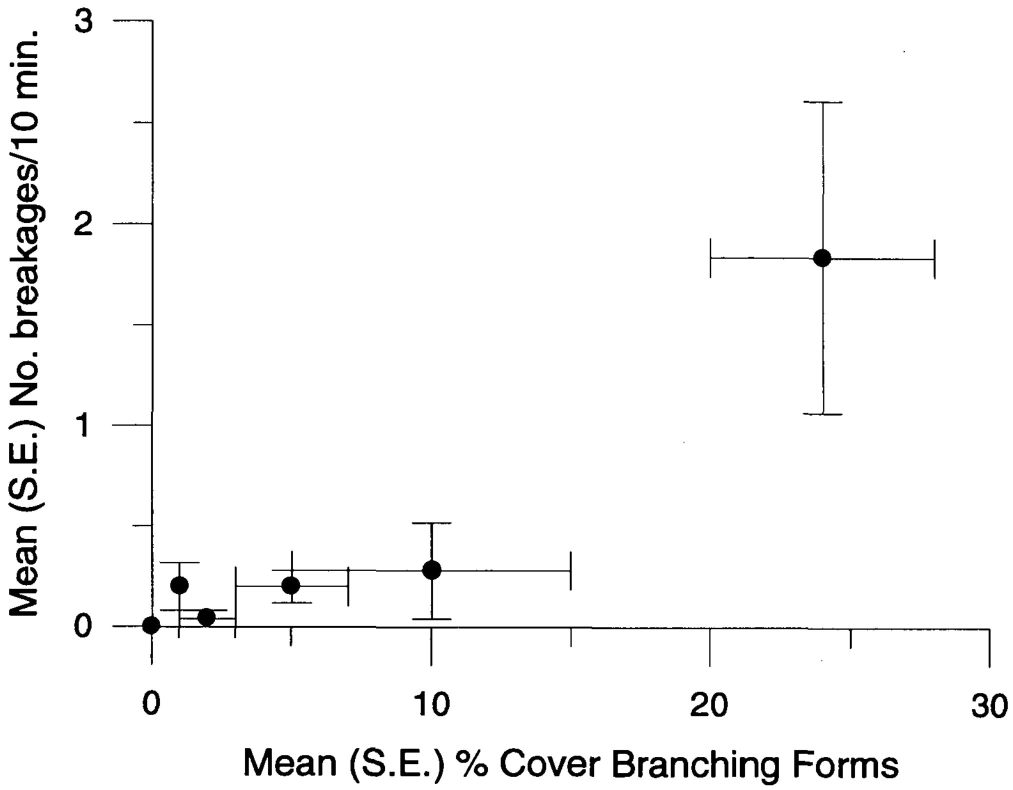


Figure 12: *Relationship between mean breakage rates (± SE) and mean (± SE) percentage of branching coral cover at the six study sites.*

4.5 *Discussion*

We suggest that some dive sites are more susceptible to diver damage and that this is due to the relative per cent cover of branching corals that exist there. Based on our study on the behaviour of divers (reported in section 3 of this report) and findings from other researchers (Hawkins and Roberts, 1992) branching corals are less resistant to disturbance from divers than other hard coral growth forms. Reef topography seems to have little influence in determining the rate at which divers made contact with the substratum. The rate of damage, however, was not comparable across sites. A significantly larger mean number of damaging incidents per diver was recorded at one of the Shoulder Sites than the other sites. We suggest that the relàtively large percentage cover of branching corals at this site was influential in determining this pattern.

Despite the large number of incidents of damage that we recorded at Shoulder Site 1, the coral assemblages appeared to be in good condition. There were relatively few signs of recently damaged coral colonies (personal observations). The lack of obvious physical damage at this site may be attributable to two factors. Firstly, this site is used infrequently. On average this site is visited once per week (approximately 460 dives per year). The rate of damage experienced by this site is likely to be well within the repair and regenerative capacity of these corals to 'mask' the damage caused by this number of divers. The capacity for some corals to rapidly repair tissue and skeletal damage is well documented (Stephenson and Stephenson 1933, Loya 1976, Bak et al, 1980). Linear rates of growth in some branching corals have been recorded at 10 cm or more per annum (Shinn 1966). Loya (1976) reported broken branches of the coral *Stylophora pistillata* grew faster than intact branches. This allows damaged colonies to regenerate rapidly following disturbance. Secondly, the dominant branching coral found at this site had a 'bottlebrush' morphology characterised by short side branchlets projecting out from the main branch. Fin kicks to this branching growth form usually resulted in crushed or severed branch tips. Physical impact to this morphological type does not leave behind the large visible fractures associated with damaged arborescent (staghorn) colonies and, therefore, will generally go unnoticed.

In conclusion, our study suggests that the vulnerability of dive sites to the activities of SCUBA divers is related to the abundance of fragile branching corals. Coral assemblages at most dive sites are susceptible to some degree of disturbance caused by divers regardless of topography. For the type and intensity of diving observed here, obvious physical damage is most likely to manifest itself only in areas containing a large abundance of branching corals. Further, high rates of diver damage experienced by some dive sites, including those sites with a large abundance of branching coral colonies, will not necessarily lead to a noticeable reduction in their biological or aesthetic values. This will be dependent on the frequency of visitation, the number of visiting divers, the regenerative capacity of the corals and the dominant branching morphology present.

A limitation associated with the results of this study was that we did not quantify the amount of coral damage that existed at the sites, only the rate at which it is caused. This prevented us from identifying whether a relationship exists between the intensity of use of the six study sites with the amount of coral damage. In order to determine the long term effects of divers on reef sites that have previously not been visited in high numbers by divers, two new dive sites have been established in the Agincourt Reefs. This experiment (described in detail in Section 6: Future direction of the study) will help us determine whether the level of coral damage at dive sites is correlated to the intensity of use.

5. MANAGEMENT IMPLICATIONS

5.1 *Minimising the impact of SCUBA divers on reef benthos*

In our study, few SCUBA divers damaged corals. The amount of damage and the frequency with which it occurred was small. Ninety-five per cent of all contacts which resulted in damage to corals were caused by fin kicks. In addition, the amount of damage caused by divers to a dive site appears to be influenced by the relative per cent cover of branching corals rather than to the topography of the reef. Based on these findings we suggest that the impacts attributable to divers can be minimised in at least two ways.

5.1.1 Managing diver behaviour to minimise impacts

Most contacts resulting in damage to corals were caused by fin kicks, which suggests poor buoyancy may be a major reason why some divers damage corals. A lack of 'environmental awareness' by visiting divers may also contribute to a greater number of impacts by divers on reef benthos. Divers may simply be unaware that their actions can injure sessile organisms, such as corals. Poor buoyancy skills will need to be addressed at the dive school level whereas increasing diver's awareness of the fragility of some marine organisms can be achieved prior to each dive. The relative success of the latter technique in minimising impacts of divers is difficult to assess without adequate comparison of the rates of damage in situations where divers are not actively encouraged to be more environmentally aware. Additional research is also required to determine whether the use of an underwater camera can significantly increase the rate and severity of damage caused by divers to reef benthos. This is important, as cheap underwater cameras become more accessible to SCUBA divers.

Some simple steps dive operators can implement to help reduce diver impacts by their clientele include:

* presenting a short commentary in the pre-dive briefing on the vulnerability of reef benthos to handling and physical stress;

* encouraging divers to stay at least 1 metre above or away from corals, particularly around prominent features at sites, such as giant clams or large plate corals;
* carrying out activities, such as fish feeding, away from areas where there is a large cover of branching corals;
* encouraging divers not to congregate around the mooring base at the beginning of a dive. If divers must wait for a dive staff member then they should hold onto the mooring line well above the reef. An alternative would be to locate moorings in large sand patches well away from living coral; and
* encouraging divers who use underwater cameras to be more aware of their actions when taking photographs.

Many of these steps are obvious and have been reported in the literature before (Talge 1990, Gleason 1991). Nevertheless, findings from this study confirm their usefulness in the management of divers. It is inevitable that some degree of damage, attributable to divers will be sustained at frequently used sites, but proper on-site management can ensure that it is kept at very low levels.

5.1.2 Managing impacts through dive site selection

In common with other studies (e.g Hawkins and Roberts 1992a) we found that branching corals were most vulnerable to SCUBA divers and that dive sites with a relatively large cover of branching corals (> 20%) were more susceptible to impacts by divers than sites with a minimal cover of branching corals (< 10%). The obvious implication to management is that reefs dominated by fragile branching corals are more likely to sustain high levels of coral damage if used as dive sites.

5.2 *Assessing impacts: diver damage assessment technique*

A major objective of this study was to develop a precise and cost-effective technique to assess the impact of SCUBA divers on coral reef benthos. Such a technique would theoretically provide an 'early warning' of reef deterioration at heavily used dive sites. Hawkins and Roberts (1992a) and Scura and Van't Hof (1993) quantified the effect of SCUBA divers on coral reef benthos using different sampling techniques. Hawkins and Roberts (1992a) used 20 randomly placed 1 m^2 quadrats per site to quantify the number of recently damaged and partially dead corals, as well as the number of living coral fragments. Scura and Van't Hof (1993) used a photo-analysis technique to quantify damage along a distance gradient leading out from dive tender mooring. Photographs were taken of the reef benthos along the gradient for a distance up to 110 metres away from the mooring (photos were spaced three fin kicks apart). They compared changes in coral cover and species diversity over time and between sites. In both studies different sampling units (quadrats versus photographic-transects) were used with the choice being influenced by the variables that were measured. Both methods have their relative advantages and disadvantages as techniques for assessing the impacts of divers. The quadrat method, compared with photographic techniques, is likely to be quicker and simpler to execute in the field, particularly for personnel who are not trained in survey techniques (an advantage if dive operators intend to monitor their own sites). The photo-analysis technique, however, has the advantage of providing a permanent record of the coral assemblage for future reference.

The experience gained during this study highlighted a number of issues which should be considered in the development of an assessment protocol.

I. Are there adequate controls? It is difficult to distinguish between damage caused to corals by divers and that caused by natural phenomena, such as grazing by fish or storms. 'Appropriate' control sites are, therefore, essential for any assessment of the impact of SCUBA divers. Appropriate control sites would be reefs that do not regularly receive divers and which share similar biological and physical characteristics to the 'impact' site. In particular 'impact' and control sites should have similar coverage of branching corals. Even if only a single 'impact' site is being assessed, more than one control is desirable (see Underwood 1994).

II. What variables should be quantified when assessing diver impacts? Previous monitoring studies on the impact of SCUBA divers have used a variety of variables ranging from the mean number of coral lesions per quadrat through to per cent changes in the cover of living coral. Reef managers and marine scientists advocate the use of indicator variables, such as the number of corals exhibiting recent structural damage, which may provide early warning of site deterioration. Impact assessments designed exclusively to quantify changes in per cent cover of living coral or changes in species diversity indices are not particularly useful in this instance because changes in these variables usually indicate that major disturbance has already occurred.

Other issues relevant to assessing the effect of divers on coral reef benthos include:

I. The need to verify whether corals close to specific features of interest at a dive site, such as giant clams or moorings, are more prone to damage from divers.

II. The need to define an appropriate level of minimal detectable difference to ensure adequate power (1 - ß) is catered for when making the assessment. This leads to the important question of what constitutes a significant impact to a dive site. An ecological impact may be measured in terms of loss of coral cover or changes in species diversity indices, whereas assessing the impact of the aesthetic value may be more difficult to define. For example, how much coral damage must occur before it compromises the 'reef experience' of recreational divers?

6. FUTURE DIRECTION OF THE STUDY

As reported earlier in this report, Hawkins and Roberts (1992a) and Scura and Van't Hof (1993) suggested that diving activity at heavily used dive sites can lead to increased amounts of broken or partially dead corals compared with sites that receive few divers. Neither study, however, was able to assess the initial condition of the reef benthos because sampling began well after divers had begun to visit the sites. It must be assumed, therefore, that the level of natural coral damage, at both dived and control sites, was similar before the commencement of sampling. Further, without adequate base line data it is difficult to assess the early and cumulative effects of diving activities on previously non-dived reefs. Hawkins and Roberts (1992a) monitored heavily used dived sites for 12 months to assess temporal change in the amount of physically damaged corals. They suggested that no increase in coral damage was detected because reef degradation attributable to divers may have stabilised to the point where additional impacts were difficult to observe or quantify. This is difficult to verify without the benefit of temporal controls. Lastly, neither study accurately documented the intensity of use of these dive sites and, therefore, it is difficult to assess the relationship between the number of dives at each site and the level of reef deterioration.

To overcome some deficiencies inherent in these earlier monitoring studies, an experiment has been established to assess the effects of divers at two new dive sites. The aim of this experiment is to investigate the relationship between the amount of use that the sites receive over a 12 month period and any change in the condition of coral assemblages. Intensity of use is being measured in terms of the number of visiting divers over the experimental period. Accurate records of the number of divers taken there are being maintained by the dive staff who tend the sites. The experiment is also designed to assess whether more damage occurs close to dive boat moorings in comparison to other areas of a dive site. Findings from this experiment will be published in a second volume of this technical report series.

7. ACKNOWLEDGMENTS

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9. APPENDICES

Appendix I: Results of pilot studies.

Pilot studies were done to; 1) determine the most cost-effective time period ('duration') over which to observe the behaviour of divers, 2) determine the most cost-effective number of divers to be observed per site, and 3) identify the most cost-effective number of sampling points and video frames for estimating the cover of sessile benthic organisms using video sampling techniques. By 'cost-effective' we mean obtaining the most precise estimate for the least expenditure of time. The methodology and results of these studies are explained in detail below.

Pilot studies to determine the most cost-effective duration in which to observe individual divers to obtain the most precise estimate of contact rate per diver and the number of divers to be observed per site.

Three time periods were compared: 10, 15 and 30 minutes. Three divers were observed for each duration at each of three dive sites. The frequency of interactions made with the substratum was recorded. Estimates of mean precision [precision = Standard Error (SE) / mean] were calculated for each time period based on three replicates obtained from three sites (Table 1). A one-way ANOVA failed to demonstrate a significant difference between estimates of precision obtained for each of the three time periods ($F_{2,6} = 2{\cdot}33$, $P > 0{\cdot}05$).

Table 1: *Mean precision and standard error (SE) of diver contact rates with the substrata for 10, 15 and 30 minute durations.*

	10 MINUTES	15 MINUTES	30 MINUTES
MEAN PRECISION	0·44	0·58	0·46
SE	0·05	0·03	0·06

The 10 minute period was chosen because it allowed a great number of divers to be observed given the limited field time. Secondly, adopting the 10 minute time period meant that subjects could be observed in either the first, second or third 10 minute period of each dive allowing an analysis of differences in the rate of contact at various stages throughout a dive.

Pilot studies to determine the most cost-effective number of divers to be observed at each site.

Three levels of sampling precision (0·1, 0·15 and 0·2) were compared for three types of reef topography to determine the most cost effective number of replicate divers (n) to be observed per site (Table 2). The formula used to estimate the optimal number of replicates was n = [standard deviation / (precision * mean)]^2 (Andrews and Mapstone 1987). Mean number of contacts per 10 minute interval and standard deviations were obtained from the pilot study described in the previous section.

Table 2: *The number of divers for each reef topography type needed to achieve a level of sampling precision of 0·1, 0·15 and 0·2. Unbracketed numerals represent the most cost-effective level of replication per topography type, whereas bracketed numerals represents the level of replication per site given that two replicates sites per topography type will be examined.*

	0·1	0·15	0·2
10 MINUTES			
SHOULDER	96(48)	43(22)	24(12)
PINNACLE	129(65)	58(29)	33(17)
GARDEN	46(23)	21(11)	12(6)

Seventeen replicate observation periods, per site, per topography for a precision of 0·2 was initially chosen given limited field time. The field trip was subsequently extended, however, allowing 25 divers to be observed per site.

Pilot studies to determine the number of sampling points and video frames used to estimate the cover of sessile benthic organisms in video transects.

a) **The most cost-effective number of sampling points per video frame.**

Mean estimates of the precision of the sampling procedure were obtained for 5, 10 and 20 sampling points per frame (Table 3). For each number of points, 3 groups of 5 video frames per transect were used in the analysis. A one-way ANOVA failed to detect a significant difference between the estimates of sampling precision ($F_{2,5} = 0.15$, $P > 0.05$).

Table 3: *Mean (M) precision and standard error (SE) estimates of coral cover obtained for 5, 10 and 20 point treatment levels and the mean time needed to record living coral beneath the points.*

TREATMENT	M PRECISION	SE	M TIME
5 SAMPLE POINTS	0.26	0.03	6.2 MIN
10 SAMPLE POINTS	0.28	0.02	7.3 MIN
20 SAMPLE POINTS	0.28	0.01	9.4 MIN

Ten points were chosen for the analysis in the main study. Even though more time was required to use this number of points, compared with five points, a greater level of precision might be achieved with higher levels of replication than used in the pilot study. The extra 2 minutes required to sample 20 points made it less attractive to use than 10 points. In addition, increasing the number of sampling points per frame increases the risk of auto-correlation between sample points on the same frame (Bruce Mapstone pers. comm.).

b) The most cost-effective number of replicate video frames per transect.

To determine the most cost effective number of video frames to be viewed per transect estimates of per cent cover of living coral, using 10, 20, 30 and 40 frames per transect, were calculated and compared. Ten sampling points were used for the analysis. Three transects were used for each number of frames (Table 4).

Table 4: *Mean (M) precision of the procedures used to estimate per cent cover of living coral and mean estimates of time to complete the analysis when 10, 20, 30 and 40 replicate video frames were used.*

TREATMENTS	M PRECISION	SE	M TIME
10 FRAMES	0.4	0.06	7.3 MIN
20 FRAMES	0.22	0.04	14 MIN
30 FRAMES	0.19	0.01	20 MIN
40 FRAMES	0.14	0.02	26 MIN

A one-way ANOVA recorded a significant difference between mean precision of estimates of per cent cover of corals when different numbers of frames were used per transect ($F_{3,8} = 6.33$, $P < 0.05$). Post-hoc multiple comparisons, using a Tukey HSD test, suggested that estimates made with only 10 frames were less precise than those made with 30 and 40 frames, but that there was no difference between estimates made with 10 or 20 frames. The relatively small amount of time required to identify cover of coral under the 20 frames, compared with 30 and 40 frames, made it the most desirable choice.