

# Impact of Recreational Divers on Scleratinian Corals at Looe Key, Florida

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**Abstract.** Recreational diver impacts on scleratinian corals were evaluated by quantifying diver interactions and by experimentally "touching" corals. Twelve coral species were subjected to four types of impacts for ten weeks. No corals died. Histological studies revealed no changes in morphology, composition of tissue or cells nor in reproductive cycles. Systematic observations of 206 divers revealed that the average diver touched or finned living coral 10 times per dive trip. Comparisons of frequency and area of coral tissue touched to the amount of live coral cover in high use areas indicate that 4-6% of the corals are touched each week by the dive population.

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## Introduction

The beauty, diversity and uniqueness of the coral reefs of Florida have attracted large numbers of visitors from all over the world. National Marine Sanctuaries, created to manage and protect pristine coral reefs and associated resources, have become choice areas to visit for divers. In six years, from 1985 to 1990, coral reef use at Looe Key National Marine Sanctuary (LKNMS) increased 400%, from 17,000 to 68,000 people per year (unpublished Sanctuary records).

As a non-polluting, renewable asset, the reefs of the Florida Keys are vital to South Florida's economy. In 1990, diver-related tourism generated an income of almost 400 million dollars (Jaap 1990).

Coral reefs are hardy and highly diverse within their environmental limits and are able to tolerate natural episodic events such as hurricanes. They need intermediate level "stress" or ecological perturbations to remain healthy and diverse (Connell

1978; Pearson, 1981). However, they are very fragile when those environmental limits are surpassed by man-made alterations in the environment (Rogers 1985) and are unable to tolerate chronic, low-level, man-made stresses (Stoddart 1982; Jaap and Hallock, 1990).

Recent studies investigating decline in vitality (Rogers et al. 1988; Grigg and Dollar 1990) and incidence of disease (Peters 1984) in corals have led to the suspicion that man's deleterious effect on reefs is rapidly increasing.

Until recently, the major direct human damage to the reef was thought to be boat grounding, anchor breakage and reef walking (Liddle and Kay 1987; Tilmant 1987). Diver damage was considered negligible. However, as diver populations increase and become more concentrated into relatively small favored areas, concern has grown about direct damage by divers (Miller 1988).

Divers directly interact with corals by touching with their hands, body, gear and fins or by breaking corals. Touching and "finning" remove mucus, which may leave the coral open to invasion by disease, bacteria or algae (Benson et al. 1978; Rützler et al. 1983). While breakage of branching corals can be a means of asexual reproduction (Bothwell 1981), it can also be detrimental when fragments are too small to survive or reproduce (Liddle and Kay 1987; Szmant 1986).

To determine if direct damage by the diving population contributes to coral reef decline, it is necessary to answer these questions: 1) How do stony corals react to repeated physical contacts with divers? 2) What is the frequency and nature of the physical contact that divers make with reefal organisms? 3) Is this physical contact sufficient to add to the ecological stress the reefs are experiencing? This paper will address the questions: (1) how do

coral respond to physical contacts with divers and (2) are those contacts ecologically stressful.

## Materials and Methods

### Touching Study

The study site was in the vicinity of mooring buoy number 16 in the core area of Looe Key National Marine Sanctuary (LKNMS) which is located 12.9 km southwest of Big Pine Key (24° 37'N, 81° 24'W) in the Florida Keys.

On the advice of Sanctuary Management, three colonies of each of twelve species (Table 1) of scleractinian corals were selected from corals unlikely to be impacted by divers, mapped, numbered, and photographed.

The experimental procedure consisted of "touching" and "finning" corals at two intensities. Heavy intensity consisted of touching or finning six times or holding for one minute (Treatments 1 & 3). Light intensity consisted of touching or finning twice or holding for ten seconds (Treatments 2 & 4). The unmanipulated areas of the corals were considered control areas. Logistical support limited the experiment to once a week for 10 weeks beginning in May 1989 with follow-up observations in November 1989 and in February and July 1990.

At the end of the experiment (August 11, 1989), tissue samples were collected for histological study using a hammer and chisel. Because no response was seen in the light treatments and limited re-

sponse in heavy treatments, only the Treatment 1 experiments and controls were collected for each experimental coral. Corals sampled for histological study and date of collection are listed in Table 1. Within 3 hours of collection, samples were fixed in Zamboni's solution. The samples were decalcified with a solution of 22% formic acid in 10% citric acid, rinsed for 24 hours in tap water, infiltrated and embedded in glycol methacrylate (JB-4), serial sectioned 3.5  $\mu$ m thick, stained with alcian blue and Weigert's hematoxylin and eosin, or periodic acid Schiff's with methanil yellow (following protocols developed by the Histology Laboratory at the Florida Institute of Marine Research).

### Estimate of Diver Impact on Corals at LKNMS

To determine if touching corals once a week was a reasonable approximation of actual diver interactions with corals, the quantity of live corals in the LKNMS reef core was estimated using data from Wheaton and Jaap (1984), the amount of coral that divers might touch with hands and fins was estimated using LKNMS diver census data and the number of interactions by an average diver, determined from the Diver Observation Study (Talge 1990), was 10 interactions per dive trip.

The reef area at LKNMS was determined by measuring the two-dimensional area of hard substratum discernable in an aerial photograph using a MicroComp Integrated Image Analysis System. Height of the spurs was approximated using Whea-

Table 1. Coral species experimentally manipulated during the summer of 1989 and sampled on August 11, 1989 for histological study.

Species	Experimental Treatments*				Corals Sampled**		Gonads Seen
	1	2	3	4	1	C	
<i>Acropora palmata</i>	3	3	3	3	3	3	No
<i>Colpophyllia natans</i>	3	3	3	3	4	4	No
<i>Dendrogyra cylindrus</i>	1	1	1	1	1	1	Yes
<i>Diploria labyrinthiformis</i>	3	3	3	3	3	3	No
<i>Montastrea annularis</i>	3	3	3	3	3	3	Yes
<i>Montastrea cavernosa</i>	3	3	3	3	2	2	Yes
<i>Mycetophyllia lamarckiana</i>	2	2	2	2	2	2	Yes
<i>Mycetophyllia ferox</i>	2	2	2	2	2	2	Yes
<i>Porities porities</i>	3	3	3	3	2	2	No
<i>Porities asteroides</i>	3	3	3	3	2	2	No
<i>Siderastrea siderea</i>	3	3	3	3	3	3	Yes
<i>Agaricia agaricites</i>	2	2	2	2	2	2	Na

\*number of colonies

\*\*number of colonies; C = control

Na = no data available

ton and Jaap's (1984) estimate of 2 m. Because spur topography diminished toward and away from the reef front, only the two-dimensional measurements were used for areas within the reef crests and for small patches of hard substratum at the base of the spur. Total area of live coral accessible to divers was calculated using Wheaton and Jaap's (1984) estimate of live coral cover at LKNMS of 16–18%.

## Results

### *The Touching Study*

The corals showed little visible response to weekly touching. No reaction was seen after Treatments 2 and 4 (light impact) but subtle color changes were seen after Treatments 1 and 3 (heavy impact) in some corals. After the sixth week of manipulation, the head and platy corals appeared whiter in Treatment 1 areas, but returned to normal coloration in approximately 24 hours. Branching corals showed no response to the treatments.

All corals exhibited normal feeding responses when observed either during the day or at night. Histological examination showed no sublethal effects; in all species, the epidermis was normal and intact, the mucus secretory cells were normal and the gastrodermis was filled with zooxanthellae.

Most corals are thought to be reproductively active during the summer months. Of the 12 species studied, 6 had mature gonads (Table 1).

### *Estimate of Diver Impact on Corals at LKNMS*

Using the assumptions discussed in the Methods section, reef surface area is estimated as  $1.3 \times 10^5$  m<sup>2</sup>. Applying Wheaton and Jaap's (1984) estimate of 17% live coral cover in 1983, I estimated that there were  $2.2 \times 10^4$  m<sup>2</sup> of live coral cover in the core reef area. However, in a study from 1984 to 1986, Porter (pers. comm.) found that coral cover was decreasing 4% per year. Thus, I corrected the above estimate to approximately  $1.7 \times 10^4$  m<sup>2</sup> of live corals on the fore reef of LKNMS core area. However, most scuba divers stay in the sand grooves and cross over the spurs in areas of low or no relief. Considering only these high-use areas, i.e., the sides of the spurs with an average relief of 2 m (Wheaton and Jaap, 1984) and the low relief areas, the area of live coral most apt to be impacted by divers is approximately  $4.5 \times 10^3$  m<sup>2</sup>. A diver observation study conducted in the Florida Keys in 1989 (Talge 1990) showed that in an average dive trip (two dives, 45 minutes each) the average diver touches corals 5 times and fins corals 5 times (Table

2). Using a hand size of 145 cm<sup>2</sup> and a fin size of 270 cm<sup>2</sup>, the amount of corals impacted per year by 50,000 divers would be about  $1.0 \times 10^4$  m<sup>2</sup> or 190 m<sup>2</sup> per week. This means approximately 4% of the corals in the high use area would be impacted once per week. But, the touching data are not normally distributed. Therefore, additional calculations were made to attempt to realistically predict touching by the diver population based on observations that most divers touch the reef relatively infrequently but that 2% interact approximately once a minute (Table 2).

## Discussion

### *Touching Study*

As an exploratory study, the experimental design was aimed at qualitative rather than quantitative results. Touching three individual colonies of each species provided for a minimum number of replicates while holding diving time within the limits of logistical support. Treatment types and durations were designed to simulate occasional interactions by passing divers (Treatments 2 and 4) as compared with more intense impacts by underwater photographers, or several divers (Treatment 1 and 3).

Using different areas of the same coral head for control sites and treatment sites had advantages and disadvantages. The advantage was that manipulations were conducted on genetically identical individuals. The disadvantage is that, in theory, polyps at "control" sites might have been neurologically responding to touches at the manipulative sites.

Responses of corals to manipulations was evaluated using a chart created by Peters and Pilson (1985) that summarizes possible stress responses (Table 3). The results of this study, shown in Table 4, indicate that weekly touching had no detectable lasting influence on the health of 11 species of corals, either visibly or histologically. However, physiological responses were not measured and should be evaluated in future studies.

A subtle color change was seen in head and platy corals. Since the histological study showed no abnormalities in the epidermal layer, the reason for the color change is unknown and could be the result of coral polyps contracting quickly and tightly into their calices when touched. Additional touching might cause the coral to pull in even further causing an apparent color loss. (E.C. Peters pers. comm.)

Reduction or changes in reproduction of corals is considered a method of determining stress

**Table 2.** Projected yearly diver impact on corals based on two 45-minute dives per diver at present diver populations of 50,000 diver/year (Talge 1990). Total area of living coral in high use area is estimated to be  $4.5 \times 10^3$  m<sup>2</sup>.

Interactions <sup>1</sup>	Divers <sup>2</sup> (%)	Touched <sup>3</sup> (m <sup>2</sup> )	Finned <sup>4</sup> (m <sup>2</sup> )	Total <sup>5</sup> (m <sup>2</sup> )	Weekly <sup>6</sup> (m <sup>2</sup> )	Weekly <sup>7</sup> (%)
0-3 (2)	44	319	594	913	17	0.4
4-30 (17)	48	2958	5508	8466	163	3.6
31-65 (45)	6	978	1822	2800	54	1.2
>60	2	435	810	1245	24	0.5
Total	100	4690	8734	13424	258	5.7
Average (10) <sup>7</sup>	100	3625	6750	10375	200	4.4
Unrestricted (45) <sup>8</sup>		16313	30375	46688	898	20.0

<sup>1</sup>50% hand touches, 50% finning; calculations based on number in parenthesis.

<sup>2</sup>Percent of the diving public in each interaction ranking.

<sup>3</sup>Area of live coral touched by diving public; calculations based on contact area of 0.0145 m<sup>2</sup> per incident.

<sup>4</sup>Area of live coral finned by diving public; calculations based on contact area of 0.027 m<sup>2</sup> per incident.

<sup>5</sup>Area of live corals impacted annually by divers.

<sup>6</sup>Area of live corals impacted weekly by divers.

<sup>7</sup>Estimate based on "average" diver (see text).

<sup>8</sup>Estimated interactions if sanctuary diver populations were unrestricted.

**Table 3.** Criteria for monitoring coral response to stress (Peters and Pilson, 1985).

Visual observations (behavior and appearance)
1. Unusual polyp contraction or expansion
2. Extrusion of mesenterial filaments
3. Unusual mouth opening responses
4. Change in feeding behavior
5. Increased mucus production/muco-ciliary activity
6. Decrease in zooxanthellae concentrations
7. Appearance of bare skeleton or abnormal tissue growth
Histopathological examinations
1. Reduced gonad development or change in reproduction cycle
2. Change in morphology and/or composition of tissues and cells, abnormal accumulations of biogenic deposits
3. Presence of microparasites or pathogens

(Brown and Howard 1985). Of the 12 species of corals examined in this study, 6 species had maturing gonads (Table 1). Four of these 6 species are broadcast spawners with summer gametogenesis and are expected to be reproductively active in August (Szmant 1986). *Acropora palmata*, also a broadcast spawner, could be reproductively active in August, but was not. According to Bythell (1988), colonies of *A. palmata* are sometimes found to be non-reproductive in any given year. The other corals are brooders and would be expected to have maturing gonads at various times during the year but in this study, only the *Mycetophyllias* had maturing gonads. However, since the Treatment 1

areas were on the periphery of the colony, lack of gonads might be due to outer edge sampling, in that polyps near the periphery of the colony were less apt to be reproductive than polyps in the center of the colony because they are young and immature (Chornesky and Peters 1987).

Both experimental and control specimens contained a variety of endoparasites that consisted of endoparasitic copepods, a coccidium, and bacterial aggregates (E.C. Peters per. comm.) but no necrosis or cellular deformation was seen.

On the follow-up dives in November 1989, February 1990 and July 1990, all the corals appeared healthy and the areas from which tissue samples had been taken were either grown over by polyps or algae.

#### *Estimate of Diver Impact on Corals in LKNMS*

Touching once a week was sufficient to simulate diver interactions with coral. Comparison of estimated area of live stony corals with frequency of diver impacts in high use areas show that 4-6% of the live coral area are touched weekly (Table 2).

While calculations indicate that divers interact with approximately 4-6% of living coral area at LKNMS, restrictions should not be relaxed concerning the touching ban. Divers observed in this study were diving in protected waters and were not only instructed not to touch corals, but were closely monitored. If divers were allowed to touch at will and touched corals approximately every two minutes, as 6% of the monitored population did (Table



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