1 Title: Importance of environmental briefing and buoyancy control on reducing negative
2 impacts of SCUBA diving on coral reefs

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Abstract

Scuba diving is a growing industry as a form of ‘nature tourism’ allowing enjoyment of the beauty of coral reef ecosystems. However, as the recreational diver population has increased, diving activities in some heavily dived sites have caused negative ecological impacts, with divers unintentionally contacting live corals and causing physical damage. In this research, we investigated the rate of divers’ contacts and physical damage by observing divers’ underwater behavior in Okinawa, Japan, and tested the effectiveness of pre-dive briefings as a mitigation measure. Of 105 divers observed, 7% contacted the live coral cover and caused skeletal breakage, and 91% made contact at least once but did not cause visible damage. The average contact frequency of the divers during 30 min of dive time was 0.53 times/min. The contact frequency of the divers decreased significantly after they listened to an environmental briefing among the divers who could maintain neutral buoyancy, but not in the divers who could not. This study suggests that buoyancy control training for divers may also be important for coral reef conservation in addition to environmental education.

Key words: tourism management, scuba diving, environmental impact, pre-dive briefing, environmental education, neutral buoyancy, coral reefs

1. Introduction

Dive tourism has grown significantly in many tropical regions and has become an important source of income for local communities (Lew 2013). The number of recreational divers is growing rapidly, with around 1 million new divers being trained each year (Davenport and Davenport, 2006). The development of more reliable dive gear and inexpensive underwater cameras have accelerated this trend (Davis and Tisdell, 1996).

Impacts of marine tourism on the environment have been studied by some researchers. These include impacts of boat anchoring (Davis 1977, Dinsdale and Harriott 2004), snorkeling (Allison 1996), and trampling (Woodland & Hopper 1977, Kay and Liddle 1989, Neil 1990, Hawkins & Roberts 1993). In earlier years, scuba diving was seen as having little ecological impact on coral reef ecosystems (Tilmant and Schmahl, 1981; Talge, 1992; Hawkins & Roberts, 1992, 1993, Harriott et al., 1997), probably because of the relatively small diver population at that time. However, with the rapid increase in the number of recreational scuba divers, the cumulative impacts they have on reefs have become more and more substantial (Tlatalos & Austin 2001, Jameson et al. 2007). Some studies conducted more recently at very popular diving sites have found unsustainable levels of diving impact at those locations (Zakai and

Chadwick-Furman 2002, Hasler and Ott 2008, Au *et al.* 2014). At many reef sites across the globe, coral reefs are showing increasingly visible signs of deterioration, caused by intensive recreational use (Guzner *et al.* 2010).

Some researchers have addressed the question of how large the “carrying capacity” of coral reefs is for diving activities. Chadwick-Furman (1995) gave an estimate as low as 500 dives/year/site for the US Virgin Islands. Other estimates are somewhat larger and consistently around 6000 dives/year/site. Hawkins and Roberts (1997) suggested a carrying capacity of 5000–6000 dives/year/site. Schleyer and Tomalin (2000) estimated 7000 dives/year/site for South African coral reefs.

Degradation of the coral reef ecosystem by tourism overuse may influence tourists’ satisfaction and preferences, and may lead to a reduction in the economic value of the ecosystem (Pendleton 1994, Uyarra 2009).

Furthermore, some researchers have made observations of diver behavior underwater to determine which types of divers are more likely to cause ecological damage. Factors that have been assessed include diving experience, gender, and use of photographic equipment. Worachananant *et al.* (2008) found divers with increased levels of experience caused less damage than inexperienced divers, while Roupheal and Inglis (2001) found no correlation between dive experience and coral breakage.

1 Regarding gender, Rouphael and Inglis (2001) reported that male divers were more
2 likely to cause damage, while Worachananant (2008) reported that female divers caused
3 more damage. Some researchers found divers carrying photographic equipment were
4 more likely to cause more damage (Barker & Roberts 2004, Rouphael & Inglis 2001,
5 Kreiger & Chadwick 2013), whereas Worachananant (2008) reached the opposite
6 conclusion. In this study, the effects of personal dive experience, buoyancy control skill,
7 and use of photographic equipment were tested and correlated to diver contact rates
8 with the substrate.

9 To continue tourism activities in a sustainable way, negative ecological impacts of
10 tourism need to be reduced or minimized. Some mitigation measures suggested so far
11 include the implementation of a “no-use zone” (Epstein et al. 1999), limiting the
12 number of divers to below the carrying capacity (Hawkins and Roberts 1994), pre-dive
13 environmental briefings for divers (Medio et al. 1997, Worachananant et al. 2007,
14 Camp and Fraser 2012, Krieger and Chadwick 2013), and the use of artificial reefs to
15 reduce diving pressure (van Treck and Schumacher 1998, Polak and Shashar 2012).
16 However, few studies have analyzed the effectiveness of such management strategies.

17 The effects of environmental briefings have been tested. Barker and Roberts (2004)
18 found that the inclusion of only one or two brief sentence(s) on environmental impacts

was not effective whereas Medio *et al.* (1997), Warachananant *et al.* (2008), Camp and Fraser (2012), and Krieger and Chadwick (2013) found that divers who listened to pre-dive briefings caused significantly less damage. In this study, the effects of a pre-dive environmental briefing on reducing divers' contact frequency with the reef were also investigated.

2. Materials and Methods

2.1 Study Sites

The study was conducted at four locations in the Ryukyu Islands, Japan (Gino Bay, Onna-son, Kerama, and the Yaeyama Islands) in September 2009, October 2010, July August 2012, and July August 2014. The locations of the study sites are shown in Figure 1. The Ryukyu Islands lie in the subtropical region of Japan, and consist of around 50 inhabited islands and more than 300 uninhabited islands. The Islands are surrounded by well-developed fringing coral reefs. They are a popular tourism destination in Japan, and receive 5–6 million tourists per year, roughly 10% of whom are recreational divers. Diving is possible all year round, although the peak season is from March to September.

Figure 1. Map of the study sites

2.2 Observation of diver behavior underwater

With the cooperation of dive tour operators, the surveyors joined regular dive tours as ordinary recreational divers. Fifty dive trips were made in total. The intent of the survey was not to inform the guides or the guest divers, except the boat captains and dive shop managers, to avoid influencing the divers' normal behaviors.

During each dive, each surveyor randomly selected one of the divers in the tour group and observed his/her behavior from the start of the dive for 30 min. At the start, the surveyors recorded whether the target diver had photographic equipment, and whether the diver could maintain neutral buoyancy underwater. Divers who could maintain neutral buoyancy could be distinguished readily because they swam in a horizontal position and they could hover in the water column without moving their fins (Fig. 2, left). The divers who could not maintain neutral buoyancy were constantly kicking with their fins and swam in a tilted posture to maintain their position (Fig. 2, right).

Figure 2. A diver swimming with neutral buoyancy (left) and without neutral

buoyancy (right)

The number of unintentional contacts with the substrate was counted and recorded together with the touching object (hands, fins, knees, gauge, octopus, sediment suspension, and other). When the observed diver appeared to search carefully for dead substrate before contact, such contacts were not counted. If the diver's contact broke the coral, the genus of the broken coral and the lengths of fragments were also recorded. Dive sites were determined by the tour operator staff, based on requests from guests. Almost all dives were conducted on coral reefs or on sandy bottoms with coral patches. The percentage of coral cover was also recorded at each dive site by visual assessment (Ministry of the Environment of Japan 2004).

2.3 Questionnaire survey

With prior consent from the dive tour operators, each guest diver was asked to complete a questionnaire during a surface interval time between dives. This was voluntary, but almost all divers that were asked complete it. The questionnaire contained a total of 20 questions regarding past dive experience, awareness of the coral reef environment, and perceptions about diving activities.

2.4 Administration of environmental briefing

Educational material for the divers was developed using a PowerPoint presentation, explaining the basic biology and ecology of coral reefs, environmental issues, and possible conservation efforts (Fig. 3). The topics covered in the briefing were coral taxonomy and biodiversity, coral symbiosis, life cycle and reproduction, calcification and growth rates, threats to coral reef ecosystem, conservation efforts, what divers can do to protect coral reefs, and tips to avoid coral damage while diving. During the surface time between the first and second dive of the day, a print-out of the presentation was shown to the divers and an environmental briefing was given by the surveyor. The length of the briefing was approximately 15 min. The presentation was designed to include interactive content, such as simple quizzes, in an attempt to capture the attention of the audience as much as possible.

Fig. 3 Outline of the environmental briefing

Following the protocol described in section 2.2, the same divers were observed before and after the briefing, and the results were compared to see whether there was

any change in the frequency of contacts with the substrate. The difference was tested statistically with the Wilcoxon signed-rank test.

3. Results

3.1 Diver profiles

In total, 350 written questionnaires were collected. Of these, 45% were males and 55% were females. Their ages ranged from 16 to 68, but most (88%) were in their 20s (33%), 30s (31%), or 40s (24%). In all, we observed 105 of these divers while they dove, and 14 divers were observed twice, before and after the educational briefing. The participants' diving certification levels and diving experience are shown in Figure 4. The relationship between dive experience, certification level, and buoyancy control ability is shown in Table 1.

Figure 4. Participants' diving certification levels and diving experience

Table 1. Relationship between participants' experience and buoyancy control skill

3.2 Frequency of diver contact with the reef

On average, the divers contacted the reef 15.9 times per 30 min of dive time, or 0.53 times/min. Most of the contacts were made with fins, either touching the substrate or resulting in sediment suspension (Fig. 5).

Figure 5. Average frequency of the contact with substrate

The divers without buoyancy control made significantly more contacts with the reef (Fig. 6). The contact frequency was higher for the divers with cameras among the divers who could not control buoyancy, but not among the divers with buoyancy control. However, the differences were not statistically significant.

Figure 6. Total contact frequency of divers by buoyancy control ability and use of a camera

Overall, the contact frequency was less in divers with more diving experience (Fig. 7). The frequency of contact with fins and sediment suspension were significantly lower in more experienced divers, who had made more than 50 dives in the past. Other types of

contact (hand, knees, gauge, octopus, and other) did not vary with the diver's level of experience.

Figure 7. Average contact frequency by divers with different levels of experience

Of the 105 divers observed, only 2% made no contact with the substrate during the whole dive, 91% made contact at least once but did not cause visible damage, and 7% contacted the live coral cover and broke the coral skeleton.

3.3 Effects of environmental briefing

Table 2 shows the results of the comparison of diver contact rates before and after administration of the environmental briefing. When the data for all divers were analyzed together, the difference in contact rates before and after the briefing was not statistically significant (Wilcoxon signed-rank test, $p > 0.1$). However, when the data were analyzed in two groups—divers without neutral buoyancy and those with neutral buoyancy—the contact rates before and after the briefing were significantly different, but only in the latter group (Wilcoxon signed-rank test, $p < 0.05$).

- 1 **Table 2. Comparison of diver contact rates before and after the environmental**
- 2 **briefing**

4. Discussion

Most of the coral reefs of the world have already been damaged by various types of anthropogenic disturbances (Richmond 1993, Hodgson 1999, Hughes *et al.* 2003).

While the impact of tourism may be minor compared to other types of disturbances, it tends to affect reefs that are in relatively good condition and ‘attractive’ to the tourism industry.

In this study, the proportion of divers who contacted the reef substrate and caused visible physical damage was only 7%. However, the cumulative effect may not be negligible if the total number of divers using a given dive site is large enough. For example, 5.92 million people visited Okinawa during fiscal year 2012, of which 9.5%, or 562,400, were divers. Assuming each diver has four dives per trip on average, it can be estimated that about 160,000 coral breakages per year are caused by diving activities. It is estimated that around 500 dive sites are being used in Okinawa, but some of the frequently visited sites may receive more damage than others.

The physical damage caused by diving activities not only directly reduces coral biomass but also has indirect negative impacts. Physically injured coral colonies suffer from slower growth rates and become more susceptible to disease and predation (Guzner *et al.* 2010, Lamb *et al.* 2014). Likewise, suspended sediment, if it accumulates

on live corals, may lead to mortality or slower growth rates (Rogers 1990, Lamb *et al.* 2014). Thus, any management efforts to reduce the contact rates of divers with reefs will reduce the chance of physical injury or sediment accumulation, and contribute to reef conservation and sustainable tourism practices.

According to the results of our study, the average contact rate of scuba divers with the reef was 0.53 times/min of diving time. This value is slightly higher than those reported previously (Medio *et al.* 1997, Barker and Roberts 2004, Camp and Frasier 2012, Krieger and Chadwick 2013)).

The present study showed that the buoyancy control ability of divers was the factor most strongly related to contact rate. Consistent with this, the contact rate decreased significantly in experienced divers (more than 50 dives), because they have learned buoyancy control skills. Thus, novice divers (fewer than 50 dives) are the group most likely to have negative impacts on the reef. Therefore, any management strategy should take into account how to better manage novice divers.

This is the first reported study to examine the relationship between divers' contact rate and buoyancy control. Among previous studies that have tested diver characteristics (such as dive experience, gender, and use of photographic equipment), the results have been inconsistent. In these studies, different proportions of divers with and without

1 buoyancy control skill among the different subject groups may have been a confounding
2 factor causing the inconsistent results. Thus, in the future, similar studies should be
3 designed carefully to control for the influence of variation in diver buoyancy control
4 skills.

5 Our study also provides direct evidence that pre-dive briefings help reduce physical
6 contacts with reefs, at least for divers with adequate buoyancy control skills. In previous
7 studies, differences in contact rate were compared between two distinct groups of
8 divers: those who listened to an environmental briefing and those who did not. In this
9 study, because the contact rates of the same individuals were compared before and after
10 the briefing on the same day, the comparison is more direct, ruling out influences of
11 other factors, such as the personal level of dive experience of individual divers.

12 The types of environmental briefing offered to the divers were also different among
13 previous studies. The simplest type of briefing was that used by Barker and Roberts
14 (2004) and Warachananant et al. (2008), which was the inclusion of only one or two
15 brief sentence(s) on environmental impacts in a regular pre-dive briefing by dive guides.
16 Barker and Roberts (2004) found that the briefing was not effective while
17 Warachananant et al. (2008) concluded that such a briefing was effective. In Medio *et*
18 *al.* (1997), the briefing they offered was similar to the one we used, which covered

1 various aspects of coral biology and impacts caused by divers, supported by
2 photographs and diagrams, and they also found a significant decrease in the contact rate.
3 Pre-dive briefings should be prepared by coral biologists and cover basic aspects of
4 coral biology with visual materials, rather than just a few sentences mentioning “please
5 do not touch live corals.”

6 However, that the briefing was only effective for divers with buoyancy control
7 suggests that an environmental briefing alone is not enough to reduce the negative
8 impacts of diving activities on coral reef ecosystems. In fact, 4 of 8 divers showed
9 *increased* contact rates after listening to the briefing. The divers with poor buoyancy
10 control skills may have tried to avoid contact after listening to the briefing, but could
11 not do so because of their lack of ability. Thus, environmental briefings should be
12 combined with buoyancy control training targeted at inexperienced divers. In the
13 present study, 83.8% of the divers answered that they could maintain neutral buoyancy
14 underwater in the questionnaire, but only 37.5% of divers could actually do so
15 according to our observations. Thus, there was a huge gap between divers’ skills and
16 self-assessments. In addition, as shown in Table 1, not even all experienced divers could
17 maintain neutral buoyancy, because approximately 30% of divers with higher levels of
18 certification and experience of more than 100 dives could not do so. Diving instructors

1 should note this gap; more time and effort should be spent training divers regarding
2 buoyancy control skills.

3 Although no direct effect of the briefing was supported by the statistical analysis,
4 for divers with poor buoyancy control skills, indirect effects of the briefing may be
5 expected, such as raising their environmental awareness and interests in coral reef
6 conservation, and motivating them to learn better diving skills in the future.

8 **5. Conclusions**

9 In present study, divers without buoyancy control skills tended to contact the reef more
10 often and thus had a higher chance of damaging benthic organisms, and an
11 environmental briefing was effective for divers with proper buoyancy control skills.

12 Although the divers without buoyancy control skills are the group that tended to create
13 more damage to the reefs, an environmental briefing alone is not effective for reducing
14 the damage. Therefore, management strategies for the impact of tourism should include
15 how to reduce damage made by these inexperienced divers. One possible strategy is to
16 provide training opportunities for these divers on buoyancy control skill, and the effects
17 of such training on reducing the negative ecological impacts of scuba diving should be
18 examined in a future study.

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Figure 1

Figure 2

Figure 3

Unique biology of corals

- Reef-building corals are animals that have hard skeleton and create coral reefs
- They make colonies and each individual organism is called a polyp.
- They have simbiotics which transfer photosynthetic product to the host.
- They propagate by sexual and asexual reproduction.
- There are about 800 known species of corals, about 350 of which occur in Okinawa.

Vulnerability of coral reef ecosystems

- Reef-building corals are slow growing organisms, and their growth rates (calcification rates) vary among species. Even the fastest growing species have only about 10-20cm annual growth (branch extension) rate.
- The skeleton of most species of corals is fragile and easily breakable.
- Coral reef ecosystems are threatened and getting widely degraded by various threats, such as bleaching, outbreak of crown-of-thorns starfish, pollution, and coral diseases.

How divers can help protect coral reef ecosystems

- When diving, each diver should take care not to break corals and other organisms, especially when using underwater camera.
- It is better to secure your gauges, regulators and other equipment so they do not drag over reefs.
- Maintaining neutral buoyancy can reduce coral breakage.
- Divers can also change to eco-friendly lifestyle back home.

Figure 4

Figure 5

Figure 6

Figure 7

Table 1

Dive experience	Percentage of participants who could maintain neutral buoyancy
1–50 dives	14.8%
51–100 dives	52.8%
More than 100 dives	72.2%
Certification level	Percentage of participants who could maintain neutral buoyancy
Open Water	10.0%
Advanced	66.7%
Rescue or higher	70.0%

Table 2

Diver #	Gender	Diving experience	Neutral buoyancy	Underwater Camera	Total number of contacts	
					Before briefing	After briefing
Divers without neutral buoyancy						
1	F	3	N	N	28	30
2	M	50	N	Y	25	19
3	M	80	N	Y	44	10
4	F	90	N	N	4	29
5	M	130	N	N	5	14
6	M	145	N	N	29	11
7	F	160	N	Y	9	40
8	M	185	N	N	21	10
Divers with neutral buoyancy						
9	M	6	Y	N	4	0
10	M	80	Y	Y	2	1
11	F	80	Y	N	13	4
12	F	100	Y	N	7	3
13	F	450	Y	Y	8	5
14	M	600	Y	Y	6	4

Note: F=female, M=male, Y=yes, N=no