Impact of snorkelers on shallow coral reefs in the

Rock Island Southern Lagoon

Victor Nestor, Evelyn I. Otto, Marine Gouezo, Lincy Marino, Geory Mereb, Dawnette Olsudong, Randa Jonathan, John Swords, Yimnang Golbuu

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Abstract

Palau, like many Pacific islands are popular travel destinations for tourists, especially for underwater excursions. From 2010 to 2015 total visitors to Palau nearly doubled, reaching approximately 160,000 visitors. Although this intense growth may be good for the economy, information on the impact of tourists on shallow coral reefs in Palau is limited. This study sets out to document the impact of snorkelers on snorkeling sites in the Rock Island Southern Lagoon (a UNESCO World Heritage Site). In 2015-2017, surveys were conducted at 5 popular snorkeling sites (visit sites) and 5 reference sites (non-visit sites) to quantify fish density and biomass, benthic cover, and the number of visitors (boats and snorkelers). Results illustrated that coral fragments at the non-visit sites (30 fragments per $0.25m^2$) was half of that found at the visit sites (60 fragments per $0.25m^2$). Benthic cover, including coral and rubble, was similar between visit and non-visit sites. Fish biomass was greater inside the visit site (14 kg per $70m^3$) than non-visit sites (8 kg per $70m^3$). On average 1 out of 5 groups of snorkelers damaged live corals. Although regulations are in place, we must improve and enforce them to help protect our reefs from the negative impacts of human activities, such as snorkeling.

Introduction

Coral reefs are important for many reasons, and among them are the services they provide (Moberg and Folke 1999, Costanza et al. 2014). Coral reefs provide habitat and source of food for many organisms (Moberg 1999). They also break high wave energy, whichdecreases theerosion of shorelines. For islandnations, coral reefs are an important source of food (fish, edible invertebrates and marineplants). Lastly, coral reefs support high biodiversity making them very attractive for tourists, which generates an important source of income (Costanza et al. 2014).

Located in the north-west Pacific region, Palau is an island-nation that is well known for its marine environment. Palau's reefs are home to over 1,000 species of fish and 700 species of corals and anemones (Golbuu et al. 2005). Tourists around the world travel in great numbers to visit Palau's uniquereefs. Figure 1 shows annual visits to Palau from 2008-2016,based on data collected by the Palau Visitors Authority (PVA).

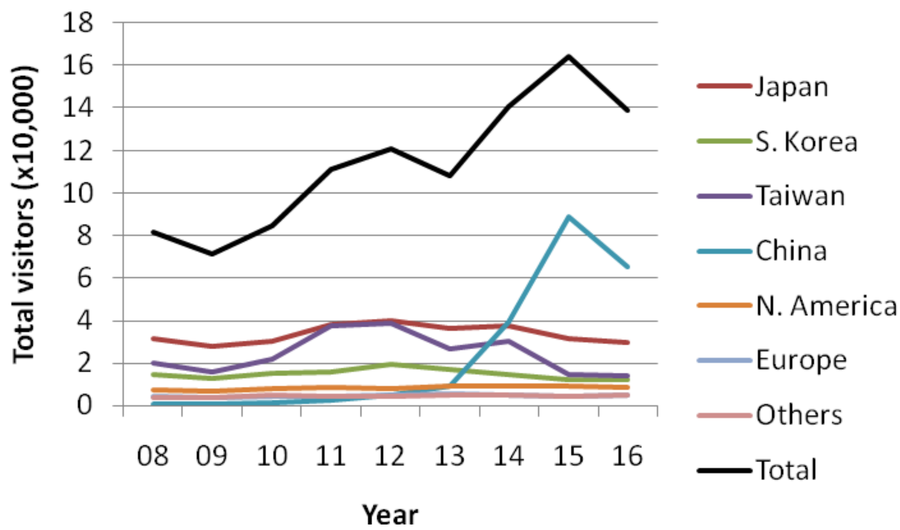

Figure 1. Annual visitors (total) from year 2008 to 2016. *Data includes all Visitor type purposes, and any unspecified purposes upon arrival (PVA).

The number of tourists visiting Palau rose steadily from 2008 to 2015, with a slight drop in 2013. In a period of 5 years (2010-2015), the number of visitors nearly doubled. Visitors that came within this time period were mainly from Japan, Taiwan, and South Korea. In 2015, there was a spike in the number of Chinese visitors, which contributed the most to the rapid growth of visitors from 2013 to 2015.

Tourists in Palau enjoy recreational activities in the Rock Island Southern Lagoon (RISL, or Rock Islands in short). The RISL covers an area of 100, 200 ha, harbors 445 limestone islands, and has high biodiversity in the marine and terrestrial environments (UNESCO, 2017). The Rock Islands is managed by Koror State Government, and the regulations on its use (Rock Islands Use Act) was passed in 1997(UNESCO, 2017). Then in 2012, RISL was inscribed as a UNESCO World Heritage Site.

The massivegrowth in the number of tourists may be a significant gain for Palau's economy, but what impact does tourism have on marineenvironment? Some studies that have looked at behavior of divers, and concluded that divers have negative impact on coral reefs (Rodgers and Cox 2003). However, few studies have been done in Palau to address this issue. Therefore, the objective of this study is to determine the impact of snorkeling tourism on shallow coral reefs in Palau, specifically within the Rock Islands.

Method

This study was conducted in Koror State's Rock Island Southern Lagoon. Sites were visited bi-annually to consider the annualfluctuation of visitors to Palau. According to data collected by PVA, the peak season of visitors is during the months of February and August while low season is during the months of May and October. In this study, surveys wereconducted in July 2015 and January 2016 (referred to as 2015), as well as July 2016 and January 2017 (referred to as 2016). Five popular snorkeling sites (referred to as visit sites) were selected for this study. Theyare Big Drop Off, Wonder Channel, Rose Garden, Fantasy Island, and Cemetery Reef. Reference sites, or non-visit sites, were selected based on the proximity to the respective visit sites and had similar physical characteristics, such as reef type and wave exposure. All surveys were conducted at a depth of 2m. Refer to Figure 2 for the map of all study sites.

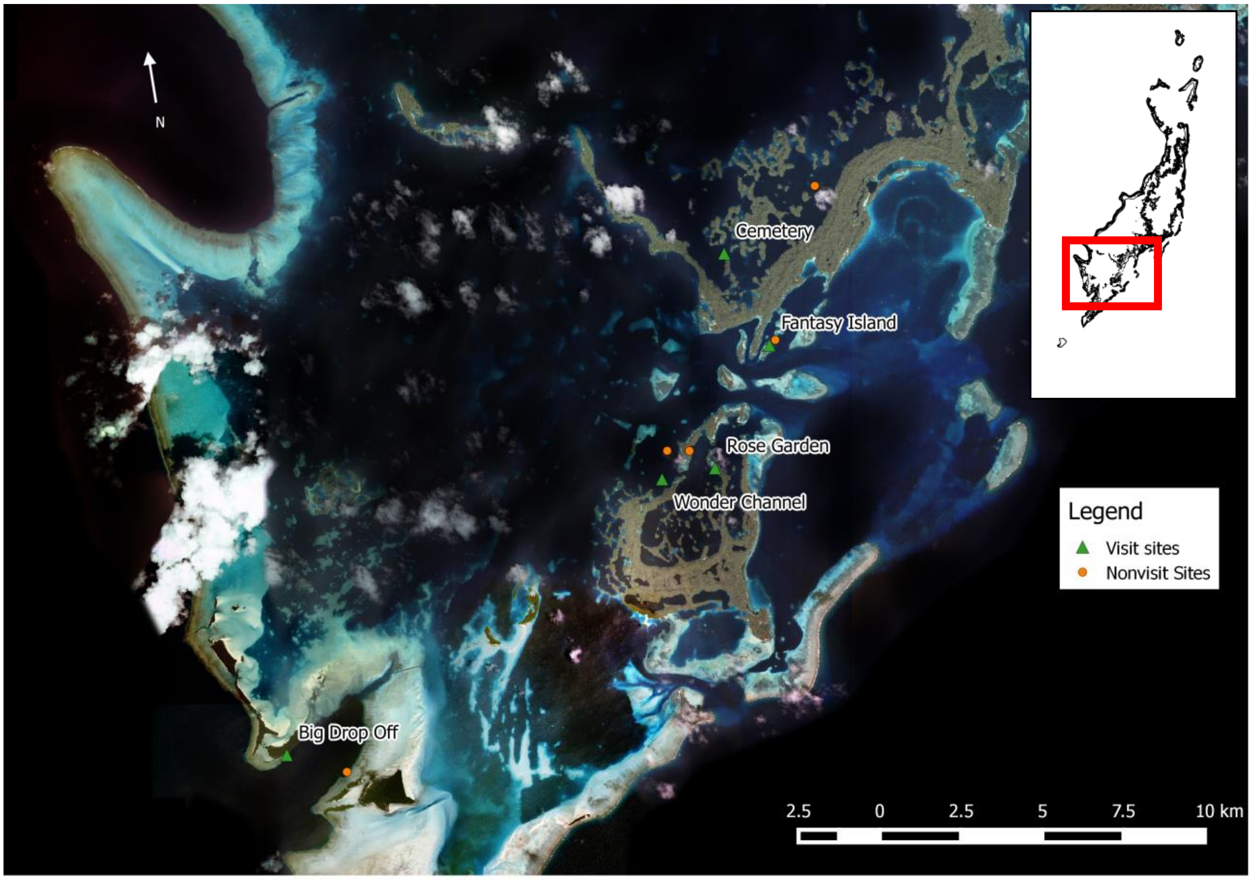

Figure 2. Map of study sites in Koror State's Rock Island Southern Lagoon.

Coral fragments

A photoquadrat (0.25m^2) was used to record the number of coral fragments at each site. A coral fragment is a piece of coral that has broken off from the coral colony,and is still living while it rests loosely on the reef. At each site, the photoquadrat was tossed in a randomdirection. An underwater camera (Canon PowershotG16 or Sea & Sea G2) was used to take a picture of the quadrat once it landed on the reef. The area of the visit site determined the required number of pictures for each visit and non-visit site(Table 1).Abundance of coral fragments within each photo quadrat was then summed up.

Table 1. Area of study sites as well as the number of pictures required for coral fragment analysis on each of the five visit sites. Note that non-visit sites have the same size and number of pictures as their respective visit sites.

SITE	SIZE (km^2)	NUMBER OF PICTURES
Big Drop Off	1.59	60
Cemetery Reef	0.57	50
Fantasy Island	1.18	55
Rose Garden	0.48	50
Wonder Channel	0.59	50

Benthos

The same pictures used for coral fragment analysis above was used for benthic analysis at the respective sites. Images were analyzed using the computer software Coral Point Count with Excel extension (CPCe, Kohler and Gill 2006) for percent cover of the following categories: hard corals (identified to the genus level), rubble, and hard substrate (carbonate and turf algae). Carbonate is the hard structure composed of dead corals that are cemented together, and turf algae are fine algae that cover most bare surfaces in marine environments.

Fish

Fish surveys were conducted at each site using the method Stationary Point Count (SPC). The surveyor swam to 3 random points on the reef. At each point, the surveyor recorded all target fish species (commercially important fish, Appendix 1) within a circular area of 5m in diameter (total of 20 m^2) for 3 minutes. Data collected are targeted species identified to the species level as well as the size of each individual fish observed. The estimate of fish biomass was acquired using the length-weight relationship (Eq. 1) published by Kulbicki et al. (2005).

$$B = a * L^{b} \qquad \text{(Eq. 1)}$$

Where B = biomass (in grams), L = length (in centimeter), and the constant variables *a* and*b* are acquired from Kulbicki et al. (2005) and the online source Fish Base (www.fishbase.org).

Data analyses

Linear-mixed model was used to compare means of coral fragments, live coral cover, loose substrate cover, and fish density and biomass between status (visit vs. non-visit) with season and year nested in sites.Sampling time was incorporated into the model as a random term to account for repeated measurements over time. Analysis was done in R program (R Core Team 2017).

Observation of boats and snorkelers

Surveys were conducted during the day when snorkelers visited the RISL, generally from 9am to 3pm. Although there were some survey days that were longer or started earlier than 9am. On some occasions in 2015, more than 2 visit sites (with the respective non-visit sites) were surveyed in one day. While in 2016, each visit site with its reference site was surveyed in one day. At each site, the number of visiting boats was recorded for a period of 45 minutes. Data collected were the number of boats, estimated number of snorkelers onboard, and if anybody onboard was feeding the fish.

Observation of snorkelers in the water was conducted for a period of 5 minutes per cluster (or group) of snorkelers. Data collected were: thenumber occurrences of physical contact with the reef by the snorkelers, including the contact type (e.g. kick and stand). Descriptive analysis of data was done in R program and MS Excel.

Results

Coral fragments

The average density of coral fragments at the non-visit sites (30± 7 fragments per $0.25m^2$) was significantly lower than at the visit sites (60±16 fragments per $0.25m^2$, p = 0.012, Fig.3).

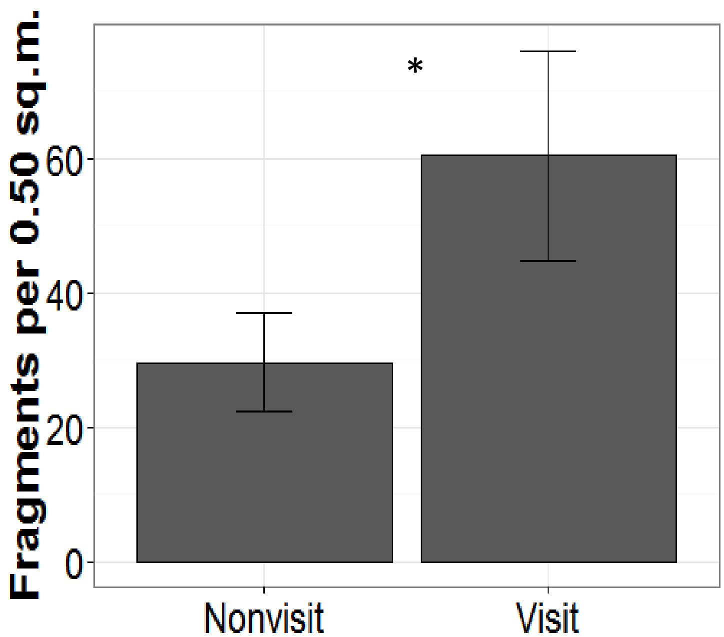

Figure 3. Density of coral fragments (mean ± SE per $0.25m^2$) of non-visit and visit sites in 2015 and 2016. Asterisk (*)shows significant difference. *n* = 20

Benthos

Live coral cover was similar between visit(45± 5%) and non-visit sites(43 ±4 %, p = 0.8, Fig. 4). Percent cover of macroalgae was significantly higher in visit (3 ± 1 %) than non-visit site (2 ± 1 %, p = 0.0437, data not shown).

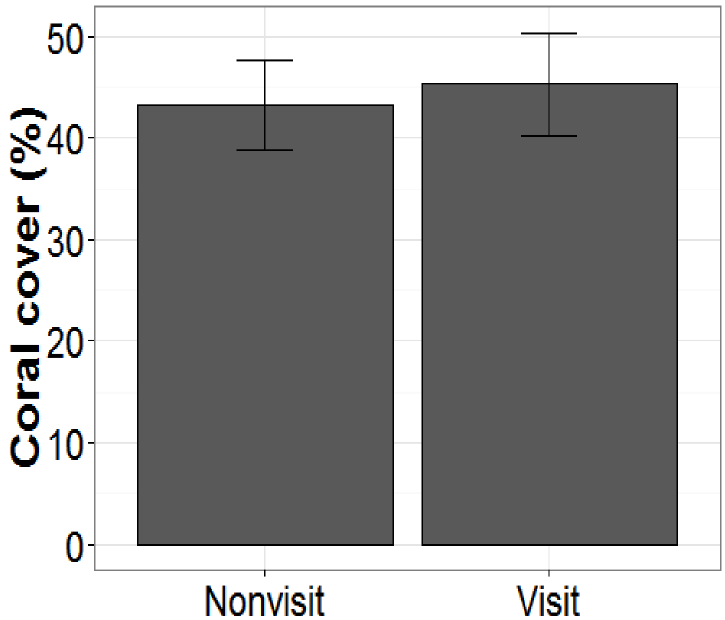

Figure 4. Percent cover (mean ± SE %) of hard corals between non-visit and the visit sites in 2015 and 2016.*n* = 20

The percentage cover of rubble was not significantly different between the visit sites (3 ± 1 %) and non-visit sites (4 ± 1 %, p = 0.144, Fig. 5).

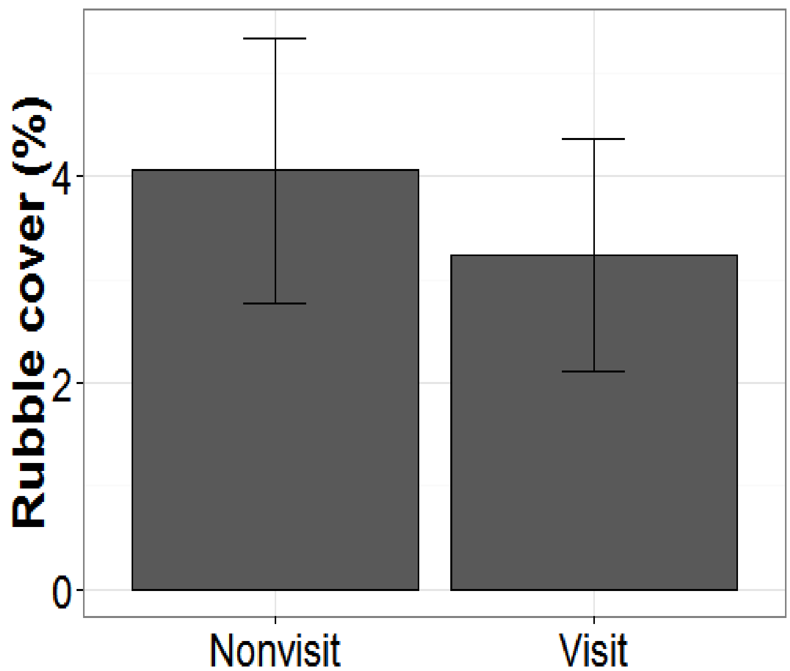

Figure 5. Percent cover (mean ± SE) of rubble at the non-visit and visit sites in 2015 and 2016. *n* = 20

The percentage cover of hard substrate was similar between non-visit sites (45 ± 4 %) and visit sites (42 ± 5 %, p = 0.7567, Fig. 6).

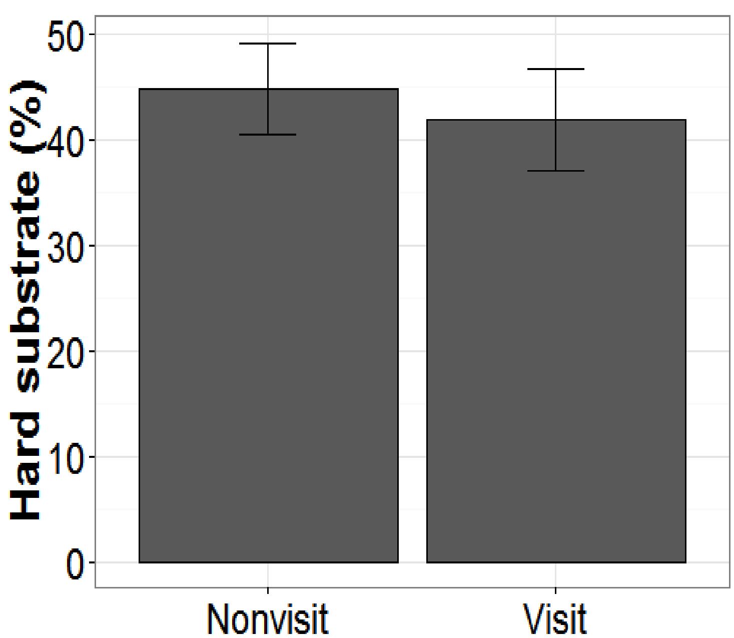

Figure 6. Percent cover (mean ± SE %) of hard substrate (carbonate + turf algae) in 2015 and 2016. Asterisk (*) indicate significant difference. *n* = 20

Reef fish

Throughout the study, the average fish density was similar between the non-visit sites (15 ± 2 fish per 20m^2) and the visit sites (16 ± 3 fish per 20 m^2, p = 0.635, Fig. 7).

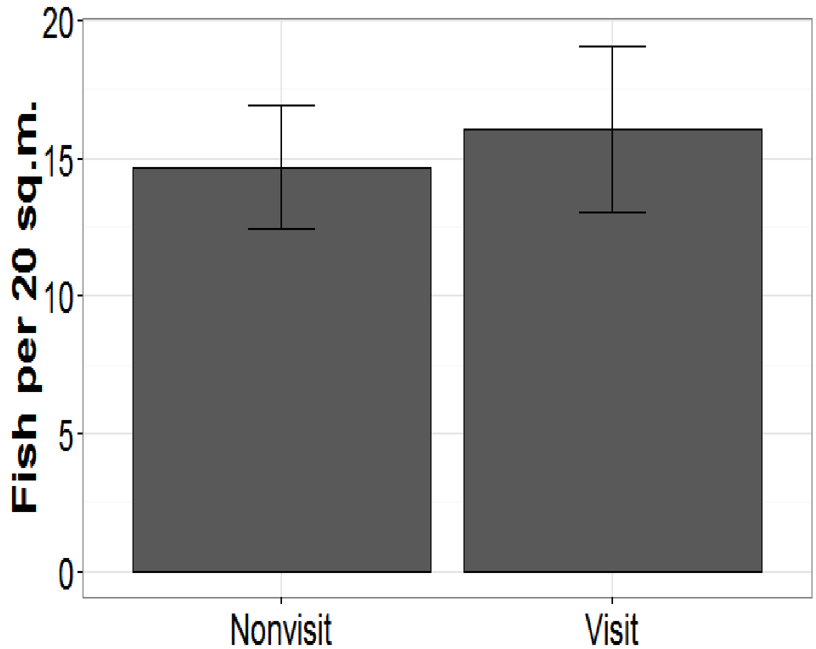

Figure 7. Density of reef fish (mean ±SE per 20 m^2) inside the non-visit sites and the visit sites for 2015 and 2016 sampling periods. *n*= 20

The mean biomass of reef fish was significantly higher at the Visit site (14.0 ± 2.2 kg per 20 m^2) than the non-visit site (8.4 ± 2.3 kg per 20 m^2, p = 0.019, Fig. 8).

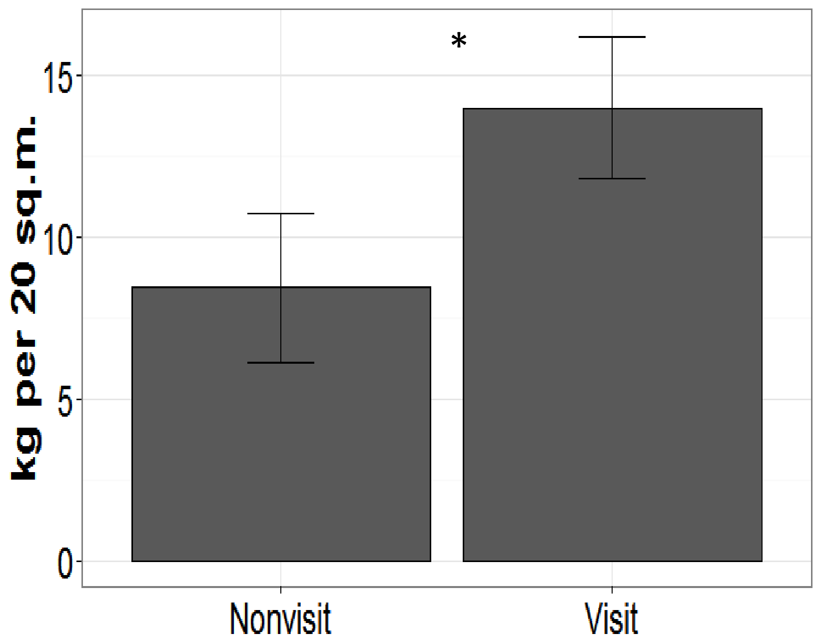

Figure 8. Biomass of fish (mean ± SE kg per 20 m^2) for the non-visit sites and the visit sites in 2015 and 2016. Asterisk (*) shows significant difference. *n* = 20

Observation on visitors

No tourists went to the non-visit sites, so the data presented below are from observations done inside the visit sites only. Within45 minutes, an average of 4 (in 2015) and 6 (in 2016) boats made a stop at a visit site (Fig. 9). These boats carried an average of 40 (in 2015) and 70 (in 2016, Fig. 10). And for both 2015 and 2016, an average of 1-2 boats visiting in a 45-minute period fed the fish when they entered the visiting sites (Fig. 11).

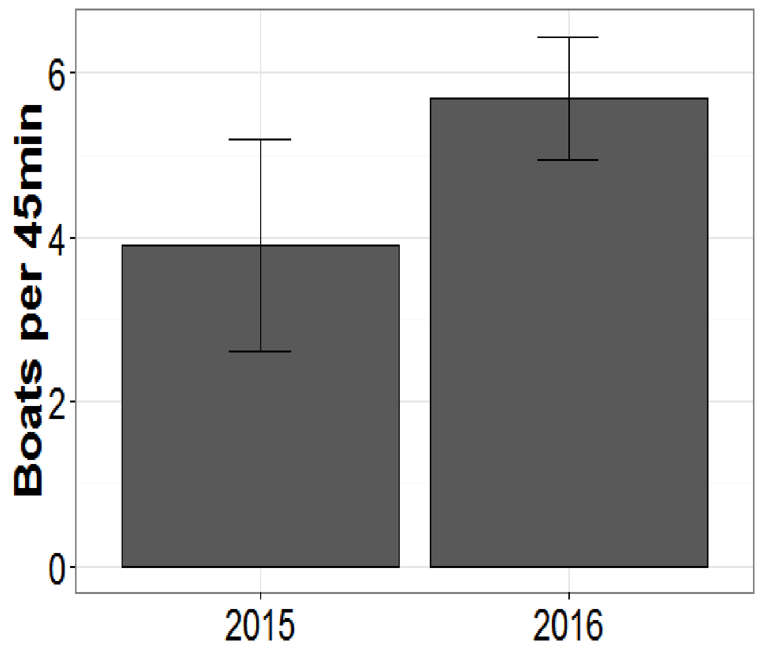

Figure 9. Number of visiting boats (mean ± SE) in a 45-minute period at a visit site. *n* = 10

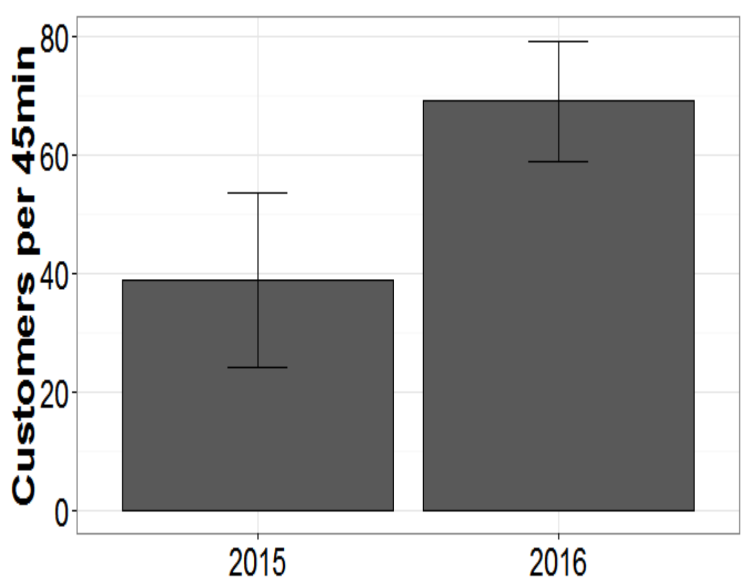

Figure 11. Number of customers (mean ± SE) visiting a site in a 45-minute period for 2015 and 2016. *n* = 10

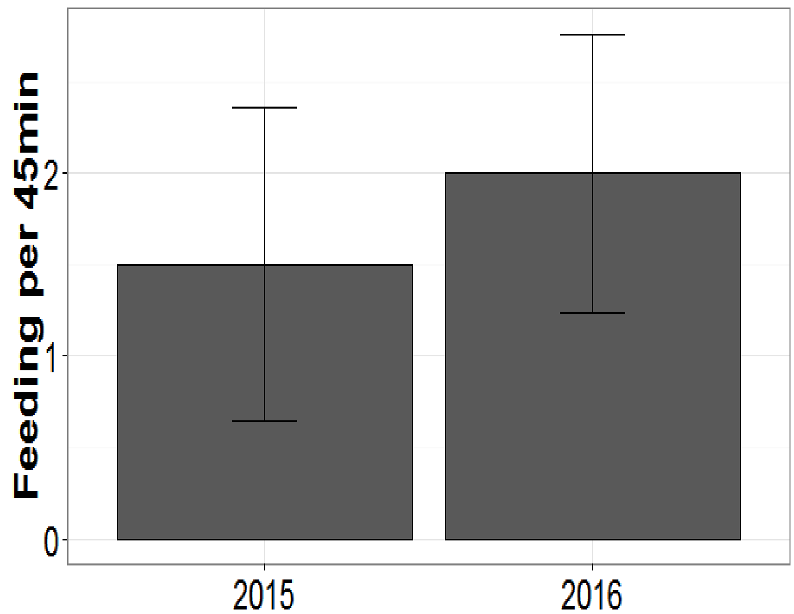

Figure 12. The number of boats (mean ± SE) within a 45-minute period that fed fish inside the visit sites for 2015 and 2016. *n* = 10

On average, five groups of snorkelers were observed in both 2015 and 2016 (Fig. 13). Each group consisted of 6-8 snorkelers and a tour guide. In 5 minutes, at least one person from 1 group (in 2015) made contact to the reef and damaged the reef (Figs 14 and 15). Damage caused were mainly on thin branching corals (e.g. branching Acroporids). Then in 2016, in 5 minutes one out of three groups made contact to the reef and made damage to the reef (Figs 14 and 15). Similar to 2015, thin-branching corals were most vulnerable to being damaged.

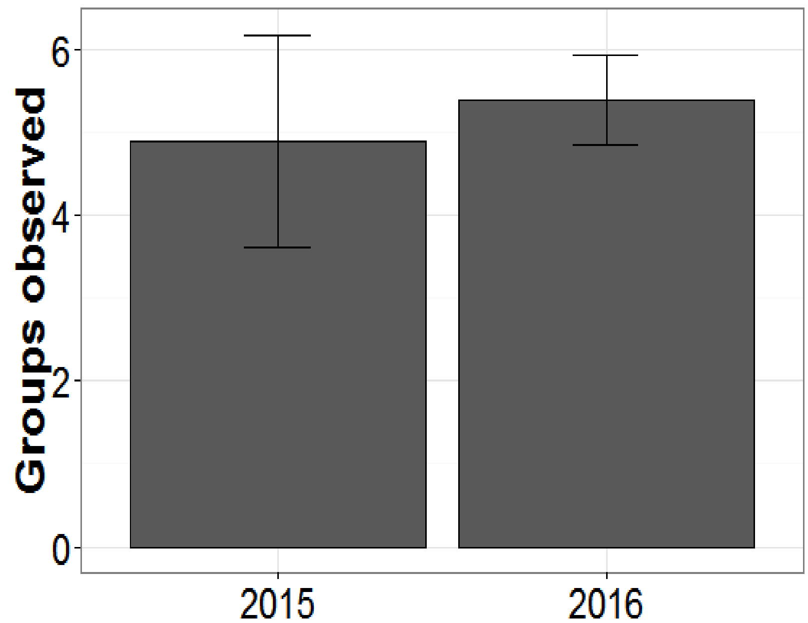

Figure 13. The number of groups observed (mean ± SE) underwater for 2015 and 2016. *n* = 10

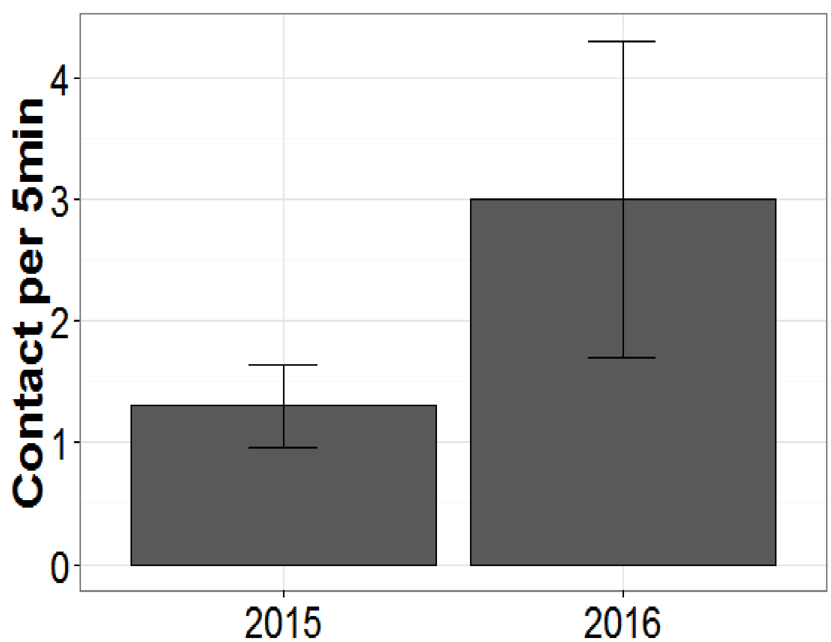

Figure 14. Number of groups (mean ± SE) that made contact to the reef in 5 minutes for 2015 and 2016. *n* = 10

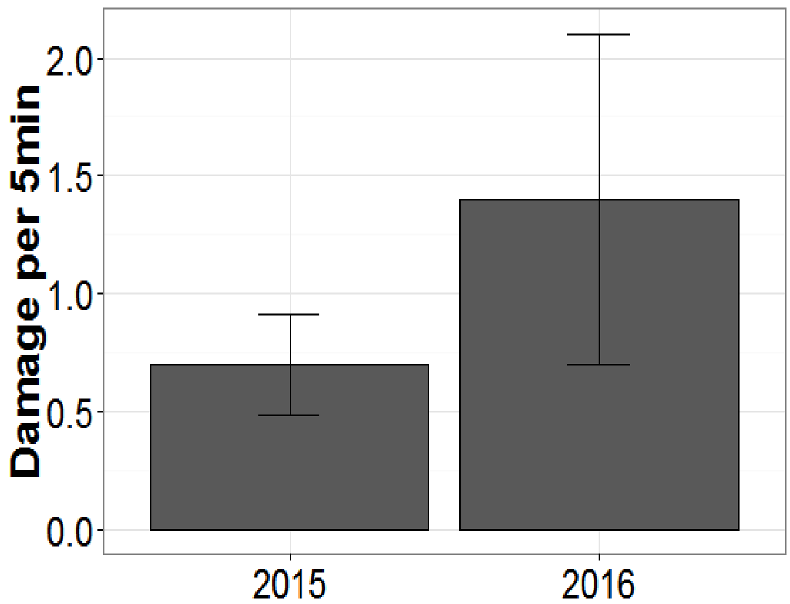

Figure 15. Number of groups (mean ± SE) that made caused damage to the reef in 5 minutes for 2015 and 2016. *n* = 10

In 2015, all contacts to reef was 50% standing and 50% kicking (data not presented). While in 2016, most contacts were from kicking (60%), followed by standing (13%). Figure 10 describes all the contact types observed in 2016.

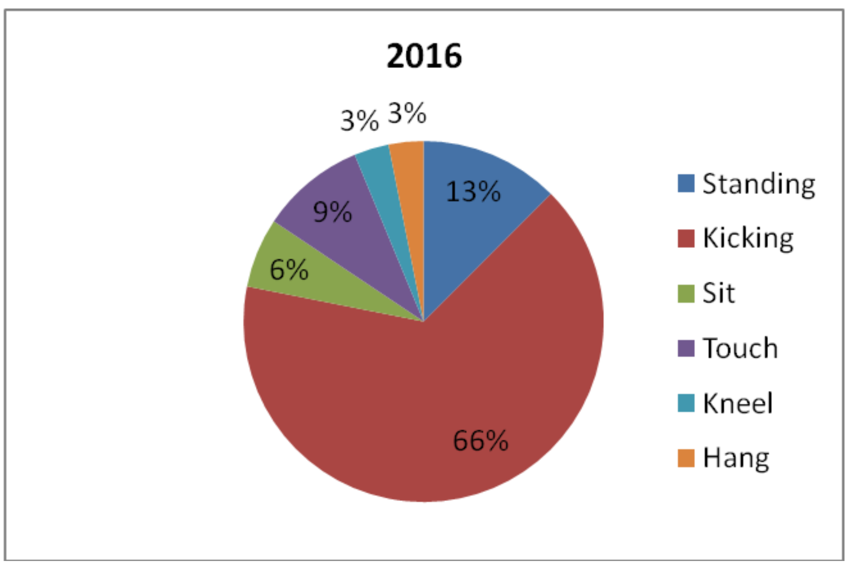

Figure 10. Percent of all contact types to reef by snorkelers in 2016. *n* = 10

Discussion

Main findings of this study indicated that snorkelers had some impacts on shallow reefs in RISL. Density of coral fragments at the non-visit sites was half of that present at the visit sites. Percent cover of substrates were similar between sites, except for macroalgae. Though coral cover was approximately 10 times greater than macroalgal cover, so a shift to algal-dominated reef is unlikely to happen. Fish density was similar between sites, but larger fish were more common at visit sites than at non-visit sites. Four to six boats carrying about 40-60 snorkelers visited a popular site within 45 minutes. Of these boats, two were found to be feeding fish. Finally, approximately one-fifth of the groups of snorkelers observed underwater damaged living corals.

Coral fragments were higher in visit sites than non-visit sites. Snorkelers were present only at the visit sites, and were observed to be causing damage to the living corals. These findings support previous studies, which have shown that snorkelers trampling on corals do increase coral fragments on a reef (Plathong et al. 2000, Zakai et al. 2000, Otto et al. 2016, Hawkins et al. 1993, Rodgers and Cox 2003). Therefore, this study shows that snorkelers, not natural processes (i.e. typhoons),caused damage to coral reefs in RISL tourists sites, resulting in coral fragments.

This is important to consider because the condition of individual corals affect the reef as a whole. An important component of reef recovery following a disturbance is the reproduction and settlement of coral planulae (Jones et al. 2009). Planulae reproduction is significantly reduced between an intact coral colony and coral fragments (Rodgers and Cox, 2003). Therefore, when there is an increase of coral fragments there is a decreasein coralfecundity, reproduction and abundance of coral larvae in shallow reefs of RISL.

The fish biomass, which is directly associated with fish length, was greater at visit sites than non-visit sites. There was no baseline information of fish size at the visit sites; therefore, this study fails to determine if snorkelers had an influence (e.g. fish feeding) on fish community at the visit sites. Visited sites are among the popular snorkeling sites in RISL, and they are no-fishing zones while non-visit sites are open to fishing. So the larger fish observed inside visited sites maybe a positive effect of the no-fishing regulation at these popular sites.

To ensure that we do not lose our reefs, we must decrease the threats. Using 5 hours as an estimate of visit time to RISL in one day, 10 snorkelers will be damaging live corals at one popular snorkeling site in one day. With increased coral fragments, we know that planulae reproduction decreases; therefore, we recommend that snorkelers avoid coming into contact with any life form on the reef at any time. One suggestion is to avoid snorkeling at these sites when the tides are extremely low, and aim to snorkel in the sites when the water is greater than 2m deep.

Fish feeding has potentially negative effect on fish since most of the food fed to fish (e.g. rice and bread) is not in a fish's natural diet. Further study is needed to determine what affect fish feeding has on fish within the RISL. A more alarming observation is the change in fish behavior due to feeding. Fish get into a feeding frenzy when they are being fed food scraps by snorkelers. As a result, the fish are more vulnerable to spear fishermen outside of the no-fishing zone, or poachers inside the no-fishing zone, since the fish will potentially swim close to the fishermen in search of food. Therefore, it is recommended that fish feeding be prohibited until further study is conducted to determine the effect fish feeding have on fish's diet and the fish's behavior.

In conclusion, we must manage the activities on shallow reefs in order to prolong the survival of our rich coral reefs and its resources. There are regulations at the popular sites in RISL, such as the no-fishing zones. However, RISL is a large area, and with limited number of rangers, enforcement is one of the main challenges in RISL management. Increased awareness to visiting snorkelers on the effects of damaging hard corals is one recommendation. Another recommendation is to fine tour companies that fail to follow the regulations set by Koror State management. Over time, responsible tourism would be encouraged and our reefs would move closer to being free from the impacts of snorkelers.

Acknowledgement

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Appendices

Appendix 1. Commercially important fish species

Commercially important fish species in Palau			
	Common name	**Palauan name**	**Scientific name**
1	Bluefin trevally	Erobk	*Caranx ignobilis*
2	Giant trevally	Oruidel	*Caranx melampygus*
3	Bicolor parrotfish	Beadle/Ngesngis	*Cetoscarus bicolor*
4	Parrotfish species	Melemau	*Cetoscarus/Chlorurus/Scarus* spp
5	Yellowcheek tuskfish	Budech	*Choerodon anchorago*
6	Indian ocean long nose parrotfish	Berkism	*Hipposcarus hariid*
7	Pacific longnose parrotfish	Ngeaoch	*Hipposcarus longiceps*
8	Rudderfish	Komud, Teboteb	*Kyphosus spp (vaigiensis)*
9	Orange stripe emperor	Udech	*Lethrinus obsoletus*
10	Long face emperor	Melangmud	*Lethrinus olivaceus*
11	Red gill emperor	Rekruk	*Lethrinus rubrioperculatus*
12	Yellow lip emperor	Mechur	*Lethrinus xanthochilis*
13	Squaretail mullet	Uluu	*Liza vaigiensis*
14	River snapper	Kedesau'liengel	*Lutjanusargentimaculatus*
15	Red snapper	Kedesau	*Lutjanusbohar*
16	Humpback snapper	Keremlal	*Lutjanusgibbus*
17	Orangespine unicornfish	Cherangel	*Naso lituartus*
18	Bluespine unicornfish	Chum	*Nasounicornis*
19	Giant sweetlips	Melimralm,Kosond/Bikl	*Plectorhinchus albovittatus*
20	Yellowstripe sweetlips	Merar	*Plectorhinchus crysotaenia*
21	Pacific steephead parrotfish	Otord	*Scarus micorhinos*
22	Greenthroat parrotfish	Udoudungelel	*Scarus prasiognathus*
23	Forketail rabbitfish	Benut	*Siganus argenteus*

24	Lined rabbitfish	Kelsebuul	*Siganus lineatus*
25	Masked rabbitfish	Reked	*Siganuspuellus*
26	Goldspotted rabbitfish	Bebael	*Siganuspunctatus*
27	Bluespot mullet	Kelat	*Valamugil seheli*
Protected Fish Species (yearly and seasonal fishing closure)			
28	Bumphead parrotfish	Kemedukl	*Bolbometopon muricatum*
29	Humphead wrasse	Ngimer, Maml	*Cheilinus undulatus*
30	Brown-marbled grouper	Meteungerel'temekai	*Epinephelus fuscoguttatus*
31	Marbled grouper	Ksau'temekai	*Epinephelus polyphekadion*
32	Squaretail grouper	Tiau	*Plectropomus areolatus*
33	Saddleback grouper	Katuu'tiau, Mokas	*Plectropomus laevis*
34	Leopard grouper	Tiau (red)	*Plectropomus leopardus*
35	Dusky rabbitfish	Meyas	*Siganus fuscescens*

Appendix 2. GPS coordinates (UTM, 53 N zone) of study sites.

SITE	LATITUDE	LONGITUDE
Fantasy Island	432084	797862
Fantasy Island (Ref)	432263	798027
Rose Garden	430408	794066
Rose Garden (Ref)	429624	794604
Wonder Channel	428781	793728
Wonder Channel (Ref)	428939	794607
Cemetery	430689	800696
Cemetery (Ref)	433477	802785
Big Drop Off	417240	785214
Big Drop Off (Ref)	419089	784693