IMPACT OF SNORKELERS ON SHALLOW CORAL REEF COMMUNITIES IN PALAU

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ABSTRACT

With the increasing numbers of visitors arriving in Palau, most of whom come to dive and snorkel on the reefs, there are concerns about the impact of the increased number of visitors on the shallow coral reef communities. Because of the importance of our coral reefs to both the people of Palau and the visitors that come to enjoy them, it is important to determine if the increased usage of these resources is negatively affecting them. In this study, we examined the effects of the high number of snorkelers on five popular snorkeling sites. The crowded snorkeling sites were compared to reference sites, which were similar in exposure to wind and currents, and benthic communities, but had little or no tourist activity. At each site, benthic and fish surveys were conducted, as well as observations of snorkelers' behavior. Our findings demonstrate that the snorkeling sites had significantly higher rubble cover and coral fragments. In contrast to corals, fish sizes were significantly larger at the snorkeling sites compared to the reference sites.

INTRODUCTION

Palau has some of the richest coral reefs in the world with over 1000 species of fish and 700 species of corals and anemones (Golbuu *et al*. 2005). After the World War II (WWII), Palau became a destination many people wanted to visit and a must see for ocean enthusiasts. Palau offers an array of experiences from diving with manta rays to exploring the wreckage of WWII. Palau has an established reputation for its rich marine resources and the unique experience with nature (Dent, S. R, 1991).

Over the years, tourism had shifted greatly in Palau. According to the Palau Visitors Authority, the Department of Budget and Planning, and Index Mundi, tourism has risen by 114,000 visitors over the past 20 year. Tourism rose 38.4% between 1995 and 2010. Numbers then exponentially rose 46.3% in the five year span between 2010 and 2015 (Immigration / Tourism Statistics. 2015; Palau - International tourism. 2013) (Fig 1.)

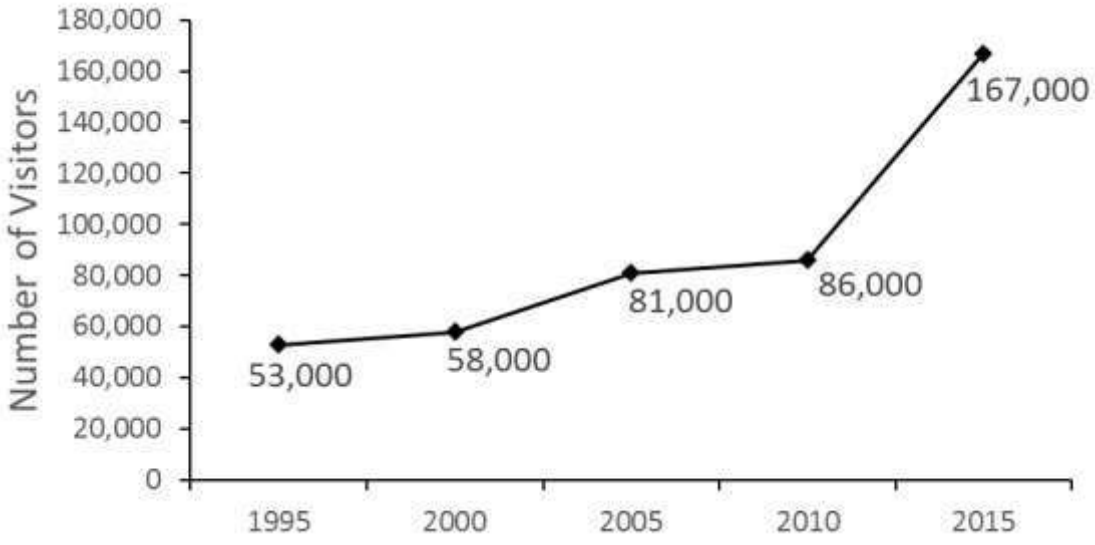


Figure 1: Visitor statistics from 1995 to 2015 with intervals representing five year

This study's main objective was to assess the impact of snorkelers on Palau's shallow coral reefs. The study was conducted on two occasions within a one year time frame, once during visitor peak season between June and August, and again during visitor low season between January and March.

METHODS

This study was conducted bi-annually during tourism high season in July 2015 (hereon referred to as "2015") and again during tourism low season in January 2016 (hereon referred to as "2016"). The survey targeted five highly popular snorkeling sites and corresponding reference sites within Koror State's Rock Island Southern Lagoon (RISL). The study sites are found within the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site. Sites were selected based on the popularity for snorkelers. Reference sites were chosen based on proximity to the study sites as well as similarities in benthic communities and exposure to wind and currents. Snorkeling sites are referred to as "visit sites" and reference sites are referred to as "non-visit sites". The dive sites selected were Big Drop Off, Wonder Channel, Rose Garden, Fantasy Island, and Cemetery Reef (Fig 2).

Figure 2: A map of the five popular snorkeling sites and each of the designated reference sites (Satellite Image IKONOS, QGIS)

1.1 Fish

Fish surveys targeted those that are commercially important (Appendix 1) and were conducted using a stationary point count (SPC) method (CREP Reef Fish Data – Overview of Data Gathering). The fish observer remained stationary on the surface of the water for 3 minutes and recorded all commercially important fish that came within a cylinder 5 m in diameter.

Through SPC, the surveyor recorded the abundance as well as the estimated length of each fish (in centimeters) (Fig 3). Survey was conducted at a depth up to 2 m.

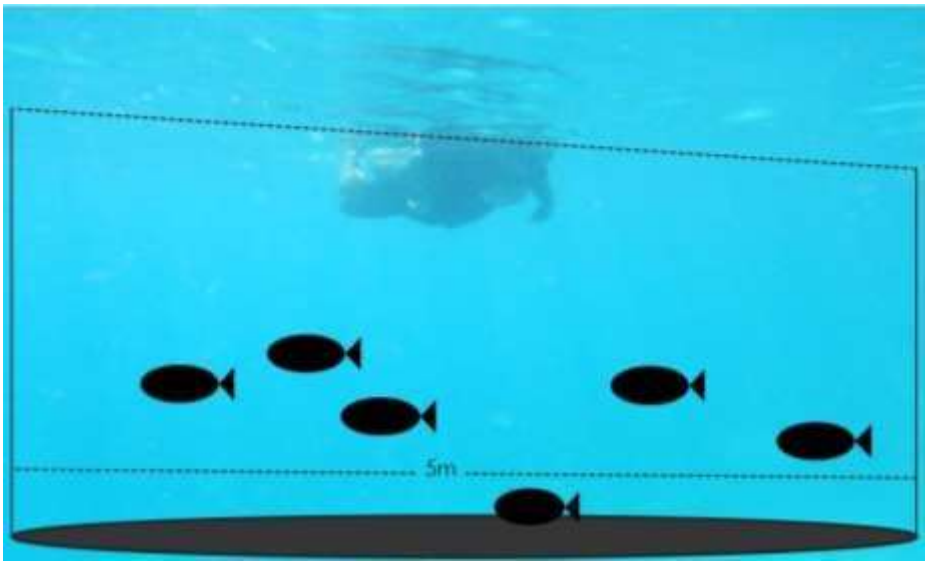


Figure 3: Fish survey using Stationary Point Count method

1.2 Benthic

Benthic coverage which includes coral cover, rubble percentage, and number of fragmented coral was recorded by taking pictures using a wide angle lens camera (Canon G16 with attachable fish eye) and a 0.5 m² quadrat (Fig 3). Benthic cover was collected by randomly throwing the 0.5 m² quadrat 50 to 60 times per site depending on the size of the area (Table 1). The quadrat included six intersecting lines to indicate the nine points from each frame used to determine benthic cover classified into categories (Fig 3) (Appendix 3).

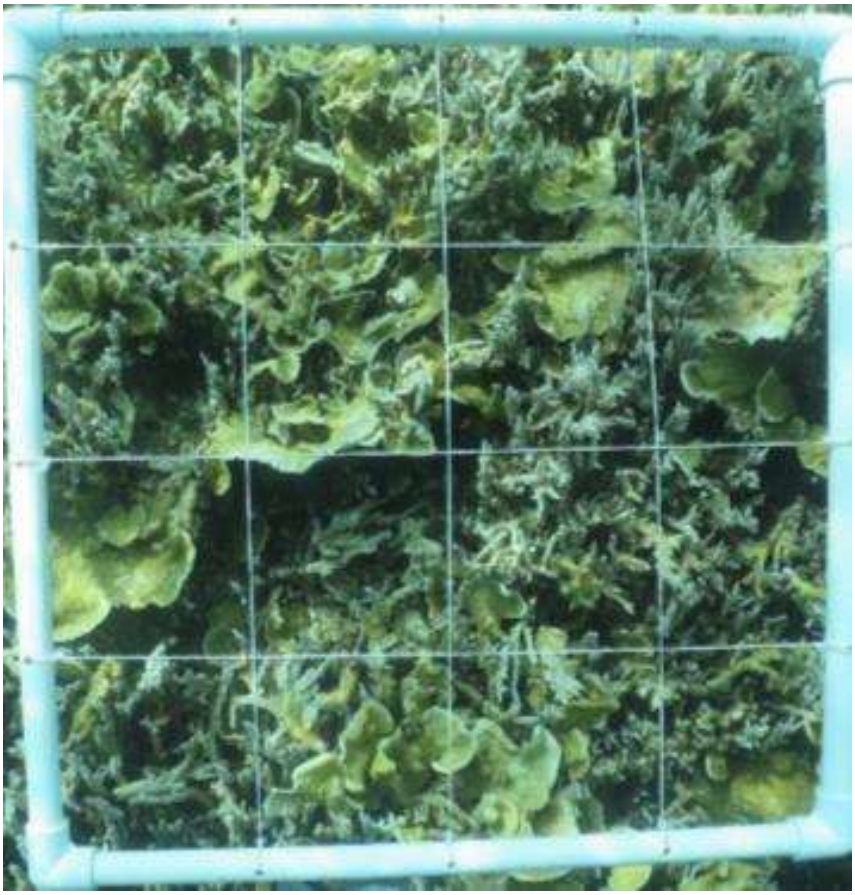


Figure 3: 0.5 m^2 quadrat using intersecting lines to designate nine points for benthic identification

SITE	SIZE (km^2)	NUMBER OF THROWS
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

Table 1: Number of 0.5 m^2 quadrat throws were determined based on the size of the study sites

Fish surveys were conducted to estimate density and biomass, where size was recorded in

centimeters and biomass (g) was calculated using the length-weight relationship, a(L^b), where *L*= length in centimeters, and *a* and *b* as constants values published biomass-length relationships from Kulbicki et al. (2005) and from Fish Base (www.fishbase.org).

1.3 Observation

Observations of snorkelers were conducted at each of the five visit sites for 45 minutes. Observer recorded the total number of boats that visited the site within the 45 minute time frame. Number of snorkeling customers and tour guides were logged, although it was hard to truly distinguish which group came from which boat. Surveyor documented the equipment used by each group under observation, as well as the tour guide to customer ratio while in the water.

In-water observation were conducted in five minute intervals where the observer followed one cluster of snorkelers and recorded any contact to the benthic made by any individual within the cluster. Contact included but was not limited to kicking, touching, sitting, standing, and holding on to the benthic environment.

RESULTS

2.1 Fish Abundance

Of the 10 sites surveyed, both Big Drop Off visit and non-visit sites had the highest number of fish observed during each of the separate survey periods. In 2015, Big drop off non-visit had higher average fish count (54 [± 8.9 SE]) than the visit site (24 [± 7.3 SE]). In 2016, this changed

to the visit site having the higher average fish count (68.7 [± 51.2 SE]) than the non-visit site (57.3 [± 19.5 SE]).

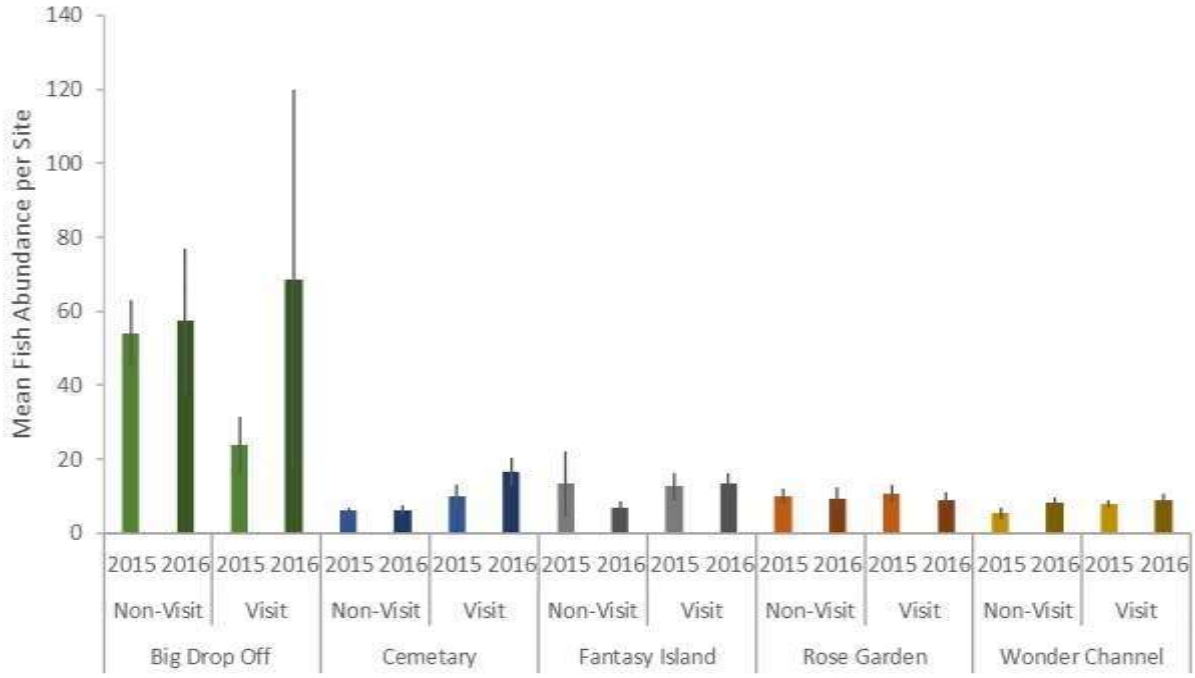


Figure 4: Mean fish abundance of commercially important fish during each survey period at each of the 10 locations.

ANOVA was conducted and there was no significant difference between fish abundance at each site and the status of visit or non-visit sites (p-value >0.5) (Fig. 5).

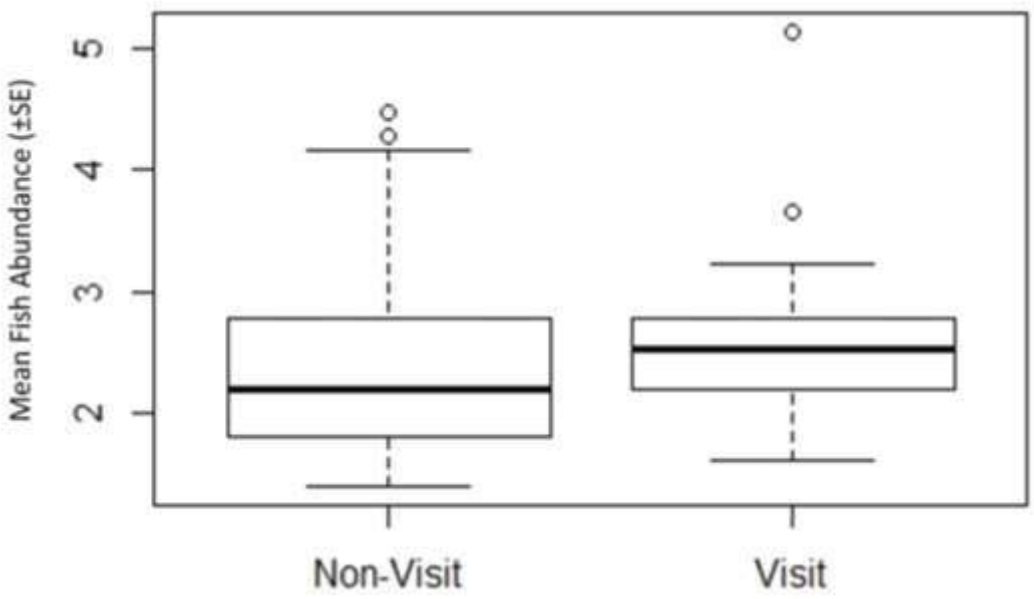


Figure 5: Plot of mean fish abundance recorded at all non-visit sites and tourist visit sites. Logged One-Way ANOVA p-value >0.05.

2.2 Fish Size (cm)

With the exception of Rose Garden and Wonder Channel in 2015, fish sizes (cm) were higher in the visit sites compared to that of the non-visit site. Cemetery Reef visit site indicated larger fish in 2015 and 2016 (37.9 cm [± 5 cm SE] and 41.3 cm [± 3.7 cm SE] respectfully) compared to the fish size in the non-visit site (22.5 cm [± 3.2 cm SE] and 22 cm [± 0.5 cm SE], respectfully) (Fig 6).

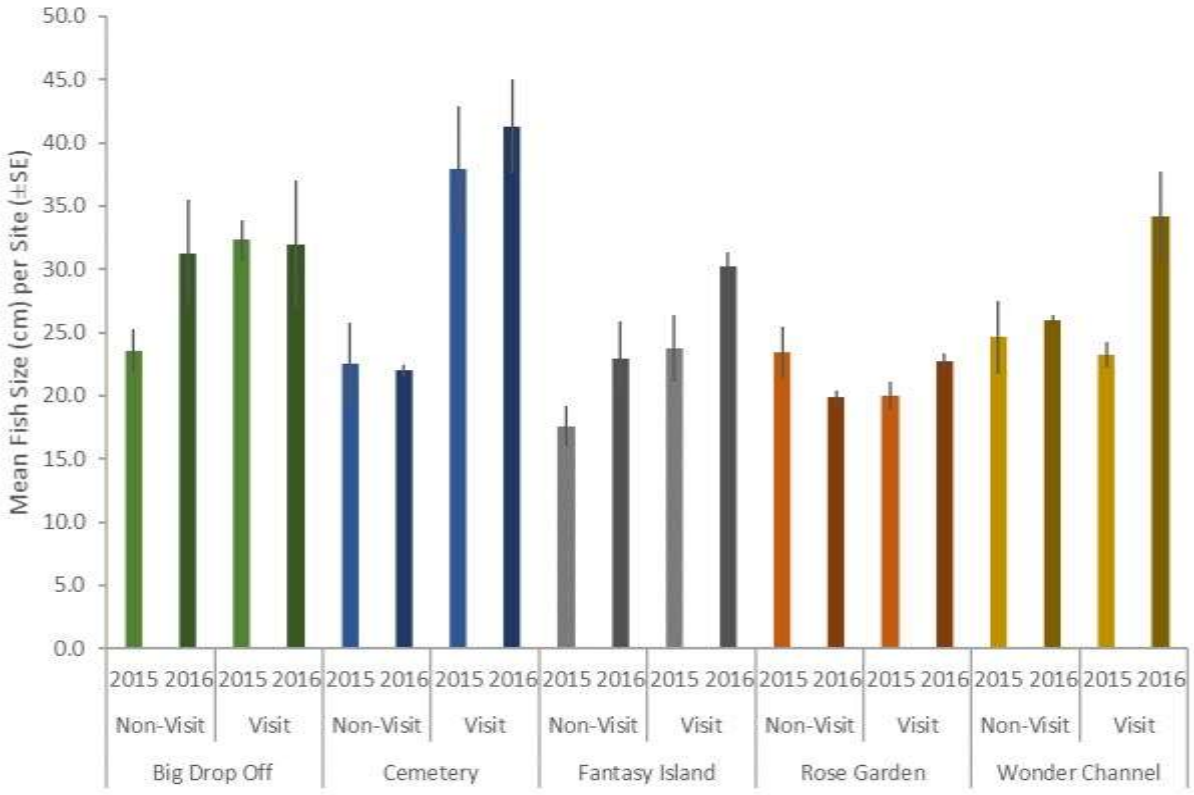


Figure 6: Mean fish size in cm of all commercially important fish observed within the 10 locations

2.3 Fish Biomass

Figure 7 illustrates the biomass comparison between the visit sites and the respective non-visit sites. In addition, it showcases the difference between the different survey periods. Big Drop Off showed higher biomass (34400.9 g [± 12495 g SE]) at the visit site in 2015 compared to that of non-visit site (19969.9 g [± 8371.4 g SE] but in 2016, the non-visit site indicated a slightly higher biomass (40622.4 g [± 6637.1 g SE]) compared to that of the visit site (35008.6 g [± 7120.6 g SE]). Cemetery Reef, Fantasy Island and Wonder Channel clearly showed higher biomass on both occasions at the visit sites compared to that of the respective non-visit sites (Fig 7).

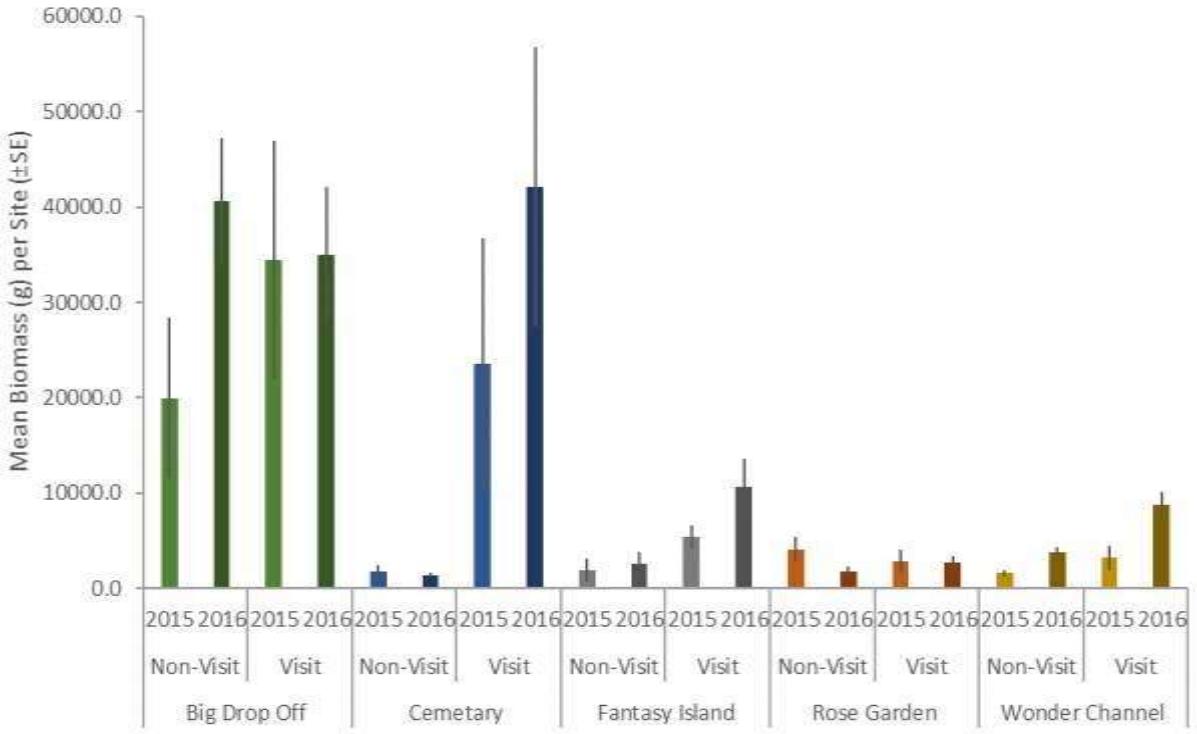


Figure 7: Mean biomass of all commercially important fish observed within the 10 locations

Fish biomass was significantly higher at highly visited sites compared to non-visit sites (ANOVA, p-value <0.001). Figure 8 illustrates fish at visit sites were significantly larger than those recorded at non-visit sites.

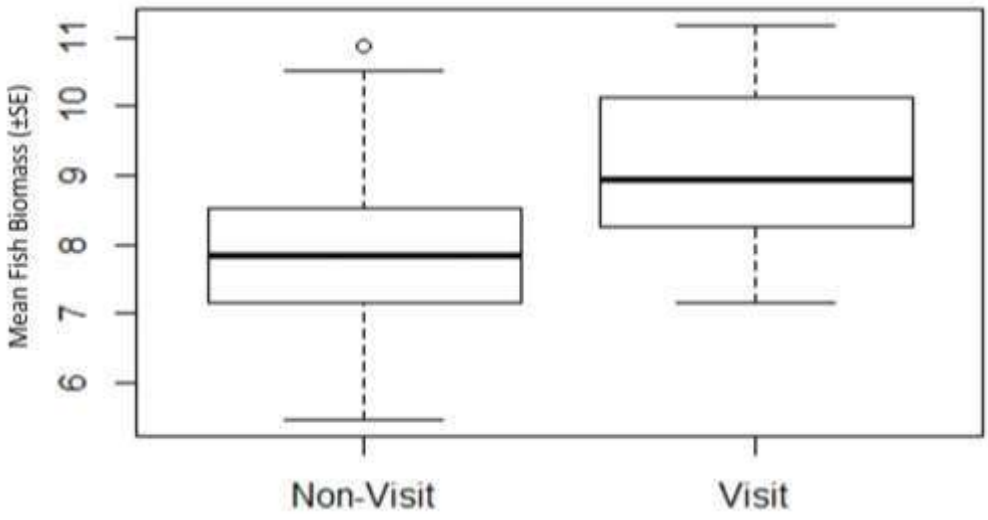
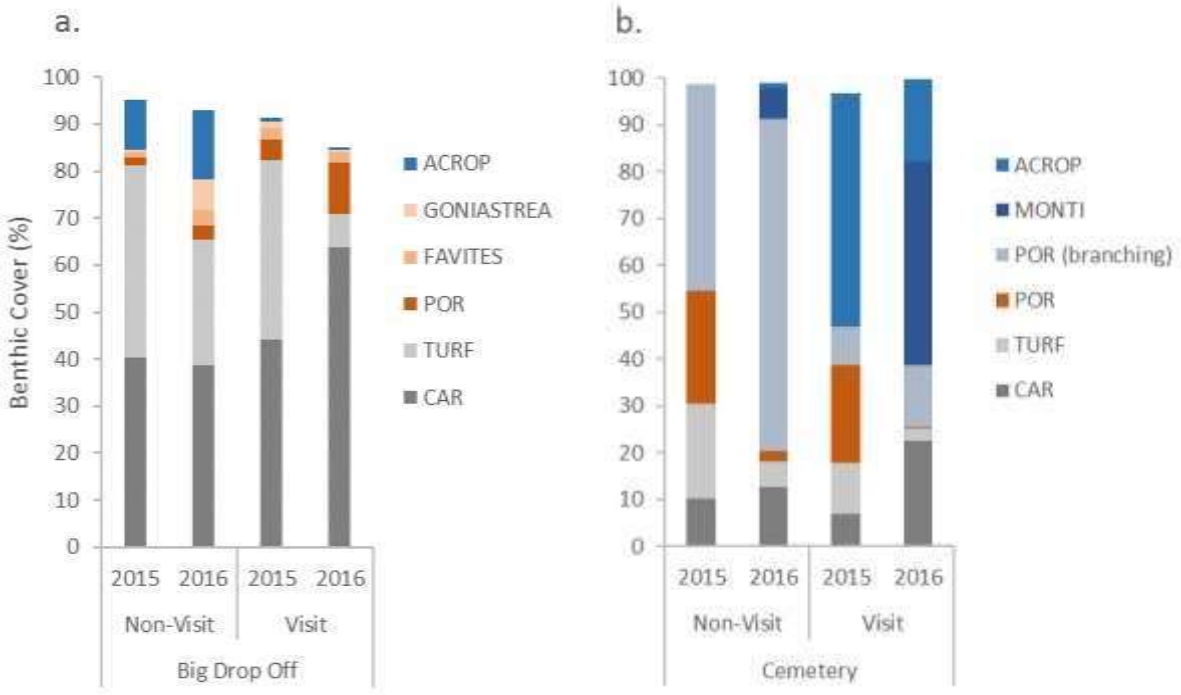


Figure 8: Boxplot of fish biomass recorded at all non-visit sites and tourist visit sites (ANOVA, p-value <0.001)

2.4 Benthic cover

Benthic cover was similar between visit sites and respective non-visit sites. Big Drop Off was dominated by carbonate and turf at both visit and non-visit sites. Cemetery Reef non-visit site had a higher percent cover of branching *Porites,* whereas the visit site indicated higher percent cover of branching *Acropora* in 2015 and *Montipora* in 2016. Both Cemetery Reef visit and non-visit sites indicated similar substrate branching coral. Fantasy Island had similar benthic composition of *Acropora* followed by carbonate. Rose Garden was primarily dominated by carbonate substrate, followed by *Porites.* Wonder Channel indicated similar benthic structure to Fantasy Island where the primary substrate was *Acropora* and carbonate (Fig 9a-e).



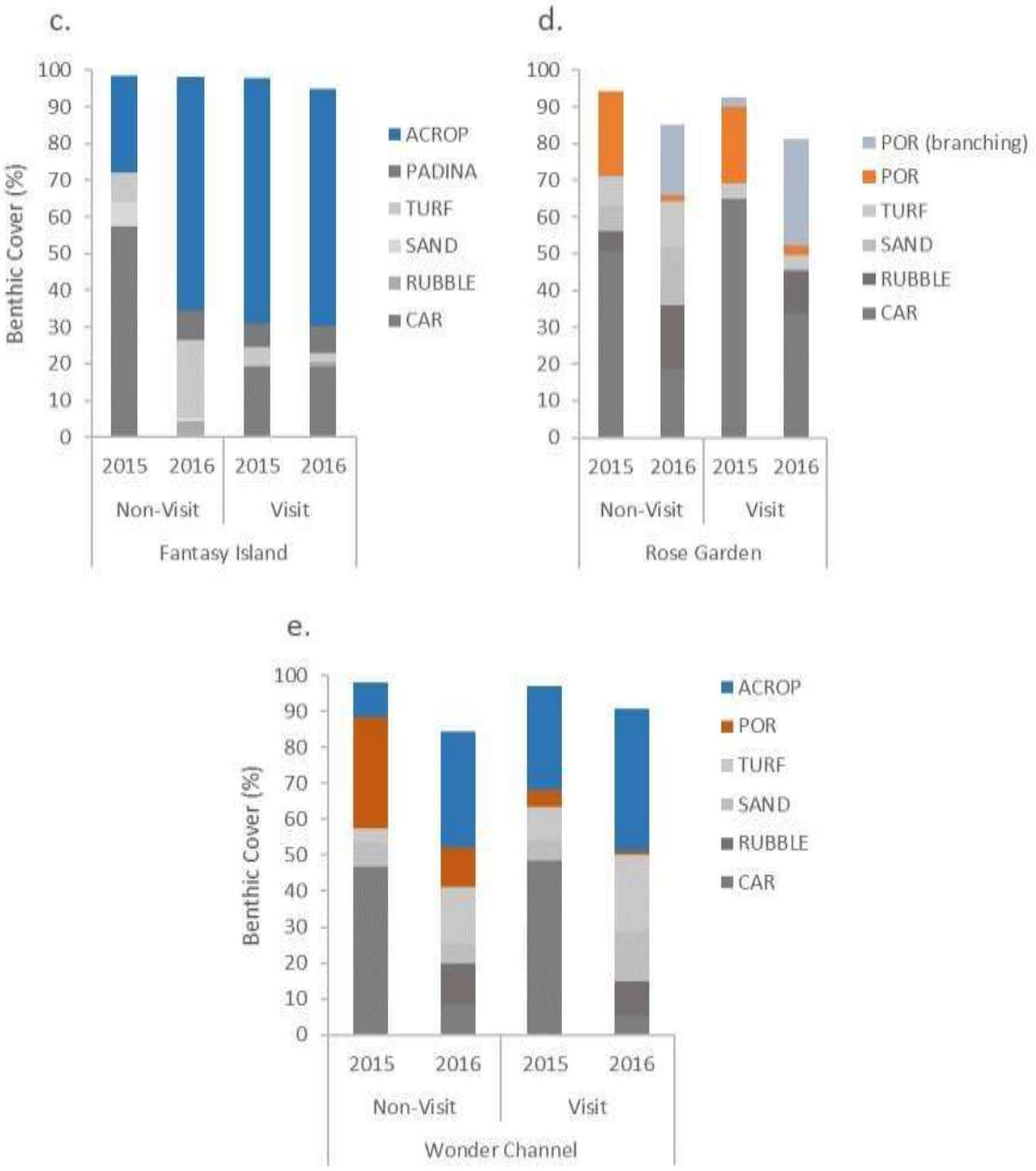


Figure 9 a-e: Benthic composure in percentage of each site.

2.5 Rubble Percentage

Percentage of rubble coverage per site was also explored and illustrated in Figure 10 below. With the exception of Fantasy Island and Rose Garden at high season, all sites showed higher

percentage of rubble at the visit sites compared to the non-visit sites. With non-visit sites being indicated first followed by visit sites, the following details 2016 data per location. Big Drop Off: 6.8% (± 0.6%), 18.8% (± 2.2% SE); Cemetery Reef: 9.4% (± 3.1%), 27.1% (± 5.7% SE); Fantasy Island: 13.1% (± 5.4% SE), 25.3% (± 4.9% SE); Rose Garden: 34.9% (± 4.4% SE), 42.3% (± 5.9% SE); Wonder Channel: 20.2% (± 3% SE), 27.7% (± 5% SE) (Fig 10).

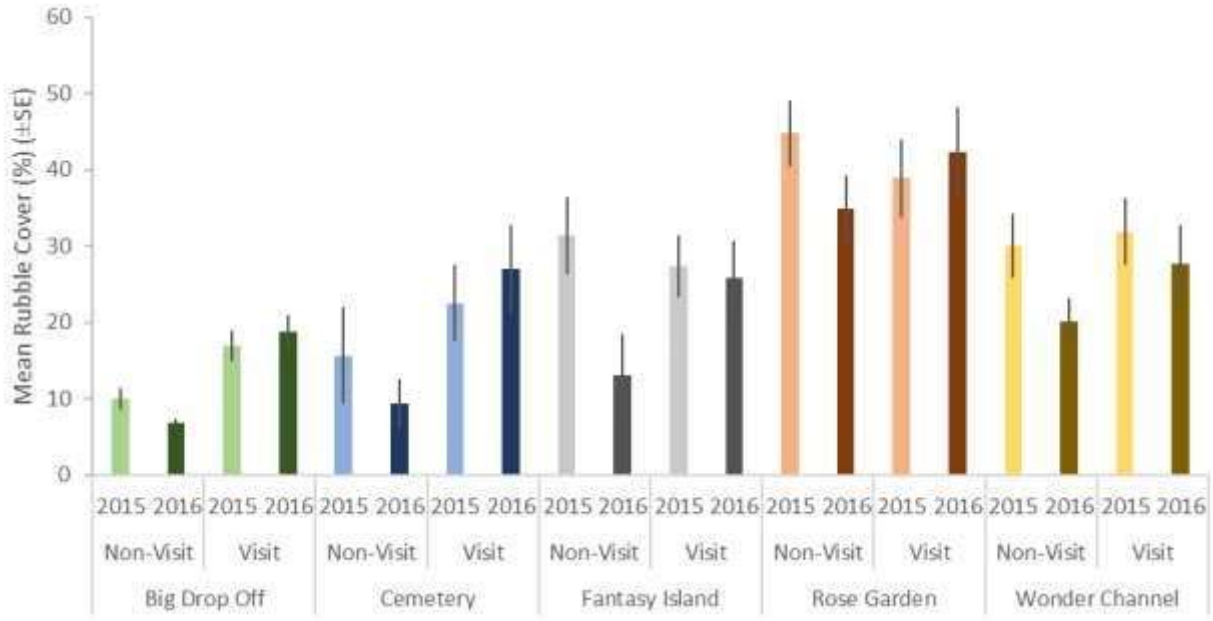


Figure 10: Mean rubble cover per visit site compared to the respective non-visit site

There was significantly higher rubber coverage at the sites that tourists visit compared to the non-visit sites (ANOVA, $p<0.001$) (Fig 11).

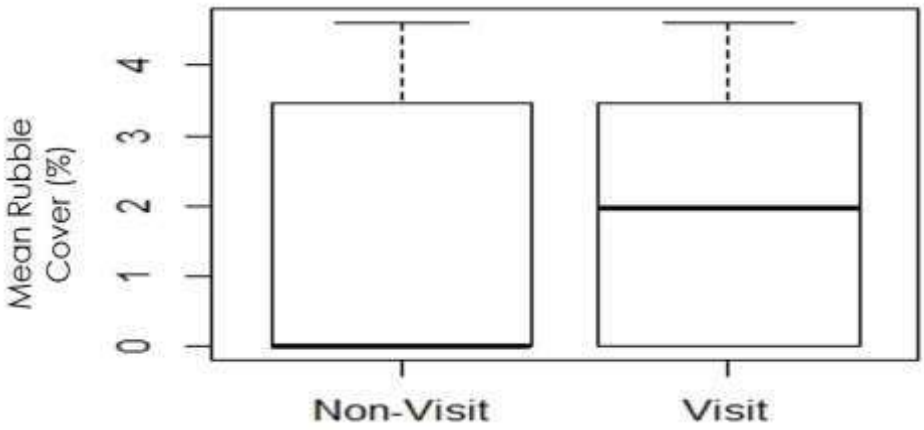


Figure 11: Boxplot of rubble coverage (%) at visit and non-visit sites

2.6 Coral Fragments

Figure 12 (below), illustrates the recorded mean of fragments per site. In 2015, fragments were highest at the non-visit site with Cemetery Reef visit site having had the highest count at 6.9 (±1.8 SE). With the exception of Fantasy Island and Rose Garden in 2015, results indicated higher count of fragments at the visit sites compared to that of the non-visit site (Fig 12).

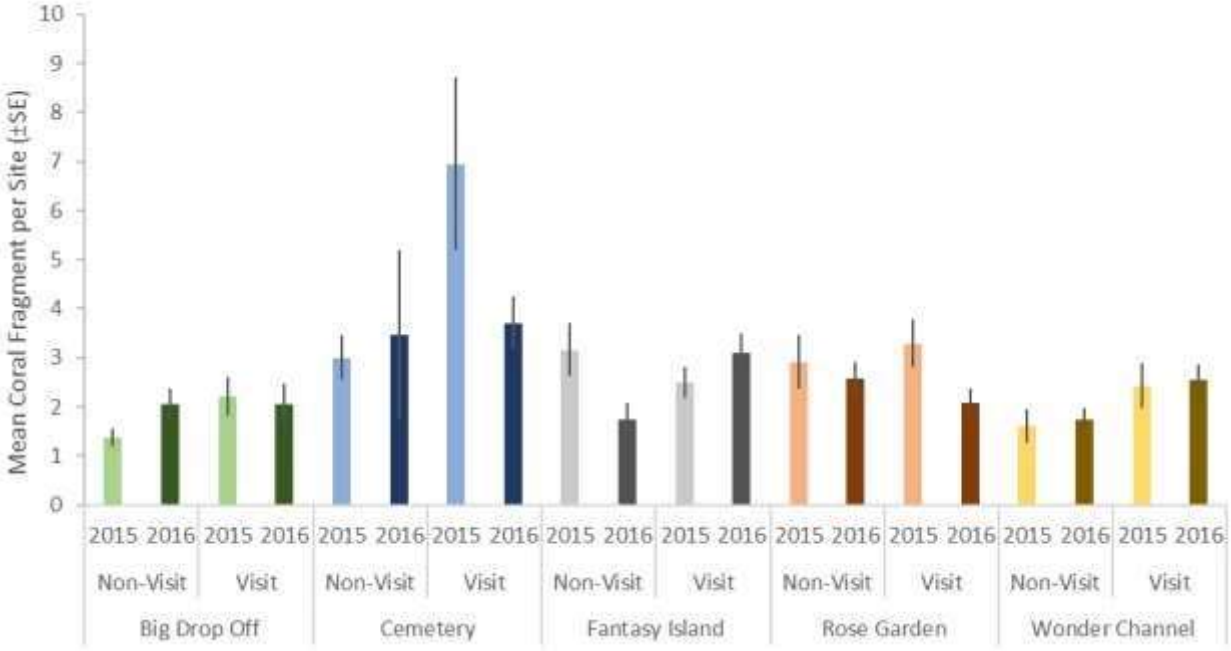


Figure 12: Mean fragment count per site compared to the respective non-visit sites

Overall, there was a significantly higher coral fragmentation at visited sites compared to reference sites (ANOVA, $p<0.001$) (Fig 13).

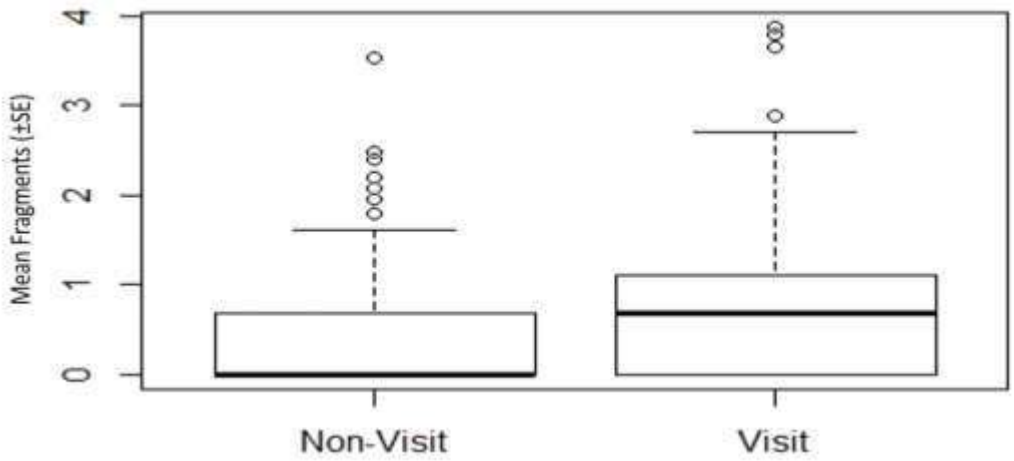


Figure 13: Boxplot of coral fragments counted at visited sites and non-visit sites

2.7 Observation

Surface observation were conducted at each visit site for a duration of 45 min. Table 2 below reports observation findings of the visitor traffic at each visit site. Cemetery Reef was recorded on both occasions to have the highest number of people at one given time. The average number of customers under the supervision of one tour guide at a given time was between 5-8 people (Fig 14).

	Site Size (km^2)	July 2015		January 2016	
		Boats	People	Boats	People
Big Drop Off	1.59	16	36	2	32
Cemetery Reef	0.57	9	154	11	193
Fantasy Island	1.18	7	47	2	20
Rose Garden	0.48	5	64	5	67
Wonder Channel	0.59	2	14	5	93

Table 2: Number of boats and people observed at each site in 2015 and 2016 within 45 minute observation window

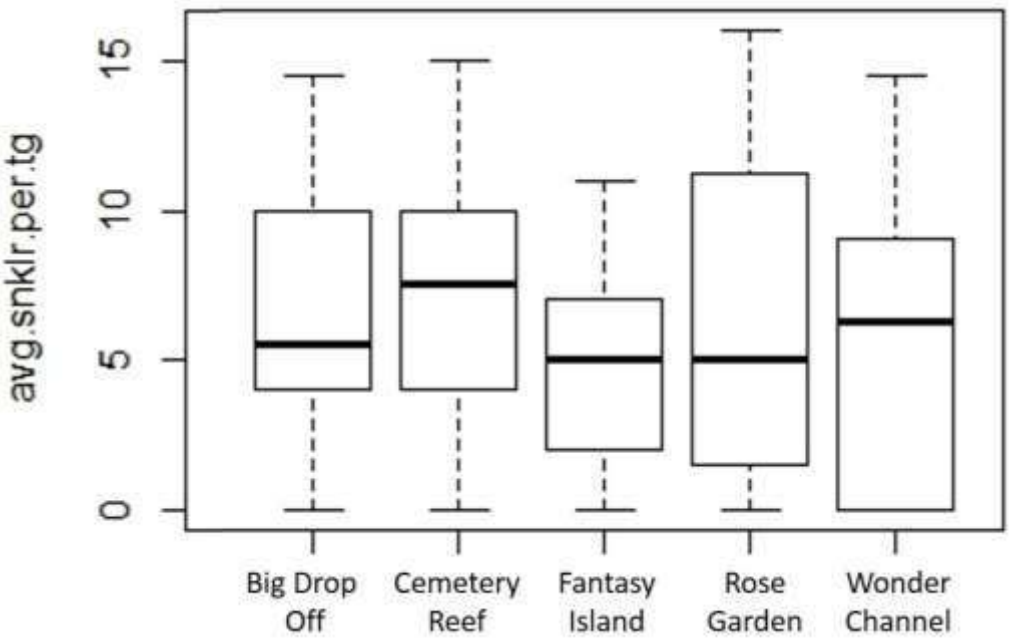


Figure 14: Average number of snorkelers per one tour guide throughout all observations in 2015 and 2016.

Surveyor also observed and recorded any visible signs of briefing prior to tour guides letting the customers in the water, as well as visible fish feeding. Of the 30 boats observed in 2015, 13% showed some type of briefing. Of the 25 boats observed in 2016, 40% showed some type of briefing. Fish feeding was observed at four out of the five visit sites with no feeding at Big Drop Off and 13 counts of fish feeding at Cemetery Reef (Fig 15).

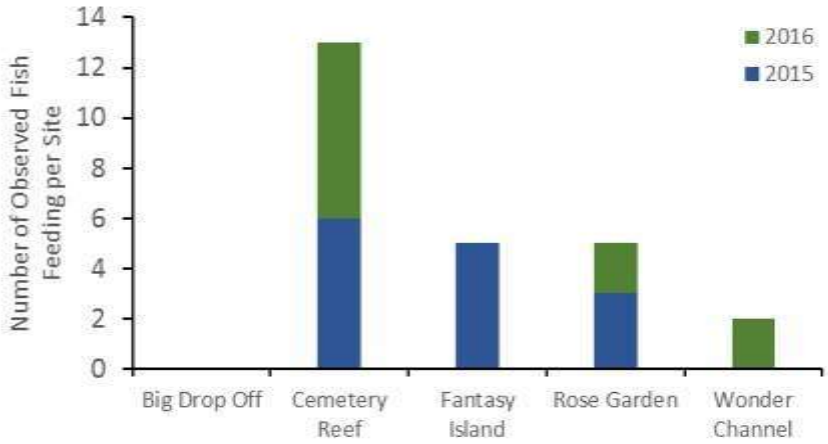


Figure 15: Observed fish feeding at the five visit sites.

During the in-water observation, surveyor observed both the patrons as well as tour guides. This observation showed that 43% of patrons and guides had made some type of contact with the benthic community. Of the 43%, 15% caused some type of fragmentation to the coral. Figure 16 below illustrates the overall observation as well as the behavior between the two tourist seasons.

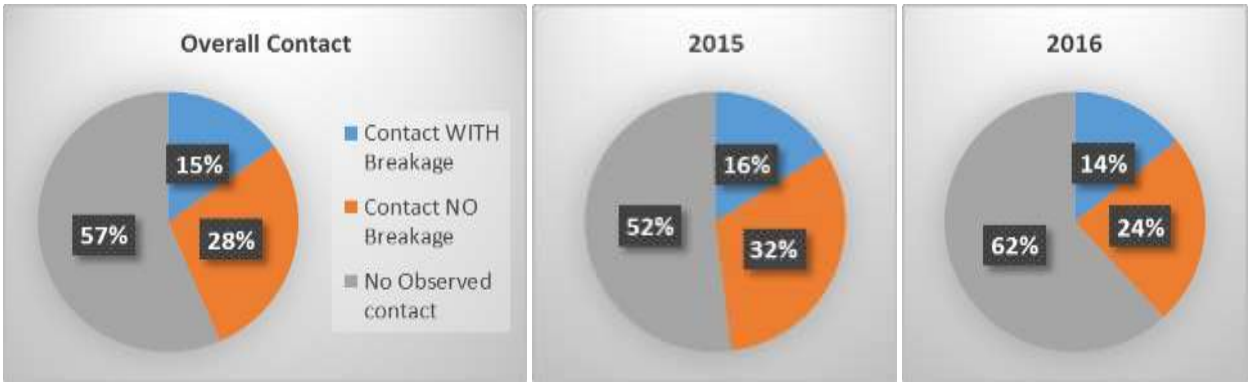


Figure 16: Overall observed visitor contact with the substrate throughout the entire study as well as between tourist seasons.

Discussion

This study showed that overall, there were higher coral fragmentation and higher fish biomass at highly visited sites compared to non-visit sites. The destruction of shallow coral reef communities due to high number visitors was observed during surveys. The results showed that the percentage of rubble cover at each visit site is higher than its non-visit sites, with the exception of Fantasy Island and Rose Garden in 2015. This same effect was observed in the number of coral fragments identified and counted at each site.

For fish size and biomass, our findings showed that it was significantly higher at sites with high number of tourists. This is possibly correlated with the practice of feeding the fish which attract fish around the snorkelers. For fish numbers, there was no significant difference in fish numbers from the visited sites and the non-visited sites.

It is recommended that precautionary measures be taken to reduce damage to the sites.

The following are recommendations for management:

- To create regulations on site usage. For example, creating a schedule for each site, classifying an area "open" during mid to high tides and "closed" during low tides would assist in reducing contact by snorkelers on the corals. With the exception of Big Drop Off, all the other study sites are highly susceptible to contact during low tides when more of the coral substrate are in reach of kicking, standing, or touching. For Big Drop Off, the opposite is true, where snorkeling during low tide is ideal, because the shallow coral areas are not accessible during low tide. Tourists will able to observe the reef from the drop off, away from the corals.
- To increase public and visitor awareness of the proper behavior to follow while in the water. This could be done by way of reading materials or posters at the airport while the visitors wait for their baggage, brochures at the hotel and tour companies, and brochures at the permitting offices.

It is recommended to replicate this study over a longer period of time to determine long-term impacts at these popular sites.

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Appendix 1: Commercially important fish species in Palau

Commercially important fish species in Palau			
	Common name	**Palauan name**	**Scientific name**
1	Bluefin trevally	Erobk	*Caranxignobilis*
2	Giant trevally	Oruidel	*Caranxmelampygus*
3	Bicolor parrotfish	Beyadel/Ngesngis	*Cetoscarus bicolor*
4	Parrotfish species	Melemau	*Cetoscarus/Chlorurus/Scarus*spp
5	Yellow cheek tuskfish	Budech	*Choerodonanchorago*
6	Indian ocean longnose parrotfish	Bekism	*Hiposcarusharid*
7	Pacific longnose parrotfish	Ngeaoch	*Hipposcaruslongiceps*
8	Rudderfish	Komud, Teboteb	*Kyphosusspp (vaigiensis)*
9	Orangestripe emperor	Udech	*Lethrinusobsoletus*
10	Longface emperor	Melangmud	*Lethrinusolivaceus*
11	Red gill emperor	Rekruk	*Lethrinusrubrioperculatus*
12	Yellowlip emperor	Mechur	*Lethrinusxanthochilis*
13	Squaretail mullet	Uluu	*Liza vaigiensis*
14	River snapper	Kedesau'liengel	*Lutjanusargentimaculatus*
15	Red snapper	Kedesau	*Lutjanusbohar*
16	Humpback snapper	Keremlal	*Lutjanusgibbus*
17	Orangespineunicornfish	Cherangel	*Nasolituartus*
18	Bluespineunicornfish	Chum	*Nasounicornis*
19	Giant sweetlips	Melimralm,Kosond/Bikl	*Plectorhinchusalbovittatus*

20	Yellowstripe sweetlips	Merar	*Plectorhinchuscrysotaenia*
21	Pacific steephead parrotfish	Otord	*Scarusmicorhinos*
22	Greenthroat parrotfish	Udouungelel	*Scarusprasiognathus*
23	Forketailrabbitfish	Beduut	*Siganusargenteus*
24	Lined rabbitfish	Kelsebuul	*Siganuslineatus*
25	Masked rabbitfish	Reked	*Siganuspuellus*
26	Goldspottedrabbitfish	Bebael	*Siganuspunctatus*
27	Bluespot mullet	Kelat	*Valamugilseheli*
Protected Fish Species (yearly and seasonal fishing closure)			
28	Bumphead parrotfish	Kemedukl	*Bolbometoponmuricatum*
29	Humpheadwrasse	Ngimer, Maml	*Cheilinusundulatus*
30	Brown-marbled grouper	Meteungerel'temekai)	*Epinephelusfuscoguttatus*
31	Marbled grouper	Ksau'temekai	*Epinepheluspolyphekadion*
32	Squaretail grouper	Tiau	*Plectropomusareolatus*
33	Saddleback grouper	Katuu'tiau, Mokas	*Plectropomuslaevis*
34	Leopard grouper	Tiau (red)	*Plectropomusleopardus*
35	Dusky rabbitfish	Meyas	*Siganusfuscescens*

Appendix 2: Macroinvertebrates targeted by the local fisheries

Common names	**Palauan name**	**Scientific name**
Black teatfish	Bakelungal-chedelkelek	*Holothurianobilis*
White teatfish,	Bakelungal-cherou	*Holothuriafuscogilva*
Golden sandfish	Delalamolech	*Holothurialessoni*
Hairy blackfish	Eremrum, cheremrumedelekelk	*Actinopygamiliaris*
Hairy greyfish	Eremrum, cheremrum	*Actinopyga sp.*
Deepwater red fish	Eremrum, cheremrum	*Actinopygaechinites*
Deepwater blackfish	Eremrum, cheremrum	*Actinopygapalauensis*
Stonefish	Ngelau	*Actinopygalecanora*
Dragonfish	Irimd	*Stichopushorrens*
Brown sandfish	Meremarech	*Bohadschiavitiensis*
Chalk fish	Meremarech	*Bohadschiasimilis*
Leopardfish /tigerfish	Meremarech, esobel	*Bohadschiaargus*
Sandfish	Molech	*Holothuria scabra*

Curryfish	Delal a ngimes/ngimesratmolech	*Stichopushermanni*
Brown curryfish	Ngimes	*Stichopusvastus*
Slender sea cucumber	Sekesaker	*Holothuria impatiens*
Prickly redfish	Temetamel	*Thelenotaananas*
Amberfish	Belaol	*Thelenotaanax*
Elephant trunkfish	Delal a molech	*Holothuriafuscopunctata*
Flowerfish	Meremarech	*Pearsonothuriagraeffei*
Surf red fish	Badelchelid	*Actinopygamauritiana*
Crocus giant clam	Oruer	*Tridacnacrocea*
Elongate giant clam	Melibes	*Tridacna maxima*
Smooth giant clam	Kism	*Tridacnaderasa*
Fluted giant clam	Ribkungel	*Tridacnasquamosa*
Bear paw giant clam	Duadeb	*Hippopushippopus*
True giant clam	Otkang	*Tridacnagigas*
Sea urchin	Ibuchel	*Tripneustesgratilla*
Trochus	Semum	*Trochus niloticus*

Appendix 3: Benthic categories

CPCe Code	Benthic Categories
"C"	"Coral"
"SC"	"Soft Coral"
"OI"	"Other Invertebrates"
"MA"	"Macroalgae"
"SG"	"Seagrass"
"BCA"	"Branching Coralline Algae"
"CCA"	"Crustose Coralline Algae"
"CAR"	"Carbonate"
"S"	"Sand"
"R"	"Rubble"
"FCA"	"Fleshy Coralline algae"
"CHRYS"	"Chrysophyte"
"T"	"Turf Algae"

"TWS"	"Tape
"G"	"Gorgonians"
"SP"	"Sponges"
"ANEM"	"Anenome"
"DISCO"	"Discosoma"
"DYS"	"Dysidea Sponge"
"OLV"	"Olive Sponge"
"CUPS"	"Cup Sponge"
"TERPS"	"Terpios Sponge"
"Z"	"Zoanthids"
"NoIDINV"	"Not Identified Invertebrate"
"AMP"	"Amphiroa"
"ASC"	"Ascidian"
"TURB"	"Turbinaria"
"DICT"	"Dictyota"
"LIAG"	"Liagora"
"LOBO"	"Lobophora"
"SCHIZ"	"Schizothrix"
"HALI"	"Halimeda"
"SARG"	"Sargassum"
"BG"	"Bluegreen"
"Bood"	"Boodlea"
"GLXU"	"Galaxura"

"CHLDES"	"Chlorodesmis"
"JAN"	"Jania"
"CLP"	"Caulerpa"
"MICDTY"	"Microdictyton"
"BRYP"	"Bryopsis"
"NEOM"	"Neomeris"
"TYDM"	"Tydemania"
"ASP"	"Asparagopsis"
"MAST"	"Mastophora"
"DYCTY"	"Dictosphyrea"

"PAD"	"Padina"
"NOIDMAC"	"Not ID Macroalgae"
"CR"	"C.rotundata"
"CS"	"C.serrulata"
"EA"	"E. acroides"
"HP"	"H. pinifolia"
"HU"	"H. univervis"
"HM"	"H. minor"
"HO"	"H. ovalis"
"SI"	"S. isoetifolium"
"TH"	"T.hemprichii"
"TC"	"T. ciliatum"
"SG"	"Seagrass"
"ACAN"	"Acanthastrea"
"ACROP"	"Acropora"
"ANAC"	"Anacropora"
"ALVEO"	"Alveopora"
"ASTRP"	"Astreopora"
"CAUL"	"Caulastrea"
"CRUNK"	"Coral Unknown"
"COSC"	"Coscinaraea"
"CYPH"	"Cyphastrea"
"CTEN"	"Ctenactis"
"DIPLO"	"Diploastrea"
"ECHPHY"	"Echinophyllia"
"ECHPO"	"Echinopora"
"EUPH"	"Euphyllia"
"FAV"	"Favia"
"FAVT"	"Favites"
"FAVD"	"Faviid"
"FUNG"	"Fungia"
"GAL"	"Galaxea"

"GARD"	"Gardininoseris"

"GON"	"Goniastrea"
"GONIO"	"Goniopora"
"HELIO"	"Heliopora"
"HERP"	"Herpolitha"
"HYD"	"Hydnophora"
"ISOP"	"Isopora"
"LEPT"	"Leptastrea"
"LEPTOR"	"Leptoria"
"LEPTOS"	"Leptoseris"
"LOBOPH"	"Lobophyllia"
"MILL"	"Millepora"
"MONT"	"Montastrea"
"MONTI"	"Montipora"
"MERU"	"Merulina"
"MYCED"	"Mycedium"
"OULO"	"Oulophyllia"
"OXYP"	"Oxypora"
"PACHY"	"Pachyseris"
"PAV"	"Pavona"
"PLAT"	"Platygyra"
"PLERO"	"Plerogyra"
"PLSIA"	"Plesiastrea"
"PECT"	"Pectinia"
"PHYSO"	"Physogyra"
"POC"	"Pocillopora"
"POR"	"Porites"
"PORRUS"	"Porites-rus"
"PORMAS"	"Porites-massive"
"PSAM"	"Psammocora"
"SANDO"	"Sandalolitha"
"SCAP"	"Scapophyllia"
"SERIA"	"Seriatopora"
"STYLC"	"Stylocoeniella"
"STYLO"	"Stylophora"

"SYMP"	"Symphyllia"
"TURBIN"	"Turbinaria"
"CCA"	"Crustose Coralline"
"CAR"	"Carbonate"
"SC"	"Soft Coral"
"Sand"	"Sand"
"Rubble"	"Rubble"
"Tape"	"Tape"
"Wand"	"Wand"
"Shadow"	"Shadow"
"FCA"	"Fleshy-Coralline"
"CHRYOBRN"	"Brown Chysophyte"
"TURF"	"Turf"
"BCA"	"Branching Coralline general"
"BC"	"Bleached Coral"

Appendix 4: GPS Coordinates (in UTM)

SITE	LAT	LONG	LAT (UTM)	LONG (UTM)
Fantasy Island	7°13'3.78"N	134°23'5.39"E	432084	797862
Fantasy Island (Ref)	7°13'9.15"N	134°23'11.23"E	432263	798027
Rose Garden	7°11'0.09"N	134°22'10.90"E	430408	794066
Rose Garden (Ref)	7°11'17.59"N	134°21'45.32"E	429624	794604
Wonder Channel	7°10'49.01"N	134°21'17.88"E	428781	793728
Wonder Channel (Ref)	7°11'17.64"N	134°21'23.00"E	428939	794607
Cemetery	7°14'36.01"N	134°22'19.76"E	430689	800696
Cemetery (Ref)	7°15'44.14"N	134°23'50.58"E	433477	802785
Big Drop Off	7° 6'11.21"N	134°15'2.04"E	417240	785214
Big Drop Off (Ref)	7° 5'54.33"N	134°16'2.36"E	419089	784693