Evaluation of effects of tide on recreational activities in coral reefs

(潮汐がサンゴ礁におけるリクエーション活動に及ぼす影響評価)

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Abstract

Coral reefs ecosystem has enormous value in marine diversity and contributes to recreational tourism growth in coastal areas. However, inappropriate recreationalist behavior warrants local concern about coral health, subsequently requiring reef friendly recreational activities. The study was conducted at Shimoji Island, Miyako Islands, Okinawa Prefecture of Japan with the aims of classifying depreciative recreationalists' behaviors; conclude and suppose different damage patterns of behaviors in relation to tidal change; and provide recommendations to alleviate recreational damage for the sake of coral conservation as well as local sustainable development. The study consisted of three stages: the first stage including an *in situ* survey (September and October, 2013) and an inquiry survey of a local diving shop; the second stage being data analysis and developing suppositions of reef damage patterns (September to November, 2013); and the last stage of proposing recommendations on reef friendly recreational manners. Results of the *in situ* survey showed the most vulnerable coral species as *Porites rus* (69% of overall accounted broken coral branches) following by *Porites cylindrica* (accounting for 30% of the total damage), and *Acropora muricata* suffered the least amount of damage (only 1%). The damaged *P. rus* colonies were found close to the sea surface and its breakage mainly concentrated in the central and the edge of the colonies. This is considered as a direct consequence of sequential occurrence of depreciative behaviors by swimmers and snorkelers. The study consider that boots kicking is the initial damage that weakens the *P. rus* colonies' tensile strength. It occurred when the depth between the sea surface and the surface of *P. rus* colonies (hereinafter refer to depth) was within the range of

100cm to 150cm. Based on the primary damage, behavior of standing upon reef colonies contributes to a massive and rapid expansion of breakage, which is perceived as the secondary damage which occurred when the depth was between 50cm to 150cm. Breakage of *P. cylindrica* colonies were mainly found in the middle-layer of the sea and its damage concentrated at the tips of the branches. The study considered that this is caused by tide-induced direct coral contact by divers due to the variation in the diving space, since subsequent occurrences of unstable current cause difficulties for divers in buoyancy controlling and thereby increases the contact potentially. Therefore, the shallow area has a relatively high frequency of the occurrence of coral contact, especially during the low tide period. Insufficient awareness and lack of comprehensive guidelines of recreational use towards reefs are considered as the main factors which lead to the existence of depreciative behavior patterns and the setting of notice boards of reef friendly manners is suggested. The notice boards are designed to provide information beforehand in order to raise recreationalists' awareness towards their behaviors as well as the consequent impacts on coral reefs ecosystem. Besides, suggestions also emphasize the importance in being equipped with the proper gears and the necessity in pre-training for recreationalists. These counterplan suggestions are considered of great value in contributing to sustainable reef tourism in long term.

Key Words: tide, recreationalists' behavior, damage pattern, public awareness, coral conservation

Chapter 1 Introduction

1.1 Conceptual Background of Coral Reefs Worldwide

Coral reefs worldwide are reportedly declining rapidly at a rate of 1-2% annually. It is one of the most fragile ecosystems that is affected by a range of global factors (e.g. global warming and ocean acidification) mingled with local factors (e.g. destructive fishing, land-use change and recreational activities) (Pandolfi *et al*., 2003; Hoegh-Guldberg, 2011). While efforts towards coral conservation should be made regardless of the scale of the drivers, given the fact that it is extremely difficult to prevent corals from degrading on a global scale, moderating local drivers is of greater urgency. Moreover, under the various local drivers, prioritizing controllable factors is known as a better solution for maintaining coral reefs resilient ability against rapid global climate change as well as for the sake of local sustainable development (Yara *et al*., 2014).

Coral reefs only covers 1.2% of the world's continent shelves but are the most productive and biologically diverse ecosystems and are considered as the global centers of biodiversity. They are home to an estimated 1 to 3 million species and some 30 million people completely rely on reef-based resources as their primary means of food production, income, as well as livelihood (Sukhedv *et al*., 2010). The benefits of coral reefs are owed to their ecosystem services (Moberg and Folke, 1999). Ecosystem services include provisioning, regulating, cultural and supporting service (Millenium Ecosystem Assessment, 2005). Provisioning services refer to the products obtained from the ecosystem. Coral reefs in particular, are important fishing grounds and other seafood resources for tropical coastal communities.

Reefs ecosystem generates a variety of seafood products such as fish, mussels, crustaceans, sea cucumbers and seaweed. Meanwhile, reef-based fishery constitutes approximately 9-12% of the world's total fisheries that support hundreds of millions people who depend on fish catches for their livelihood, the caught fish also forms a big part of their protein intake (Smith, 1978; Whittingham *et al*., 2003). In addition, coral reefs serve as one of the main raw materials for construction and the production of lime, mortar and cement (Dulvy *et al*., 1995). Lime is also used as a pH regulator in agriculture and in some regions coral debris is collected and crushed to be used as fertilizer (Kuhlmann, 1988).

Regulating service stands for the benefits obtained from the regulation of ecosystem processes. Coral reefs play a significant role in protecting the coastal areas otherwise there will be severe loss of land due to erosion caused by currents, waves and storms. For example, Cesar (1996) estimated that in Indonesia alone, $820-1,000,000 per km of coastline was lost due to decreased coastal protection as a consequence of coral destruction. Besides, the capability of wave energy dissipation of coral reefs creates lagoons and sedimentary environments, which are favorable for the growth of sea-grasses and mangrove ecosystems (Birkeland, 1997). Previous studies also suggest the possible role of coral reefs as nitrogen fixers in the oligotrophic environment (e.g. Sorokin, 1993). The capacity of microbial and cyanobacterial association makes coral reefs possess a considerably high rate of nitrogen fixation compared with other marine ecosystems (Moberg and Folke, 1999).

Cultural services refer to non-material benefits obtained from ecosystem and coral reefs embedded with distinct educational, social, recreational as well as aesthetic values. In

Hawaii for instance, the annual recreational value for diving and snorkeling is estimated to reach $325 million US dollars (Cesar and Van Beukering, 2004). Other intangible benefits, such as the educational value of the presence of coral reefs has an indirect influence on the public awareness towards the environment acquired by fieldwork experiences. Coral reefs also support cultural and spiritual activities of local indigenous communities by providing places for hunting, medicinal products collection, and spiritual divination (Drew, 2005).

1.1.1 Economic Values of Coral Reefs Ecosystem

Coral reefs ecosystem services are with enormous values in both tangible (e.g. food production, commercial fishery) and intangible (e.g. cultural and regulation services) aspects. There have been technical difficulties as well as ethical concerns about monetizing the “intangibles”, but such an evaluation is considered instructive for policy decision makers to ensure the optimum allocation for the use of resources (Spurgeon, 1992; Costanza *et al*., 1998). Numbers of previous studies attempted to quantify the economic value of coral reefs ecosystem. For example, Caser *et al*. (2003) estimated the annual economic value of goods and service of global coral reefs to be at 29.8 billion US dollars. Costanza *et al*. (1998) managed to measure more meticulously in a unit of 1994 US dollars per ha per year. They concluded that the values of global coral reefs are conservatively at $3,008 in recreation, $2,750 in disturbance regulation, $220 in food production, $58 in waste treatment and $40 in biological control, habitat, cultural and raw material in total.

1.1.2 Drivers of Coral Degradation

1.1.2.1 Global Drivers

Despite the provision of multi-valuable services, coral reefs are not immune to threats that are a combination of direct human impacts and global climate change. The trend of increasing ocean acidity from rising atmospheric CO_2 concentrations and continuously increased sea surface temperature (SST) result in less diverse reef communities and eventually driving reefs towards the tipping point of functional collapse (Hoegh-Guldberg *et al.*, 2007). The increased level of anthropogenic CO_2 has caused an average decrease of 0.1 units of pH in the oceans since 1750 making the water to be more acid, which negatively impacts the ability of calcification of marine shell organisms including corals (Yamada, 2010). Sea-level rise is another factor that is affecting coral reefs function. It potentially leads to the erosion of the coastal zone, intrusion of salinity into rivers and underground that would impair the growth of corals at different levels depending on the coral species (Case and Tidwell, 2007). According to the findings of the Fifth Assessment Report (AR5) of Intergovernmental Panel on Climate Change (IPCC), the global mean sea level rise will be around 0.24 meters by 2065 and its mean range is predicted to be between 0.4 and 0.6 meters for all scenarios by the end of the century (Lewis, 2014). Hoegh-Guldberg (2011) argues that corals could hardly keep up with the rapid increase and thereby are under the damage of drowning or back-stepping along shorelines in the future.

1.1.2.2 Local Drivers

At the local level, coral reefs are being affected by declining water quality (e.g. nutrient from disturbed coastlines), over-harvesting of key marine species and pollution (Hughes *et al.*, 2003; Hoegh-Guldberg, 2011). Overuse of coastal land due to rapid population expansion subsequently changes the associated nutrient cycling by precipitation, and the runoff from the land causes eutrophication and pollution in the costal ocean. In addition, excessive recreational pressure also has been implicated in reef degradation thus leading to widespread concerns (Ward, 1990).

1.1.2.3 Recreational Impacts

Recreational reef-based activities are popular among recreationalists to enjoy the biodiversity that reef ecosystem supplies. They were generally perceived as non-destructive activities whose economic benefits come with little adverse influences until the 1980s (Tilmant, 1987). Since then, a large number of studies have demonstrated that recreational activities such as scuba diving and snorkeling damages reefs in both direct and indirect ways. The direct adverse impacts can result from inappropriate behavior of touching, kicking, trampling, walking, holding or standing on benthic organisms that generate physical damage that furthermore deteriorates coral reefs and their ecosystem (Rouphael and Inglis, 1997; Hodgson, 1999). The indirect disturbance affects reef health by putting external stress on microorganisms that corals live upon (Hawkins and Roberts, 1992). Sediment re-suspension caused by stirring up sand while diving, will smother reef organisms and reduce light availability for photosynthesis therefore eventually impairing the biological process of reef-building organisms (Rogers, 1990).

The characteristics of individual recreationalists including their levels of skills, attitudes and sexuality, are considered as influential factors which contribute to the damages on reefs. Previous studies have pointed out that divers with cameras generally cause more significant contact and damage than divers without cameras (Rouphael and Inglis, 2001; Barker and Roberts, 2004). Different demographic groups are proven to possess different damaging potentials. For example, male divers tend to have more direct contacts with corals than female divers, and most of the contacts are caused by fin kicking (Rouphael and Inglis, 2001). Divers with specified motivation of certain marine creatures has proved to cause more direct coral contact (Uyarra and Côté, 2007), and the topography of dive sites also affects the type and amount of damage caused by scuba divers (Rouphael and Inglis, 1997). Besides, studies focused on examining recreationalists' value orientation towards coral reefs (e.g. human-centered, natural-centered) found that recreationalists who possess protection orientation (coral reefs have value whether human are present or not) make more effort to save reefs rather than other orientations (Needham, 2010). Such correlations between awareness and the consequent behavior indicates the significance of raising recreationalists' cognition of their behavior toward reefs in order to mitigate recreational impacts. The magnitude of awareness is also emphasized by Krieger and Chadwick (2013) that divers who received pre-dive ecological briefings actually caused significantly less coral damage than those who did not.

Coral reefs ecosystem benefits humankind in both long-term (e.g. coastal protection) and short-term way (e.g. financial income) (Figure 1.1). However, as immediate social and financial returns from destructive practices often outweigh the potential long-term benefits of coral conservation and protection (Dearden *et al*., 2006). Therefore, it is critical to moderate short-term factors of recreational impact in particular, in order to achieve reef conservation as well as sustainable tourism development.

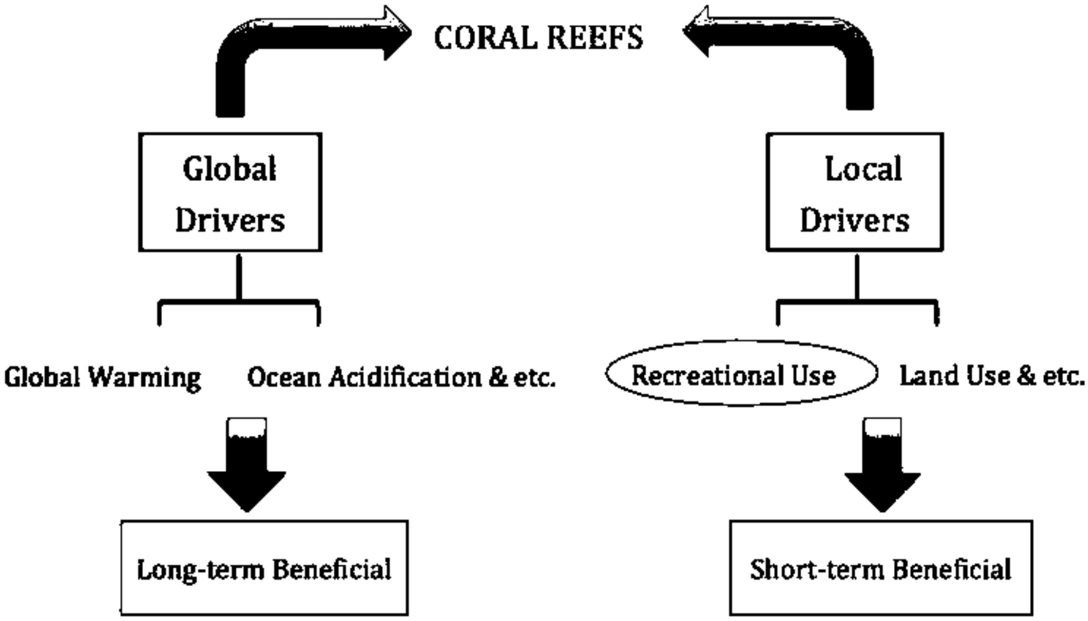


Figure 1.1 Drivers of coral degradation.

1.2 Coral Reefs Condition in Japan

1.2.1 Overview of Coral Reefs in Okinawa

Japan, surrounded by the sea with 3,400 km coastal line, possesses a wide range of climatic regions, from subpolar zones in the north and subtropical zones in the south. Okinawa Prefecture is located in the subtropical region within Japan, extending from 26° 40’ N to 128° 0’ E and with an annual average temperature of 22.9°C. The Kuroshio Current from the tropical regions in the south maintains the necessary conditions for coral reef ecosystems in southern Japan (Mahichi *et al*., 2012).

1.2.2 Importance of Coral Reefs in Okinawa

Okinawa attracts almost 6 million tourists annually, although the number fluctuated by years but there is a consistent increasing trend from inbound tourist illustrated as the red bar in Figure 1.2. The lives of people in Okinawa are closely dependent on reefs for fishing, aquaculture and tourism (Okinawa Prefecture, 2013). The annual average economic values of coral reef ecosystems in Japan were calculated at a minimum of 2.8 billion JPY for industries related to tourism and recreation, 10.7 billion JPY for commercial fishery resource and 7.5-83.9 billion JPY for coastal protection respectively (Ministry of Environment, 2010). Among them, financial income from tourism and recreation accounts for approximately 5% of the total prefectural GDP of Okinawa (Okinawa Prefecture, 2012). Therefore, coral reefs are vital components of the economy in Okinawa. Apart from economic benefits, the reef ecosystem also contributes to the diverse insular culture. Okinawans have been blessed with a long-term relationship with coral reefs, creating unique cultures involving foods and folk customs influenced by and derived from reefs (Ministry of Environment, 2010).

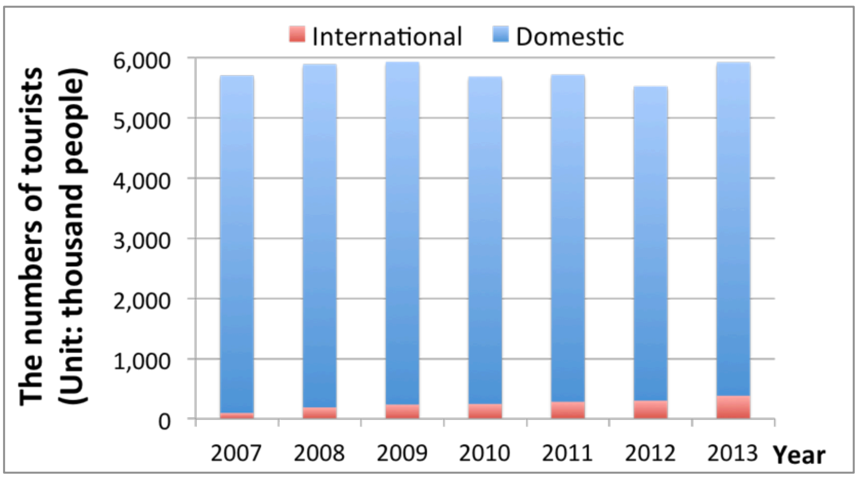


Figure 1.2 The annual tourist numbers of Okinawa Prefecture from 2007 to 2013.
Source: Okinawa Prefecture, 2014.

1.2.3 Drivers of Coral Reefs Degradation

1.2.3.1 Global and Local Drivers

Coral reefs in Okinawa Prefecture have experienced a severe decline since the 1970s. In terms of global drivers, accompanied by the increasing SST and ocean acidification under the scenario of "business as usual", the coral habitats in the sea around Japan are projected to expand northward and the coral coverage will be halved between 2020 to 2030, meanwhile the severity and frequency of the event of coral bleaching is also predicted to increase (Yara *et al*., 2009; 2012). On the other hand, the sea-level along the coastal area of Japan is reported to have been rising at a rate of 5mm per year since 1993, which negatively influences the diversity of coral species (Japan Meteorology Agency, 2007). Local human-induced drivers are considered as the major causes of coral degradation in Okinawa since 1972 as a result of massive infrastructure construction and extensive economic development after being returned to Japan. The mismanagement of reclaimed land and land-based construction resulted in red soil run-off and water pollution from inland causing chronic damages on coral health by reducing corals recruitment success, altering coral community structure and reducing coral photosynthetic as well as light compensation points (Omori, 2010). What's more, the recent fast growing tourist population raised the local concerns of coral condition (Wilkinson *et al.*, 2008).

1.2.3.2 Recreational Impacts

Miyako Island is experiencing a rapid tourism surge, with the number of visitors maintained between the range of 300,000 to 400,000 yearly during the last decade (Figure

1.3), which equals over 7 times of the local population. Furthermore, according to Miyako City's First 10-year Comprehensive Plan (Miyakojima City, 2007), the annual number of incoming visitors is expected to reach 500,000 by 2016 and encouraging marine sports, especially diving and snorkeling activities, are adopted as one of the major means. Under such circumstances, the completion of the Irabu Bridge in early 2015 connecting Shimoji Island to Miyako Mainland is predicted to contribute to future visitor increased of Shimoji Island consequently.

Nonetheless, the drastic increase in the number of visitors with unsustainable use of the resource is negatively affecting the health of coral reefs (Ministry of Environment, 2010). Additionally, as Shikida *et al*. (2001) concluded that direct physical contact to corals like trampling on corals and breaking coral branches result in massive coral breakage in Okinawa that hampers its resilient ability towards the consequences of global climate such as global warming and ocean acidification. Thus, it is imperative to understand local-scale recreational damages as a part of coral reef conservation.

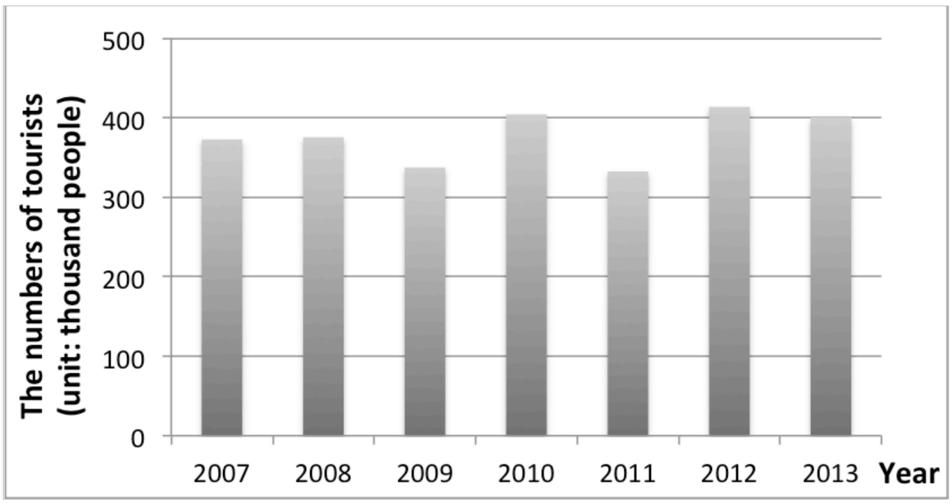


Figure 1.3 The annual numbers of visitors to Miyako Islands from 2007 to 2013.
Source: Miyako City, 2012.

1.2.3.3 Conservation Strategy

Japan has taken part in activities related to coral reefs monitoring and restoration domestically and internationally since the establishment of the International Coral Reef Initiative (ICRI) in 1994. A total of 70 out of 4968 global coral monitoring sites are located in Japan (Mahichi *et al*., 2012). Besides, varieties of reef relevant activities encourage citizen's participation in order to increase social capital towards coral reef conservation. Public educational symposiums and field studies are provided by NPOs as well as scientific research institutions such as The Nature Conservation Society of Japan (NACS-J) and Akajima Marine Science Laboratory (AMSL). Some international organizations also have set up branch offices in Japan, such as Reef Check Japan. It engages partners of community volunteers, government agencies, universities and so forth to participate in regular monitoring of coral health. Individual companies, also zealously take part in reef conservation activities. The partner of this study—Eco Guide Café for example, devotes itself in promoting eco-tourism by advocating and practicing reef friendly recreational manners and implementing crown-and-thorns starfish extermination. It schedules beach-cleaning activities as part of the routine work for staffs and package tours for tourists. By the virtue of its devotion to eco tourism, it won the special prize of the 5th Ecotourism Award bestowed by the Japan Ecotourism Society (JES) in 2009.

However, these efforts are still not enough to compensate for coral reefs degradation in Okinawa. There are already signs of concern among the travelers as they indicated in the survey conducted by Okinawa Prefecture that they would like to see the natural environment properly protected (Mahichi *et al*., 2012). In terms of the survey area, there are noticeable comments revealing the condition of reefs which has been deteriorated yearly according to a web log (Offshore Islands of Okinawa dot com, 2005). Although the study area is zoned within the range of the prefectural natural park, no rigid plans and regulation is applied in the area except for massive construction. Thus, the setting of guidelines towards recreational utilization is perceived as an essential approach to establish conservation awareness among recreationalists and standardized behavior towards reefs.

1. 3 Study Objective

Despite the achievement in categorizing various divers' characteristics and the consequent depreciative behaviors, the characteristic of the damage appears on reefs caused by harmful behaviors however has received very little investigation. Besides, our knowledge of the ultimate causes of destructive behaviors is still less developed. Hence, the study aims to:

1. identify depreciative behaviors of recreationalists and the depth of the occurrence, and meanwhile investigate the characteristic of coral damage;
2. elucidate the patterns of destructive behaviors by taking the types of recreationalists and the tidal change into consideration;
3. based upon the findings, propose suggestions on sustainable and reefs friendly equipping manners towards reefs.

This study is of fundamental importance in clarifying the origins of inappropriate recreational behaviors by relating it to tidal change. It is a new perspective that has barely been examined before. The study hypothesized that there are two patterns of destructive behaviors, one occurs at the sea surface and the other underwater. Based on this hypotheses, a proposal of sustainable manners on reefs are suggested which are expected to help prevent coral reefs from recreational damage, especially from in-shore recreational activities.

The thesis is organized into four chapters. Chapter 1 introduces the conceptual background of coral reefs ecosystem in general and reviews the current condition of coral reefs in Japan; the increasing focus on recreational impact on reefs in particular; and indicates the necessity for further study of identifying the original causes of recreational damages. Chapter 2 describes the survey site and methodology applied in this study. Chapter 3 provides the results of the field study. On the basis of the outcome, patterns of tide-induced reef damage at sea surface and underwater are discussed respectively. Chapter 4 is the summary of the study and with regards to the findings, proposals for raising recreationalists' awareness and popularizing proper recreational manners at the study area are suggested.

CHAPTER 2 Methodology

2.1 Study Site

The survey was conducted at Shimoji Island of Miyako Islands, Okinawa Prefecture, Japan, with the assistance of a local diving shop—Eco Guide Café. Shimoji Island is located 300 km South West of Okinawa Mainland and about 6 km North West of Miyako Islands (Figure 2.1). It is about ten minutes distance by ferry from Miyako mainland, which is also the only available access at the time of writing this thesis. There are numerous diving sites distributed around the western coastal area of Shimoji Island that are famous for the caves and the underwater arches made of Ryukyu limestone. The study area is within the region of site number 17 shown in Figure 2.2. Due to its in-shore location, the overall depth of the study area is comparatively shallow compared to out-reef places, the deepest survey point (Point 7 in Figure 2.3) does not exceed 8 meters during grand tide. Besides, its estuary location maximally minimizes the influence from wind and the water condition is comparatively stable making it a favorable place for recreational activities, especially for beginners. However, no general unified guideline for recreational activity is applied in the study area. Recreationalists with tour packages are managed by each agency's regulations, and personal recreationalists are simply self-managed.

Figure 2.1 Location of Shimoji Island of Miyako Islands, Okinawa Prefecture, Japan (marked in red). Source: The Tourism Institution of Miyako Islands, 2014.

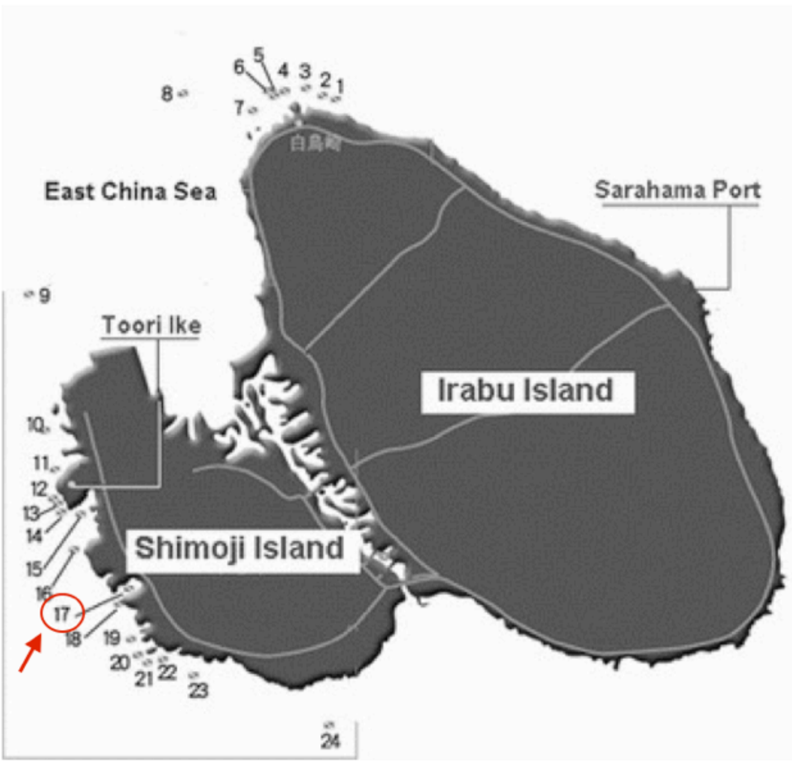


Figure 2.2 Study area (circled in red and pointed by arrow). Source: Okinawa Information, 2008.

2.2 Field Study

The field study is divided into two periods. First period is between 10th September and 10th October of 2013, when an *in situ* observation and survey were conducted. Based on the results, the second period from 20th November to 12th December 2013, mainly focused on analyzing the correlation between tidal change and its consequence on recreational behaviors towards coral reefs.

2.2.1 Tide Data

Tide data was derived from an online source of fishing-labo.net (Powerful information for fishing, 2004), which updates the horal tide information of Sarahama Harbor, the harbor of Irabu Island. As shown in Figure 2.2, Shimoji Island is adjacent to Irabu Island therefore the tide condition in these two islands is assumed to be consistent and the slight variations is not taken into account. The data of full tide and low tide were recorded on a daily base from 1st July to 30st September of 2013, and then inputted in a Microsoft Excel spreadsheet for the convenience of creating a tide graph. Since the arrival of recreationalists tend to peak in the afternoon when the water temperature is warm enough, the average tide at 9 a.m., 12 p.m., 3 p.m. and 6 p.m. are listed in order to provide a macroscopic view of tide variation during the day. It enables a better understanding of the relationship between tide condition and the recreationalists' behavior.

2.2.2 *In situ* Survey of Coral Damage

The investigation of the condition of reef damage was conducted during the first field study period. It includes a quantitative calculation of the amount of broken coral branches (25th and 27th September, 2013) and a qualitative observation of the characteristic of the damage shape. The investigation is specified into 7 points illustrated in Figure 2.3. The survey points were chosen along the regular diving/snorkeling routine after consultation with shop staffs of the study partner so that the recreational impact can be well demonstrated whilst other non-artificial factors can be eliminated at the maximum level. Point 1 is located between diving/snorkeling entry to the first view spot—Point 2 (habitat of groups of onebacked anemonefish) and Point 3 is half way to next view spot—Point 4 and 5, where whitebacked anemonefish inhabit. Point 6 is the only place where clownfish can be found in the area and Point 7 is the deepest spot enriched with coral species and colorful tropical fish, which is known as "the forest of corals". All the points have high visiting frequency so are considered suitable for investigation. The survey aims to:

1. identify the vulnerable coral species across the survey area;
2. quantify the amount of broken branches of the identified coral species;
3. verify the characteristic of the shape of the breakage.

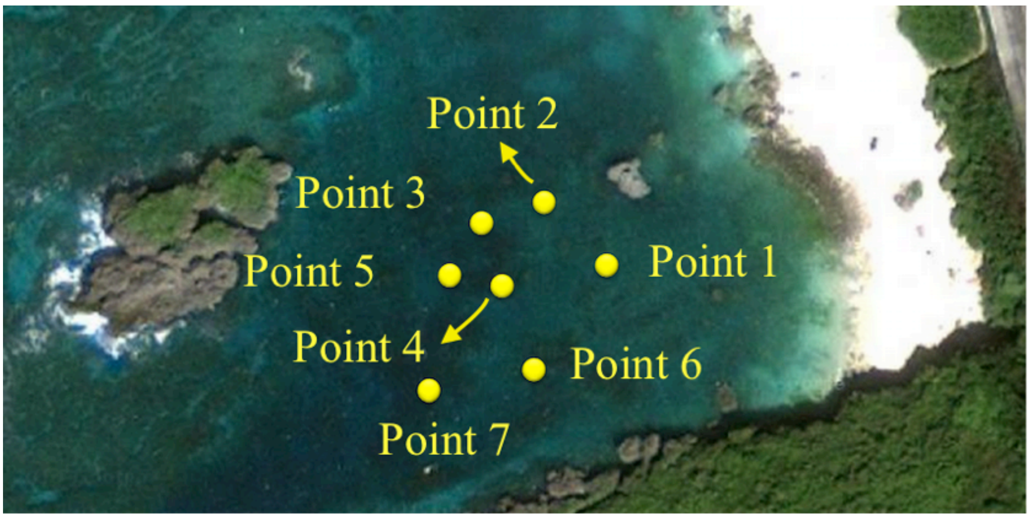


Figure 2.3 Map of survey points. Source: Google ZENRIN, 2015.

2.2.3 *In situ* Observation on Recreationalists' Behavior

Observation on recreationalists' behavior includes from both ashore and underwater and it was conducted during the first period of field study in collaboration with shop staffs. Ashore observation enables a general view of recreationalists' behavior at the beach and sea surface, while underwater observation provides a clear view of the exact behavior of recreationalists when in the sea. The water depth was measured immediately after depreciative behavior was observed and the measurement is shown in Figure 2.4. The joint observation at both ashore and underwater aims to:

1. distinguish the general types of recreationalists in the study area according to the types of their activities and, the typical destructive behaviors among each type;
2. sort out the common gears often equipped by each type of the recreationalists in relation to the typical destructive behaviors;
3. measure the depth of the typical destructive behaviors when they occur.

Figure 2.4 Measuring the occurrence depth of depreciative behavior.

Pictures of typical harmful behaviors are taken for record while observing. Three pictures were taken of staff simulating the behaviors which were unable to be taken at the occurrence moment. And pictures illustrating behaviors of actual recreationalists are only taken with their consent.

2.3 Inquiry Survey Target at Local Diving Shop (Eco Guide Café)

In order to complement information of the long lasting recreational damage at the study area, an inquiring survey targeted at the shop staffs of Eco Guide Café was carried out mainly by the means of emails. The survey aimed to have a general understanding of Kayafa Beach, including the overall kinds of recreational activities and the consequent impacts on reefs. The survey was conducted throughout the study period from 10th September to 12th November, 2013. Also, there were follow-up emails even after the study period which were included in the study. Inquiry survey targets at the regular employees at the moment (four of them), and the survey includes the following questions:

1. What are the common reef-based activities that often takes place at Kayafa Beach?
2. What are the potential drivers you perceive contribute to coral degradation in Kayafa Beach (natural factors and human-induced factors)?
3. Could you describe the recreational impacts you consider affecting coral reefs condition at Kayafa Beach?

2.4 Analysis of Correlation between Tidal Change and Depreciative Behaviors

The analysis was conducted by constantly comparing and testing the results and outcome with the *in situ* survey. The supposition of the damage pattern occurs at the sea surface is established firstly by categorizing the types of recreationalists according to their equipped gears and the scope of their activities. Secondly, two typical tide-induced depreciative behaviors were identified in relation to the different tidal conditions. Meanwhile, the characteristics of the observed damage on *P. rus* colonies raised the suspicion of a repeated occurrence of sequential destructive behaviors. Under such circumstances, several possible patterns were drafted and discussed during the second period. Via thorough consultation with shop staffs and the owner, and whilst verifying the results gained *in situ,* one possible damage pattern at sea surface was developed.

Considering its depth and visiting frequency by divers, damage caused under the water was mainly examined at Point 7. The supposition about the possibility of coral contact by divers was developed through measuring the available range of diving space at different tidal conditions and then comprehensively comparing the depth to divers' behaviors afterwards. And likewise, by thoroughly consulting and discussing with shop staffs and the owner, a tide-induced change in potential coral contact among divers was recognized for the first time.

CHAPTER 3 Results and Discussion

3.1 Tide

3.1.1 Tide Condition

Tide condition during the study period is illustrated as Figure 3.1. The x-axis represents the time series from 1st July to 30th September of 2013. The y-axis represents the tide height set from -10cm to 200cm from the bottom to the top, respectively. It can be seen that tide varies significantly but also periodically along with time. In order to have a close view of tidal range, time series of grand and neap tide periods are shown for comparison in Table 3.1. During the grand tide period, in average, the full tide is at 172cm and the low tide is 33cm, and therefore, the average gap is 139cm. During the neap tide period, on the other hand, tide values are relatively stable without severe change. The mean full tide and low tide is 137cm and 69cm, respectively, and the average gap is 68cm. The gap at the grand tide was twice as large as it at the neap tide. As was mentioned before, all the study points are in shallow water areas thus such variation leads to remarkable differences of the water depth as a consequence (Fujita and Kato, 2011).

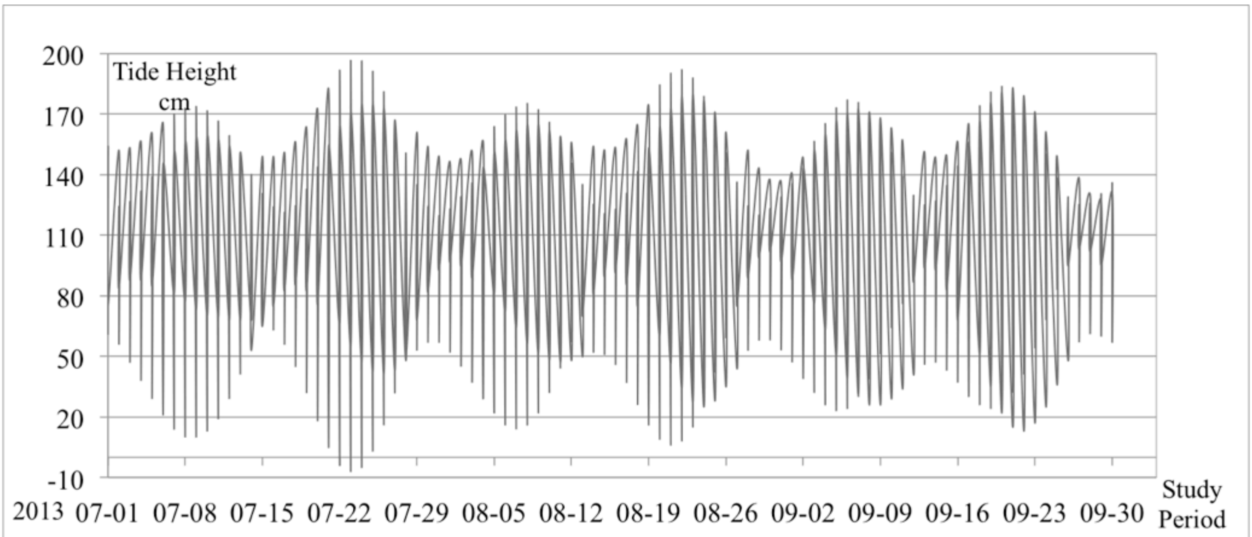


Figure 3.1 Time series of tidal change at Sarahama Harbor of Irabu Island from 1st July to 30st September, 2013.

Table 3.1 Tide condition during the grand tide and neap tide periods.

Grand Tide			Neap Tide		
Day	**Full Tide (cm)**	**Low Tide (cm)**	**Day**	**Full Tide (cm)**	**Low Tide (cm)**
6/07/13	165	21	1/07/13	154	61
	145	-		127	75
7/07/13	169	81	2/07/13	152	56
	151	14		124	84
8/07/13	172	77	14/07/13	140	68
	156	10		-	53
9/07/13	173	73	15/07/13	149	66
	158	10		131	65
21/07/13	182	5	16/07/13	149	63
	154	-		124	75
22/07/13	191	66	29/07/13	161	53
	163	-4		135	68
23/07/13	196	55	30/07/13	154	57
	171	-7		124	82
24/07/13	196	47	31/07/13	149	57
	175	-5		119	93
5/08/13	163	81	13/08/13	135	50
	151	22		-	70
6/08/13	169	72	14/08/13	154	52
	157	16		125	81
7/08/13	173	64	15/08/13	152	51

	162	14
8/08/13	175	56
	165	16
20/08/13	184	60
	164	9
21/08/13	190	46
	173	6
22/08/13	192	34
	179	8
23/08/13	188	27
	180	15
4/09/13	165	63
	160	26
5/09/13	173	50
	167	23
6/09/13	177	39
	171	24
18/09/13	174	51
	167	26
19/09/13	181	35
	176	24
20/09/13	184	22
	181	26
21/09/13	181	15
	183	32
Mean	**172**	**33**
Mean Gap	**139**	

	120	90
28/08/13	120	53
	152	89
29/08/13	143	58
	119	99
30/08/13	137	58
	122	102
11/09/13	139	34
	157	76
12/09/13	129	41
	—	87
13/09/13	151	46
	124	94
27/09/13	138	57
	124	103
28/09/13	130	61
	125	102
Mean	**137**	**69**
Mean Gap	**68**	

3.1.2 Tide Variation

The diurnal peak of recreational use of this study site appears in the afternoon when the water temperature is warm enough, and the number of recreationalists gradually decreases until the evening. Therefore, it is important to understand the daily variation of tidal condition, especially during the peak period of recreational use. Tide values at 9 a.m., 12 p.m., 3 p.m. and 6 p.m. throughout the study period are shown in Figure 3.2. During the study period, tide height was relatively higher in the morning than at noon, the lowest tide value appeared to occur around 3 p.m. in the afternoon and then bounced back in the evening. At the meanwhile, hourly tide values from 9 a.m. to 6 p.m. were also collected and are shown in Table 3.2. The average values verified that tide was higher, maintained at about 110cm during 9 a.m. and then dropped to 84cm at noon. The tide level continually decreased and reached its minimum value around 70cm between 2 p.m. and 3 p.m., and rebounded to 100cm at 6 p.m. Overall, the tide in the early afternoon (from 1 p.m. to 4 p.m.) was sustained at a relatively low level between 70cm and 80cm.

It is clear that the peak period of recreational use coincided with the occurrence of low tide when the depth of the water was the shallowest during the study period. This indicates a high possibility of tide acting as an influential driver of coral damage caused by recreationalists' behavior under the water.

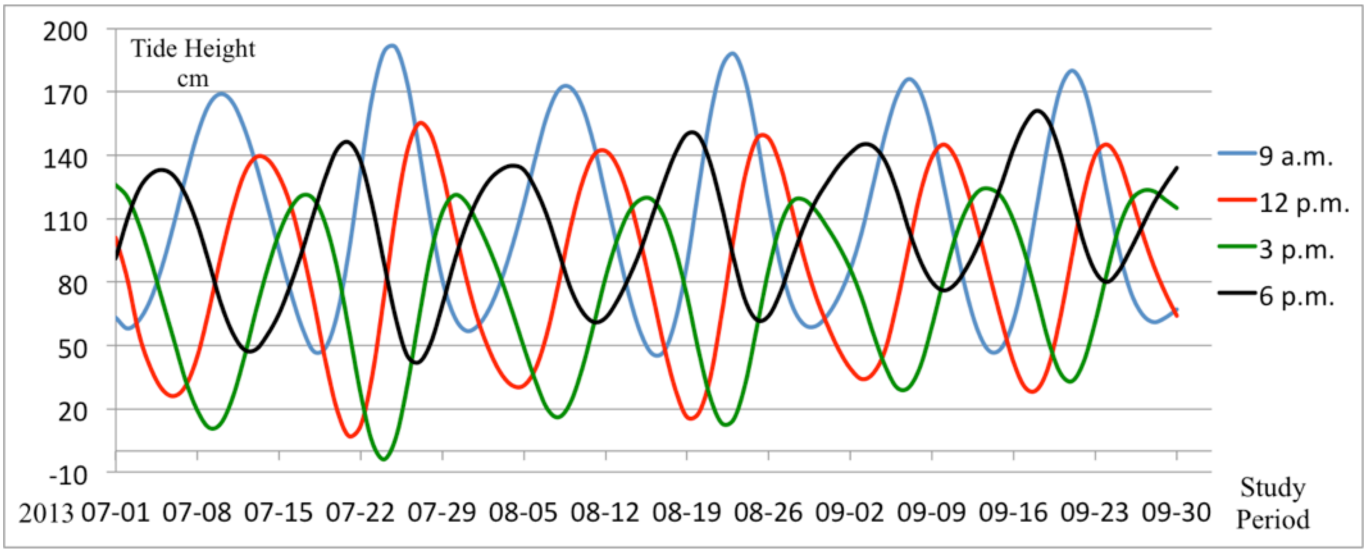


Figure 3.2 Time series of tidal condition at Sarahama Harbor of Irabu Island from 1st July to 30st September, 2013.

Table 3.2 Hourly tide level from 9 a.m. to 6 p.m. during sampling period.

Time / Day	9 a.m.	10 a.m.	11 a.m.	12 p.m.	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.	6 p.m.
1/07/13	63	71	85	101	116	125	126	118	105	91
2/07/13	58	56	63	81	93	109	120	124	120	110
3/07/13	62	50	47	55	70	88	107	120	126	124
4/07/13	72	51	40	39	49	68	90	110	125	131
5/07/13	88	60	39	29	33	48	71	97	119	133
6/07/13	108	75	46	26	21	31	52	80	108	130
7/07/13	130	96	60	31	16	17	33	61	92	121
8/07/13	150	119	81	45	20	10	25	42	73	107
9/07/13	164	140	105	67	33	13	11	26	54	89
10/07/13	169	156	128	92	54	26	13	18	39	70
11/07/13	165	162	144	114	79	46	25	20	31	56
12/07/13	153	159	151	131	102	70	44	30	32	48
13/07/13	136	148	149	139	119	92	66	47	41	48
14/07/13	116	131	139	138	128	109	86	67	55	55
15/07/13	95	111	124	130	129	119	103	86	72	65
16/07/13	75	89	104	116	123	123	115	103	89	79
17/07/13	58	66	80	95	109	118	121	116	106	95
18/07/13	47	46	54	70	88	106	119	124	122	113
19/07/13	49	35	32	42	61	85	107	124	132	130
20/07/13	65	37	20	19	32	57	86	114	134	143
21/07/13	95	56	24	7	8	27	57	92	124	146
22/07/13	133	89	46	12	-3	3	27	64	103	137
23/07/13	168	129	81	36	4	-7	4	34	75	116
24/07/13	189	163	121	73	29	2	-4	13	46	89
25/07/13	191	182	154	112	66	27	6	6	27	63
26/07/13	174	181	170	142	102	62	31	16	22	45
27/07/13	143	162	166	155	129	96	63	40	32	42
28/07/13	109	132	147	150	140	119	93	68	53	51
29/07/13	81	101	119	132	135	128	113	94	78	69
30/07/13	64	76	91	107	119	124	121	111	99	89
31/07/13	57	60	69	83	98	110	118	119	114	106
1/08/13	59	52	54	63	77	93	108	120	122	120
2/08/13	67	52	45	48	59	76	96	113	124	128
3/08/13	80	57	42	37	44	60	82	104	122	133
4/08/13	97	68	51	31	31	44	66	92	117	135
5/08/13	117	85	53	31	22	29	49	77	107	133
6/08/13	139	107	70	39	20	18	33	60	93	133

7/08/13	159	131	94	56	27	15	20	43	76	111
8/08/13	171	151	119	80	45	21	16	30	59	94
9/08/13	172	164	140	106	69	38	23	26	46	77
10/08/13	163	166	153	127	94	62	39	32	42	66
11/08/13	145	156	155	140	115	86	60	45	46	61
12/08/13	121	139	146	142	128	105	82	64	57	63
13/08/13	97	116	129	135	131	118	100	83	72	71
14/08/13	74	91	108	120	125	122	113	100	88	82
15/08/13	56	68	83	99	112	119	119	114	104	95
16/08/13	46	49	59	75	93	109	119	122	119	111
17/08/13	47	38	39	50	69	91	111	125	130	127
18/08/13	62	39	27	29	44	68	95	120	136	141
19/08/13	89	54	28	16	22	42	73	106	133	150
20/08/13	125	83	45	18	9	20	47	83	120	149
21/08/13	159	120	75	35	11	7	25	58	98	136
22/08/13	182	153	111	66	29	10	13	36	73	115
23/08/13	188	175	143	101	59	27	15	25	52	91
24/08/13	175	178	163	131	92	56	32	28	42	71
25/08/13	148	164	164	148	120	87	59	43	45	62
26/08/13	116	138	150	148	134	111	86	67	59	64
27/08/13	88	109	126	135	134	124	107	90	78	75
28/08/13	69	84	100	114	122	124	118	108	98	91
29/08/13	60	67	78	92	105	115	119	118	112	106
30/08/13	59	58	63	74	88	102	114	121	122	118
31/08/13	64	55	53	60	72	89	106	119	127	127
1/09/13	73	56	47	48	59	76	97	116	129	135
2/09/13	86	62	45	39	46	62	86	110	130	141
3/09/13	104	75	49	34	34	47	72	100	127	145
4/09/13	127	94	61	37	27	33	55	86	118	144
5/09/13	150	119	82	48	28	25	40	69	104	137
6/09/13	168	144	108	70	39	25	30	53	87	123
7/09/13	176	162	133	96	61	36	30	43	71	106
8/09/13	170	169	151	122	87	57	40	42	60	90
9/09/13	152	162	158	139	111	82	59	51	58	80
10/09/13	126	145	151	145	127	104	81	67	65	76
11/09/13	99	120	134	139	133	119	101	85	77	79
12/09/13	74	94	112	124	129	125	115	102	92	87
13/09/13	56	71	88	104	117	123	123	116	107	98
14/09/13	47	53	65	82	100	115	124	126	121	112
15/09/13	49	43	47	61	80	102	120	131	134	127
16/09/13	62	44	37	42	59	84	109	131	142	143

17/09/13	85	56	36	30	40	63	93	123	145	155
18/09/13	116	80	48	29	27	43	73	107	139	161
19/09/13	147	110	71	40	25	29	52	87	124	156
20/09/13	171	141	102	63	35	26	37	66	104	141
21/09/13	180	163	131	92	57	35	33	51	83	120
22/09/13	172	171	152	121	85	56	42	46	68	99
23/09/13	151	163	159	140	111	82	61	54	63	85
24/09/13	123	142	150	145	129	106	84	71	69	80
25/09/13	96	117	132	138	134	121	105	90	83	85
26/09/13	76	93	110	122	128	126	118	108	99	95
27/09/13	65	76	90	104	116	122	123	119	113	106
28/09/13	61	66	75	88	102	115	123	125	122	117
29/09/13	63	60	65	75	90	106	119	128	130	126
30/09/13	67	58	57	64	79	97	115	129	136	134
Mean	**109.9**	**102.9**	**93.4**	**83.7**	**76.1**	**72.6**	**74.5**	**81.4**	**92.0**	**104.5**

3.2 Results of Inquiry Survey

According to the responses to questions of the inquiry survey described in Chapter 2, possible activities at Kayafa Beach include tour packages of snorkeling, diving (e.g. experience-based diving, fun diving) and kayaking. There are other special activities provided at certain periods, such as graduation trip during summer (April to July) and winter season (October to February). The graduation trip includes activities of learning coral reefs through lectures as well as diving and snorkeling and its target object ranges from elementary students to college students. Apart from tour packages provide by shop agencies, individual recreationalists are often found. Such as family groups and couples who mainly come to Kayafa Beach for snorkeling and swimming. While recreationalists engaging in stand-up surfing, fishing and barbecue are also occasionally found.

The responses to the second and third question towards possible influential factors affecting coral health at Kayaka Beach are shown in Table 3.3. Typhoon, coral disease, predator attack and wave-induced breakage were conceived as natural factors resulting in coral degradation and among them, predator attacks was mentioned by two of the respondents. In terms of human-induced factors, global drivers such as ocean acidification and global warming and localized drivers of contact by discarded waste and recreational impacts were deemed to affect the coral condition of the study area. Thereto, contact by waste was mentioned by two respondents and noticeably, recreational impact was emphasized by each one of the respondents. By asking them to specify the recreational impact, the behaviors of touching and kicking were referred to by over half of the respondents and standing upon reef colonies in particular, were mentioned by every respondent.

Table 3.3 Outcome of the inquiry survey towards potential drivers about coral degradation at the study sites. Factors underlined denote the most frequently mentioned answers by the four respondents.

Respondent	Natural Factors	Human-induced Factors	Recreational Impacts
Respondent A	predator attack, ultra influence on coral bleaching	ocean acidification, global warming, <u>recreational impacts</u>	touching, feeding tropical fish, kicking, <u>standing upon reef colonies</u>
Respondent B	N/A	<u>recreational impacts</u>	<u>standing upon reef colonies</u>
Respondent C	typhoon	<u>recreational impacts</u>, coral contact by discarded waste in sea	<u>standing upon reef colonies</u>, fin kicking
Respondent D	predator attack, coral disease, wave	<u>recreational impacts</u>, current induced damage (damage caused by direct contact of floating wastes, sediment accumulation smother the corals)	Snorkelers' behaviour (touching, fin kicking, stirring up sand, <u>standing upon reef colonies</u>), divers' behaviour (fin and gauge contact, touching and stirring up sand), kayaking

3.3 *In situ* Survey of the Coral Damage Condition

3.3.1 The Extent of Coral Breakage

Three coral species, i.e. *Porites rus, Porites cylindrica* and *Acropora muricata* shown in Figure 3.3, were found to have received the most noticeable damage at the survey points.

Figure 3.3 The most damaged species found in the survey area (from left to right: *P. rus, P. cylindrica*, and *A. muricata*, respectively).

The result of coral damage investigation is shown in Table 3.4. A total number of 2,143 legible broken branches of corals were found. Among them, *P. rus* had the severest damage: as many as 1,472 branches were found broken which accounts for almost 69% of the total breakage. Most of its damaged colonies were found close to sea surface and therefore is considered been caused by swimmers and snorkelers who concentrated at shallow water area (Allison WR, 1996). An amount of 643 branches of *P. cylindrica* were recorded broken that accounts for 30% of the overall breakage. However, unlike *P. rus*, most of the damaged *P. cylindrica* colonies were found in the middle layer of the water. *A. muricata* suffered the least from the man-made damage, and only 28 broken branches were found which accounts for merely 1% of the entire breakage.

Table 3.4 The number of broken corals with regard to coral species at each survey points.

Point	*P. rus*	*P. cylindrica*	*A. muricata*
1	84	21	28
2	6	55	-
3	478	42	-
4	18	74	-
5	102	41	-
6	271	-	-
7	513	410	-
In Total	**1,472**	**643**	**28**
Percentage	**69%**	**30%**	**1%**

The breakage was distributed uniformly among the 7 points as illustrated in Table 3.5. Over half of the branches were distributed at Points 3 and Point 7, there into, Point 7 had the most distinct damage that more than 900 broken branches were found at this point. This is considered due to the abundant coral and tropical fish species of Point 7, which drives recreationalists to linger longer thus increasing the potential of damage occurrence (Uyarra and Côté, 2007). The coral damage condition at the rest of the points turned out to be relatively lighter, except for point 6, less than 200 broken branches were found at each of the remaining points. However, it is mentionable that several breakages of *P. rus* colonies found at Point 4 were too severe to be legibly recognized so were not considered. As a result, the number of the quantified broken branches is considered to be underestimated.

Table 3.5 The distribution of coral breakage among the 7 survey points collected on the 25th and 27th of September, 2013. Water depth stands for the distance between sea surface and the top of the breakage.

Point	1	2	3	4	5	6	7
Water depth (cm)	50	100	100	200	50	50	200
The numbers of broken branches	133	61	520	92	143	271	923
In total	2,143						

3.3.2 Characteristic of Coral Damage

The characteristic of damage on *P. rus* and *P. cylindrica* colonies is judged by the shape of its breakage. The damage on *P. rus* was mainly concentrated in the central and the edge of the colonies (Figure 3.4), while the damage on *P. cylindrica* was mainly found at the tips of the branches (Figure 3.5). Besides, the breakage of *P. rus* colonies was formed in a distinct way of white branches scattering on the top and massive brownish branches lying beneath. The brownish color of the breakage is given by he algal growth on the broken sections, indicating that the damage had been generated long before (e.g. Riegl and Velimirov, 1991). White breakages on the other hand, indicate recent breakage before algal growth. As a result, the breakage with different color signifies that the damages were caused by various factors at different timings.

Figure 3.4 Central (left) and edge (right) concentrated breakage of *P. rus* colonies.

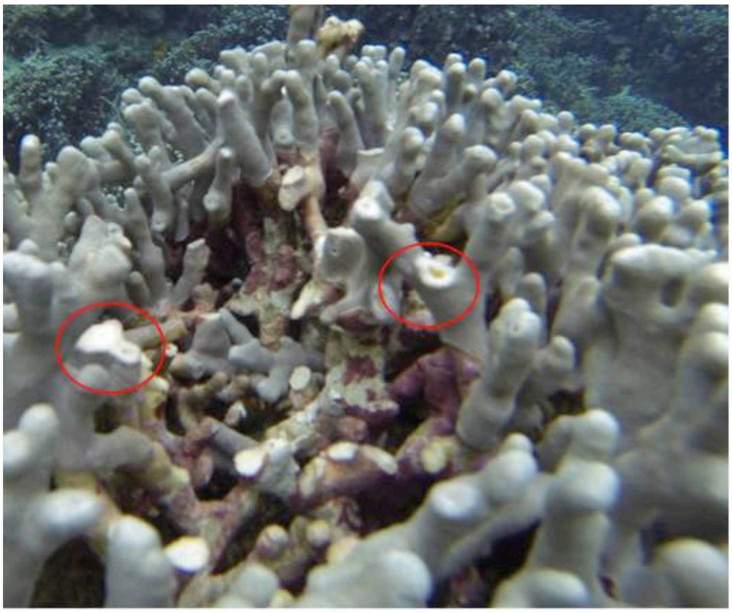


Figure 3.5 Tips breakage of *P. cylindrica* branches.

3.4 *In situ* Observation on Recreationalists' Behavior

There are diverse activities available at Kayafa Beach and swimming, snorkeling, diving and kayaking can commonly be seen. Among them, kayaking is only provided by Eco Guide Café and the users receive pre-training beforehand which helps to prevent damaging behaviors.

3.4.1 Observed Results at Sea Surface

3.4.1.1 Destructive Behaviors in Relation to Gears

Swimming and snorkeling do not require professional instructions and gears so that are suitable for various age groups of recreationalists with any skill level. Because of the flexibility, depreciative behaviors such as touching and kicking corals and standing upon *P. rus* colonies were often observed. Among them, boots kicking and standing on *P. rus* colonies in particular, are identified as the two typical behaviors (Figure 3.6). The occurrence of the behaviors is considered to be closely related to the gears equipped by swimmers and snorkelers.

Figure 3.6 Kicking as a result of treading water (left) and standing upon *P. rus* colonies (right).

A variety of gear combinations among swimmers and snorkelers were noticed, and the combination is entirely dependent on the individual recreationalist's preference. Goggles, fins, swimming tubes, wetsuits, marine boots, and lifejackets are some of the common gears. Through comparing the differences between recreationalists' behavior in line with their equipment, relationships between recreationalists' equipment and their consequent behaviors were examined. Wearing neither masks nor lifejackets but only marine boots is the typical combination which leads to harmful behavior of boots kicking. Due to the lack of buoyancy supportive gears, recreationalists would intensely tread water in order to maintain the floating state at the sea surface and eventually their bodies will maintain at a vertical state in the water. Besides, recreationalists have poor vision without goggles and masks under water (Inglis *et al*., 1999). Under such condition, coral branches of *P. rus* were found to be broken by aggressive kicking.

According to the follow-up inquiry about the damage found in *P. rus* colonies, the following points were pointed out by a staff responsible for the snorkeling course:

- The combination of swimming tube with marine boots is the most likely cause of the damage found at *P. rus* colonies;
- Recreationalists get used to pressing the swimming tube while treading water without wearing goggles or masks, the consequent behavior caused breakage on reef colonies without being aware;
- The percentage of wearing buoyancy-supportive gears (e.g. lifejacket) during the last 5 months was slightly over 50%, whilst less than 20% of recreationalists were estimated to have been equipped properly (lifejacket together with marine boots, mask and buoys).

The result is consistent with the findings from *in situ* observation that boots kicking without proper gears for buoyancy control proved to be the reason of breakage on *P. rus* colonies. Simultaneously, the behavior of standing upon *P. rus* colonies was observed among swimmers and snorkelers regardless of wearing boots, fins or bare feet. In addition, they tend to stand at the same point repeatedly.

3.4.1.2 Tidal Condition and the Consequent Impacts

The depth between the sea surface and the top of *P. rus* colonies was measured when depreciative behaviors were observed. The depth at which boots kicking happened was found to be between 100cm to 150cm and the depth of the occurrence of standing upon *P. rus* colonies was between 50cm and 150cm. Depending on individual conditions, the precise occurring depth of each type of the behavior is slightly different. Nevertheless, when the water depth ranges within the first extent (100cm-150cm), swimmers and snorkelers in general are capable of having direct contact with *P. rus* from the sea surface. While when the depth changes to the second scope (50cm-150cm), the water is about waist-deep if recreationalists standing upon the colonies.

3.4.2 Underwater Observation

3.4.2.1 Destructive Behaviors in Relation to Buoyancy Control

Compared to swimming and snorkeling, basic gears for diving are compulsory and hence are relatively standardized. Standard gears such as fins, goggles, buoyancy control devices (BCDs) and tanks are necessary. But depending on the skill level of individual divers and diving courses they are interested in, there are various types of additional attachments available. For example, a white board, which enables under water communication among members, act as a useful tool for sharing information about marine creatures between divers and instructors during diving. Underwater cameras are popular among divers, especially for underwater photographers. Additional attachments, on one hand, could be useful to call divers' behaviors thereby minimizing the impact to a certain extent, but it is at the premise of mastering the ability of buoyancy control. For unskilled divers, additional attachments may increase the risks of coral contact on the contrary. The behavior of holding to the sea floor is often observed among photographers, especially among unskilled divers when they try to stay stable for the sake of taking photographs (Figure 3.7).

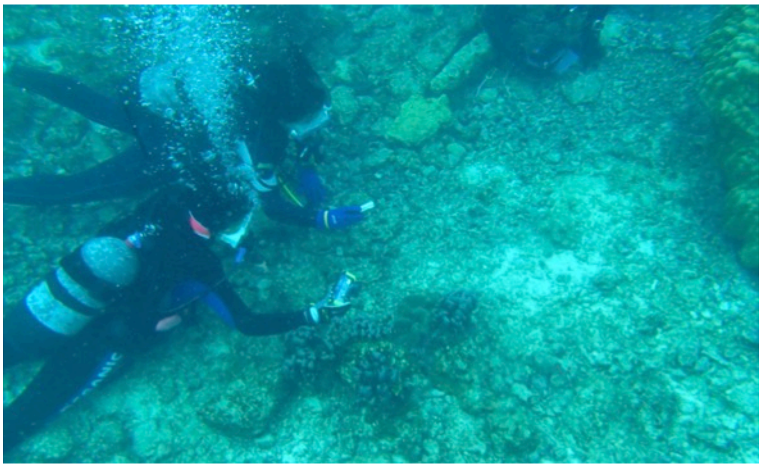


Figure 3.7 Behavior of holding to the sea floor among divers.

Other behaviors of coral contact by gauges and body were also frequently observed. The occurrence of stirring up sand by fins due to poor ability in buoyancy control can commonly be seen. Unskilled divers result in gradually descending while diving, and tread water to try to go up or move forward subsequently, stirring the sand up at the sea floor (Figure 3.8). In addition, when they are unable to maintain balance while diving, some of the divers also tend to contact corals directly to maintain balance (Figure 3.9).

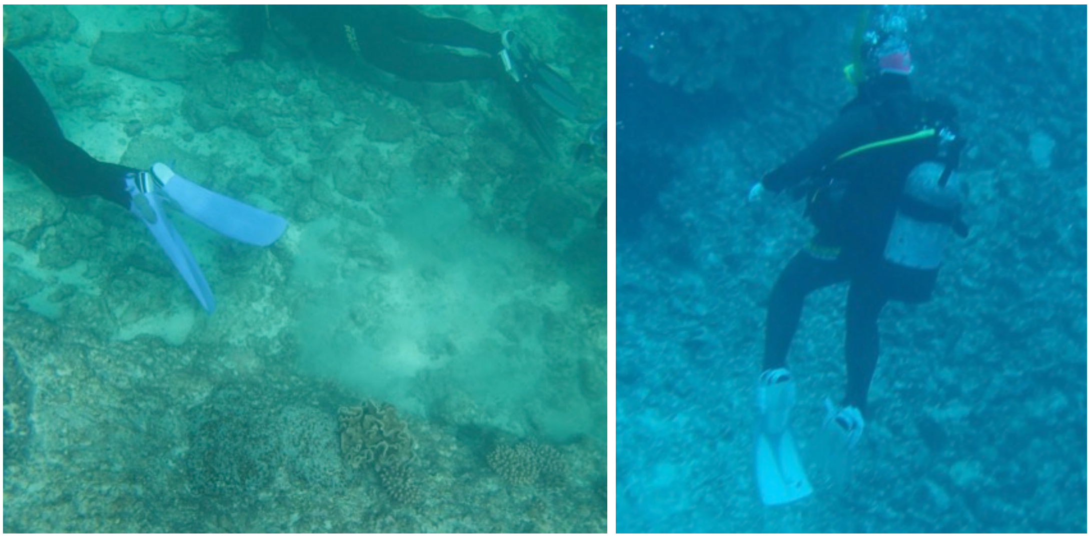


Figure 3.8 Stirring up sand at the sea floor in order to move forward (left) and to go up (right).

Figure 3.9 Direct coral contact for maintain body balance.

According to a staff responsible for diving course, the breakage found at *P. cylindrica* colonies is confirmed caused by divers whom are inexpert at buoyancy controlling:

- The damage found at the *P. cylindrica* colony is caused by unskilled divers using incorrect methods to maintain buoyancy. Aggressive water treading when they try to hover in water broke *P. cylindrica*'s branches at tips by the edges of their fins.

- Divers with poor buoyancy control often drop on reefs from either the front side or the backside of their body, and the consequent body contact caused damages appear like round holes at reef colonies;
- Holes with 10cm wide diameter could be caused by contact via knees and hands and diameters as wide as 30cm are deem to be caused by tank contact;

3.5 Suppositions of Tide-induced Damage on Reefs

As buoyancy control is a dominating factor that affects the potential of coral contact, factors affecting the buoyancy control also have an influence on the potential of coral contact. As the water depth at the study site is comparatively shallow in general, the tidal change consequently leads to significant variation in suitable diving space. Especially accompanied by low tide, the emergence of unstable current could increase difficulties in controlling buoyancy. Therefore, the potential of coral contact is closely relevant to tidal condition.

3.5.1 Damage Pattern at Sea Surface

Tide-induced damage pattern found at the sea surface is discussed by reflecting on the breakage found at *P. rus* colonies. Most of its damaged colonies are found close to the sea surface therefore are considered to be caused by swimmers and snorkelers. By examining the color of the breakage sections, the damages on *P. rus* colonies are deemed to be caused at different timings. The possibility of caused by a primary and secondary damage in particular will be described in detail in the following sections and in Figure 3.10.

3.5.1.1 Primary Damage

Reef colonies of each coral species are subjected to certain level of compressive forces that are intended to simulate trampling forces caused by human standing or walking on the colony (Rodgers *et al*., 2003). And initially, the branches of *P. rus* are intensively structured that are resistant to external forces. Under healthy conditions, *P. rus* colonies are resistant to relatively minor behaviors such as touching and behaviors with relatively large contact area such as standing upon reef colonies. However, behaviors such as boots kicking have strong power with small contact area that is embedded with considerably invasive impact force. The accumulative force is fairly aggressive and ultimately beyond the tensile strength of *P. rus* branches. As a consequence, kicking by recreationalists when water depth ranges from 100cm to 150cm generates the primary breakage. In short, the primary damage weakens the carrying capacity of *P. rus* colonies' resistance to stress, and the generated breakage by exposing the branches aside to external forces makes the colonies sensitive and vulnerable to further physical contacts.

3.5.1.2 Secondary Damage

Behaviors that are capable of causing secondary damage on *P. rus* colonies are not limited to boots kicking since the resistant ability have been broken down. Depreciative behaviors, which not suppose to generate damages initially including the relatively minor behaviors (e.g. standing upon reefs) are now put *P. rus*'s health at risk potentially. When water depth ranges from 50cm to 150cm, the behavior of standing upon *P. rus* colonies is considered to cause secondary damage regardless of wearing boots, fins or bare feet.

Based upon the primary damage, the secondary damage leads to a massive and rapid expansion of the damaged area, which helps to explain the appearance of central and edge concentrated breakage found *P. rus* colonies. The difference in color indicates a sequential occurrence of damaging behaviors and the supposition is justified considering a primary damage of boots kicking followed by secondary damage of standing upon reef colonies. The primary damage proceeds and slowly reduces *P. rus* colonies' resistant capacity, acting as a proof of the occurrence of secondary damage. Along with the process of secondary damage, the breakage area gradually become flat and rock-like, and eventually appears to provide a place for recreationalists to take a rest in the sea. Besides, it is often seen *in situ* that recreationalists tend to stand at the same spot, which is considered to reflect the former recreationists' behaviors. By witnessing fellow recreationalists standing on reef colonies, it might influence others to perceive standing as legitimate behavior. And therefore, it was repeatedly observed at the same site.

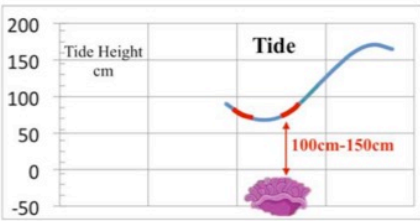
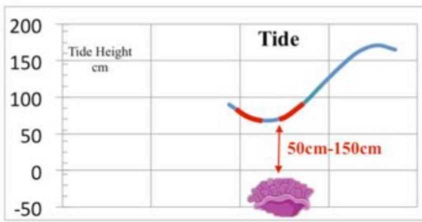
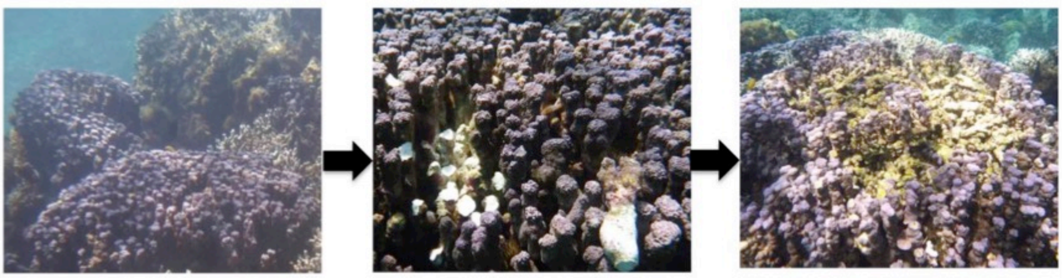
	Primary Damage	**Secondary Damage**
Tide Condition	 	
Depreciative Behavior	Boots kicking by treading water in vertical state	Stand upon reefs for taking a rest (by boots, fins or bare feet)
Damage Process		

Figure 3.10 Damage pattern at the sea surface.

3.5.2 Potential Coral Contact Under the Water

Diving activity is usually considered to be affected less by tidal change. As the current in deep water is comparatively stable, the ability of buoyancy control at the deep site is not greatly affected by the emergence of the current. However, all the survey points of the study area happen to be shallow and the diving space varies dramatically as a consequence of tidal change. Hence, a shallow spot is considered embedded with a high rate of coral contact, especially during low tide periods (Figure 3.13). Here, Point 7 was chosen as an example as the point is the most favorable diving spot with the most massive breakage having been found.

Figure 3.11 Variation of diving space at Point 7 in different tide conditions (left: at low tide; right: at full tide).

As shown in Figure 3.11, during full tide (except grand tide period), the diving space of Point 7 usually has approximately a 4-meter depth while in low tide the depth drops down to approximately 2 meters (excluding neap tide period). Such variations have a great influence on the potential of coral contact because of its impact on divers' behavior. During low tide when the depth begins to draw back, the impact of unstable current will amplified, especially in shallow water areas and increases difficulties in buoyancy control. In the case of unskilled divers, who haven't mastered the ability in buoyancy control and could hardly maintain their balance. Diving with the current would lead to recurrent coral contact by hands, fins, knees and gauges, while if they intend to maintain balance against the current, it would further result in touching, fin kicking and consequently cause damage at tips of *P. cylindrica* branches (Figure 3.12).

Figure 3.12 Contact by body and gauge during low tide period.

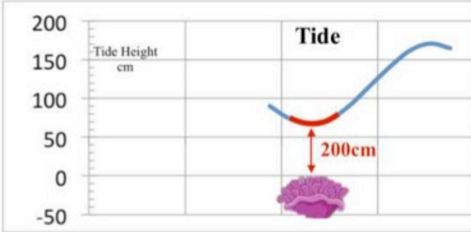
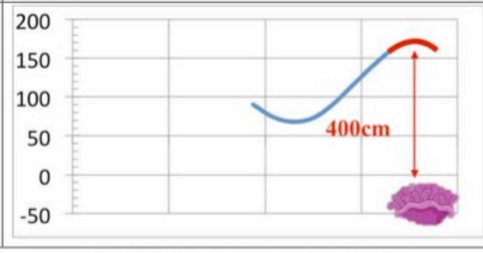
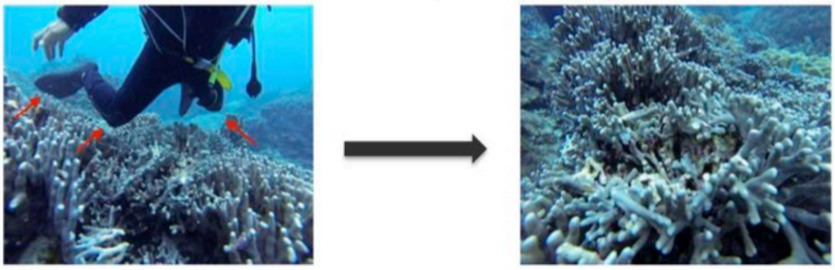
<table>
<tr><th></th><th>Full Tide</th><th>Low Tide</th></tr>
<tr><td>Tide Condition</td><td>
</td><td>
</td></tr>
<tr><td>Depreciative Behavior</td><td colspan="2">
Coral contact through body (knees, hands), gauges (fins, tank) and other attachment (camera, white board and etc.)</td></tr>
<tr><td>Contact Potential</td><td>Comparatively high</td><td>Comparatively low</td></tr>
</table>

Figure 3.13 Process of tidal induced damage caused by divers.

3.6 Discussion

Based upon the findings above, this study manages to develop suppositions with regards to each type of recreationalist and the observed coral breakage. It is new to interpret coral breakage from the perspective of the differences in recreationalists' gears and tidal condition.

However, the suppositions are not always universal. For instance, snorkeling and diving activities conducted at out-reef regions are exclusive as the water depth is considerably deep and tidal change has little influence on the depth variation. This study discusses the situation of recreational damage which occurs at in-shore areas where tidal variation leads to remarkable changes in space for performing recreational activities. Besides, as tide changes periodically so that water depths at certain times are not always the same and the lowest tide appears at different times during different seasons. The study only verified the shallowest water depth occurred in the afternoon during the summer season from July to September. Only under such conditions, direct contact to corals by recreationalists is available. Therefore, the suppositions have regional and seasonal limitations that are only valid under certain prerequisites.

CHAPTER 4 Conclusion and Recommendations

4.1 General Conclusion

The study manages to explain the unique damages found at colonies of *P. rus* and *P. cylindrica* by finding the relationship between recreationalists' depreciative behaviors and their correspondent gears at the sea surface and underwater in relation to different tidal conditions.

The breakages found at *P. rus* colonies are considered to be caused by a damage pattern which consists of boots kicking and standing upon reef colonies. Boots kicking caused the primary damage on *P. rus* when water depth was between 100cm to 150cm, and as a consequence, the resistant ability of reef colonies is weakened and thereby becomes vulnerable to further physical contact. Under such context, standing upon reefs leads to the secondary damage, which happened while the depth was within the ranges between 50cm to 150cm. It attributed to massive and rapid breakage expansion and accompanied by its repeated occurrence, the damage area would become flat and eventually appear to be a place for recreationalists for taking a rest in sea.

Damages found at *P. cylindrica* colonies are deeply evolved with the tide variation. Along with the decrease in water depth, the hardness of buoyancy management increases inversely. Therefore, the frequency of coral contact is considered to be relatively high at shallow water areas, particularly during the low tide as the difficulties in buoyancy management will be multiplied by the occurrence of erratic currents.

4.2 Recommendations toward Conservation Strategy

4.2.1 Proposals of Reef-friendly Equipping Manners

Recreationalists' poor cognition of the impacts by improper gears plays a critical role in the occurrence of the depreciative behaviors and, popularizing reef-friendly equipping manners could help to prevent the typical depreciative behaviors from happening beforehand. For snorkelers and swimmers, as the most aggressive damage caused by kicking is due to the lack of buoyancy-supportive gears as well as underwater vision, thus putting goggles, lifejackets and fins are highly recommended.

For divers, the ability of buoyancy control is the key factor influencing divers' behavior. Therefore we suggest divers to take pre-training courses of buoyancy management regardless of their former experience, particularly for underwater photographers. Considering that taking photographs of marine creatures under the water requires even higher levels of buoyancy control, we recommend cameras are only allowed to be used by skilled divers. Or if only photographers are carried by instructors while photographing so that they could stay in water stably and avoid potential coral contact.

Besides, we also suggest diving shops to arrange more flexible arrangement for diving and snorkeling courses by taking the tide condition into consideration. Alternative plans can be prepared in advance in case of the tide condition at the original destination is not suitable for conducting recreational activities at the moment.

Nonetheless, the recommendations are not suggested for setting rigid rules but are with an intention to extend the proper manners among the study area.

4.2.2 Setting Notice Boards

Kayafa Beach is an open access area but no generalized recreational guidelines have been applied. As discussed by Kuo (2002), soft visitor management strategies including the provision of various information and education can support the hard strategies (e.g. regulations and rules) by increasing visitors' knowledge. Hence, setting notice boards is deemed to be effective and can be widely reached. By using simple but influential slogans and posting the ascertained risky behaviors concluded by this study, the notice boards are designed to encourage recreationalists in general, to act responsibly towards coral reefs. An example of notice board for swimmers and snorkelers is shown in Figure 4.1. After consulting with the study partner, messages of "No Feeding", "No Touching" and "No Walking" were picked out as they disturb the balance of coral reefs ecosystem and cause direct physical breakage on reef colonies. Slogans of "keep the sea as beautiful as it used to be" and "the more we dive the more beautiful Kayafa will be" were originally derived from the Eco Guide Café. Both of them contain the morals of sustainable use of natural resource and thereby are considered pertinent to be used in public. Similarly, notice boards for divers have the same design, except that "No Up and Down" is emphasized instead of "No Feeding", as skillful buoyancy management directly impacts divers' behavior under the water (Figure 4.2).

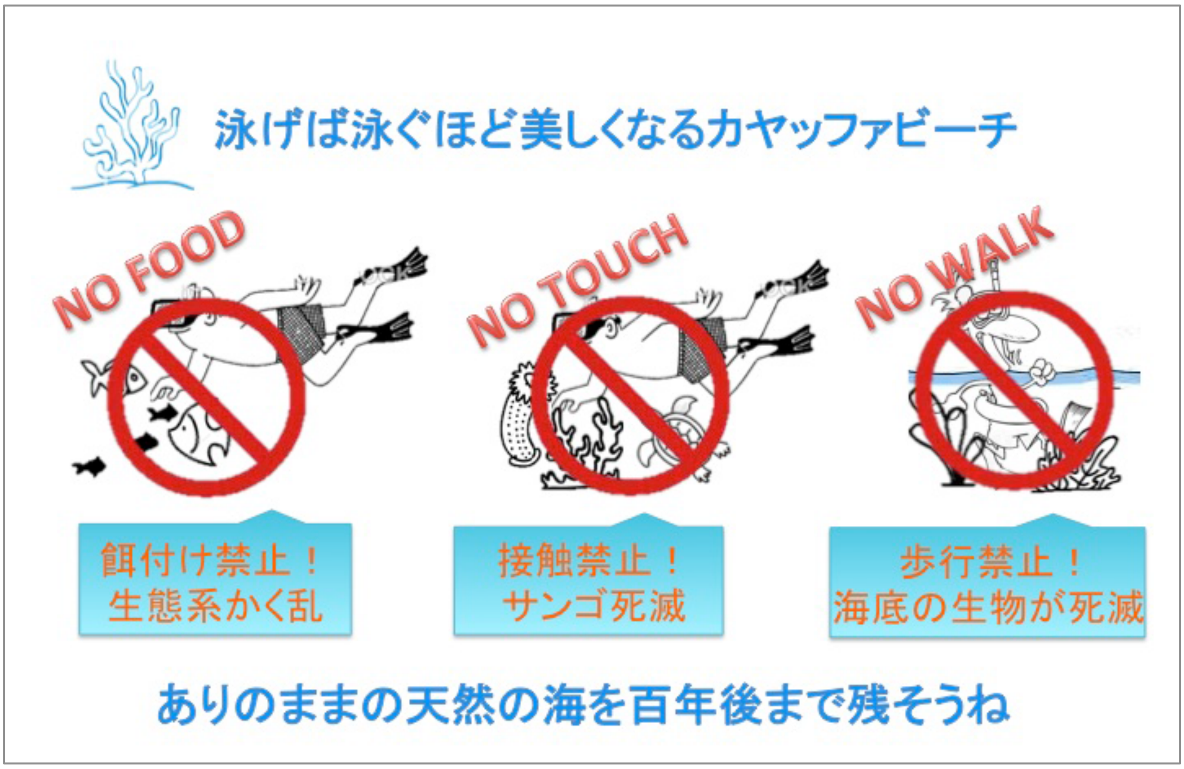


Figure 4.1 Notice board for recreationalists at the sea surface.

Figure 4.2 The same as in Figure 4.1 but for divers.

In addition, it is worth mentioning that after designed the samples shown above, the notice board has been updated several times and the latest version is shown in Figure 4.3. It is more informative compared to the initial designs by adding two more typical depreciative behaviors of standing on and kicking reefs. In order to implement the outcome of this study, the detail about the design and the establishment of notice board will be discussed and finalized as soon as the author visits Miyako Islands again in the late February of 2015, while at the present stage, the envision of notice board setting at the study area is illustrated as Figure 4.4. By doing so, the outcome of this study could be practically beneficial for promoting reef-friendly recreational activities at Kayafa Beach and furthermore contributing to local sustainable reef-based tourism development in a long run.

Figure 4.3 The latest version of notice board.

Figure 4.4 The envision of notice board setting.

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APPENDIX

Based on the findings of this study, an urgent need to alleviate the occurrence of the inappropriate behaviors is recognized. Look up to the world's best known and well structured conservation framework of Great Barrier Reef (GBR) in Australia, in order to comprehend its conservation strategy and furthermore figure out the potential implication for reef conservation in Okinawa, author took a two-weeks internship at a local NGO—Australian Marine Conservation Society (AMCS) based at Brisbane of the State of Queensland of Australia. The organization cares and has fighting for the best for the development of GBR for decades.

The GBR stretches for more than 2,300 km along the coast of Queensland, Australia and comprises about 2,500 individual reefs, which support a great diversity of corals and fish species. It has been listed under the World Heritage Convention in 1981 and is the largest World Heritage Area ever established (Roebeling and Kragt, 2009[1]). GBR has an extremely wide range of habitats including islands, mangrove forest, lagoons, open waters and so forth that make it environmentally, economically and societally important in national as well as international scale (Great Barrier Reef Marine Park Authority, 2009[2]). However, GBR is under great pressure from the consequences of rapid coastal industry development, especially from port expansion. As an island country, ports are considered extremely

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[1] Roebeling PC, Kragt ME (2009) Effects of Great Barrier Reef degradation on recreational reef-trip demand: a contingent behaviour approach. The Australian Journal of Agricultural and Resource Economics 53:213-229.

[2] Great Barrier Reef Marine Park Authority (2009) Great Barrier Reef Outlook Report 2009 in brief. Townsville, Qld, Australia.

important for Queensland and national economy, meanwhile the ports are all state-owned corporations, which make the government both the operator and regulator. The port expansion has grew by 297% meanwhile the value of exports increased by 550% (Great Barrier Reef Marine Park, 2014[3]). Regard to the construction of port expansion, it can lead to fragmentation, modification or loss of coastal ecosystem if not well managed. In the case of GBR region, the construction of port result in near doubling in shipping, major coastal reclamation works and massive seabed dredging, and the dredge spoil disposal can hinder the reproduction of coral shown in Figure 5.1 (AMCS, 2014[4]).

Figure 5.1 Sediment plumes from dredging occurred at Queensland coastal area.
Source: Australian Marine Conservation Society, 2014.

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[3] Great Barrier Reef Marine Park Authority (20014) Great Barrier Reef Region Strategic Assessment: Strategic assessment report. Townsville, Qld.

[4] Australian Marine Conservation Society (2014) Dredging, Dumping and the Great Barrier Reef. Brisbane, QId, Australia. Available at: http://www.marineconservation.org.au/data/REEF_DREDGE_Doc_Spreads.pdf. Accessed at: 20th July 2014.

By fully aware of the differences in the cores of reef management strategies among the two countries, the goal of the internship is not aims to duplicate the reef conservation strategy of GBR region to Kayafa Beach, instead, author is more interested in:

1. what has AMCS been act upon for the sake of the health of GBR;
2. conclude the implications for the conservation of coral reefs in Shimoji Island of Japan.

Partnered up with stakeholders and local communities, AMCS organizes campaigns and public petitions to ensure the concern of industry impact on reef condition among public will be heard and urge government to implement moratorium on approving new development until a sustainable development plan is complete and, author was evolved in public petitions in particular. As an effective approach for attracting politics attentions, there are four stages for complete the process of petition illustrated as Figure 5.2. The first stage is holding stall at public event and explaining the purpose of the activity to public, citizens who agree to sign the petition will put their name, address, email (optional) at the postcard; the second stages is data input includes address, which will be sorted in the order of electoral district so that the postcards could be posted; the last stages is posting cards to the members of the local parliamentarian. By doing so to demonstrate public concern of impacts from current industrial development plans on GBR region and furthermore pushing both state and federal government to stop the investment in inconsiderable port project until a relatively sustainable plan is established, such as consulting with multiple stakeholders of researchers and local communities.

Figure 5.2 The process of collection of public petition towards GBR conservation.

Via the short period of internship, author find out that regardless of the multiple factors attributing to coral degradation in GBR region, raising public awareness has been put in priority by local environmental organization. This reconfirms the recommendation of setting of notice board to increase recreationalists' awareness towards reef at the study area is indispensable. Although reef conservation is a considerably long-term project that requires participation from all kinds of communities in interest, public awareness improvement is the principal for further comprehensive and participatory framework for reef conservation.