Comparison between Coral Reef Ecosystem in the Marine Tourism Zone and Core Zone in Toyapakeh, Nusa Penida, Bali, Indonesia

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***Abstract**: Nusa Penida in Indonesia is one of the islands in the Lesser Sunda Ecoregion, which is one out of 11 ecoregions included in the coral triangle. The objectives of this study were to determine and compare coral cover percentage and reef fish community structure between the coral reef ecosystem in the core zone and marine tourism zone, in Toyapakeh, Nusa Penida. Data collection was conducted in Samuh Cape which represents the core zone (Site 1) and a pontoon area (Site 2) which represents the marine tourism zone, in July 2014. Coral cover was recorded using the line intercept transect (LIT) method, whereas diversity and abundance of reef fish was recorded by visual census. Observations and data collection were conducted using a 100-meter-long transect at a depth of 3 and 10 meters with three repetitions at each station and depth. The percentage of live coral cover in Site 1 at 3 and 10 meter depth were 74.4% and 75.9% respectively. Reef fish diversity (H') was relatively low (H'=0.497 at 3 meter depth and H'=0.932 at 10 meter depth), dominated by <u>Pseudanthias squammipinnis</u> (Serranidae). Live coral cover percentage in Site 2 at 3 and 10 meter depths were 40.9% and 64.2% respectively. Reef fish diversity (H') was moderate (H'=2.61 at 3 meter depth and H'=1,439 at 10 meter depth), dominated by <u>Pomacentrus</u> <u>moluccensis</u> (Acanthuridae) and <u>Pseudanthias</u> <u>squamipinnis</u> (Serranidae) at respective depths. Reef fish species richness (s) in Site 1 was higher than in Site 2, both at 3 meter and 10 meter depths (s=27 and s=34 in Site 1; s=26 and s=21 in Site 2, respectively). Overall data on live coral cover percentage and species richness of reef fish indicate that the coral reef ecosystem in Site 1, or core zone, is in better condition than in Site 2, or marine tourism area.*

***Keywords**: Ecology, coral reef, reef fish, Toyapakeh, Nusa Penida, Bali*

1. Introduction

Nusa Penida is an island in the province of Bali, Indonesia. This island is part of the Lesser Sunda Ecoregion, which is one out of 11 ecoregions included in the coral triangle, a marine area located in the western Pacific Ocean that is protected due to its high conservation value and rich coastal habitats, including coral reefs [1]. Nusa Penida's coral reef covers an area of 1,409 Ha. An assessment of coral and fish diversity was carried out in 2008 by a team from the Marine Rapid Assessment Program. They estimated that there are 298 species of corals and 576 species of fish in Nusa Penida's waters [2], including sunfish and manta rays, which are the main charismatic species of this island. In 2010, the waters of Nusa Penida was designated as a Marine Protected Area (MPA) with an area of about 20,000 Ha [3]. The MPA is divided into four main zones; (1) the core zone; (2) sustainable fisheries zone, with traditional fisheries sub-zone, special use sub-zone, and seaweed farming sub-zone; (3) utilization zone, with marine tourism sub-zone and harbor sub-zone; and (4) other zone, which consists of traditional sacred sub-zone [3].

As marine tourism in Nusa Penida becomes more popular, recreational activities carried out in the area has grown. Those activities include snorkeling and SCUBA diving. Recreational activities performed by inexperienced people, anchor-throwing, and coral-stepping may cause corals to break, either intentionally or not [4]. Such damage is common in shallow waters.

Activities related to marine tourism are suspected to have an impact on the condition of coral reef ecosystems in Nusa Penida; however, data and information to support this are still lacking. The following study aims to compare live coral cover and reef fish community structure between the coral reef ecosystem found in the core zone and the marine tourism zone, as well as comparing live coral cover and reef fish community

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structure between depths of 3 and 10 meters in each zone. Observations were conducted at two different depths, with the assumption that damage would be more severe in shallower waters.

2. Methods

2.1. Study area

The study was conducted in the Toyapakeh area, located in the northwestern part of the island. This location was chosen because the waters in this area fall into two distinct zones, i.e., the core zone and the marine tourism (sub)-zone [5]. Data collection was conducted at two sites: Site 1 represents the core zone, while Site 2 represents the marine tourism zone (Figure 1).

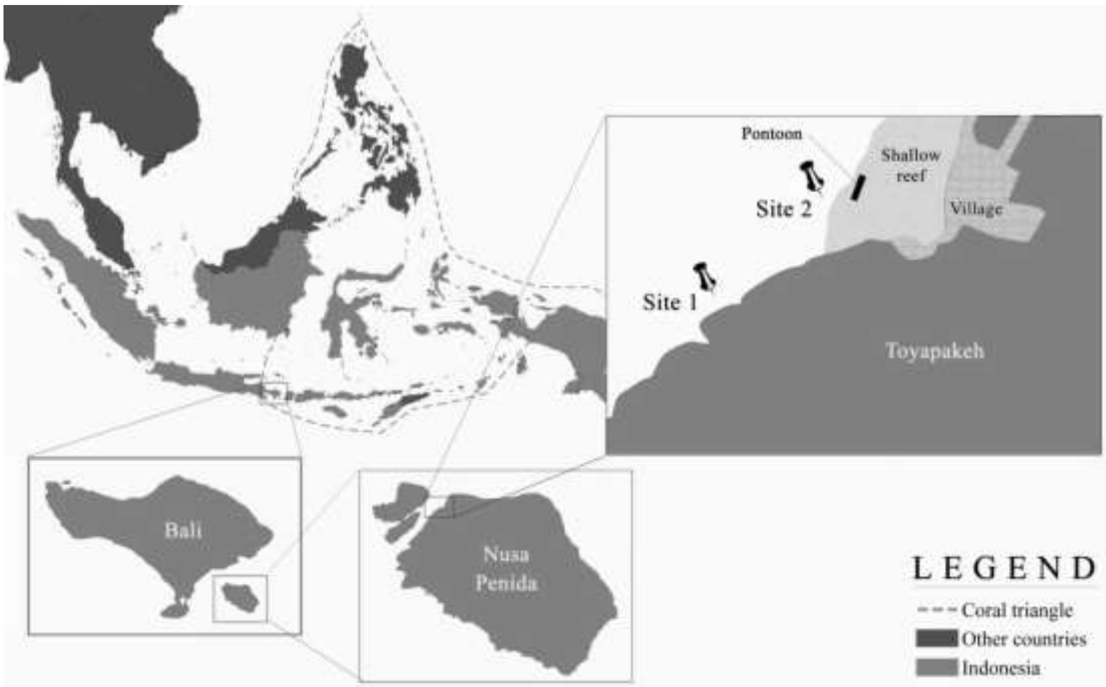

Fig. 1: Observation sites in Toyapakeh area [16]. Site 1 represents the core zone, while Site 2 represents the marine tourism zone

Data collection was completed in two weeks, from June 25th to July 9th 2014. Site 1 was located in the Cape Samuh area (08^{o} 41' 8.06" S and 115^{o} 28' 45.19" E) and Site 2 was located in the pontoon area (08^{o} 40' 55.21" S and 115^{o} 28' 57.87" E). Distance between the two sites was approximately 1 km. Site 1 was located just beside the edge of a cliff, close to Badung Strait. Grass, shrubs, and small trees were observed up the cliff. Human activity is not permitted in this area. The contour of the reefs at this site was mainly steep slopes, almost vertical. Site 2 was located off Toyapakeh beach which is crowded with human activity. Close to the site is a pontoon owned by a tourism company. Guests of the tourism company can take part in various activities on this pontoon, e.g. fish-feeding, snorkeling, and riding the subsea vessel. The contour of the reefs at this site was flat.

2.2. Data collection

Coral life-form data collection: coral life-form observation was conducted by line intercept transect (LIT) method using a 100-meter transect which was laid on top of the reef, parallel to the coastline and following the contour of the reef. Data were collected every 20 meters followed by a 5-meter interval [6] at a depth of 3 and 10 meters using video recording equipment. This was repeated three times at each depth and location. Video recordings were then studied while noting the beginning and end points (in cm) for every coral life-form, referring to English [15]. The percentage of live coral cover in each observation was calculated.

Reef fish community structure data collection: observations of reef fishes was conducted by visual census method within the observation area of 3 x 500 m^2. Observations were made along the 100-meter line transect that was used to observe coral life-form, and 5 meters wide: 2.5 meters to the right and left of the line transect.

Data were collected at a depth of 3 and 10 meters using video recording equipment. All fishes recorded were then identified using a reef fish identification book [11]. Species abundance, species richness, density per 250 m^2, and Shannon-Wiener diversity indices (H') were calculated. The trophic group of each fish species was defined based on Ferreira *et al.* [10].

3. Results and Discussion

3.1. Comparison between Site 1 and Site 2 at 3 meter depth

- Coral cover percentage

At 3-meter depth, total live coral cover percentage measured 74.7% at Site 1, and 41.5% at Site 2. At Site 1, the most common life-form is soft coral (34.3%) (Figure 2). Coral species of this life-form are found close to the mainland and can survive in water with low light penetration, thus it can be found under hard coral or rocks to a depth of 200 meters [7]. The abundance of soft corals at Site 1 is thought to be related to the contour of the reef, i.e. a steep slope, such that some surface vegetation and other organisms that grow close to the surface may block incoming light.

Hard corals are also found at Site 1. The most abundant hard coral type is encrusting hard coral (9.9%). This type of life-form is characterized by the way it makes a flat spread on top of the substrate, unlike other hard corals that grow upwards towards the source of sunlight. This encrusting form benefits the hard coral growth when compared to other forms of growth due to its wide surface area, resulting in a strong grip to the surface. Consequently, this type of hard coral can survive in times of storms and strong current [8] whereas branching hard corals are more easily broken under these conditions.

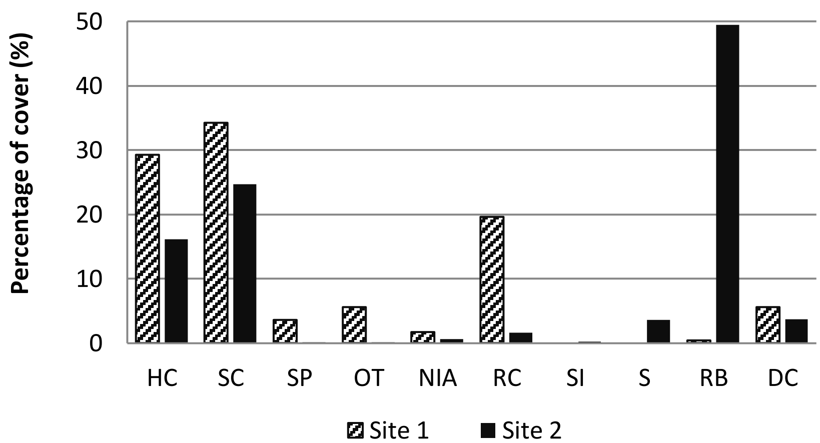

Fig. 2: Coral cover percentage by life-form in Site 1 and Site 2 at 3 meter depth (HC: Hard Coral; SC: Soft Coral; SP: Sponge; OT: Others; NIA: Nutrient Indicator Algae; RC: Rock; SI: Silt; S: Sand; RB: Rubble; DC: Dead Coral)

Meanwhile at Site 2 the most commonly found form is rubble (49.5%). This may be a result of several things, one of which is the presence of a permanent pontoon in this area. The floating pontoon is retained by a large chain that connects the pontoon to a large concrete structure on the seabed. High currents in Nusa Penida waters may cause the chain to shift. The chain's shifting motion destroys coral cover in the surrounding areas, thus rubble and sand are found around the pontoon. In addition, this pontoon also completely blocks light penetration, so that biota that can grow underneath the pontoon is limited. Other causes may be related to exposure of reef flats in the area at low tide or destructive human activities such as anchor-throwing [4]. These factors make it difficult for corals to grow back.

The most commonly found live coral life-form in Site 2 at 3 meter depth is soft coral. Soft corals have better resistance to strong currents because they are flexible and are able to swing with the flow [7]. In addition, soft corals tend to grow quickly and can live in areas with low light penetration.

- Reef fish community

At Site 1, as many as 3,889 reef fishes which are classified into 27 species from 13 families were found. The reef fish family with the highest abundance is Serranidae (Figure 3). *Pseudanthias squamipinnis* (Serranidae) is the dominating reef fish species with a density of 590.3 ± 101.4 individuals per 250 m^2. This fish is a planktivore and is often found swimming near the reef in large groups [11]. One reason for the high number of *P. squamipinnis* at Site 1 is thought to be due to the location of this site which is alongside Badung Strait, in addition to the reef's steep slope, which makes the current in this area very strong. That strong current, combined with the clear water and high light penetration in the area, brings along a large amount of plankton that the fish feeds on [10]. Other than the abundant food source, the high number of *P. squamipinnis* is thought to be associated with the high live coral cover at this site. These fish use the crevices in between corals as a place of refuge when there is a threat or strong current [11]. The Shannon-Wiener diversity index at this site is 0.497.

Meanwhile, recorded at Site 2 were 875 reef fishes which are classified into 26 species from 10 families. This is lower than the amount of fish found at Site 1. The family with the highest individual abundance is Pomacentridae (Figure 3). The high abundance of Pomacentridae is associated with its high species richness, even though the species with the highest density observed in Site 2 is *Ctenochaetus striatus* (22.7 ± 7.9 individuals per 250 m^2) which belongs to the Acanthuridae family, while the Pomacentridae species with highest density is *Pomacentrus moluccensis* (22.7 ± 7.9 individuals per 250 m^2) and *P. similis* (19.7 ± 6.9 individuals per 250 m^2). *Ctenochaetus striatus* are roving herbivores, *P. similis* are omnivores, and *P. moluccensis* are territorial herbivores. The abundance of these fishes is thought to be related to the composition of coral life-forms at Site 2, which is dominated by rubble. Omnivorous fish have a flexible diet so that it has high survival rate [12], whereas herbivorous fish are found because of the algal layer that covers the rubble. The algal layer is a food source for herbivorous fish. The Shannon-Wiener diversity index for Site 2 is 2.586.

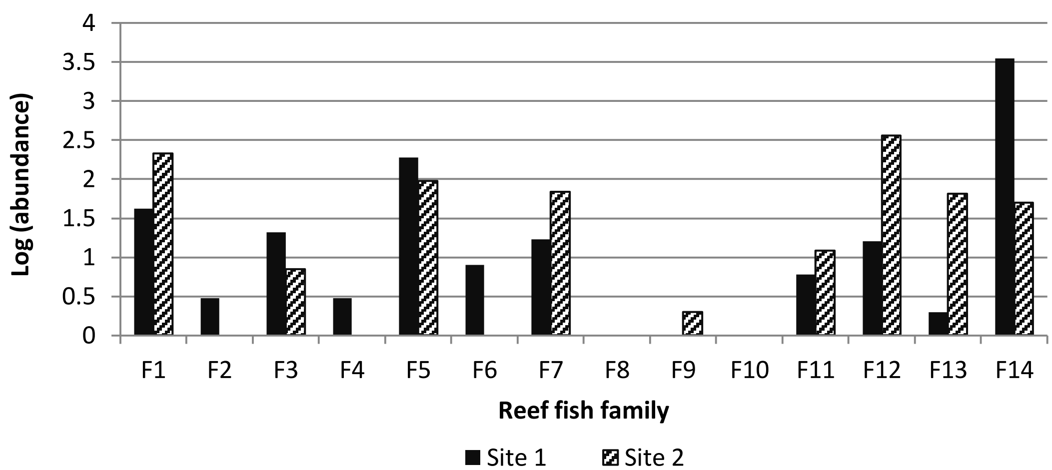

Fig. 3: Log of abundance of reef fish families at Site 1 and 2 in 3 meter depth (F1: Acanthuridae; F2: Aulostomidae; F3: Balistidae; F4: Bleniidae; F5: Chaetodontidae; F6: Fistulariidae; F7: Labridae; F8: Monacanthidae; F9: Mulllidae; F10: Ostraciidae; F11: Pomacanthidae; F12: Pomacentridae; F13: Scaridae; F14: Serranidae)

3.2. Comparison between Site 1 and Site 2 at 10 meter depth

- Coral cover percentage

In general, the percentage of live coral cover at both sites is higher at 10 meter depth (75.9% at Site 1 and 65.7% at Site 2). The most commonly found life forms of coral at Site 1 are soft coral (29.9%) and hard coral (29.9%) (Figure 4) The type of hard coral that is most abundant is the encrusting hard coral (19%). This is thought to be caused by the strong current at Site 1. Life forms that are flexible, such as soft corals, or attached to a wide surface area of substrate, such as encrusting corals, are the most suitable life forms in areas with strong current [13]. Moreover, the nearly-vertical reef slope results in shading by surface organisms, such that the amount of light that can be captured and used by reefs in deeper areas is reduced. The wide surface area coverage by encrusting corals helps to capture more sunlight to overcome this limitation.

The amount of rubble found at Site 2 decreases from 49.5% at 3 meters to 26% in 10 meters. At this depth the most common life-form is branching *Acropora*. Branching hard corals are often found in shallow waters with high light penetration [11]. This form of growth is efficient because it provides a wide surface area for corals to latch and grow on while only covering a small area of substrate. Furthermore, the flat surface of the seabed at this site supports high light penetration, compared to the slope at Site 1.

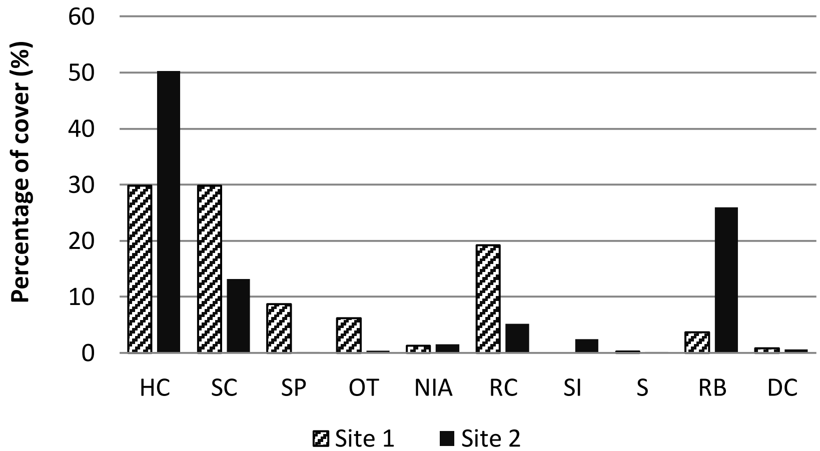

Fig. 4: Coral cover percentage by each life-form in Site 1 and Site 2 at 10 meter depth (HC: Hard Coral; SC: Soft Coral; SP: Sponge; OT: Others; NIA: Nutrient Indicator Algae; RC: Rock; SI: Silt; S: Sand; RB: Rubble; DC: Dead Coral)

- Reef fish community

Generally, the abundance of reef fish at 10 meters deep increased, both at Site 1 and Site 2. At Site 1, as many as 5,118 reef fishes classified into 34 species from 14 families were found (Figure 5). Meanwhile at Site 2 there were 1,297 reef fishes which are classified into 20 species from 11 families (Figure 5). The increase of abundance is also directly proportional to the increase of live coral cover in both sites at 10 meters depth. At both sites, the reef fish family with the highest abundance is Serranidae, represented by *Pseudanthias squamipinnis*. The abundance of *P. squamipinnis* at Site 1 and 2 are 685 ± 102.4 individuals per 250 m^2 and 139.7 ± 46.2 individuals per 250 m^2, respectively. The dominance of *P. squamipinnis* is thought to be associated with the increase of live coral cover, such as hard corals, because this fish uses the reef as shelter, swimming close to the reefs while feeding [11]. Due to the dominance of *P. squamipinnis*, at Site 1 the Shannon-Wiener diversity index (H') is 0.611, whereas at Site 2 the H' is 1.416.

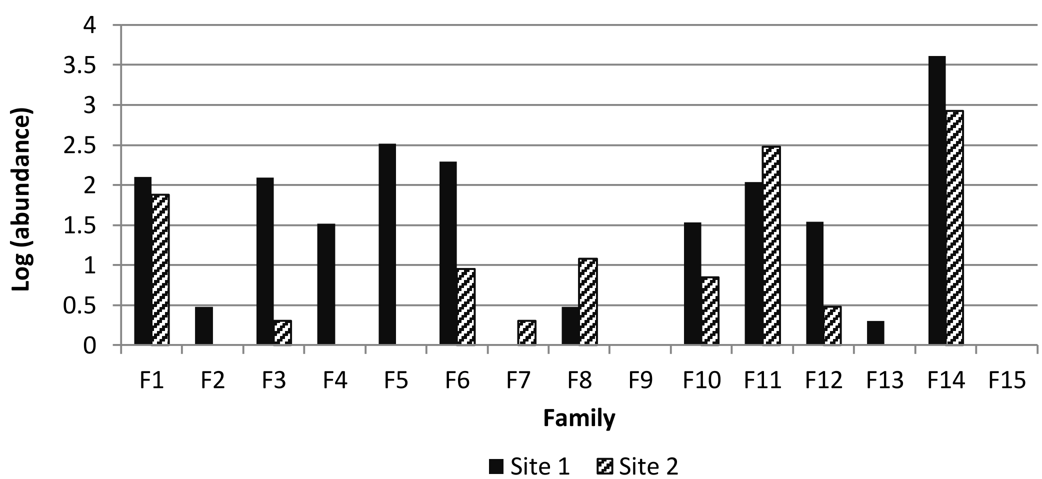

Fig. 5: Log of abundance of reef fish families at Site 1 and 2 in 10 meter depth (F1: Acanthuridae; F2: Aulostomidae; F3: Balistidae; F4: Bleniidae; F5: Caesionidae; F6: Chaetodontidae; F7: Gobiidae; F8: Labridae; F9: Mullidae; F10: Pomacanthidae; F11: Pomacentridae; F12: Scaridae; F13: Scorpaenidae; F14: Serranidae; F15: Tetraodontidae)

3.3. Comparison of live coral cover between 3 meter and 10 meter depth at Site 1

Live coral cover percentage at Site 1, both at depths of 3 and 10 meters, is higher than the live coral cover percentage at Site 2. The most common life form at Site 1 are soft corals (34.3% and 29.9% at 3 and 10 meters deep, respectively) and encrusting hard corals (7.5% and 11.65% at 3 and 10 meters, respectively). There is also

20% coverage of rocks at this site. Rocks can be used as substrate to grow on for a variety of coral reefs (Figure 6). Among others, rocks can be formed by calcareous algae, especially encrusting calcareous algae, which secrete calcium carbonate onto the surface of dead corals and rubble, which help strengthen the coral reef structure [10]. Overall, the percentage of live coral cover at the depth of 3 meters is 74.4% and is 75.9% at the depth of 10 meters. Based on the standard criteria for coral reef damage issued by the Indonesian Ministry for Environment [9], the coral reef in Site 1 at 3 meters depth is in good condition, while at the depth of 10 meters it is in excellent condition.

3.4. Comparison of live coral cover between 3 meter and 10 meter depth at Site 2

The composition of coral cover in Site 2 at 3 meters differs from the composition at 10 meters. In the 3 meter depth the most commonly found coral life form is rubble (49.5%), whereas in 10 meters the most commonly found coral life form is hard corals (50.3%), mainly branching *Acropora* (Figure 6).

At the depth of 3 meters, the most common form of live coral is soft corals. Soft corals tend to grow quicker and can live in areas with low light penetration. Some soft corals are also able to secrete chemicals that deter their competition away, such as other type of corals or sponges, thus soft corals can colonize the area [14].

At 10 meters depth, the rubble that was found at 3 meters decreases and hard coral coverage increases. The most commonly found type of hard coral is the branching *Acropora*. This genus of hard coral can grow in waters with moderately strong current, although it may break when exposed to storms. This coral also has a relatively fast growth rate compared to other types of hard corals [13]. *Acropora* grows best in clean sea water and strong light penetration, free from sedimentation or algal cover that may block the light penetration. Branching *Acropora* corals are found at a depth of 10 meters due to the flat contour of the reef at Site 2, which made the area of observation to be quite far from the center of the recreational area, mainly the pontoon.

Based on field observations and calculation of live coral cover percentage, the percentage of live coral cover at 3 meter depth is 41.5%, and is classified to be moderately damaged; whereas at 10 meter depth the percentage of live coral cover is 65.7%, thus classifying it as in good condition [9].

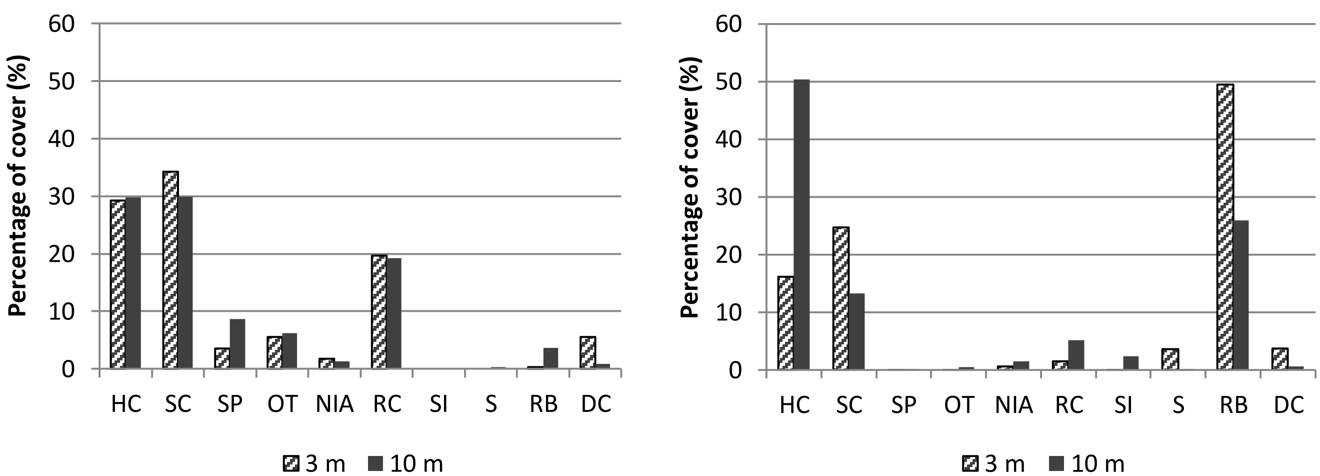

Fig. 6: Comparison of coral cover percentage by life-form in Site 1 (left) and Site 2 (right) at 3 and 10 meter depths (HC: Hard Coral; SC: Soft Coral; SP: Sponge; OT: Others; NIA: Nutrient Indicator Algae; RC: Rock; SI: Silt; S: Sand; RB: Rubble; DC: Dead Coral)

3.5. Abundance and richness of coral reef fish species

Generally, the abundance and richness of reef fishes at Site 1 increases with increasing depth. This is possibly related to the increasing percentage of live coral cover at a depth of 10 meters compared to 3 meters. Reef fish abundance at Site 2 also increases with increasing depth. However, reef fish species richness at Site 2 decreases with increasing depth (Figure 7). This is suspected to be caused by the many omnivorous reef fish species found at the depth of 3 meters. Secondly, it could also be due to the presence of several species that are adaptable to areas with low live coral cover.

Out of the 26 species of reef fishes found at Site 2 at the depth of 3 meters, six of them are omnivores. From those six species only three are also found at the depth of 10 meters. This is presumably due to human activities, such as fish-feeding. Fish-feeding alters the composition of the fish community in coral reef ecosystems by, among other things, increasing the abundance of omnivorous fish species, especially when the fishes are gathered into some food source [14]. In addition to fish-feeding activity by humans, some other reef fishes found in the 3 meter depth are well adapted to their low-coral-cover environment [12]. There are at least five species of reef fish found at Site 2 at the depth of 3 meters that have adapted to use rubble as shelters.

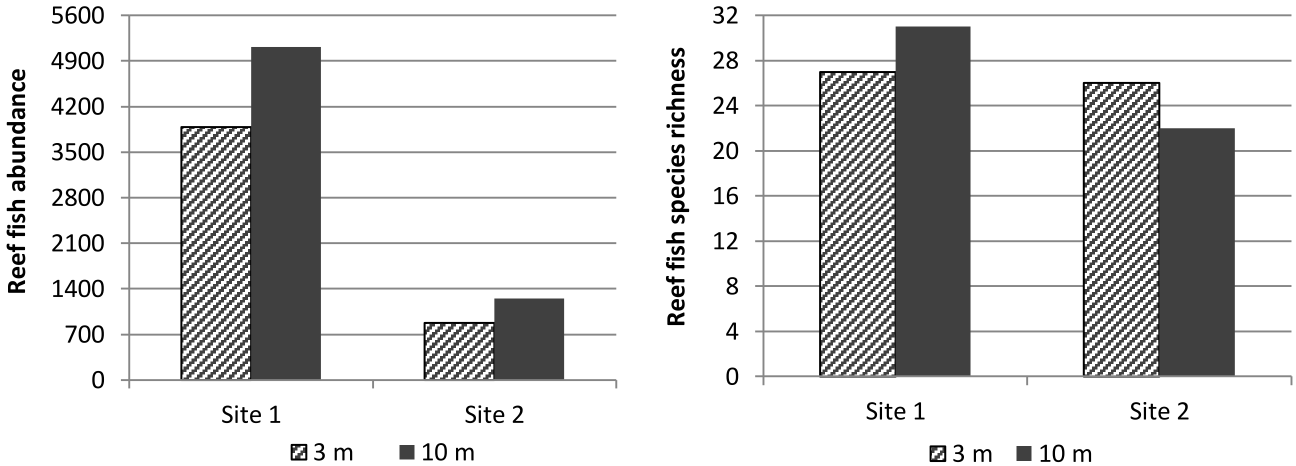

Fig. 7: Reef fish abundance (left) and species richness (right) at Site 1 and 2 at the depth of 3 and 10 meters

4. Conclusion

The percentage of live coral cover at Site 1 (core zone) is higher than in Site 2 (marine tourism area), both at 3 and 10 meter depths. Rubble covers 49.5% of the observed area in Site 2 at 3 meter depth. Reef fish abundance and species richness is higher at Site 1 than at Site 2. Reef fish species richness at Site 2 decreases with increasing depth. Reef fish diversity is relatively low (H'<1) at Site 1 and moderate (1<H'<3) at Site 2. Overall results on the percentage of live coral cover, reef fish species richness, and reef fish abundance indicate that the coral reef ecosystem in Site 1, or core zone, is in better condition than in Site 2, or marine tourism area.

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