Assessing Fish Herbivore Functions on Benthic Composition in the Wakatobi Marine Park, Indonesia

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Postgraduate Certificate in Ecological Survey Techniques

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Photo taken by the author

Abstract

Herbivorous fish are important to the coral reef ecosystem, bridging primary producers and upper trophic consumers. Their complementary functions (browsing, grazing, scraping and excavating) can limit algae, preventing it from shading corals from photosynthesis and opening up spaces for coral recruitment.

However, the debate on top-down versus bottom-up control of algae has led to disagreement on herbivorous fish protective measures and enforcement within the Indonesia government. This research aimed to explore herbivore functions and link these to patterns in benthic community composition, so to explore the contribution of herbivorous fish. Surveys were carried out at the Kaledupa region, Wakatobi Marine National Park, Indonesia. Diver-Operated Stereo-Video Counting was employed to film 3 x 50m transects (at each of 3 depth zones) for four sites.

Algae percentage cover was found to be low at all sites, but grazers/detritivores group were found different and higher in the heavily fished site. Grazing functions seemed obvious. However, no significant correlation was found between herbivorous fish and algae. It is recommended that surveying be included on more sites. Notably, the functional length categories showed absence of fish ≤ 7.5 cm (fry stage) in 4 functional groups (except farmer), this was an alarming news of losing the species, hence, Wakatobi government is recommended to enforce protection on these length categories, by restricting the mesh size, prohibiting of certain type of gears and even having fishing closed seasons (Ahamadia et al., 2013; Comeros-Raynal et al., 2012).

Acknowledgements

I would first like to thank my supervisor Dr Thomas Hesselberg; he always opened his door to me, he guided me through the troubles of water and I am growing and breaking through. I also would like to thank Dr Jocelyne Hughes, she consistently provided critical evaluation of my work, so I can become better and better throughout the whole program.

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I would like to thank many people who helped me during the expedition. To dive instructor Klaudyna Brzostowska; she was so patient through difficulties in diving and finally get my license. To the monitoring team for letting me use some of their videos for analysis when I became sick. To peer Thereas F. Dabruzzi, who shared her valuable experience of facing adversity as a field marine biologist. And to Operation Wallacea on-site staff, who were so caring and helpful.

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1. Introduction

Herbivorous fish functional contributions have long been recognized. They play a key role in controlling algae from dominating coral reefs systems (Lewis 1986, Lirman 2001, Williams and Polunin 2001, Mumby et al., 2006, 2007, Hughes et al., 2007) and directly facilitate reef-building taxa (for instance crustose coralline algae). However, many coral reefs worldwide are now undergoing non-selective overfishing, and because this reduces herbivore functions a great deal, it subsequently allows reefs to degrade from biodiverse coral to an inhospitable algal state (Bellwood et al., 2004; Bruno et al., 2009; Cheal et al., 2010; Hughes et al., 2010; Mcmanus and Polsenberg, 2004; Rogers and Miler, 2006).

In the Kaledupa region of Wakatobi Marine Park of Sulawesi, Indonesia (Figure 1), fishermen in the region have employed destructive, non-selective fishing methods (Figure 2) in attempting to compensate for the declining harvest of reef fish (Exton 2011). This negative loop caused local fishermen to fish more frequently, farther away and halved mesh size (Exton 2011). This subsequently caused fish being harvested before sexual maturity and became difficult to replenish (Operation Wallacea, unpublished data).

Subsequently, this might open up more opportunities for algae taking over coral from dominating reef systems (Edwards et al, 2014). This was a part of monitoring study looking into the state of herbivorous fish and benthic composition and to determine any correlation between them, in order to recommend key herbivore species and related issues for the Wakatobi government as advice on setting policy and enforcement to conserve herbivorous fish (Pope, Lochmann & Young 2010).

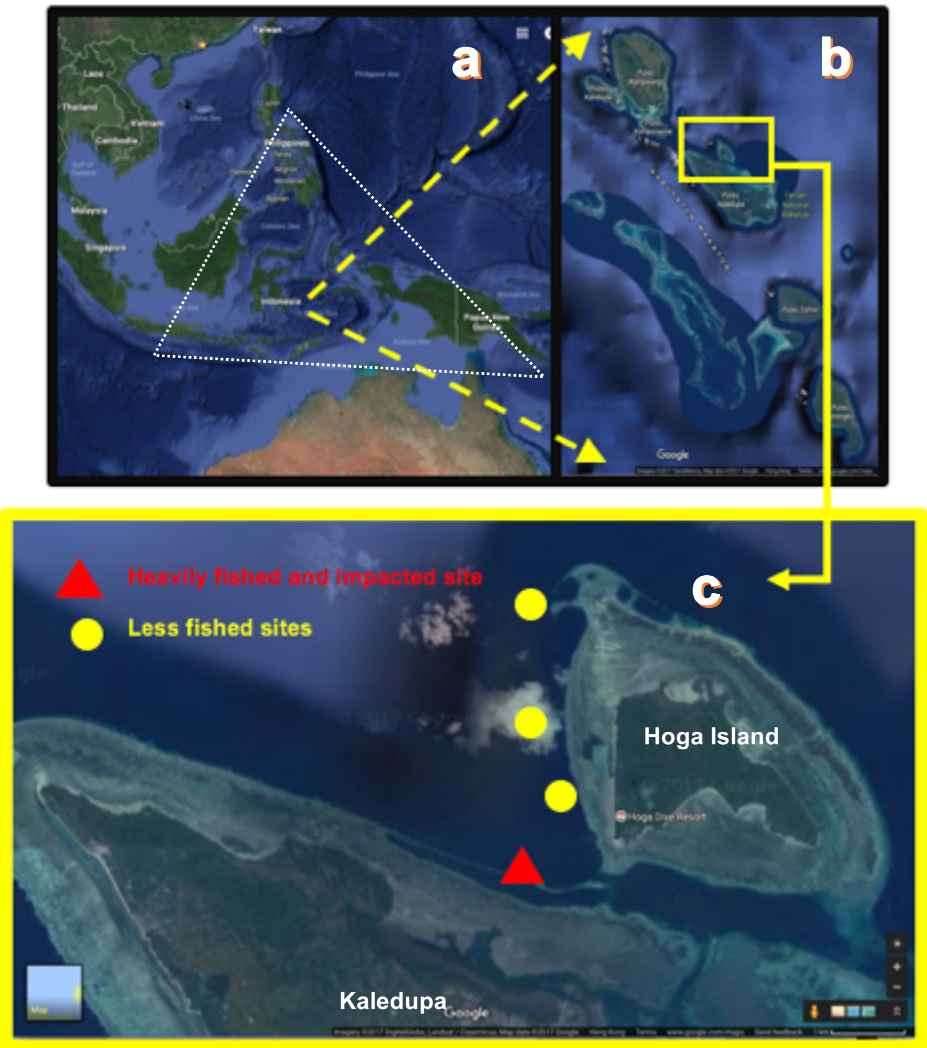


Figure 1.
Study locations.
a) Indonesia is inside the Coral Triangle
b) Zoom in view of Wakatobi Marine Park, Southeast Sulawesi of Indonesia.
C) 4 study sites are situated between Hoga Island and Kaledupa.

Adapted from Google map 2017.

Figure 2. Fish fences are widely used around study sites. They are highly unselective, designed to catch fish as the tide recedes. (Biodiversity science 2011)

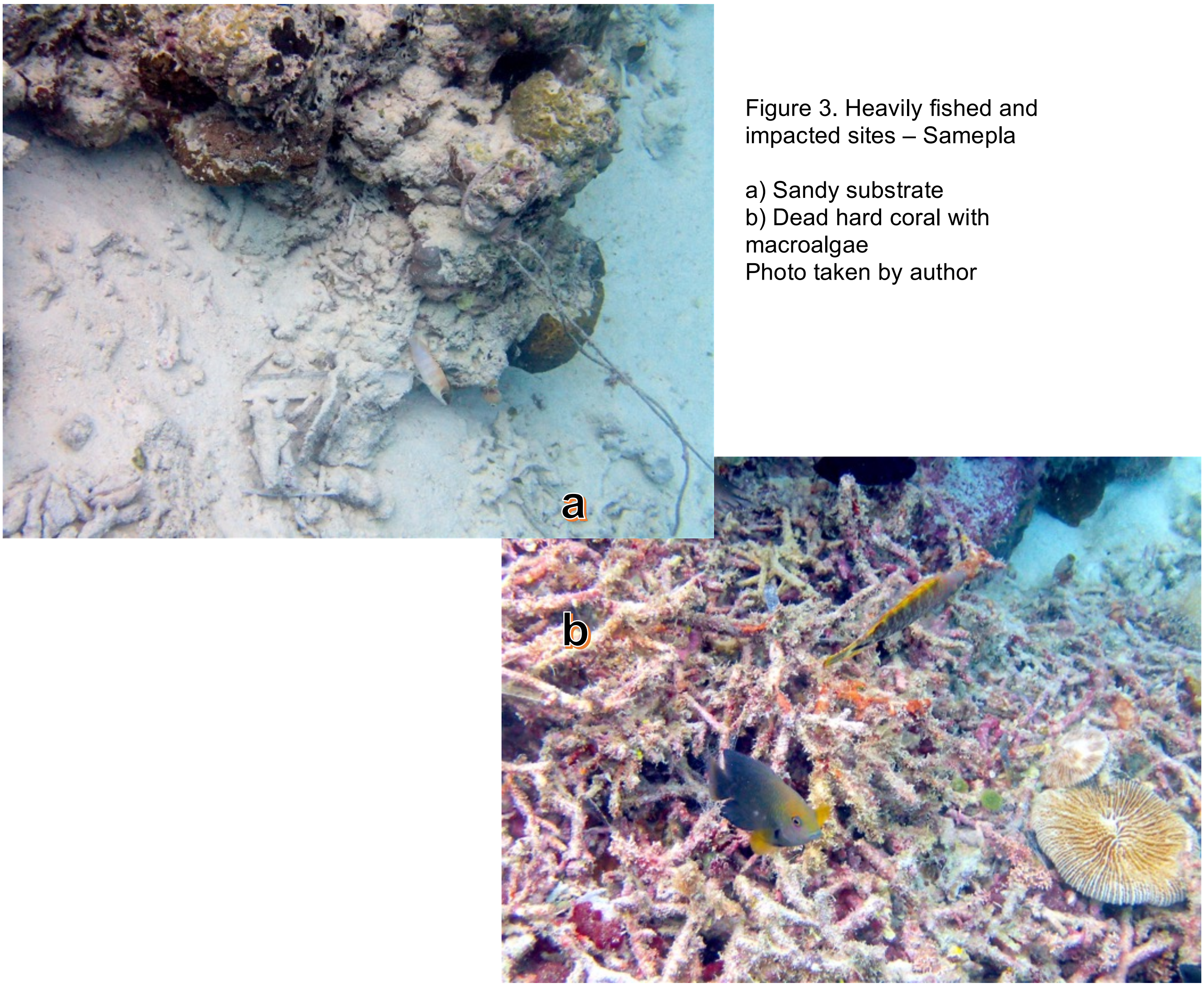


Figure 3. Heavily fished and impacted sites – Samepla

a) Sandy substrate
b) Dead hard coral with macroalgae
Photo taken by author

1.1 Literature Review

Herbivorous fishes are an important part of the coral reef ecosystem. They transport nutrients from primary producers to upper trophic levels (Cornell University, 2017).

Herbivorous fish have complementary functions, like browsing, grazing, scraping and excavating (Table 1). Since not all herbivores consume the same types of algae, at the same rates or in the same way, functional diversity within the guild should be considered and has been shown to increase coral resilience following bleaching events (IUCN 2009). This is due to by their special teeth and jaw morphology (Figure 3) (Nanami 2016)- they easily crop down macroalgae stipe, remove holdfast, and graze turf algae (Figure 4). Like browsers functional group they feed on macroalgae, they could limit the extraordinarily fast growers, preventing them from shading corals from photosynthesis and open up spaces (Cheal, Emslie et al. 2013; Fox & Bellwood 2013) for slow growing hermatypic corals recruitment and reproduction, therefore herbivorous fish are important in helping to maintain the balance between macroalgae and corals. Some of them consume seaweeds that produce allelopathic chemicals that cause coral mortality (Cornell University, 2017).

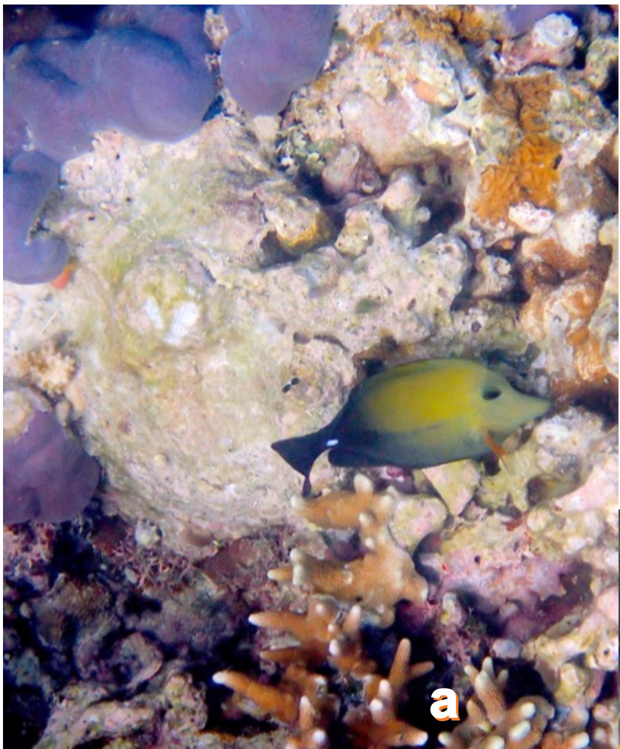
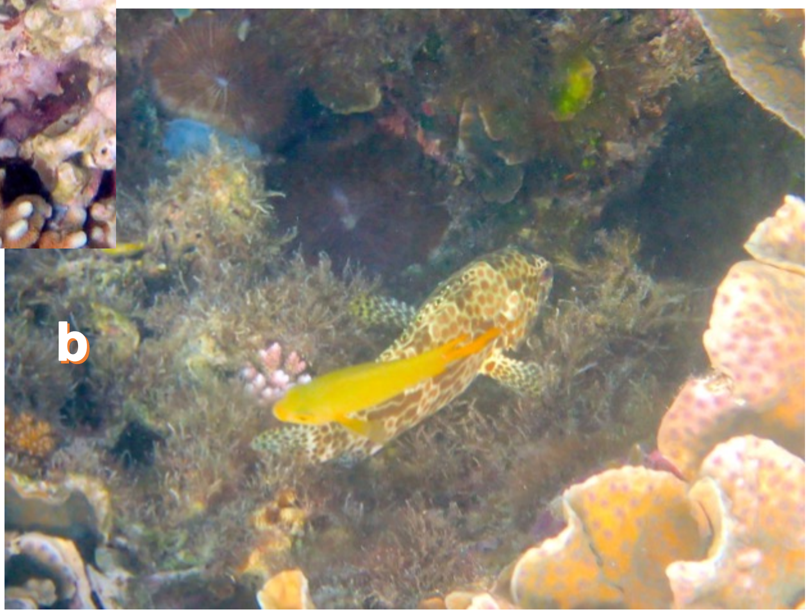


Figure 4. (left) Surgeon fish bites on algae

Figure 5. (below) turf algae occuried species between coral.

Photos taken by author



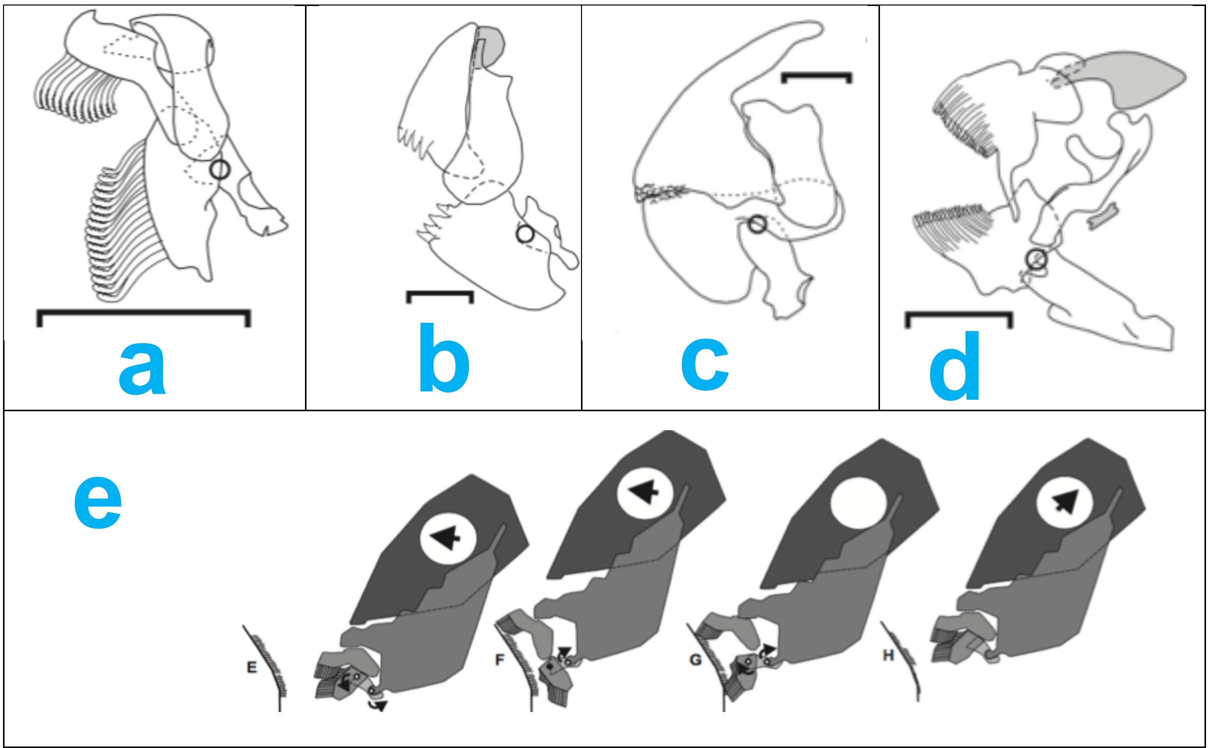


Figure 6. Herbivorous fish jaws specialized in feeding on various forms of algae. a) Ctenochaetus b) Siganus c) Scarus d) Centropyge e) biomechanical models show the widest jaw covarage of Ctenochaetus. (Konow et al., 2008)

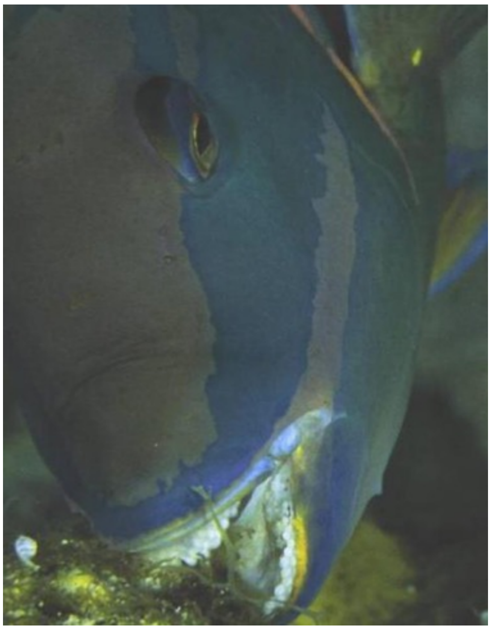


Figure 7. (left) Parrotfish closely scrapes marcroalgae. (Photo by Paul Humann)

Figure 8. (upper). Parrotfish scraped and opened new “clear” substrate.
Source: http://gcdd.tinypla.net/decision_nodes/7

Hermatypic coral (hard coral) is usually called as ecosystem engineer because it in turn, creates shelters for fishes, increasing the complexity and subsequently the biodiversity of the reef ecosystem, and ultimately maintaining food security for humans.

But, if the reefs lack the appropriate number of herbivorous fish, their controlling functions would be weakened, which may lead to macroalgae overgrowth (Helfman 2009). Caribbean and Jamaican coral reefs are well-known cases; they alerted us to stop turning a rich and biodiverse ecosystem into a barren and infertile state (Aronson and Precht, 2001; Gardner et al., 2003; Hughes, 1994; Mumby et al., 2007; Mumby 2009).

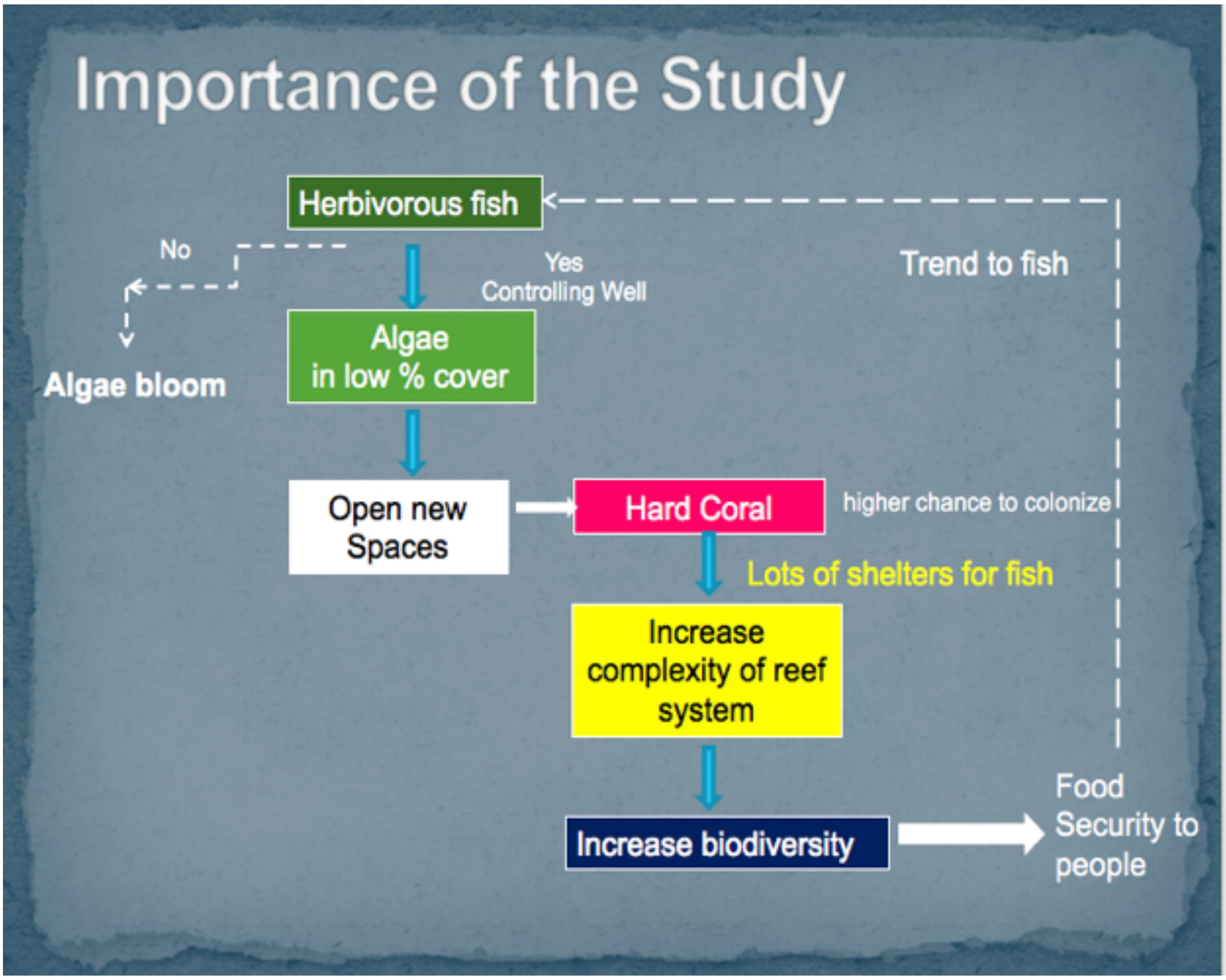


Figure 9. Consequence of with or without herbivorous functions.

However, it has been debated on macroalgal standing crops on reefs are controlled less from the top-down by herbivory but more from the bottom-up by nutrient flux (Lapointe 1997, 1999; Hughes et al. 1999; McCook 1999; Miller et al. 1999; Aronson and Precht 2000; Belliveau and Paul 2002; Jompa and McCook 2002; McClanahan et al. 2002; Diaz-Pulido and McCook 2003; Lapointe et al. 2004 ; Worm and Lotze 2006). Nonetheless, there are reef systems where both top-down and bottom-up factors are simultaneously important (Smith et al. 2001, 2010; Stimson et al. 2001), a pattern that is also evident in meta-analyses (Gruner et al. 2008). Coral-seaweed-herbivore triangle illustrated the dynamics in between (Hixon 2015).

This disagreement on herbivorous fish functions leads to dissensus on working out protective measures and enforcement among the Wakatobi government. Without governance, fishermen not only continue to catch any species and any amount of fish for their major food source, but also set up more efficient but non-selective fish fences capturing diurnal migratory fishes between coral reef and mangroves (Opwall 2017). Additionally, fishing for export worldwide (fish biomass yield) increased steadily over the past 10 years (Opwall 2017). There is a risk of overfishing, including herbivorous fishes.

Bellwood et al. documented strong evidence of fishing effects on functional roles of parrotfishes (Scaridae) in the Pacific and Indian Oceans, suggesting that fishing can systematically affect at least some functional characteristics of the herbivore community. Therefore, there is an urgent need to assess the current status of herbivore functional groups and benthic situation.

Table 1: Herbivorous Fish Functional Groups and Roles, respective Indo-pacific fish names provided. (IUCN 2009; Reef Resilience 2017)		
Functional Group	**Role**	**Family Name**
Scrapers / small excavators	• take non-excavating bites • remove algae, sediment, other material by closely chop or scape the reef surface • leave shallow scrape marks on the reef substratum • provide areas of clean substratum for coral recruitment	• Majority of parrotfishes *(Hipposcarus and Scarus species)*
Large excavators/bioeroders	• remove dead coral and expose hard reef matrix for coral recruitment • differ from scrapers by taking deeper excavating bites and remove greater quantities of substrate with each bies • major agents of bioerosion on reef	• all large individuals of excavating species (> 35cm standard length) • all *Chlorurus* species
Grazers/detritivores	• Intensely graze on epilithic algal turfs, which can also limit the establishment and even remove macroalgae before it becomes established. • don't scrape and excavate the reef substratum.	• Most rabbitfish (exc. *Signaus canaliculatus* and *S. lineatus*) • Most butterflyfish • Small angelfishes • Many surgeonfish (all Zebrasoma, Acanthurus species exc. Plankton-feeders) • *Acanthurus lineatus* are predominately territorial, but also consume algal turf outside their territories (Grag 1996)
Browsers	• Consistently feed on macroalgae, select individual algal components, remove only algae and associated epiphytic material • Important role in reducing coral from shading by macroalgae and thus in reversing coral-algal phase shift	• Surgeonfish (Acanthuridae), Unicornfishes (N. unicomis) • batfish (*Platax teira*) • rudderfishes • rabbitfish • parrotfishes • *Calotomus,Leptoscarus*
Farmers	• graze on turf algae • but also allow turf algae to grow • expel other herbivorous fish grazing	• territorial damselfish

1.2 Aims

This research aimed to explore the status of reef fish herbivores species, functional biomass, and then link these to patterns in benthic community composition, specially exploring variations in percentage cover of hard corals and algae among heavily fished and less fished study sites.

1.3 Research Questions

1. What are the temporal variances in species richness and functional biomass of herbivorous fish species over the past 5 years?
2. What are the current variations of species richness, functional biomass and length categories among heavily fished and less fished sites?

   As some functions and its effect of size may be more important than others for regulating the specific ecosystem status, hence this study is going to investigate it (Bonaldo & Bellwood 2008; Micheli & Halpern 2005).

3. What are the key herbivorous fish species?
4. What is the temporal variance in abundance (percentage cover) of benthic community (algae, coral, mobile substrate) over the past 5 years?
5. What is the current variations in abundance (percentage cover), composition and predominance of the benthic community among heavily fished and less fished sites?
6. Is there any statistical significant correlation between herbivorous functional groups and benthic community?

2. Methods

2.1 Ethical Review

The activities for this study were conducted under permission from the Wakatobi National Park Authority offered to Operation Wallacea. Only visual censuses of fish and benthic communities were conducted during this study; no fauna or flora were collected. Hence, ethical review was not required.

2.2 Study Sites

This study took place in the Indo-Pacific region, which has an exceptional record of diverse fish species (3000), almost 3 times more than the next richest marine region, the Western Atlantic. The Coral Triangle of Wakatobi Marine National Park (Indonesia) itself boasts one of the world's most diverse ecosystems (Comeros-Raynal et al., 2012); 750 coral reef species and 942 fish species.

Wakatobi Marine National Park, located within the Tukangbesi Archipelago, Southeast in Indonesia, is inside the world-famous "Coral Triangle", recognized as a global center of marine biodiversity, and a priority for conservation. There is a tropical climate, temperature ranging from 21°C to 35 °C (mean 27°C), with dry (November to March) and wet (April to October) seasons, and total rainfall is about 2,000mm/year (Whitten, Henderson and Mustafa 1987).

This study was conducted in July 2017 on the fringing reef (Figure 6) around the Island of Hoga (Figure 7), in a remote island group within Wakatobi Marine National Park (Figure 1) of about 200,000 ha, off Southeast Sulawesi in Indonesia (Elliot et al.,2001).

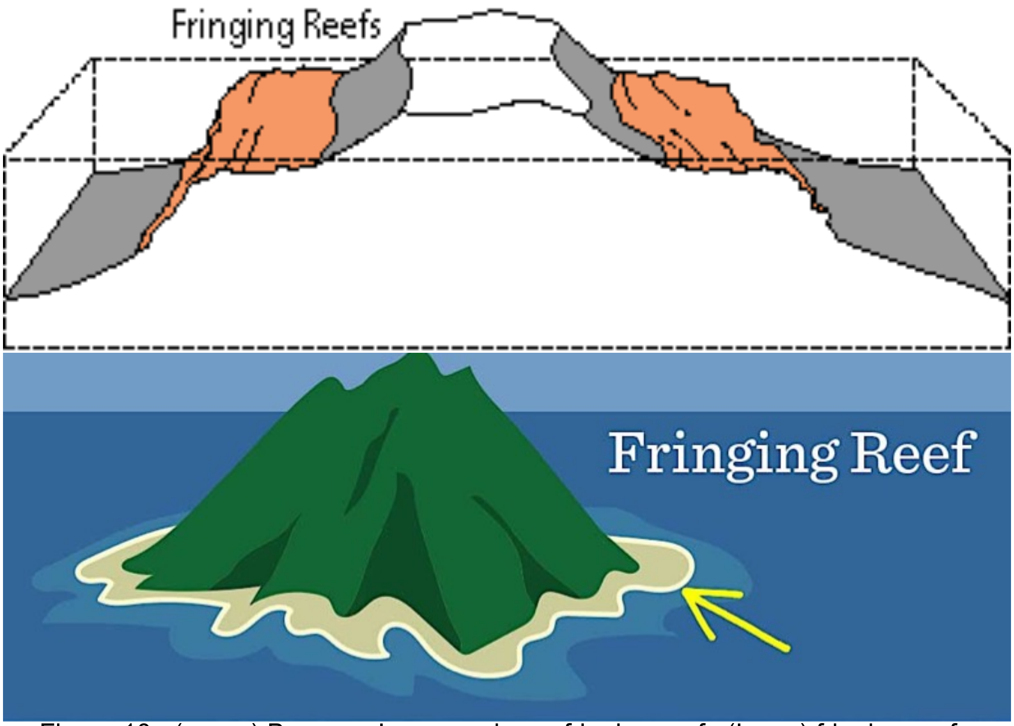


Figure 10. (upper) Brown color zone shows fringing reef. (lower) fringing reef diagram in aerial angle. Source: (upper) https://sludge.wordpress.com/2006/11/02/coral-reefs-and-oil-spills-a-guided-tour/

(lower) http://thinga.com/boom/articles/reef-brief

Figure 11. Aerial view of Hoga Island fringing reef, they develop in shallow waters along the coast of tropical islands, which are attached, laying adjacent to the shore and continent. Source: http://www.indonesia-tourism.com/forum/showthread.php?1913-Let-s-Get-Diving-To-Hoga-Island-Souteast-Sulawesi

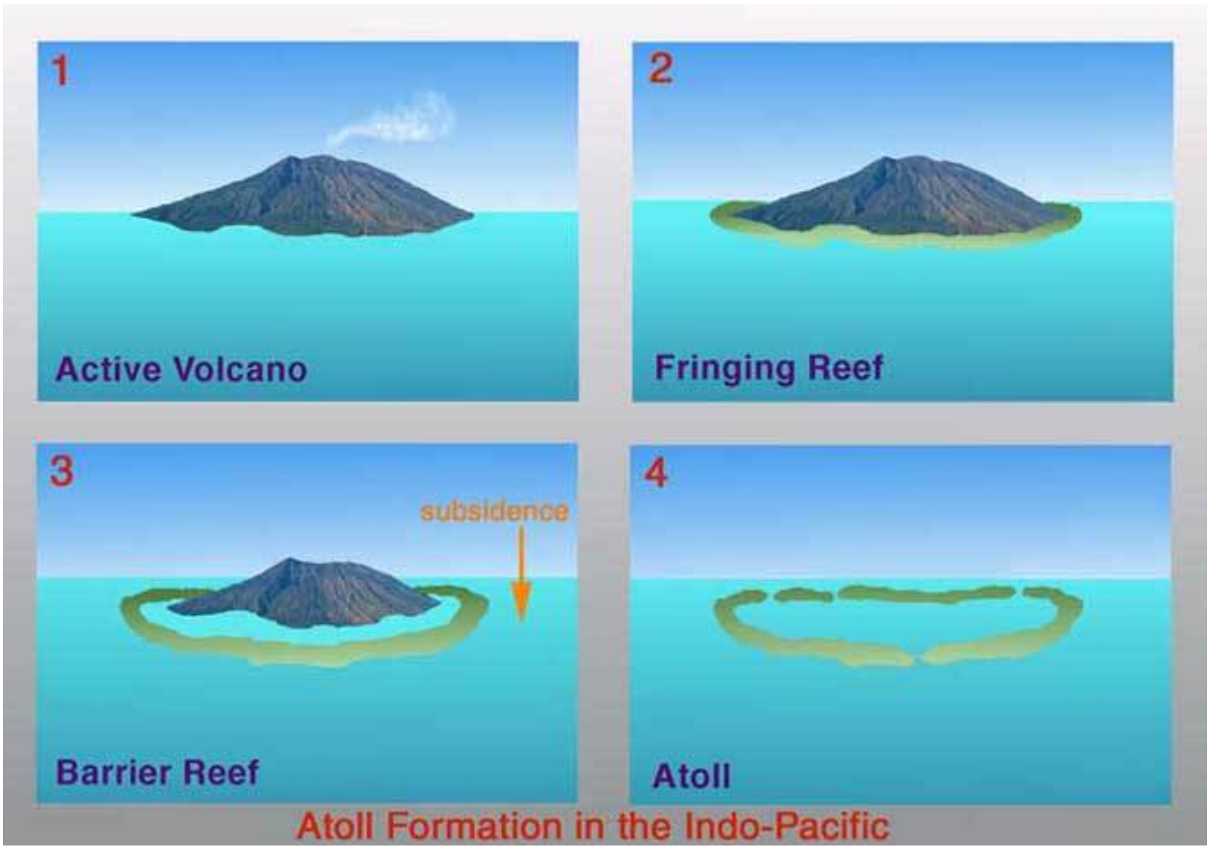


Figure 12. Long-term reef growth process. Source: https://www.pmfias.com/coral-reef-fringing-reefs-barrier-reefs-atolls/

2.2.1 Fringing Reef

The study reefs are a type of fringing reef (Figure 7). They develop in shallow waters along the coast of tropical islands, which are attached, laying adjacent to the shore and continent like this study region adjacent to Hoga Island and Kaledupa. These are the common types of reef (Coral Reef Alliance 2017) also found in the Caribbean and Red Sea. Charles Darwin (1809-1882) suggested that fringing reefs are the first kind of reefs to form around a landmass in a long-term reef growth process (Figure 9).

Four study sites were chosen with contrasting reef health from two adjacent independent reefs separated on opposite sides of a channel. The first study site, Sampela, (S1; 05°29.3S,123°45.15E) is located on a degraded reef east of Kaledupa. Sampela is the closest to the local village, and is impacted by destructive fishing, reef gleaning, mining, high turbidity and high sedimentation (Crabbe and Smith, 2005; Happkyla et al., 2007; 2009). About 1km away from Sampela, two other study sites, Pak Kasim and Buoy 3, (B3;05°28.23S,123°45. 19E) were chosen to allow reasonable distance (English et al., 1997). These sites, located west of Hoga Island, are considered a relatively healthy reef, and are subject to similar environmental conditions, have similar physical characteristics (English et al., 1997), slope and mild wave exposure and the same tidal regime. And the fourth study site, the Ridge, is situated north of Hoga Island, and it faces stronger waves and a higher nutrient load. (Operation Wallacea unpublished data).

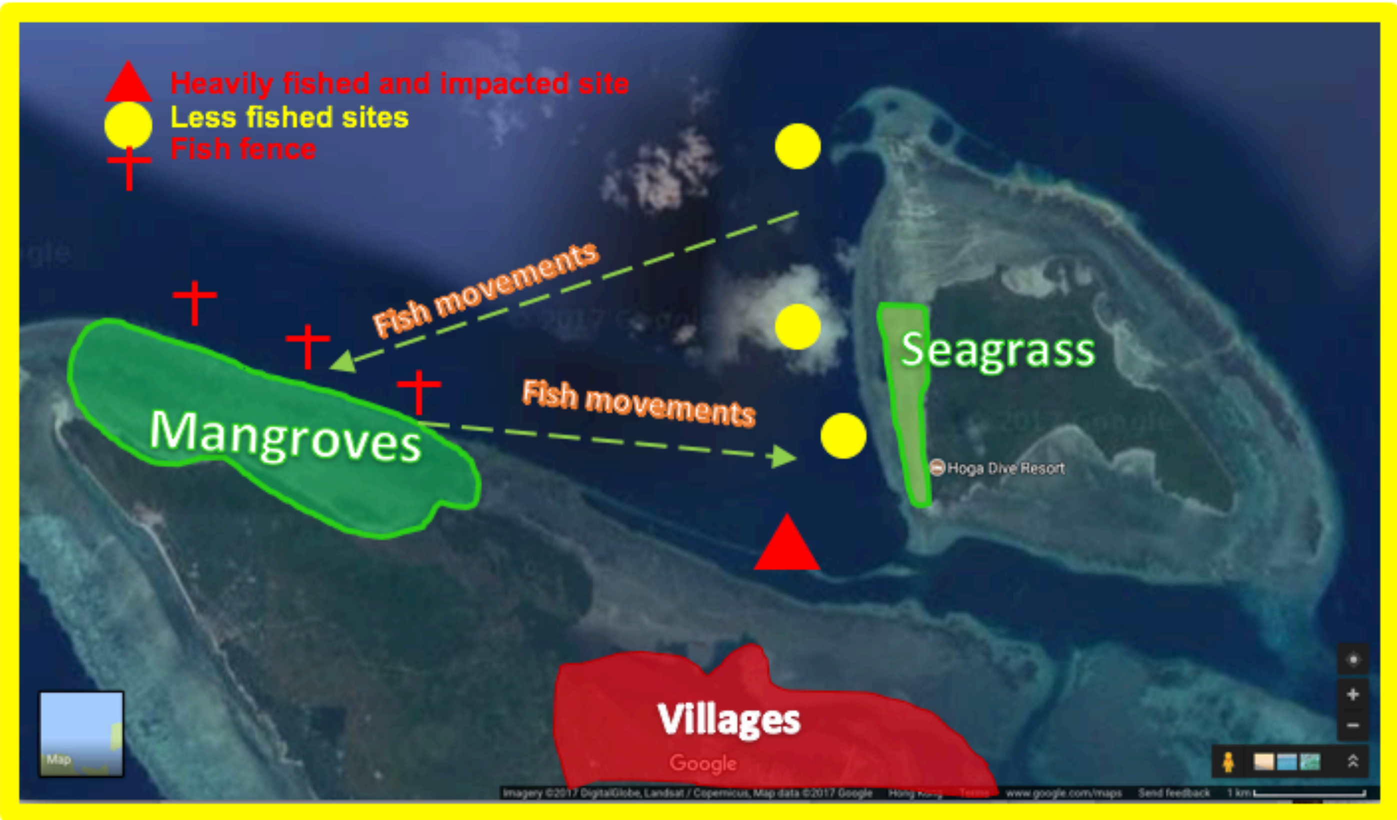


Figure 13. Characteristics of study locations. Fish move daily on and on between seagrass, coral reef and mangroves. Fishermen have set up fish fence to catch those moving fish.

2.2.2 Depth Zones

Water depth is a limiting factor of algae and coral occurrence (Morris 2005). As light becomes attenuated when interacting with the water column, different wavelengths of light penetrate the water to a varying degree, for example red light is attenuated rapidly and does not penetrate further than 5 m in clear water (Figure 5). Hence, in this study, water depths were considered to represent varying habitats (Ahmadia, Wilson & Green 2013). This study has investigated 3 habitats along depth contours, i) reef flat (ca. 2m), ii) reef crest (ca. 5m), iii) reef slope (ca. 12m) (Figure): A total of 3 transects were laid on each habitat except for the Ridge where no flat habitat exists.

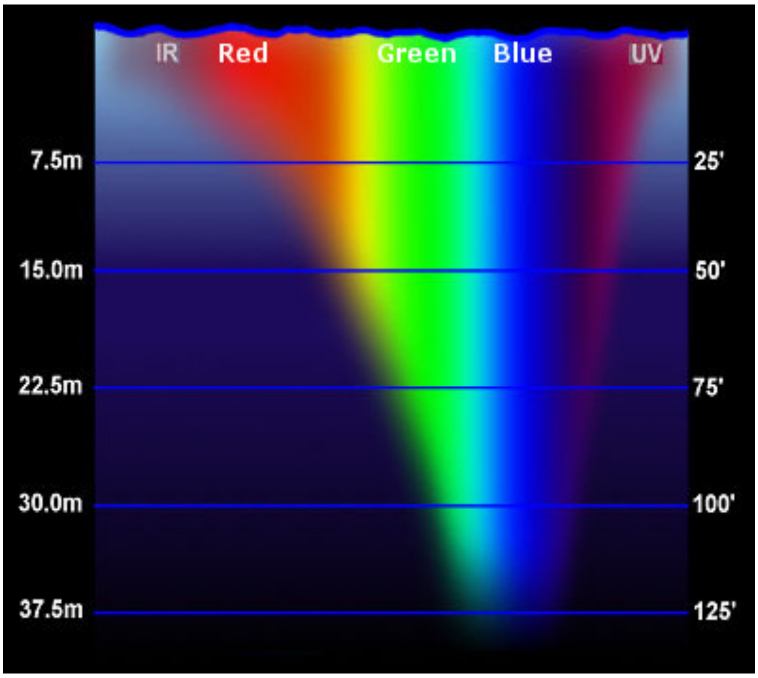


Figure 14. Patterns of light penetration into coral reef. Source: Tom Morris, Fullerton College.
Source: http://www.seos-project.eu/modules/coralreefs/coralreefs-c05-p04.htmlAccessed on: 23 Aug 2017

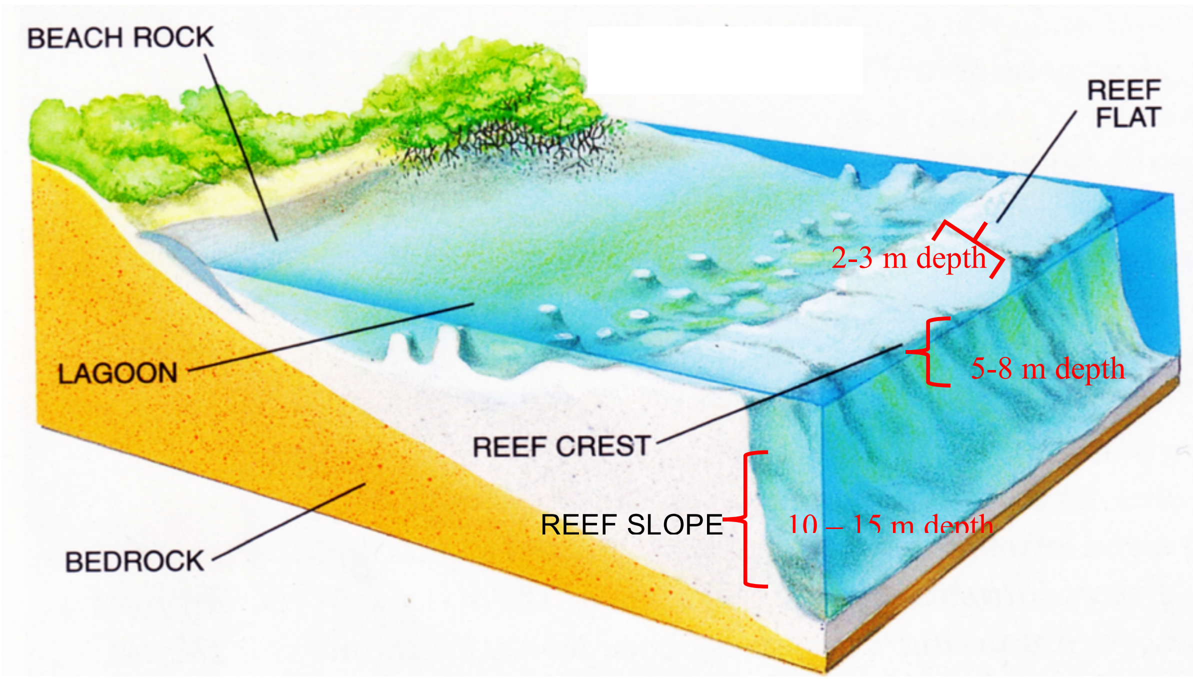


Figure 15. Fringing Reef Habitats Diagram (Reef flat, reef crest and reef slope) Source: http://amazingbiotech.blogspot.hk/2014/02/coral-reefs.html

2.3 Survey Techniques

This study had deployed underwater visual census by diver-operated stereo-video counting for both herbivorous fish and benthic composition. As research questions required only censual data, no biological information or dissection was needed; hence a non-invasive/non-destructive approach was adopted (Sutherland 2006).

The study sites have high water clarity and are suitable for underwater visual census type survey. The survey collected data down to a maximum depth of 12 m, and as Sutherland (2006) suggested that for depths deeper than 1-1.5m, scuba should be employed. Plus, a maximum depth of 12m is within the 15m limit for scuba-diving survey (JNCC, 2001). These conditions make this scuba-diving survey feasible.

2.3.1 Diver-Operated Stereo-Video Count

Due to the fact that naked-eye counting has the disadvantage of observer errors and biases, especially for fast moving and schooling fish, with difficulties of under or overestimates of count/size; too much attention on specific fish and data loss due to diver hesitation and recording delays (Labrosse et at., 2002; Suttherland 2006)) or re-censusing of fish that left and subsequently re-entered the transect area (JNCC Monitoring handbook 2001); transects were filmed using diver-operated stereo-video system, composed of two high-definition video cameras at fixed angles to allow footage of fish to be filmed simultaneously from two different positions (Figure 12 and 13) (Andradi-Brown et al., 2016; Yulianto et al., 2015). By using the EventMeasure software v3.51 (http://www.seagis.com.au), fish abundance, species and fork length were calculated without duplication and human error (Fig 8).

Using the dual images, it is possible to accurately calculate the fork length of fish (distance from tip of snout to end of the center of caudal fin rays), and then convert this into biomass estimates using standardized length-weight relationships (Andradi-Brown et al., 2016).

Figure 16. Stereo-video fish length measurement. Source: http://www.methodsinecologyandevolution.org

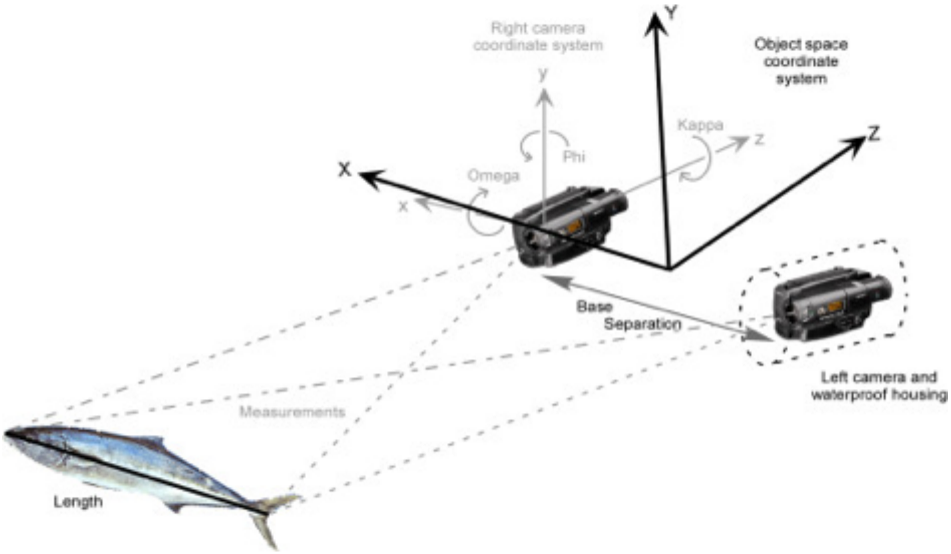


Figure 17. Fish fork length estimates. (Graph by Nada Boutros)

It has been determined that a 50mx5m transect fish visual census, with three replicates of total 750m^2 at each depth provide appropriate variability under resource and time constraint situations (English et al., 1997, IUCN 2009, Ahamadia et al., 2013).

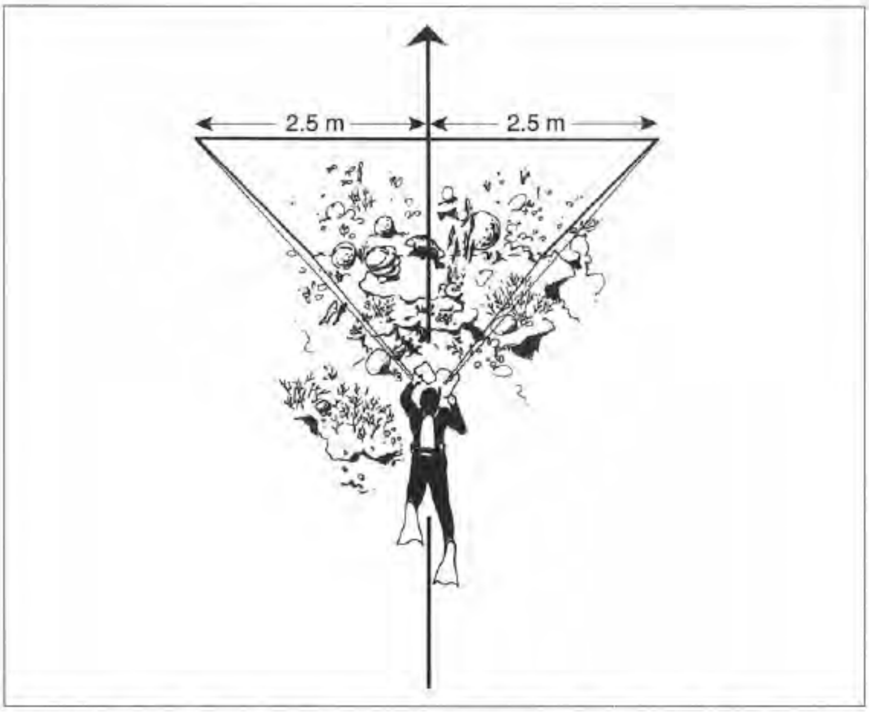


Figure 18. The diver swims along and filming the 50m long transect with 2.5m x 2.5 m wide on both sides, the total transect area is 250m^2. (Source: English, Wilkinson and Baker 1997)

2.3.2 Fish Survey Procedures

- Survey carried out during day time between 8:00am – 4:00p.m to avoid the diurnal-nocturnal changeover periods of fish (Carpenter et al., 1981; IUCN 2009).
- Permanent bolts had been previously installed by Operation Wallacea in the reef for permanent transects, so to collect benthic and fish data from the same transects.
- Monitoring has been conducted every summer, providing longitudinal data.
- Fish transects followed the depth contour but replicates were not overlapped, and they were allowed separation by 10 – 20m (English et al., 1997).
- GPS coordinates were recorded for each study site.
- The diver waited 5 mins after swim into the water to allow the fish to resume normal behavior (Carpenter et al, 1981; Ahamadia, Wilson and Green 2013)).
- Each transect was filmed as a complete 50x5m belt (English et al., 1997; IUCN 2009).
- The diver filmed the whole transect in 3 min.

After filming the transect, footage was analyzed on land (Figure 19), Fish outside 2.5m either side and 5m in front of the camera system were excluded (Andradi-Brown et al., 2016), and fish were classified down to species-level. if possible, otherwise to genus or to family level (Unsworth et al., 2007). Species scientific names, family name, abundance, length, biomass, respective sites and habitats (depth zone) were recorded in Excel sheet (Appendix 4). And the species were assigned to functional groups with reference to their feeding types: browser, scrapers/small excavators, large excavators/bioeroders, grazers/detritivores, and farmer (territorial demersalfish) (IUCN 2009; www.fishbase.org).

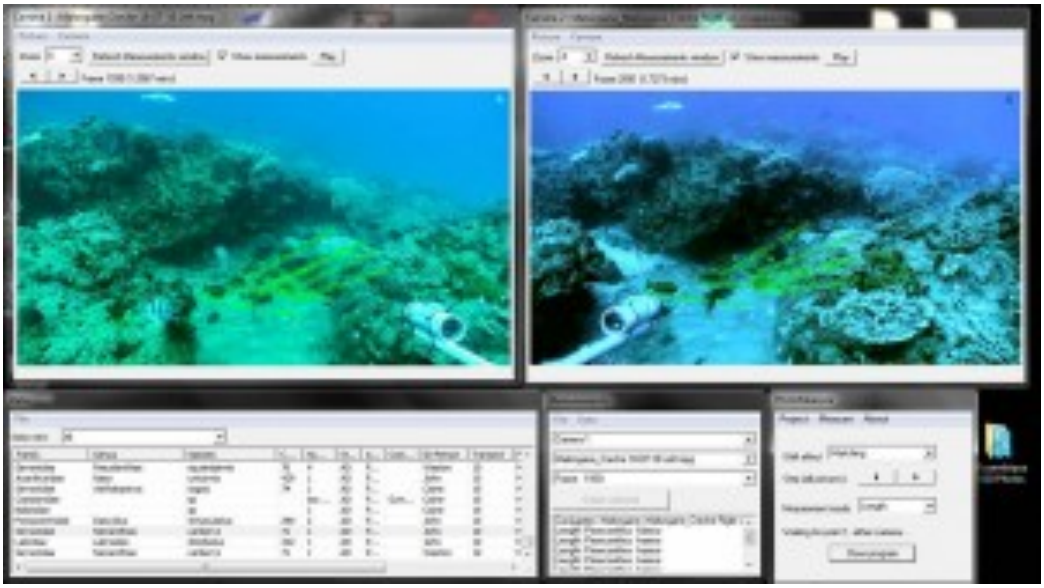


Figure 19. Screen shot of software Eventmeasure used to mark fish scientific names and measure their fork lengths.

2.3.3 Benthic Survey Procedure

Afterwards, benthic videos were filmed by the video camera. By filming the benthic substrate, divers were not restrained by maximum gas supply of their cylinder.

- Benthic survey shared the same transects of fish.
- At each site, laid 3 (replicates) transect of 50m length at each of three depths. (English et al., 1997; Wilson & Green 2009; IUCN 2009)
- The replicate transects were located haphazardly at each depth and were not overlapped (English et al., 1997).
- The transect lines should be stretched tightly and follow the depth contour (English et al., 1997).
- Camera pointing vertically down is held approximately 0.3m above the benthos, keeping the transect tape within the frame (Andradi-Brown et al., 2016).
- Percentage covers were surveyed by continuous counts along the 50m transect (Pratchett et al), which resulted a total of 201 points (English et al., 1997).

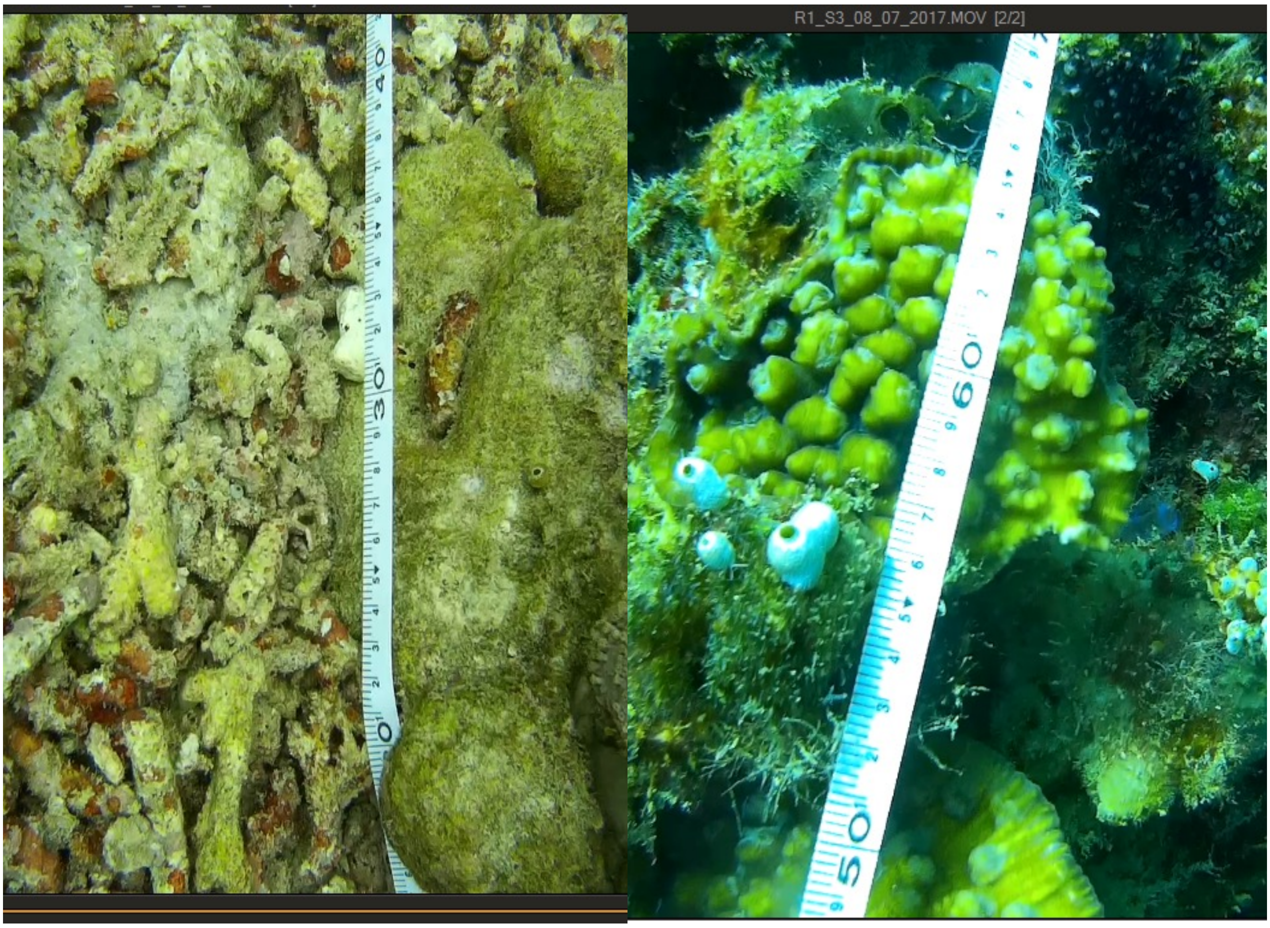


Figure 20. (left) Rubble and turf algae. (right). Turf algae and hard coral. Video analyzed on the right side of the 50m tape.

After filming the transect, the footage was analyzed on land, and benthic composition was recorded (Appendix 2) as live scleractinian (stony) corals, dead coral, turf algae, macroalgae, coralline algae, rock, and mobile substrate (i.e. unsuitable for coral recolonization, they are sand, silt, rubble and water) (Figure 21 and Appendix 1).

2.4 Quality Assurance

The study sites have an incredible diversity of life, so to assure quality of identifications (English et al., 1997; IUCN 2009), it was compulsory to take a 1 week lectures and in-water practical course on reef ecology and fish species identification and 80% marks were required before footage analysis.

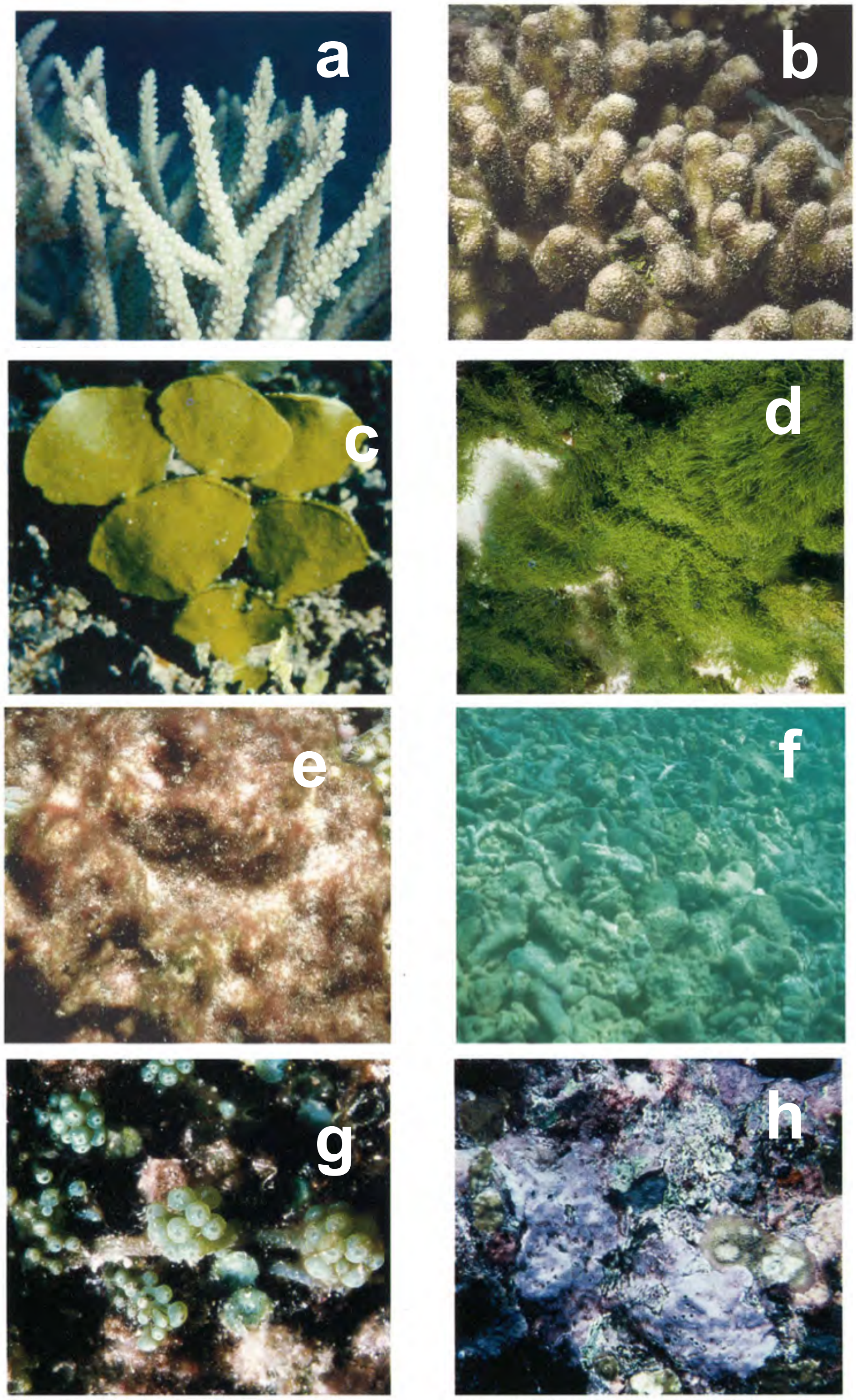


Figure 21. Benthic Lifeforms.

a) Hard coral. b) Dead coral with algae. c) Macroalgae Halimeda. d) Turtleweed. e). Turf Algae. f). Rubble. g). Algal assemblage h) Coralline algae. (Source: English, Wilkinson and Baker 1997)

2.5 Data Analysis

Fish size estimates were converted to biomass using a known length-weight relationship for each species using the formula described in Kulbicki et al., (2005):

$$\mathbf{W = aL^b}$$

Where:
W=weight of fish in grams (g); L=fork length (FL) of the fish in cm; and *a* and *b* are constants calculated for each species or genus. Biomass constants (a and b) for each species were based on www.fishbase.org. For each census, biomass was converted to total biomass per unit area mean biomass (per ha) for belt transects.

Where:
biomass (kg^5 per ha) = [(total biomass per sampling unit in g ÷ 1000) ÷ area of the sampling unit in m^2] x 10,000.

In order to investigate fish population dynamics, size (length) categorizations were used (Pope, Kevin L.; Lochmann, Steve E.; and Young 2010), with a 2.5cm interval for fishes less than 10 cm in size, and 5 cm size categories for fishes 10cm or greater in size. (i.e <5cm, 5 to <7.5cm, 7.5 to 10cm, 10 to <15cm, 15 to <20cm etc (IUCN 2009; Ahmadia, Wilson & Green 2013)). Besides, variability was shown by including error bars in the figures (Ahmadia, Wilson & Green 2013).

The primary data would be used with the secondary data (2013-2016) provided by Operation Wallacea to project a trend for the future.

Both fish biomass and benthic percentage cover data were to fulfill normality and homogeneity, hence the former one was log-transformed (when needed) and the later one was arcsine square root transformed (when needed) and were then tested by Shapiro-Wilk normality test and Bartlett Test.

In order to examine the variation of means of benthic types and the biomass of herbivorous fishes, these dependent variables were compared among fixed variables (sites and habitats), using a series of two-way ANOVA. To perform it, assumptions were fulfilled: all data of dependent variables were in continuous level, benthic covers were in percent cover. Independent variables were in two categories: sites (heavily fished, lightly fished) and habitats (reef flat, crest and slope). Also, data were expected in a normal distribution; but only algae, hard coral and mobile substrate were normally distributed after checking this with Shapiro-Wilk test, so, the rest were transformed, like rock cover was arcsine squareroot transformed. And they also fulfilled homogeneity of variances. (Appendix 9-12)

However, as not all functional groups occurred in all habitats and sites, there were zeros on raw data. Therefore, one-way ANOVA & Tukey post hoc tested were used instead. And sites were set at fixed factor.

To carry out one-way ANOVA, assumptions were to fulfill: all data of dependent variables were in continuous level, like benthic covers were in percentage, biomass was in kg/ha. Independent variables were in one categories, sites (heavily fished, lightly fished. Also, data were expected in a normal distribution; however, they were not normally distributed after checking with Shapiro-Wilk test, so, total herbivorous fish and grazing biomass were log transformed and they also fulfilled homogeneity of variances. (Appendix 7-8)

ANOVA (post hoc test - Tukey's range test) were carried out to determine where the difference occurred (Ahmadia, Wilson and Green 2013; Unsworth et al., 2007).

In addition, Principal component analyses (PCA) were used to investigate main component in the benthic community composition and herbivorous fish assemblages among sites and habitats. The analyses were based on the covariance matrix of the mean proportion of each substratum category, and the mean biomass of each herbivorous species in each habitat within each site, respectively. The biomass of each herbivorous species was square-root transformed.

Shannon 's diversity index (Penczak et al., 1994) was employed to find out how the level of fishing activities impacted across habitat quality gradients. Evenness index (Gerald et al., 2001) was used to find out abundance level of herbivorous fish species of distribution throughout sites and habitat types. Dominance Index was employed to further explore key fishes for future conservation plan.

Relationships between benthic categories and herbivore biomass were examined using Pearson correlation analysis.

3. Results

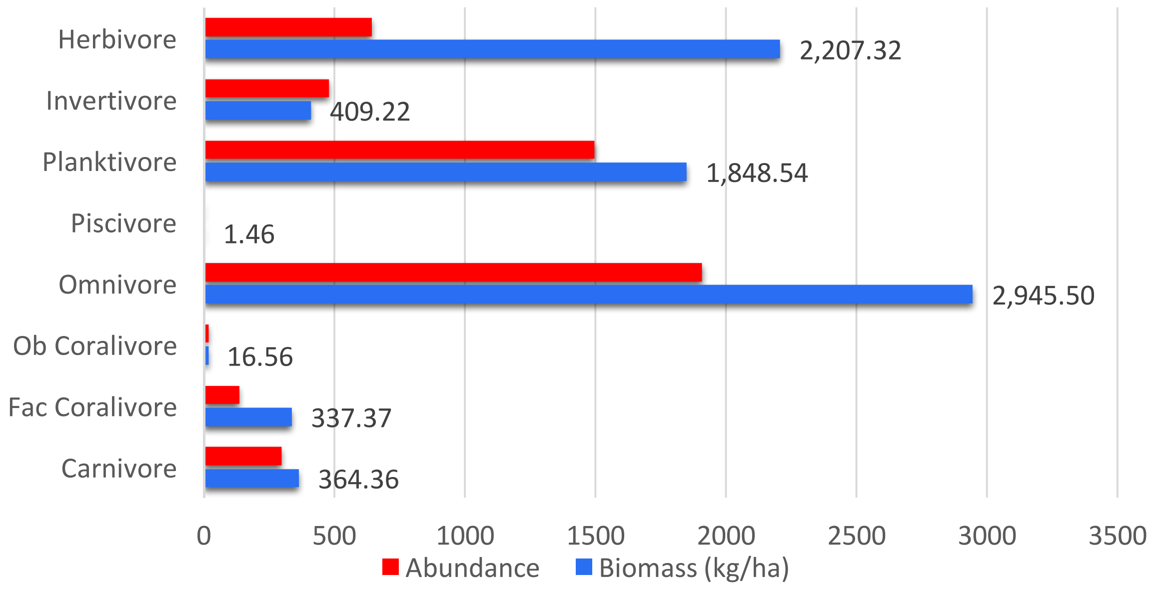
3.1 Herbivorous Fish

This part looks into herbivorous fish species richness, biomass, functional length categories with variations among different habitat quality.

3.1.1 What are the current variations of fish herbivores richness and biomass?

This year 23 species, 643 individuals and 2207.32 kg/ha of herbivorous fish were recorded in 4 study sites. In terms of biomass, herbivores were the second largest guild group (27.1%; Figure 22).

Figure 22: Bar chart compares total herbivorous fish biomass , abundance with other guild groups in 2017

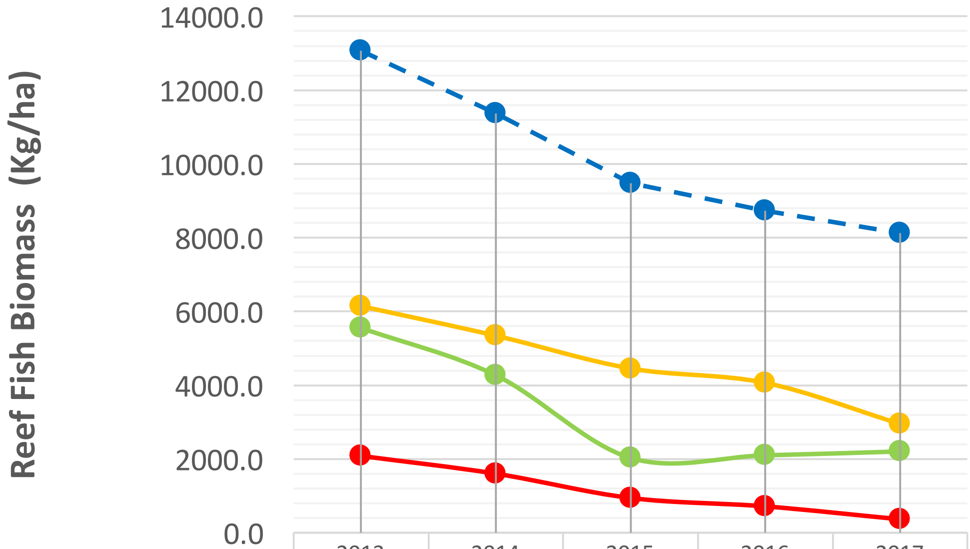


3.1.2 *What are the temporal variances of reef fish biomass over the past 5 years?*

The line chart below illustrates the changes of biomass of reef fish at the Wakatobi Marine Park between 2013 and 2017. Compared to last year, herbivore fish biomass has grown 4.95%.

However, in the past 5 years herbivore fish biomass fell 60.21%, carnivore 82.48%, omnivore 52.0% and the total fish biomass plummeted by 37.84%. 2013-2015 contributed to the largest decreases, and then going stabilized for herbivore, but slightly decreased for the rest of the groups (Figure 23). This is an obvious declining trend.

Figure 23: Line Chart shows Reef Fish Biomass Declining Trend from 2013 - 2017



	2013	2014	2015	2016	2017
Total Fish Biomass	13078.9	11372.9	9477.4	8730.5	8130.3
Herbivore Biomass	5547.7	4267.5	2032.1	2103.0	2207.3
Carnivore Biomass	2080.3	1600.2	941.3	714.2	364.4
Omnivore Biomass	6140.9	5339.9	4449.9	4059.3	2945.5

3.1.3 How do the herbivore diversity, abundance and dominance differ among sites?

The magnitude of anthropogenic impacts on the herbivorous fish diversity, abundance and dominance was obvious in the heavily fished and impacted site Sampela, which displayed the lowest Shannon-Wiener diversity and evenness Index values (0.488 and 0.191; 0.315 and 0.381), but highest to the less impacted site Ridge (1.2645 and 1.843; 0.885 and 0.789). The rest of the sites had closer values to the Ridge (Table 2).

The dominance index was negatively correlated with Shannon-Winner diversity index.

Except for reef crest on Buoy and Ridge, *Ctenochaetus striatus* was the most dominant species across the many habitats and sites (41.7 to 89.8%; Table 2). Fishing impacts on herbivorous fish diversity, abundance and dominance was obvious.

Table 2: Strength of Anthropogenic Impacts on Herbivorous Fish reflected by Shannon-Wiener Index, Dominance Index and Dominant Species

	Site	Habitat	Shannon-Wiener Index	Evenness Index	Dominance Index	Dominant Species	
						Name	Percentage
Heavily fished and Impacted	Sampela	Flat	0.4551	0.315	0.810	*Ctenochaetus striatus*	89.8%
	Sampela	Crest	1.153	0.352	0.488	*Ctenochaetus striatus*	68.2%
	Sampela	Slope	1.232	0.381	0.473	*Ctenochaetus striatus*	67.2%
Less Impacted	Pak Kasim	Flat	1.689	0.492	0.260	*Ctenochaetus striatus*	41.7%
	Pak Kasim	Crest	0.574	0.444	0.716	*Ctenochaetus striatus*	83.7%
	Pak Kasim	Slope	1.500	0.498	0.360	*Ctenochaetus striatus*	57.1%
	Buoy	Flat	1.784	0.397	0.284	*Ctenochaetus striatus*	48.9%
	Buoy	Crest	1.383	0.664	0.304	*Chrysiptera rex*	45.2%
	Buoy	Slope	0	1	1	*Ctenochaetus striatus*	100.0%
	Ridge	Crest	1.843	0.790	0.190	*Zebrasoma scopas*	32.0%
	Ridge	Slope	1.265	0.886	0.319	*Ctenochaetus striatus*	47.4%

3.1.4 What is the current functional diversity?

To look closer at the functional groups, the dominant group was the grazers/detritivores groups, which accounted for 1891.55 kg/ha (77.6%) of total biomass with 11 species and 498 individuals (Table 3), as opposed to large scraping taxa which only had 71.11 kg/ha (3.2%) with 1 species, and 64.65kg/ha (2.9%) with 3 species of scraping taxa, and 3.2%, 4 species for farming taxa.

It is important to note that the browsers (1 species), only one individual of *Naso lituratus* was found. According to IUCN red list, all the species found were either fell in least concerned or not assessed groups.

Table 3: Functional Groups Details on no. of species, group biomass, species and it respective abundance (IUCN 2009)

Functional Groups	No. of species	Group Biomass (kg/ha)	Species Name (* - IUCN red list, least concern; ** not assessed)	Frequency
Browser	1	7.04 (0.3%)	*Naso lituratus **	1
Grazers/detritivores	11	1891.55 (85.7%)	*Acanthurus grammoptilus **	3
			*Acanthurus pyroferus**	27
			*Ctenochaetus striatus**	363
			Dischistodus chrysopoecilus	1
			*Scarus dimidiatus**	2
			*Scarus russeli ***	3
			Scolopsis sp1	2
			*Siganus doliatus **	2
			*Siganus vulpinus **	6
			*Zebrasoma scopas **	61
			*Zebrasoma veliferum **	1
Scrapers/ small excavators	3	64.65 (2.9%)	*Hipposcarus longiceps **	3
			Scarus sp1	14
			*Scarus psittacus **	3
Large Scrapers/ excavators	3	172.96 (7.8%)	*Cetoscarus bicolor **	4
			*Chlorurus bleekeri **	11
			*Chlorurus sordidus **	19
Farmer	4	71.11 (3.2%)	*Chrysiptera sp1*	40
			*Chrysiptera rex ***	55
			*Dischistodus melanotus ***	19
			*Pomacentrus bankanensis ***	2
Total	22			541

3.1.5 What are the current functional length categories?

To dig deep in investigating functional health, population structures were examined by size categories. In the chart of all functional groups (Figure 18a), a bell-shaped distribution of population structure was found and the largest portion of length group was 10 to <15cm.

Grazers/detritivores (Figure 18b) have the largest sample size, and its chart was characterized by high and narrow peaks of distribution, with the mode of 10 to <15cm length categories (67.03%) which contributed the majority of frequency for figure 18a, however, declines found in growth (<7.5 cm), plus very few in larger length categories.

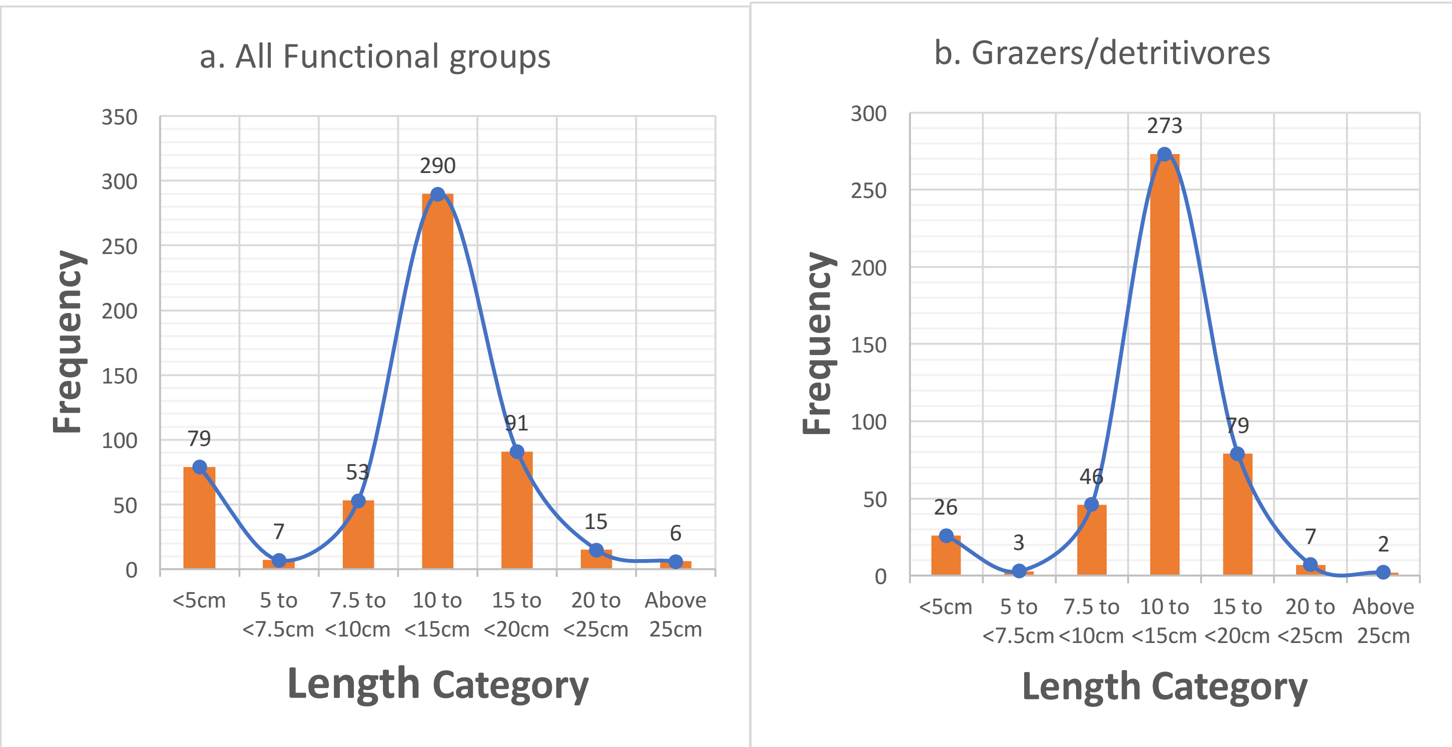


Figure 24. Frequency distribution of length category among herbivore functional group. a) all functional groups, b) Grazers/detritivores.

Large scrapers/excavators (Figure 18c) and scrapers/small excavators (Figure 18d) had much smaller sample sizes, but the mode was also 10 to <15cm length, so they had decline in growth. Especially notable is that lengths below 7.5 cm were totally absented from all transects.

Farmers (Figure 18e) had a small high and narrow right-skewed distribution of length categories, with the highest frequency on the shortest range of length group (<5cm), it had low frequency of length group from 5 cm onwards. As noted previously, in browser, only 1 individual was spotted (Figure 18f).

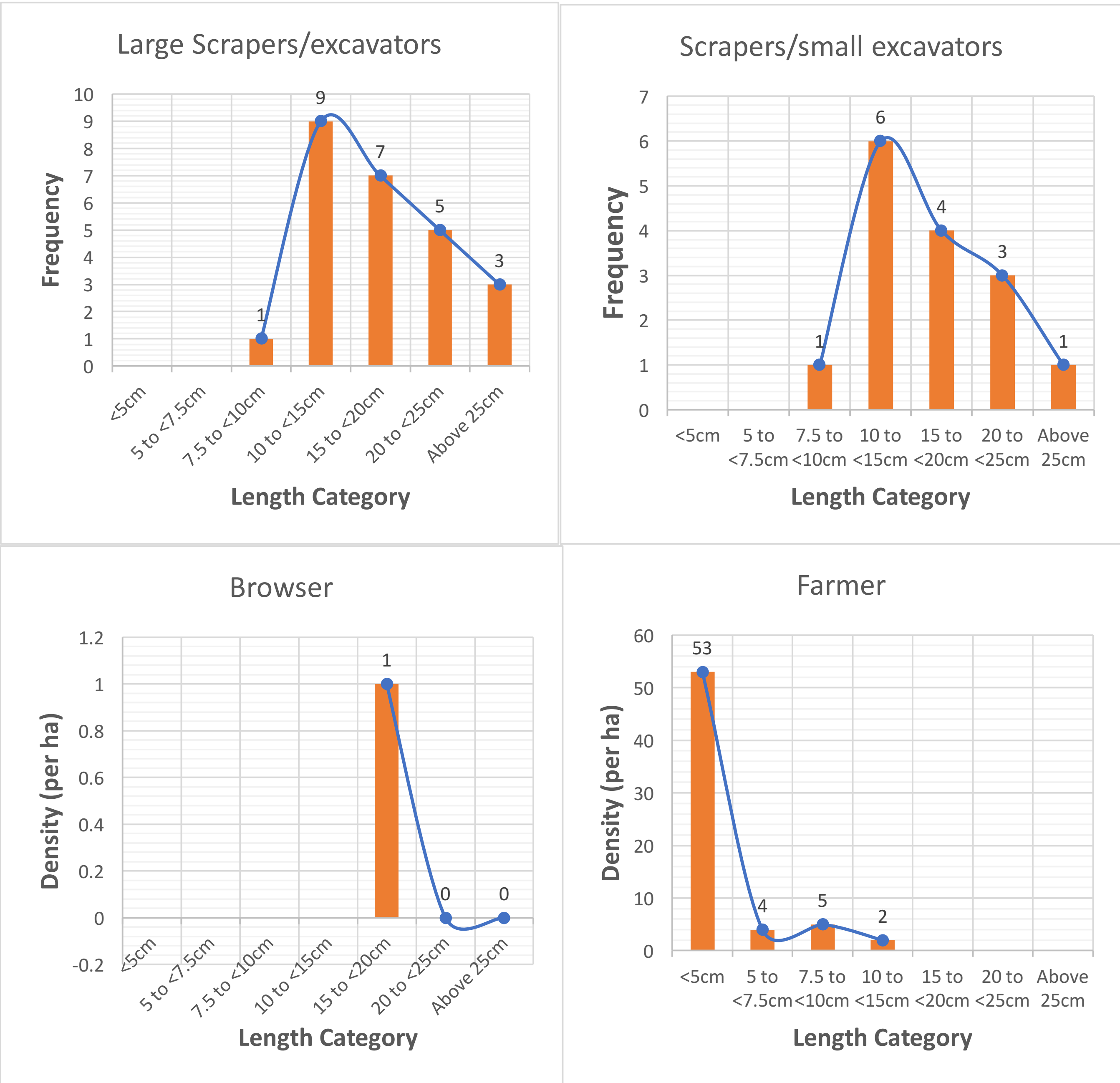


Figure 24. Frequency distribution of length category among herbivore functional group. a) all functional groups, b) Grazers/detritivores.

3.1.5 How do functional groups varied among sites?

There was a significant difference in biomass of overall herbivorous fish among all study sites (One way ANOVA, $F_{3,29}$=4.116, p<0.05). After completing the Tukey post hoc test, Sampela had a significantly higher biomass of herbivorous fish than in Buoy (Table 5A).

Grazers was significantly different among all study sites (One way ANOVA, $F_{3,29}$=4.614, p<0.05). After doing the Tukey post hoc test, Sampela had a significantly higher biomass of grazer than Buoy and Ridge (Table 5B). Figure 25 showed not all function occurred at all sites and habitats.

Table 4: One-Way ANOVA's Herbivorous Fish Communities among Sites on Wakatobi Marine National Park, SE Sulawesi, Indonesia. Significant results were given in bold.

Source of Variation	DF	Sum of Square	Mean of Square	*F* value	P	
A) Total herbivorous fish biomass						
Site	3	15.22	5.072	4.116	0.0151	**<0.05**
Error	29	35.74	1.232			
B) Grazer						
Site	3	16.42	5.474	4.614	0.0093	**<0.05**
Error	29	34.41	1.187			

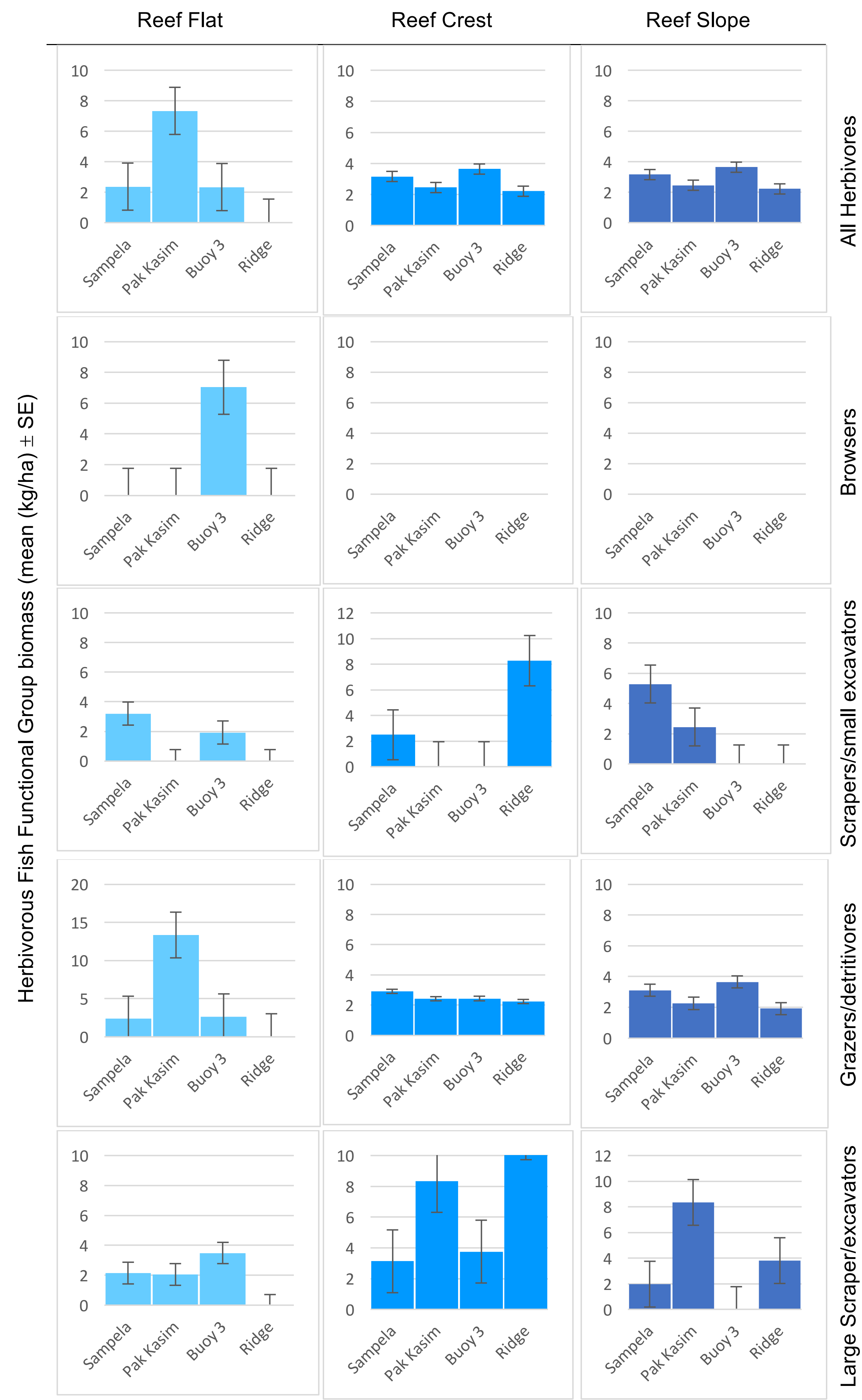
Table 5: Tukey post hoc test of total herbivorous fish biomass and Grazers/Detritivores

A) Total herbivorous fish biomass

Site (i)	Site (j)	Difference in mean	p	
Pak Ksim	Buoy	1.3148215	0.0789483	
Ridge	Buoy	0.7384728	0.5935586	
Sampela	Buoy	1.7414948	0.0120832	**<0.05**
Ridge	Pak Kasim	-0.5763487	0.7589646	
Sampela	Pak Kasim	0.4266733	0.8467241	
Sampela	Ridge	1.0030220	0.3348017	

B) **Grazers/**Detritivores

Site (i)	Site (j)	Difference in mean	p	
Pak Ksim	Buoy	1.19167162	0.1165846	
Ridge	Buoy	-0.04449914	0.9998289	
Sampela	Buoy	1.55417555	0.0250397	**<0.05**
Ridge	Pak Kasim	-1.23617076	0.1605639	
Sampela	Pak Kasim	0.36250393	0.8939073	
Sampela	Ridge	1.59867470	0.0437264	**<0.05**


Reef Flat
Reef Crest
Reef Slope
All Herbivores
Browsers
Scrapers/small excavators
Grazers/detritivores
Large Scraper/excavators
Herbivorous Fish Functional Group biomass (mean (kg/ha) ± SE)
Sampela
Pak Kasim
Buoy 3
Ridge

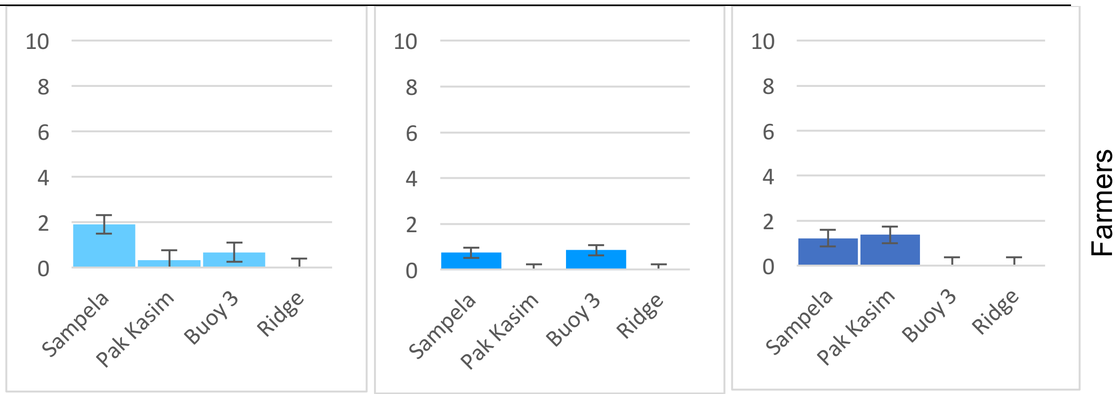


Figure 25: Variation in the biomass of functional groups of herbivorous reef fishes in Hoga Island. The mean biomass (kg/ha SE) of all herbivores, browsers, scrapers/small excavators, large scrapers/excavators and grazers and farmers.

3.2 Benthic Cover

3.2.1 What is the temporal variance in abundance of benthic community over the past 5 years?

Algae maintained an average cover of 5-9% from 2013 to 2017 except in 2014. Hard coral also kept an average cover of 17-19%. For Mobile substrate, it maintained an average cover of 32-36% (Figure 26). 5 years of PCA plots clustered together showed little variations (Figure 27).

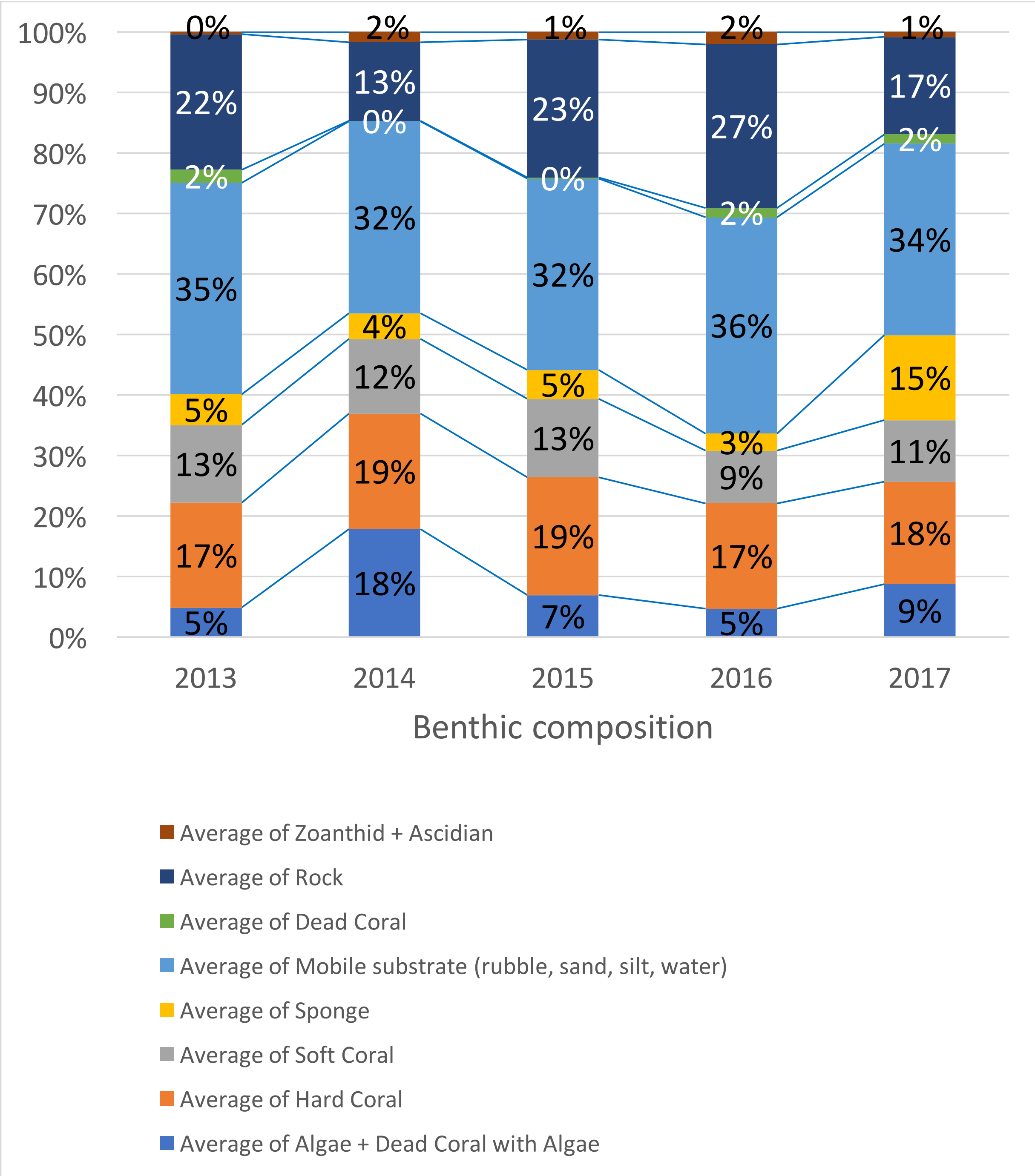


Figure 26. Variations of benthic composition between 2013 -1017.

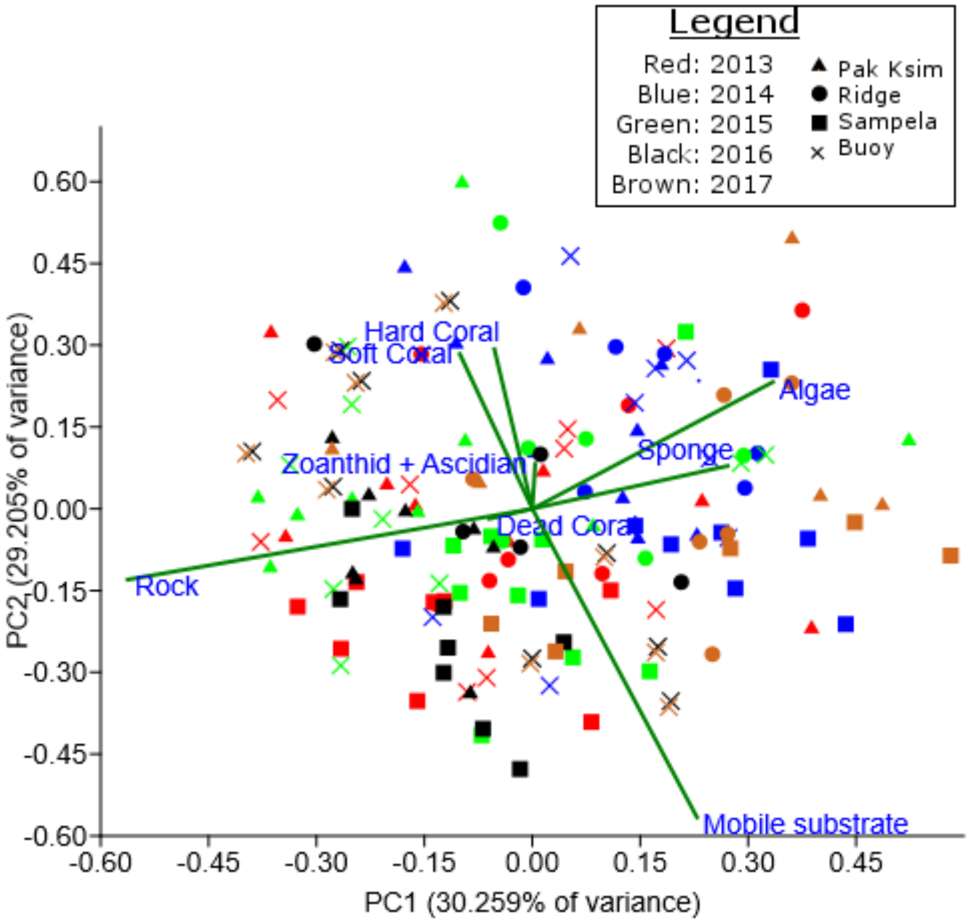


Figure 27: PCA graph showed principal component of benthic types from 2013-2017

3.2.2 Difference of benthic composition across habitat quality gradient

Hard coral was significantly less in heavily fished Sampela than the rest of less fished sites (Two-way ANOVA, $F_{3,16}$=18.062, p<0.05). The interaction between site and habitat was significant (Two-way ANOVA, $F_{3,16}$=13.9541, p<0.05). This indicated that relationship between site and percentage cover of hard coral depended on the habitat (Appendix 10).

There is no significant difference in percentage cover of algae among all sites (Two-way ANOVA, $F_{3,16}$=1.601, p>0.05), plus algae had no interaction between site and habitat (Two-way ANOVA, $F_{3,16}$=0.5614, p>0.05). The rest of benthic types had no significant difference (Appendix 9).

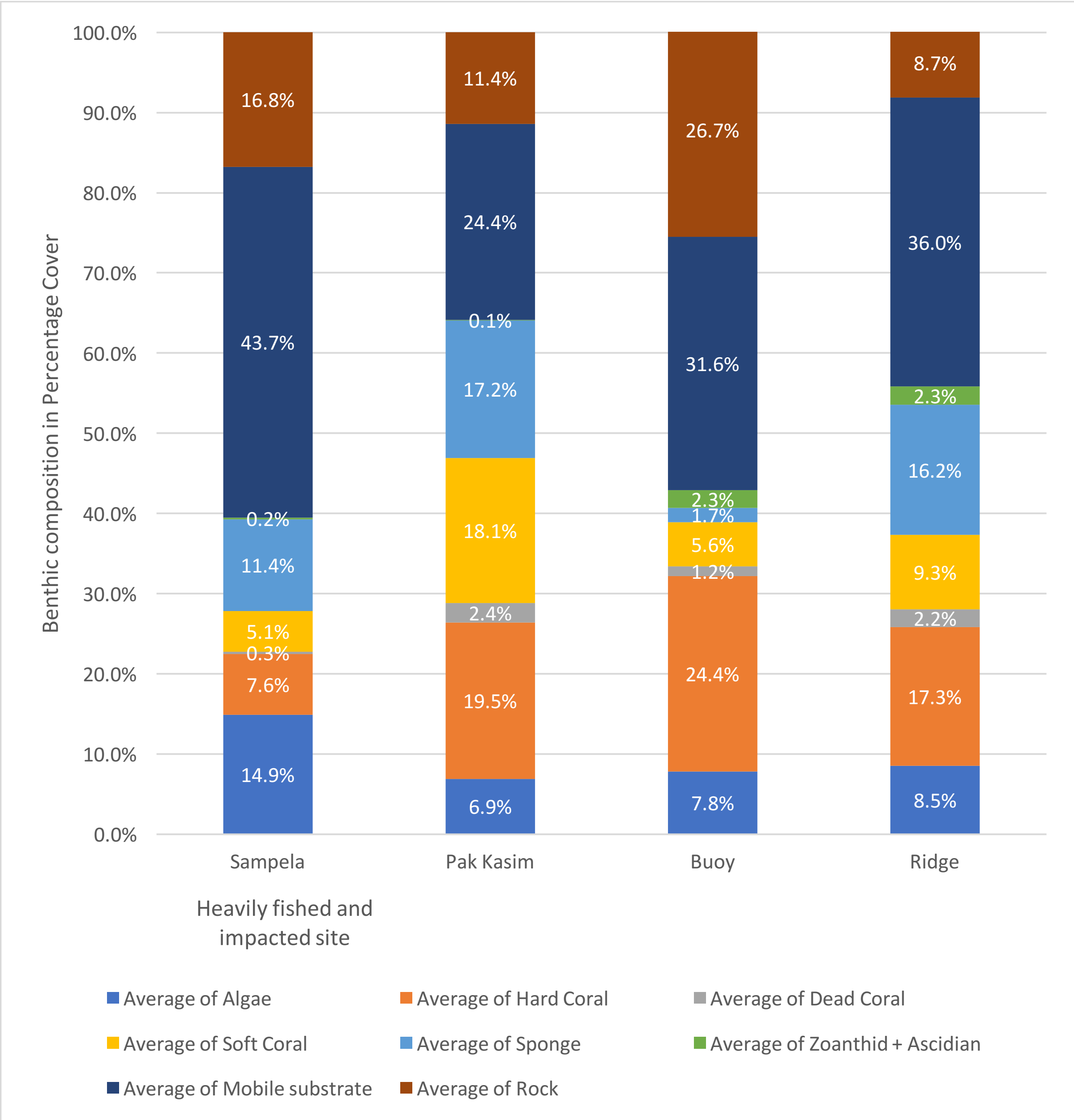


Figure 28: PCA graph showed principal component of benthic lifeforms in 4 study sites.

Table 6: 1-Way ANOVA's Benthic Communities among Habitats and Sites on Wakatobi Marine National Park, SE Sulawesi, Indonesia. Significant results are given in bold.

Source of Variation	DF	Sum of Square	Mean of Square	*F* value	P	
1) Algae Cover						
Site	3	0.0229	0.0076	1.601	0.22673	>0.05
Habitat	1	0.0010	0.0010	0.210	0.65279	>0.05
Site x Habitat	3	0.0080	0.0027	0.5614	0.64821	>0.05
Error	16	0.0759	0.0047			
2) Hard Coral Cover						
Site	3	0.1030	0.0343	18.062	2.17×10^{-5}	**<0.05**
Habitat	1	1.17×10^{-5}	1.17×10^{-5}	0.006159	0.9384	>0.05
Site x Habitat	3	0.0796	0.0265	13.9541	9.91×10^{-5}	**<0.05**
Error	16	0.0304	0.0019			

Table 7: Further Tukey post hoc test on hard coral and rock cover.

A) Hard Coral Cover

ID	Mean	Variance	SE
Buoy_Crest	0.341692	0.000240	0.01550
Buoy_Slope	0.174307	0.003049	0.05482
PK_Crest	0.209751	0.004383	0.06621
PK_Slope	0.179606	0.003181	0.05640
Ridge_Crest	0.0982921	0.001826	0.04273
Ridge_Slope	0.247624	0.001195	0.03457
Sampela_Crest	0.0542881	0.004414	0.02101
Sampela_Slope	0.0968997	0.000930	0.0305

3.3 Correlation between herbivore functional groups and benthic community

Pearson correlation showed insignificant correlations between all functional groups and algae (Appendix 13) .

3.3.1 How do PCA tell in combining two plots to analyze?

By comparing functional groups and sites PCA ordination plots, the heavily fished and impacted site -Sampela was characterized by high grazer/detritivores biomass for the mobile substrate (-0.175 along PC1).

For less fished sites, Pak Kasim was distinguished by grazer (3.684 along PC1) for rock (0.224 along PC1) and hard coral cover (0.404 along PC1) as primary contributors. And Buoy was characterized the browsers for rock cover (4.166 along PC1). Finally, the Ridge was characterized by the scrapers/excavators and large scrapers for the algae assemblage (0.178 along PC1) and macroalgal (-0.095 along PC1) respectively (Figure 29 and 30).

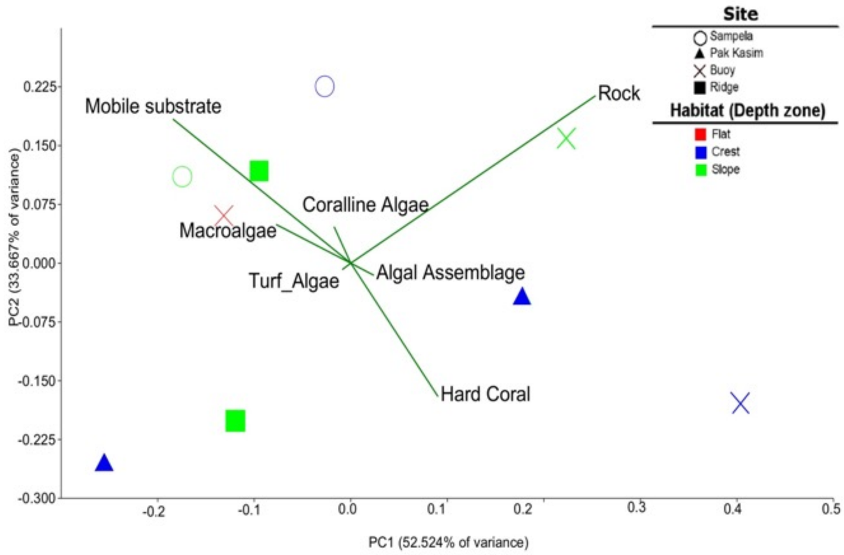


Figure 29:

PCA graph showed principal component of functional group among sites and habitat.

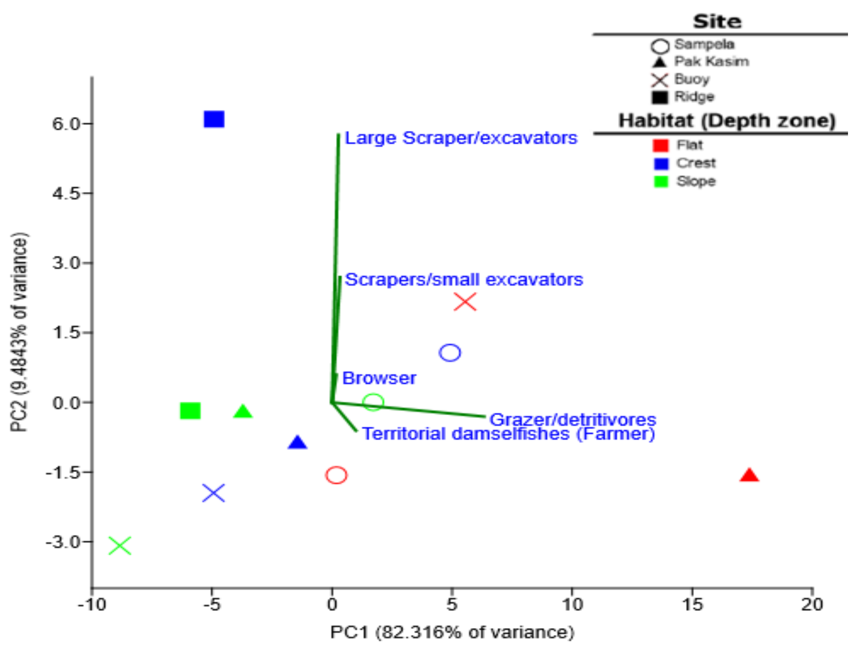


Figure 30:

PCA graph showed principal component of benthic composition among sites and habitat.

4. Discussion

4.1 Correlation between herbivore functional group and algae cover

Algae cover percentage is low this year (ranging from 6.9% to 14.9 %). There was no coral-algal phase shift seen.

Overall, herbivore fish was the second largest reef fish group across all study sites. By comparing means of sites, one-way ANOVA showed that the grazers/detritivores group has a notable difference in Sampela, however, their food had no difference among sites, which suggests that they were functioning in keeping algae under control.

However, the Spearman's rank correlation showed no significant correlations between them, which may be due to the very little variations of algae percentage cover among sites. This does not necessarily mean grazing was not functioning, because the biomass of herbivorous fish was large.

One potential explanation of the insignificant correlation is the differing scale of the studies, as this work conducted within only one region (with four sites), while the Caribbean study was conducted across a number of distant regions (Sandin et al., 2008), and even more in American Samonan Archipelago (240 study sites), so with many more data points which may resulted significantly (Heenan & Williams 2013).

Another explanation is the limitation of continuous count technique. Since algae usually grow in clusters, if points are missed, then the cover around the tape would be missed out. However, quadrats were suggested to have higher counts than continuous counts/point intercept (Jokiel et al., 2015). A study site in Makassar of Indonesia had gotten a significant result with similar surveying techniques, but the only difference was using quadrant percentage cover count; however, they selectively chose algae dominant sites to survey (Husain et al., 2013).

One final explanation is it really does not have significant correlation, as herbivore biomass declined continuously for the past 5 years, while the algae percentage cover had remained steady, plus the almost lost of browsers, but no macroalgae overgrown, hence, other factors may contribute the low algae cover stats (Adam et al., 2016), however, it does need further investigation to prove it, like collecting more sites data and environmental variables of tide, reef habitats (i.e. back reef; Russ 1984; Cheal, Emslie et al. 2013).

4.2 Limitation of the Research

This survey was constrained to a single season and only involved daytime sampling, fish communities' changes markedly over day and night (Sutherland 2006). This did not account for diel or seasonal changes, especially during Dec - Feb, that is the season of algal peak growth (citation), so how herbivorous fish and algae interacted, and how algae and hard coral interacted during growth season is unknown. Hence, this might not fully reveal the variation changes over seasons.

Also, nearby fishing activities – which may affect the fish data collected, like illegal fishing, areas of reef damage should be recorded which may deviate data collected (Ahmadia, Wilson and Green 2013). Finally, due to resource constraints, environmental variables (i.e wave, visibility, pH) should have been recorded.

4.3 Herbivory Functional Group

4.3.1 Functional group

A pattern of anthropogenic downsizing of herbivores is evident in our study where there is significantly lower biomass of all feeding guilds of herbivorous fishes, aside from the smallest-bodied taxa, in areas accessible to fishing.

The fishes in the grazer/detritivores group (mostly Acanthurids) feed almost exclusively on organic matter/detritus or turf algae. Species in this mid-sized functional group tend to have the highest bite rates and probably are major contributors to the cropping of turf algae, often the first benthic functional group to increase in abundance following coral mortality (Werner et al. 1983, Helfman et al., 2009). Thus, the large impacts will probably happen affecting reef health to certain degree in fished locations if fishing activities continue.

Large scraper/excavator species are responsible for bioerosion and extracting holdfast of macroalgae. These fish were spotted very low in number at surveying time, although they were witnessed schooling other times, which suggests that they were underrepresented in the survey data. In order to get more accurate data, it may be necessary to increase replicates from different sites and habitat complexity, since their occurrences may be affected by tides or wave exposures (Werner et al. 1983, Helfman et al., 2009). The intensity of herbivory by schooling fishes often varies unimodal with depth: low in very shallow water due to wave stress and other factors limiting accessibility by fishes, high at moderate depths, and low in deeper water where coral growth that provides shelter for fishes' declines. The browser and large scraper/excavator functional group were the most susceptible to fishing, these two groups certainly need conservation, as their functional roles are irreplaceable.

Therefore, the government should restrict the use of non-selective fishing equipment such as fish fences, and establish a fishing closed seasons for fish replenishment.

4.3.2 Size Category

Length categorizes showed a lack of short length groups below 7.5cm. It suggests that without fry stage, there is a threat of losing that species.

Investigations suggest that mature fish lay larger eggs, but younger fish are smaller in size and which consequently produce fewer and often smaller eggs, which lessens the chance that any will make it past egg and larval predators and starvation (Werner et al. 1983, Helfman et al., 2009).

This leads to an issue of shifting in the overall size structure from large to small within-species reductions or among-species shifts in relative abundance (Ochavillo et al., 2009). Both have important consequences for the emergent foraging capacity of the herbivore guild, as there are size-dependent effects, within and among species and functional groups, on algal consumption and feeding impacts. As, larger individuals generally consume more algae and expose larger areas of substratum. A shift to smaller-bodied fishes may also result in a loss of key ecological functions provided by the largest species, such as bioerosion and coral predation by large scraper/excavators. (Edwards, Friedlander et al. 2014)

4.4.3 Key Species

The highest biomass was contributed by *Ctenochaetus striatus*, so it was the dominant species. Its role is to feed on turf algae and detritus. This species therefore has a disproportionately large effect on its environment relative to its abundance. Without this keystone species, the ecosystem would be dramatically different or cease to exist altogether.

Additionally, this species has very low numbers of small size individuals, which means protecting the adults is necessary so that there will be sufficient reproduction. Therefore, the government is suggested to set a high priority on protecting the adult from fishermen.

5. Conclusion

Although the correlation was found insignificant between herbivorous fish and algae, grazer/detritivores were clearly higher in Sampela responding degraded, heavily fished and impacted situation.

As mentioned in the introduction, fish herbivore is important transporting nutrient to upper trophic consumers, if they are at risk, the upper carnivore will be at risk. This study showed important findings of the absence of fry stage on all functional groups. The government is recommended to enforce protection urgently on herbivore fry stage (Edwards et al., 2014), by setting restriction of mesh size (releasing ≤7.5cm fish), forbidden of a certain type of gear (Ahamadia et al., 2013; Comeros-Raynal et al., 2012) and even having fishing closed season.

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Appendix 1. Benthic Lifeform Categories

(English, Wilkinson and Baker 1997)

Categories		Remarks
Algae	Algae Assemblage	Consists of more than one species
	Coralline Algae	
	Halimeda	
	Macroalgae	Weedy/fleshy green, brown, reds
	Turf Algae	Lush filamentous algae, often found inside damselfish territories
Dead Coral with Algae		This coral is standing, skeletal structure can still be seen
Hard Coral	Acropora	
Dead Coral		Recently dead, white to dirty white
Mobile Substrate	Sand	
(not good for coral colony)	Rubble	Unconsolidated coral fragments
	Silt	
	Water	Fissures deeper than 50 cm
	Rock	
Soft Coral		Soft bodied corals
Sponges		
Zoanthids		e.g. *Platythoa, Protopalythoa*
Others		Ascidians, anenomes, gorgonians, giant clams. Etc.

Appendix 2. Benthic Survey Data Recording Sheet

Date:	Start time:
Site:	End Time:
Transect number:	Surveyor Name:

use the box on the right to record the environmental conditions when the survey was conducted	Water depth (m):	
	Remarks:	

Transect Distance		**Benthic Type**	**Morphology**	**Further Information**	**Remarks**
Start	**end**				
0 m					
	50 m				

Appendix 3. Screen shot of Benthic Survey Recorded spreadsheet

	Benthic Survey Data Recording Sheet						
Date:	20-Jun	Start time:	11:28				
Site:	Ridge	End time:	11:31				
Transect no.:	1	Water Depth:	5m				
For example:		HC - hard coral	SC - Soft coral	DC - Dead Coral	Rubble		
Countinous count (cm)	**Length**	**Benthic Type**	**Morphory**	**Further Information**	**Summary**	**cm**	**% cover**
0	23	hard coral	branching	Acropora	Algae	**240**	**5.5%**
23	42	sponge			Ascidian,	**0**	**0.0%**
65	30	algae			Hard Coral,	**1215**	**27.9%**
95	15	hard coral	encrusting	Pavona	Dead Coral (Corallites visible),	**104**	**2.4%**
110	103	sponge			Dead Coral with Algae,	**0**	**0.0%**
213	117	rubble			Rock (no corallites visible),	**46**	**1.1%**
330	40	sponge			Rubble,	**623**	**14.3%**
370	130	hard coral	branching	Acropora	Sand,	**0**	**0.0%**
500	5	sponge			Silt,	**90**	**2.1%**
505	15	sponge			Soft Coral,	**248**	**5.7%**
520	90	water			Sponge,	**1703**	**39.1%**
610	46	rock			Water,	**90**	**2.1%**
656	21	hard coral	branching	Acropora	Zoanthid	**0**	**0.0%**
677	13	hard coral	branching	Stylophora	Total	**4359**	**100.0%**
690	8	rubber					
698	2	hard coral	branching	Stylophora			
700	43	rubber					
743	7	hard coral					
750	150	sponge					
900	140	sponge					
1040	60	hard coral	Foliosa	unknown			
1100	130	unknown					
1230	70	sponge					

Appendix 4. Fish Survey Data Recording Sheet

Date:	Start time:
Site:	End Time:
Transect number:	Surveyor Name:

use the box on the right to record the environmental conditions when the survey was conducted	Water depth (m):	
	Remarks:	

Instructions : Use the table below to record individual fishes species, fork length and count. Species identification will be performed by Event Measure software. Length will be measured from the tip of fish snout to the end of the middle caudal fin rays. Biomass will be derived from the length: weight relationship of each species of fish.

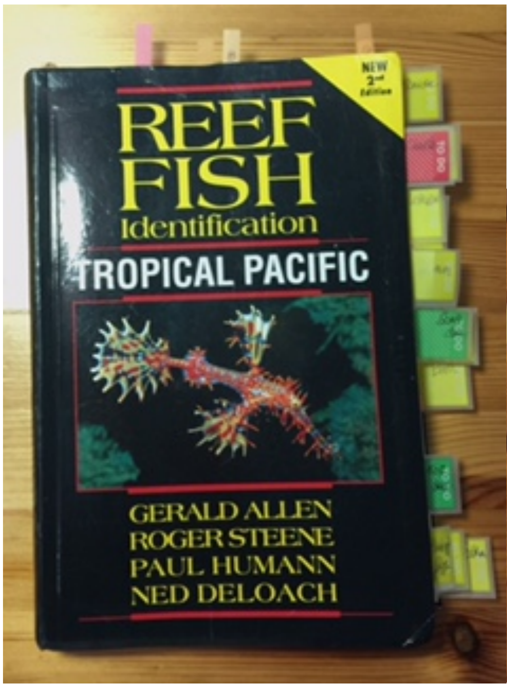
Genus	Species	Frequency	Guild	Length (mm)	A	B	Biomass (g)	Remarks

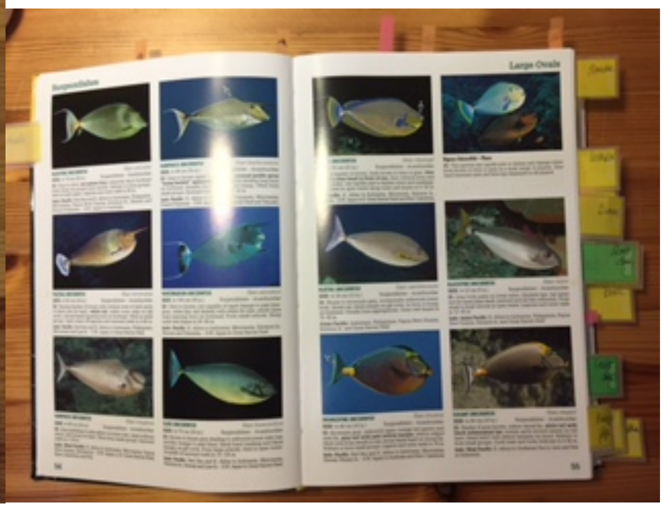
Notes:

Appendix 5. Screen shot of Fish Survey Recording Spreadsheet

				Flat 1						
Family	Genus	Species	Full name	Number	Guild	Length (mm)	Length (cm)	A	B	Biomass (g)
Acanthuridae	Acanthurus	pyroferus	Acanthurus pyroferus	1	Herbivore	108.298	10.8298	0.0213	3.081	32.81294177
Acanthuridae	Acanthurus	pyroferus	Acanthurus pyroferus	1	Herbivore	140.617	14.0617	0.0213	3.081	73.36419427
Scaridae	Chlorurus	sordidus	Chlorurus sordidus	1	Herbivore	126.917	12.6917	0.0145	3.07	35.41390206
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	138.22	13.822	0.0233	3.06	72.02824618
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	143.509	14.3509	0.0233	3.06	80.79901825
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	97.135	9.7135	0.0233	3.06	24.475169
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	120.505	12.0505	0.0233	3.06	47.34034583
Pomacentridae	Chrysiptera	rex	Chrysiptera rex	1	Herbivore	48.22	4.822	0.151	2.99	16.6658049
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	103.88	10.388	0.0233	3.06	30.05686359
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	586.026	58.6026	0.0233	3.06	5986.618563
Pomacentridae	Dischistodus	melanotus	Dischistodus melanotus	1	Herbivore	97.658	9.7658	0.0537	2.89	38.92511483
Scaridae	Cetoscarus	bicolor	Cetoscarus bicolor	1	Herbivore	173.887	17.3887	0.0194	3	102.0006817
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	135.652	13.5652	0.0233	3.06	68.01114661
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	115.386	11.5386	0.0233	3.06	41.45190201
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	128.963	12.8963	0.0233	3.06	58.26117119
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	122.385	12.2385	0.0233	3.06	49.63684727
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	137.451	13.7451	0.0233	3.06	70.80900744
Acanthuridae	Ctenochaetus	striatus	Ctenochaetus striatus	1	Herbivore	137.148	13.7148	0.0233	3.06	70.33244675

Appendix 6. Screen shot of Reef Fish Identification Guide Book





Appendix 7. One Way ANOVA's Herbivorous Fish Communities among sites

Justification of using one way ANOVA
As not all kinds of functional fish exist in 3 habitats of each site, there will has lots of zeros on fish raw data. Therefore, two-way ANOVA test cannot be conducted in this situation. Because of this, one-way ANOVA & Tukey post hoc test (if needed) are used. Site will be the fixed factor.

Assumptions
To carry out one-way ANOVA, three assumptions must be met:
Assumption 1: all samples must be independent to each other. Met. Site was independent.
Assumption 2: Data must be normally distributed. Met. Data are normally distributed after log(x+1) transformation.

```
> Herb_fish <- read.csv(file='Herb_fish_v2.csv',header=T)
> Herb_fish
      Site    Biomass
1  Sampela   7.818898
2  Sampela  84.131330
3  Sampela  40.371604
4  Sampela  58.905418
5  Sampela 143.665918
6  Sampela  88.902593
7  Sampela  52.022278
8  Sampela  93.730825
9  Sampela  46.848892
10      PK 159.146875
11      PK  80.161602
12      PK  23.516809
13      PK  52.422861
14      PK  33.184760
15      PK  24.558812
16      PK  43.022286
17      PK  13.750251
18      PK  11.942260
19    Buoy  60.914362
20    Buoy  55.403929
21    Buoy  62.609837
22    Buoy   2.814021
23    Buoy   1.433281
24    Buoy  20.566547
25    Buoy   4.748136
26    Buoy   0.000000
27    Buoy   2.550014
28   Ridge  31.979830
29   Ridge  37.330064
30   Ridge  59.179640
31   Ridge   4.694060
32   Ridge  33.117487
33   Ridge   4.326926
> shapiro.test(subset(Herb_fish$Biomass, Herb_fish$Site=="Sampela"))

        Shapiro-Wilk normality test

data:  subset(Herb_fish$Biomass, Herb_fish$Site == "Sampela")
W = 0.9636, p-value = 0.8351
```

```
> shapiro.test(subset(Herb_fish$Biomass, Herb_fish$Site=="PK"))

        Shapiro-Wilk normality test

data:  subset(Herb_fish$Biomass, Herb_fish$Site == "PK")
W = 0.77508, p-value = 0.01057

> Herb_fish$Biomass_log = log(Herb_fish$Biomass + 1)
> Herb_fish
      Site    Biomass Biomass_log
1  Sampela   7.818898   2.1768969
2  Sampela  84.131330   4.4441951
3  Sampela  40.371604   3.7225948
4  Sampela  58.905418   4.0927670
5  Sampela 143.665918   4.9744271
6  Sampela  88.902593   4.4987268
7  Sampela  52.022278   3.9707122
8  Sampela  93.730825   4.5510394
9  Sampela  46.848892   3.8680480
10      PK 159.146875   5.0760914
11      PK  80.161602   4.3964423
12      PK  23.516809   3.1993590
13      PK  52.422861   3.9782388
14      PK  33.184760   3.5317799
15      PK  24.558812   3.2409822
16      PK  43.022286   3.7846960
17      PK  13.750251   2.6912601
18      PK  11.942260   2.5604979
19    Buoy  60.914362   4.1257522
20    Buoy  55.403929   4.0325388
21    Buoy  62.609837   4.1527681
22    Buoy   2.814021   1.3386841
23    Buoy   1.433281   0.8892404
24    Buoy  20.566547   3.0711433
25    Buoy   4.748136   1.7488757
26    Buoy   0.000000   0.0000000
27    Buoy   2.550014   1.2669514
28   Ridge  31.979830   3.4958962
29   Ridge  37.330064   3.6462346
30   Ridge  59.179640   4.0973341
31   Ridge   4.694060   1.7394236
32   Ridge  33.117487   3.5298101
33   Ridge   4.326926   1.6727744
```

```
> shapiro.test(subset(Herb_fish$Biomass_log, Herb_fish$Site=="Sampela"))

        Shapiro-Wilk normality test

data:  subset(Herb_fish$Biomass_log, Herb_fish$Site == "Sampela")
W = 0.84999, p-value = 0.07449

> shapiro.test(subset(Herb_fish$Biomass_log, Herb_fish$Site=="PK"))

        Shapiro-Wilk normality test

data:  subset(Herb_fish$Biomass_log, Herb_fish$Site == "PK")
W = 0.96659, p-value = 0.8641

> shapiro.test(subset(Herb_fish$Biomass_log, Herb_fish$Site=="Buoy"))

        Shapiro-Wilk normality test

data:  subset(Herb_fish$Biomass_log, Herb_fish$Site == "Buoy")
W = 0.88771, p-value = 0.189

> shapiro.test(subset(Herb_fish$Biomass_log, Herb_fish$Site=="Ridge"))

        Shapiro-Wilk normality test

data:  subset(Herb_fish$Biomass_log, Herb_fish$Site == "Ridge")
W = 0.80062, p-value = 0.05953
```

Assumption 3: all samples must have equal variance. Met. As data from biomass of total herbivorous fish among sites had equal variance using Bartlett test (P=0.1705>0.05)

```
> bartlett.test(Biomass_log ~ Site, data=Herb_fish)

        Bartlett test of homogeneity of variances

data:  Biomass_log by Site
Bartlett's K-squared = 5.0178, df = 3, p-value = 0.1705
```

Calculation of one way ANOVA on herbivorous fish

```
> attach(Herb_fish)
> attach(Herb_fish)
The following objects are masked from Herb_fish (pos = 3):

    Biomass, Biomass_log, Site

> Biomass_log
 [1] 2.1768969 4.4441951 3.7225948 4.0927670 4.9744271 4.4987268 3.9707122
 [8] 4.5510394 3.8680480 5.0760914 4.3964423 3.1993590 3.9782388 3.5317799
[15] 3.2409822 3.7846960 2.6912601 2.5604979 4.1257522 4.0325388 4.1527681
[22] 1.3386841 0.8892404 3.0711433 1.7488757 0.0000000 1.2669514 3.4958962
[29] 3.6462346 4.0973341 1.7394236 3.5298101 1.6727744
> Site
 [1] Sampela Sampela Sampela Sampela Sampela Sampela Sampela Sampela Sampela
[10] PK      PK      PK      PK      PK      PK      PK      PK      PK
[19] Buoy    Buoy    Buoy    Buoy    Buoy    Buoy    Buoy    Buoy    Buoy
[28] Ridge   Ridge   Ridge   Ridge   Ridge   Ridge
Levels: Buoy PK Ridge Sampela
> fit <- aov(Biomass_log~Site)
> summary(fit)
            Df Sum Sq Mean Sq F value Pr(>F)
Site         3  15.22   5.072   4.116 0.0151 *
Residuals   29  35.74   1.232
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> TukeyHSD(fit)
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Biomass_log ~ Site)

$Site
                   diff        lwr      upr     p adj
PK-Buoy        1.3148215 -0.1109396 2.740583 0.0789483
Ridge-Buoy     0.7384728 -0.8555766 2.332522 0.5935586
Sampela-Buoy   1.7414948  0.3157337 3.167256 0.0120832
Ridge-PK      -0.5763487 -2.1703980 1.017701 0.7589646
Sampela-PK     0.4266733 -0.9990878 1.852434 0.8467241
Sampela-Ridge  1.0030220 -0.5910274 2.597071 0.3348017
```

Appendix 8. One Way ANOVA's Grazing fish among sites

Assumptions

To carry out one-way ANOVA, three assumptions must be met:
Assumption 1: all samples must be independent to each other. Met. Site was independent.
Assumption 2: Data must be normally distributed. Met. Data are normally distributed after log(x+1) transformation.

```
> Grazers <- read.csv(file='Grazers_v2.csv',header=T)
> Grazers
      Site    Biomass
1  Sampela   7.818898
2  Sampela  81.991673
3  Sampela  35.262076
4  Sampela  20.618735
5  Sampela 140.528317
6  Sampela  88.902593
7  Sampela  30.899038
8  Sampela  91.278518
9  Sampela  42.888437
10      PK 144.370009
11      PK  77.446947
12      PK  12.219781
13      PK  44.071531
14      PK  33.184760
15      PK  24.558812
16      PK  30.865034
17      PK  13.750251
18      PK  11.942260
19    Buoy  60.914362
20    Buoy  48.364889
21    Buoy  62.609837
22    Buoy   2.814021
23    Buoy   1.433281
24    Buoy  20.566547
25    Buoy   4.748136
26    Buoy   0.000000
27    Buoy   2.550014
28   Ridge   2.678249
29   Ridge   8.285877
30   Ridge  26.962413
31   Ridge   4.694060
32   Ridge  21.664146
33   Ridge   4.326926
> shapiro.test(subset(Grazers$Biomass, Grazers$Site=="Sampela"))

        Shapiro-Wilk normality test

data:  subset(Grazers$Biomass, Grazers$Site == "Sampela")
W = 0.92405, p-value = 0.4268
```

```
> shapiro.test(subset(Grazers$Biomass, Grazers$Site=="PK"))

        Shapiro-Wilk normality test

data:  subset(Grazers$Biomass, Grazers$Site == "PK")
W = 0.75769, p-value = 0.006656

> Grazers$Biomass_log = log(Grazers$Biomass + 1)
> Grazers
      Site    Biomass Biomass_log
1  Sampela   7.818898   2.1768969
2  Sampela  81.991673   4.4187403
3  Sampela  35.262076   3.5907724
4  Sampela  20.618735   3.0735603
5  Sampela 140.528317   4.9524998
6  Sampela  88.902593   4.4987268
7  Sampela  30.899038   3.4625759
8  Sampela  91.278518   4.5248114
9  Sampela  42.888437   3.7816509
10      PK 144.370009   4.9792823
11      PK  77.446947   4.3624226
12      PK  12.219781   2.5817143
13      PK  44.071531   3.8082508
14      PK  33.184760   3.5317799
15      PK  24.558812   3.2409822
16      PK  30.865034   3.4615093
17      PK  13.750251   2.6912601
18      PK  11.942260   2.5604979
19    Buoy  60.914362   4.1257522
20    Buoy  48.364889   3.8992394
21    Buoy  62.609837   4.1527681
22    Buoy   2.814021   1.3386841
23    Buoy   1.433281   0.8892404
24    Buoy  20.566547   3.0711433
25    Buoy   4.748136   1.7488757
26    Buoy   0.000000   0.0000000
27    Buoy   2.550014   1.2669514
28   Ridge   2.678249   1.3024368
29   Ridge   8.285877   2.2284947
30   Ridge  26.962413   3.3308612
31   Ridge   4.694060   1.7394236
32   Ridge  21.664146   3.1207842
33   Ridge   4.326926   1.6727744
```

```
> shapiro.test(subset(Grazers$Biomass_log, Grazers$Site=="Sampela"))

        Shapiro-Wilk normality test

data:  subset(Grazers$Biomass_log, Grazers$Site == "Sampela")
W = 0.94521, p-value = 0.6377

> shapiro.test(subset(Grazers$Biomass_log, Grazers$Site=="PK"))

        Shapiro-Wilk normality test

data:  subset(Grazers$Biomass_log, Grazers$Site == "PK")
W = 0.92614, p-value = 0.4454

> shapiro.test(subset(Grazers$Biomass_log, Grazers$Site=="Buoy"))

        Shapiro-Wilk normality test

data:  subset(Grazers$Biomass_log, Grazers$Site == "Buoy")
W = 0.89676, p-value = 0.2338

> shapiro.test(subset(Grazers$Biomass_log, Grazers$Site=="Ridge"))

        Shapiro-Wilk normality test

data:  subset(Grazers$Biomass_log, Grazers$Site == "Ridge")
W = 0.90023, p-value = 0.3753
```

Assumption 3: all samples must have equal variance. Met. As data from biomass of grazing fish among sites had equal variance using Bartlett test (P=0.1908>0.05).

```
> bartlett.test(Grazers$Biomass_log ~ Grazers$Site, data=Grazers)

        Bartlett test of homogeneity of variances

data:  Grazers$Biomass_log by Grazers$Site
Bartlett's K-squared = 4.7531, df = 3, p-value = 0.1908
```

Calculation of one way ANOVA on grazing fish

```
> fit <- aov(Grazers$Biomass_log~Grazers$Site)
> summary(fit)
             Df Sum Sq Mean Sq F value Pr(>F)
Grazers$Site  3  16.42   5.474   4.614 0.0093 **
Residuals    29  34.41   1.187
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> TukeyHSD(fit)
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Grazers$Biomass_log ~ Grazers$Site)

$`Grazers$Site`
                    diff        lwr       upr     p adj
PK-Buoy        1.19167162 -0.2073452 2.5906885 0.1165846
Ridge-Buoy    -0.04449914 -1.6086475 1.5196493 0.9998289
Sampela-Buoy   1.55417555  0.1551587 2.9531924 0.0250397
Ridge-PK      -1.23617076 -2.8003192 0.3279776 0.1605639
Sampela-PK     0.36250393 -1.0365129 1.7615208 0.8939073
Sampela-Ridge  1.59867470  0.0345263 3.1628231 0.0437264
```

Appendix 9. Two Way ANOVA's Algae of benthic composition among sites

Justification of using one way ANOVA

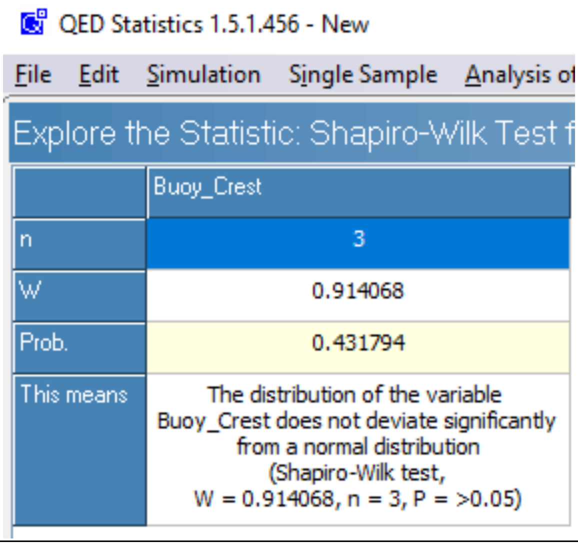
As there are two sets of factors (Site and Habitat) per sample and not only findings on two sets of comparisons, but also their interaction effect, so two-way ANOVA is best fit to use (Stevens 1998).

Assumptions

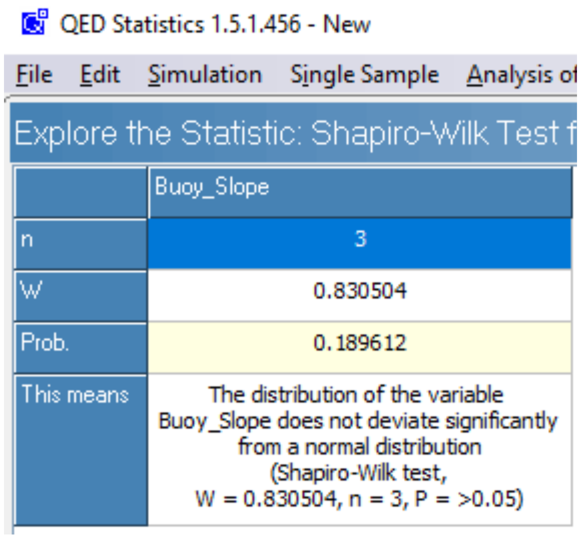
To carry out two-way ANOVA, three assumptions must be met:
Assumption 1: all samples must be independent to each other. Met. Site and Habitat were independent.

Assumption 2: Data must be normally distributed. Met. Data are normally distributed.

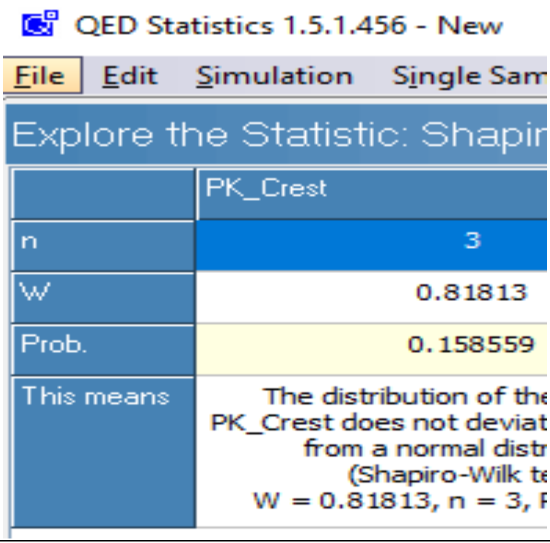
(a)



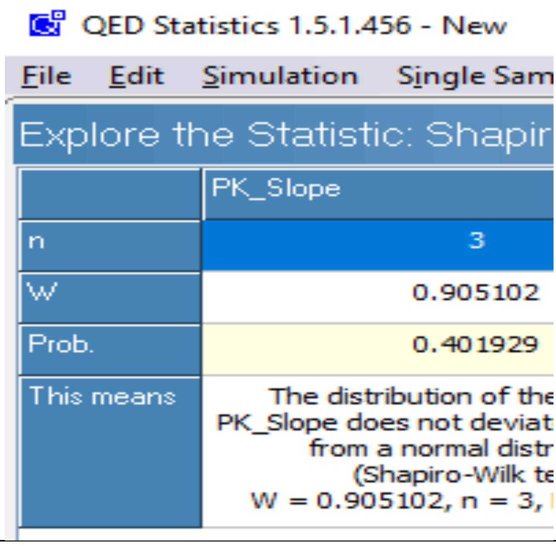
(b)



(c)



(d)



(e)

(f)

QED Statistics 1.5.1.456 - New

File Edit Simulation Single Sample Analysis of

Explore the Statistic: Shapiro-Wilk Test f

	Ridge_Crest
n	3
W	0.992483
Prob.	0.834203
This means	The distribution of the variable Ridge_Crest does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.992483, n = 3, P = >0.05)

QED Statistics 1.5.1.456 - New

File Edit Simulation Single Sample Analysis of

Explore the Statistic: Shapiro-Wilk Test f

	Ridge_Slope
n	3
W	0.847674
Prob.	0.23425
This means	The distribution of the variable Ridge_Slope does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.847674, n = 3, P = >0.05)

(g)

QED Statistics 1.5.1.456 - New

File Edit Simulation Single Sample Analysis of Fr

Explore the Statistic: Shapiro-Wilk Test for

	Sampela_Crest
n	3
W	0.991908
Prob.	0.82796
This means	The distribution of the variable Sampela_Crest does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.991908, n = 3, P = >0.05)

(h)

QED Statistics 1.5.1.456 - New

File Edit Simulation Single Sample Analysis of Fr

Explore the Statistic: Shapiro-Wilk Test for

	Sampela_Slope
n	3
W	0.921576
Prob.	0.457907
This means	The distribution of the variable Sampela_Slope does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.921576, n = 3, P = >0.05)

Appendix 9.1. Shapiro-Wilk test proved all data in normality with all P values>0.05 (a) Buoy and crest, P=0.432. (b) Buoy and slope, P=0.190. (c) Pak Ksim and crest, P=0.159. (d) Pak Ksim and slope, P=0.402. (e) Ridge and crest, P=0.834. (f) Ridge and slope, P=0.234. (g) Sampela and crest, P=0.828. (h) Sampela and slope, P=0.458

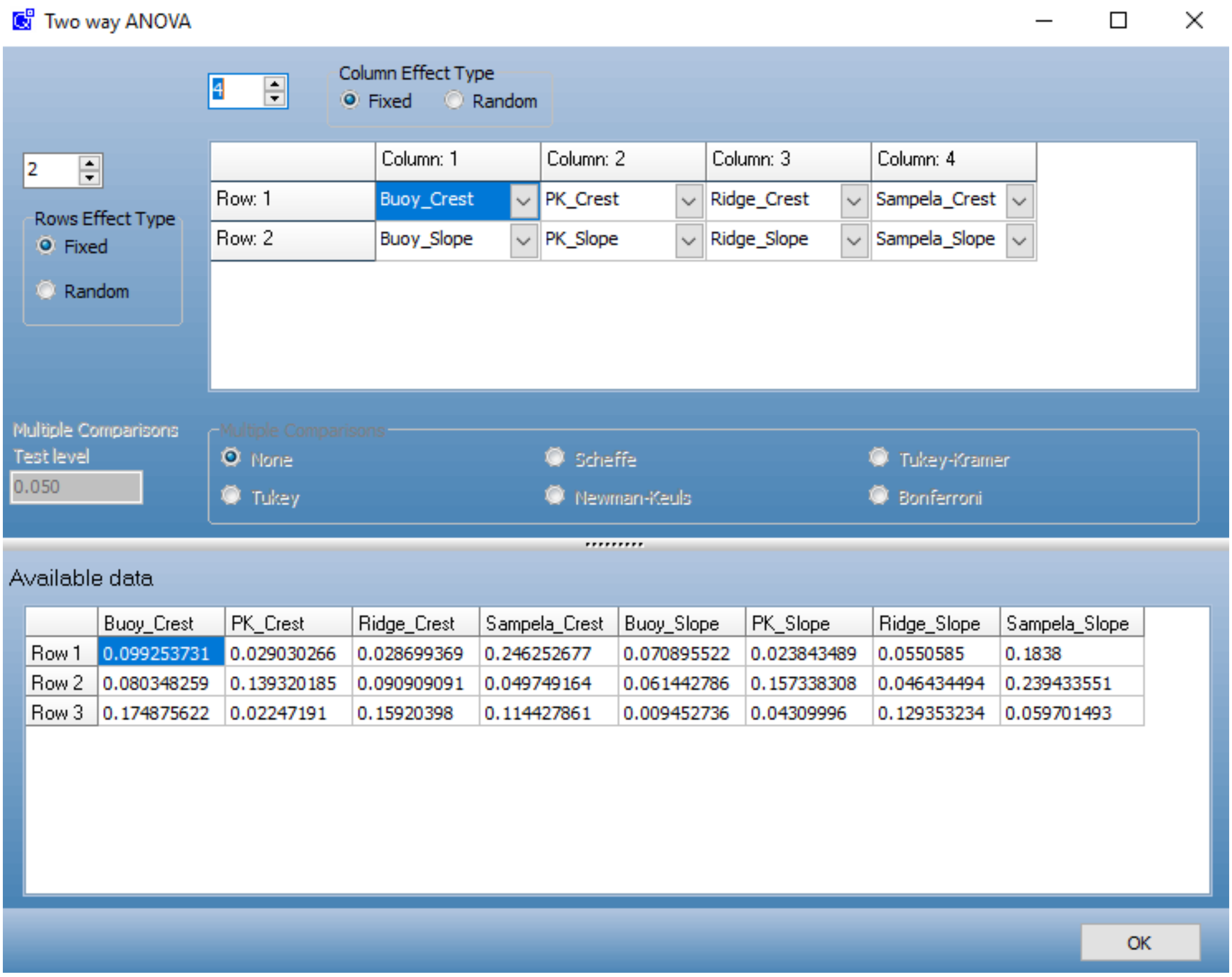
Assumption 3: all samples must have equal variance. Met. Site and Habitat had equal variance by Bartlett's test, P=0.456681 > 0.05

	Homogenity of Variance Tests		
Test	Statistic	DF1	DF2
Hartley Fmax	9.16245	8	2
Cochran C	0.264283	8	2
Bartlett Chi-square	6.7378	7	
Bartlett Probability > Chi-Square	0.456681		

Calculations

Three null hypotheses, H_0:

01. The percentage cover of algae by site (Buoy, Pak Ksim, Ridge and Sampela) factor were the same.
02. The percentage cover of algae by habitat (Crest and Slope) factor were the same.
03. There was no interaction between the two factors (Site and Habitat)



QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis of Frequency Two Samples Regression ANOVAs GLM Planning

Explore the Statistic: Two way ANOVA

Two Way ANOVA						
	DF	SS	MS	F	Prob.>F	Omega^2
Between Columns	3	0.0228899	0.00762995	1.60849	0.226731	0.0769597
Between Rows	1	0.000997016	0.000997016	0.210183	0.65279	0
Interaction	3	0.00798847	0.00266282	0.561356	0.648205	0
Within Groups/Error	16	0.0758969	0.00474356			
Total	23	0.107772	0.00468575			
Omega^2	0					
	Means and Variability					
Group	ID	Mean	Variance	StdD	N	
Cell	Buoy_Crest	0.118159	0.00250192	0.0500192	3	
Cell	Buoy_Slope	0.0472637	0.00109459	0.0330846	3	
Cell	PK_Crest	0.0636075	0.00431007	0.0656511	3	
Cell	PK_Slope	0.0747606	0.00520701	0.0721596	3	
Cell	Ridge_Crest	0.0929375	0.00426095	0.0652759	3	
Cell	Ridge_Slope	0.0769487	0.00207827	0.045588	3	
Cell	Sampela_Crest	0.13681	0.0100291	0.100146	3	
Cell	Sampela_Slope	0.160978	0.00846652	0.0920137	3	
Column	1	0.0827114	0.00294646	0.0542813	6	
Column	2	0.069184	0.00384415	0.0620012	6	
Column	3	0.0849431	0.00261238	0.0511114	6	
Column	4	0.148894	0.00757349	0.0870258	6	
Row	1	0.102879	0.00466198	0.0682787	12	
Row	2	0.0899878	0.00504486	0.0710272	12	
	Total	0.0964332	0.00468575	0.0684525	24	

Appendix 9.2: The result screen performed on algae data by the two-way ANOVA.

Appendix 10. Two Way ANOVA's Hard Coral of benthic composition among sites

Assumptions

To carry out two-way ANOVA, three assumptions must be met:

Assumption 1: all samples must be independent to each other. Met. Site and Habitat were independent.

Assumption 2: Data must be normally distributed. Met. Data are normally distributed.

(a)

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis of

Explore the Statistic: Shapiro-Wilk Test f

	Buoy_Crest
n	3
W	0.964286
Prob.	0.636887
This means	The distribution of the variable Buoy_Crest does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.964286, n = 3, P = >0.05)

(b)

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis of

Explore the Statistic: Shapiro-Wilk Test f

	Buoy_Slope
n	3
W	0.86094
Prob.	0.270164
This means	The distribution of the variable Buoy_Slope does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.86094, n = 3, P = >0.05)

(c)

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis

Explore the Statistic: Shapiro-Wilk Test

	PK_Crest
n	3
W	0.999981
Prob.	0.991717
This means	The distribution of the variable PK_Crest does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.999981, n = 3, P = >0.05)

(d)

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis

Explore the Statistic: Shapiro-Wilk Test

	PK_Slope
n	3
W	0.995987
Prob.	0.878937
This means	The distribution of the variable PK_Slope does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.995987, n = 3, P = >0.05)

(e)

(f)

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis of

Explore the Statistic: Shapiro-Wilk Test fc

	Ridge_Crest
n	3
W	0.968626
Prob.	0.659916
This means	The distribution of the variable Ridge_Crest does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.968626, n = 3, P = >0.05)

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis of

Explore the Statistic: Shapiro-Wilk Test fc

	Ridge_Slope
n	3
W	0.976591
Prob.	0.706638
This means	The distribution of the variable Ridge_Slope does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.976591, n = 3, P = >0.05)

(g)

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis of Fre

Explore the Statistic: Shapiro-Wilk Test for

	Sampela_Crest
n	3
W	0.846281
Prob.	0.230553
This means	The distribution of the variable Sampela_Crest does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.846281, n = 3, P = >0.05)

(h)

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis of Fre

Explore the Statistic: Shapiro-Wilk Test for

	Sampela_Slope
n	3
W	0.973808
Prob.	0.689541
This means	The distribution of the variable Sampela_Slope does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.973808, n = 3, P = >0.05)

Appendix 10.1. Shapiro-Wilk test proved all data in normality with all P values>0.05 (a) Buoy and crest, P=0.637. (b) Buoy and slope, P=0.270. (c) Pak Ksim and crest, P=0.992. (d) Pak Ksim and slope, P=0.879. (e) Ridge and crest, P=0.660. (f) Ridge and slope, P=0.707. (g) Sampela and crest, P=0.231. (h) Sampela and slope, P=0.690

Assumption 3: all samples must have equal variance. Met. Site and Habitat had equal variance by Bartlett's test, P=0.116 > 0.05

	Homogenity of Variance Tests		
Test	Statistic	DF1	DF2
Hartley Fmax	18.2373	8	2
Cochran C	0.288331	8	2
Bartlett Chi-square	11.547	7	
Bartlett Probability > Chi-Square	0.116473		

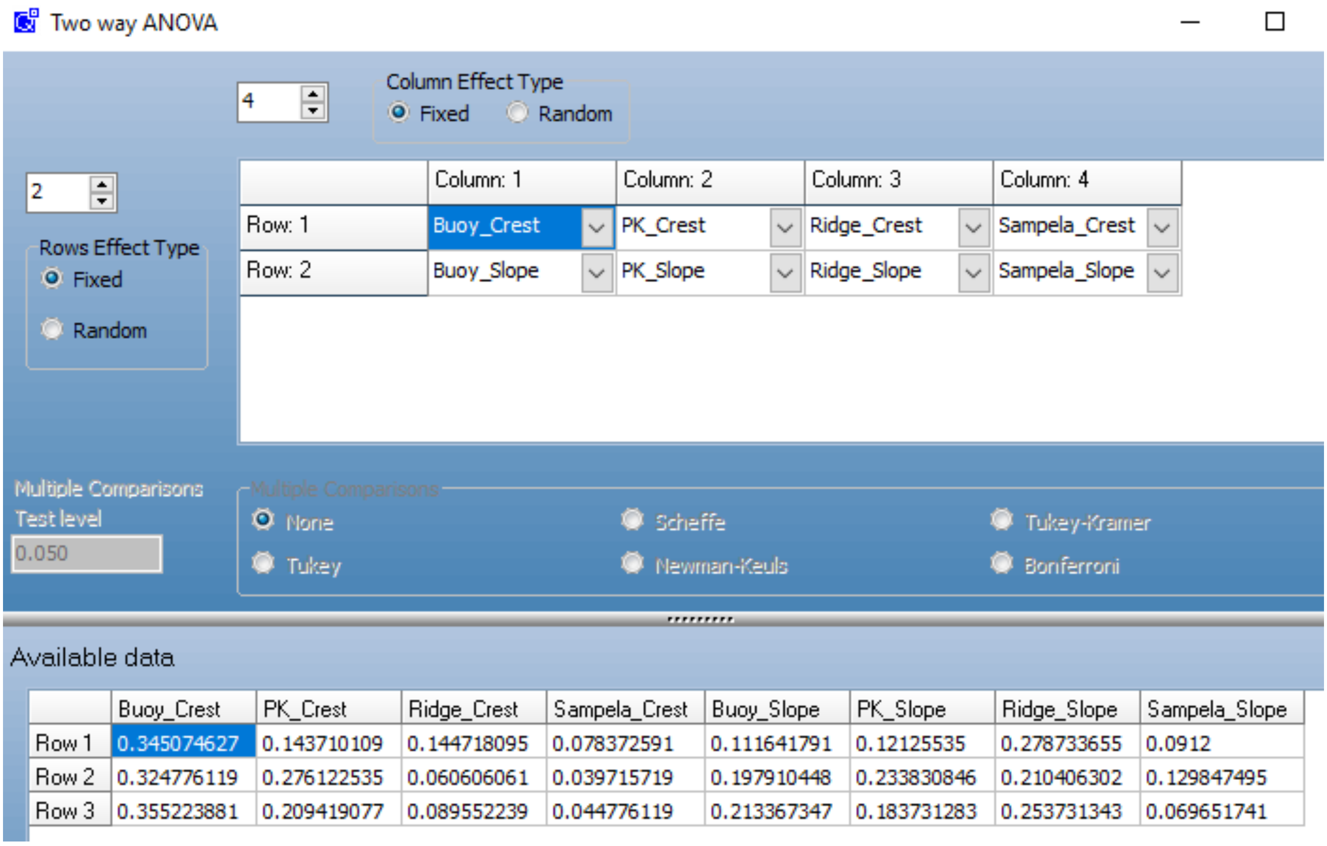
Calculations

Three null hypotheses, H_0:

01. The percentage cover of hard coral by site (Buoy, Pak Ksim, Ridge and Sampela) factor were the same.

02. The percentage cover of hard coral by habitat (Crest and Slope) factor were the same.

03. There was no interaction between the two factors (Site and Habitat)



	Buoy_Crest	PK_Crest	Ridge_Crest	Sampela_Crest	Buoy_Slope	PK_Slope	Ridge_Slope	Sampela_Slope
Row 1	0.345074627	0.143710109	0.144718095	0.078372591	0.111641791	0.12125535	0.278733655	0.0912
Row 2	0.324776119	0.276122535	0.060606061	0.039715719	0.197910448	0.233830846	0.210406302	0.129847495
Row 3	0.355223881	0.209419077	0.089552239	0.044776119	0.213367347	0.183731283	0.253731343	0.069651741

QED Statistics 1.5.1.456 - QED_Algae

File Edit Simulation Single Sample Analysis of Frequency Two Samples Regression ANOVAs GLM Planning Help

Explore the Statistic: Two way ANOVA

Two Way ANOVA						
	DF	SS	MS	F	Prob.>F	Omega2
Between Columns	3	0.102969	0.0343229	18.0617	2.17496E-005	0.452751
Between Rows	1	1.17035E-005	1.17035E-005	0.00615873	0.938422	0
Interaction	3	0.0795515	0.0265172	13.9541	9.90743E-005	0.343752
Within Groups/Error	16	0.030405	0.00190031			
Total	23	0.212937	0.00925812			
Omega2	0.787711					
	Means and Variability					
Group	ID	Mean	Variance	StdD	N	
Cell	Buoy_Crest	0.341692	0.000240351	0.0155033	3	
Cell	Buoy_Slope	0.174307	0.00300488	0.0548168	3	
Cell	PK_Crest	0.209751	0.00438335	0.0662068	3	
Cell	PK_Slope	0.179606	0.00318107	0.056401	3	
Cell	Ridge_Crest	0.0982921	0.001826	0.0427317	3	
Cell	Ridge_Slope	0.247624	0.00119513	0.0345707	3	
Cell	Sampela_Crest	0.0542881	0.000441447	0.0210106	3	
Cell	Sampela_Slope	0.0968997	0.000930248	0.0305	3	
Column	1	0.257999	0.00970342	0.0985059	6	
Column	2	0.194678	0.00329838	0.0574315	6	
Column	3	0.172958	0.00789843	0.0888731	6	
Column	4	0.0755939	0.0010934	0.0330666	6	
Row	1	0.176006	0.014738	0.1214	12	
Row	2	0.174609	0.00461886	0.0679622	12	
	Total	0.175307	0.00925812	0.0962191	24	

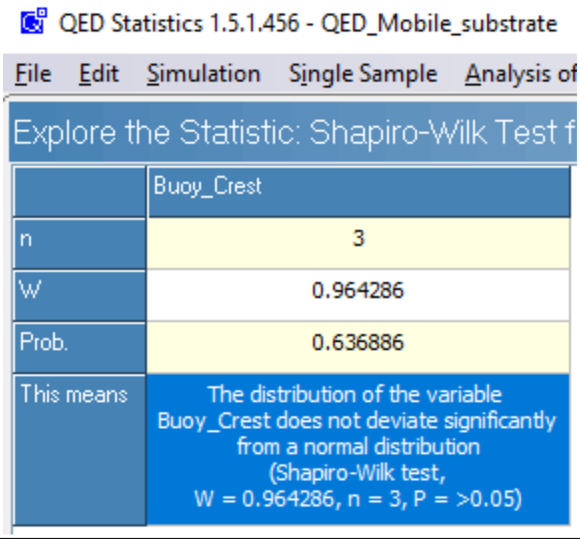
Appendix 10.2: The result screen performed on hard coral data by the two-way ANOVA.

Appendix 11. Two Way ANOVA's Mobile substrate of benthic composition among sites

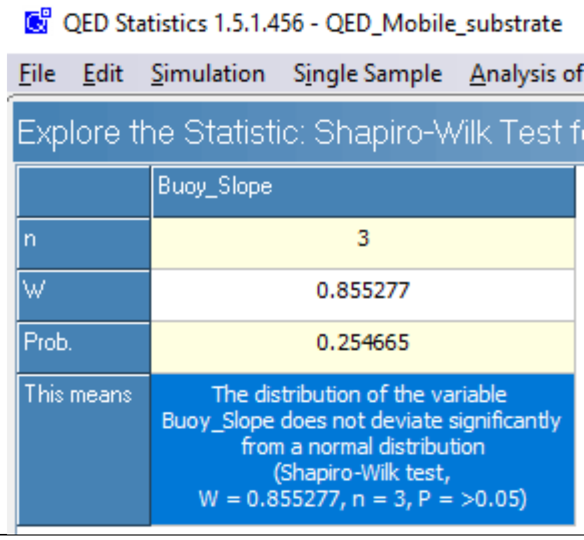
Assumptions

To carry out two-way ANOVA, three assumptions must be met:
Assumption 1: all samples must be independent to each other. Met. Site and Habitat were independent.
Assumption 2: Data must be normally distributed. Met. Data are normally distributed.

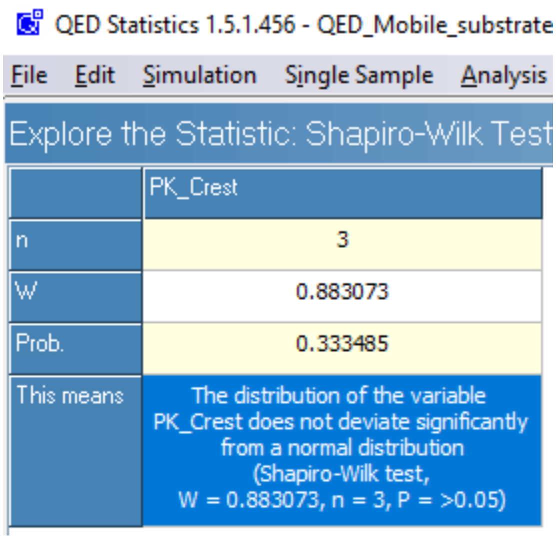
(a)



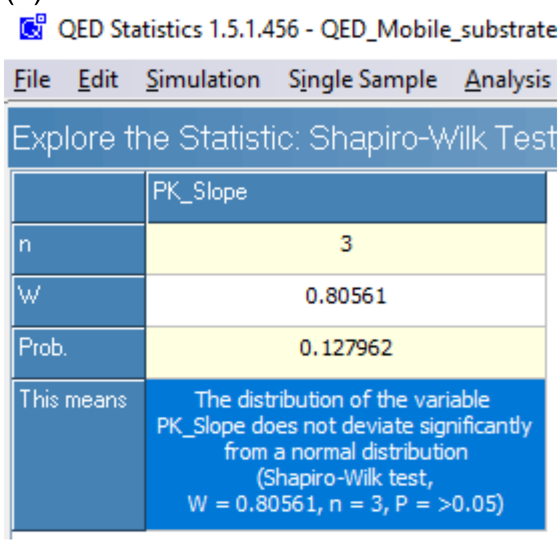
(b)



(c)



(d)



(e)

(f)

QED Statistics 1.5.1.456 - QED_Mobile_substrate

File Edit Simulation Single Sample Analysis of

Explore the Statistic: Shapiro-Wilk Test fo

	Ridge_Crest
n	3
W	0.974448
Prob.	0.69339
This means	The distribution of the variable Ridge_Crest does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.974448, n = 3, P = >0.05)

QED Statistics 1.5.1.456 - QED_Mobile_substrate

File Edit Simulation Single Sample Analysis of

Explore the Statistic: Shapiro-Wilk Test fo

	Ridge_Slope
n	3
W	0.934307
Prob.	0.504965
This means	The distribution of the variable Ridge_Slope does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.934307, n = 3, P = >0.05)

(g)

QED Statistics 1.5.1.456 - QED_Mobile_substrate

File Edit Simulation Single Sample Analysis of Fr

Explore the Statistic: Shapiro-Wilk Test for

	Sampela_Crest
n	3
W	0.990015
Prob.	0.80884
This means	The distribution of the variable Sampela_Crest does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.990015, n = 3, P = >0.05)

(h)

QED Statistics 1.5.1.456 - QED_Mobile_substrate

File Edit Simulation Single Sample Analysis of Fre

Explore the Statistic: Shapiro-Wilk Test for

	Sampela_Slope
n	3
W	0.951143
Prob.	0.574335
This means	The distribution of the variable Sampela_Slope does not deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.951143, n = 3, P = >0.05)

Appendix 11.1. Shapiro-Wilk test proved all data in normality with all P values>0.05 (a) Buoy and crest, P=0.637. (b) Buoy and slope, P=0.255. (c) Pak Ksim and crest, P=0.333. (d) Pak Ksim and slope, P=0.128. (e) Ridge and crest, P=0.693. (f) Ridge and slope, P=0.505. (g) Sampela and crest, P=0.809. (h) Sampela and slope, P=0.574.

Assumption 3: all samples must have equal variance. Not met. Site and Habitat had unequal variance by Bartlett's test, P=1.08x10^{-6} < 0.05

	Homogenity of Variance Tests		
Test	Statistic	DF1	DF2
Hartley Fmax	362.848	8	2
Cochran C	0.447448	8	2
Bartlett Chi-square	42.5471	7	
Bartlett Probability > Chi-Square	1.07933E-006		

Appendix 12. Two Way ANOVA’s Rock of benthic composition among sites

Assumptions

To carry out two-way ANOVA, three assumptions must be met:
Assumption 1: all samples must be independent to each other. Met. Site and Habitat were independent.
Assumption 2: Data must be normally distributed. Not met. (PK Slope) was not in normality, $P=-8.57 \times 10^{-7} < 0.05$ (Figure xx). So, arcsine squareroot transformation was required (Figure xx). However, transformed data was not in normality.

QED Statistics 1.5.1.456 - QED_Rock

File Edit Simulation Single Sample Analy

Explore the Statistic: Shapiro-Wilk Te

	PK_Slope
n	3
W	0.75
Prob.	-8.57151E-007
This means	The distribution of the variable PK_Slope does deviate significantly from a normal distribution (Shapiro-Wilk test, W = 0.75, n = 3, P = <0.05)

Appendix 12.1. Normality test (Shapiro-Wilk Test) showed one of raw data (PK Slope) was not in normally distributed.

Working Data

	Buoy_Crest	PK_Crest	Ridge_Crest	Sampela_Crest	Buoy_Slope	PK_Slope	Ridge_Slope	Sampela_Slope
Row 1	0.606374	0.484333	0.491182	0.364673	0.393713	0	0.102909	0
Row 2	0.643812	0.322938	0.314955	0.591169	0.75224	0.0455456	0.205569	0.163763
Row 3	0.492158	0.647759	0.34508	0.533595	0.805812	0	0.20085	0.56158

Appendix 12.2. Arcsine Squareroot transformation on all variables.

Appendix 13. Pearson’ / Spearman Correlation table

Test target	Site		Data transformation		Normality		Equal variance	Pearson test if equal variance and normality; Spearman test if unequal variance or not normality	Correlation (Yes/No)
	(i)	(j)	(i)	(j)	(i)	(j)			
Algae vs Grazers	Sampela	Pak Ksim	Arcsine Squareroot	log	Y	Y	Y	r=-0.636644, t=-1.65114, df=3, p=0.1741>0.05	N
	Sampela	Buoy	Arcsine Squareroot	log	Y	Y	N	r=-0.428571, df=6, p>0.05	N
	Sampela	Ridge	Arcsine Squareroot	log	Y	Y	N	r=-0.3, df=5, p>0.05	N
	Pak Ksim	Buoy	Arcsine Squareroot	log	Y	Y	Y	r=-0.5057, t=-1.17221, df=4, p=0.3062>0.05	N
	Pak Ksim	Ridge	Arcsine Squareroot	log	Y	Y	Y	r=-0.3279, t=-0.6011, df=3, p=0.590>0.05	N
	Ridge	Buoy	Arcsine Squareroot	log	Y	Y	Y	r=-0.8076, t=-2.3715, df=3, p=0.0984>0.05	N