The ecological state and fishing practices of coral reefs in South Buton

Thesis submitted by

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I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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STATEMENT ON THE CONTRIBUTION OF OTHERS

This thesis has been made possible through the contributions of many people, as follows:

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ABSTRACT

The Coral Triangle in South East Asia hosts coral reef ecosystems capable of supporting and securing the livelihoods of millions of people due to its high biological productivity and diversity. However, for many areas such as those found in South East Sulawesi, Indonesia, there is a dearth of socio-ecological information concerning reef condition and associated fishing practices. Coral reefs are currently under threat from anthropogenic and natural stressors, therefore it is vital to provide reef managers with reference point socio-ecological data to aid them in designing and implementing strategic reef management plans. Four standard ecological indices – benthic composition, fish biomass, invertebrate abundance, and reef structural complexity – were used to explore reef conditions in the southern point of Buton Island, Indonesia, using diver-operated stereo video systems. Fishing practices in the region were evaluated with 15 minute face-to-face surveys with fishers. Overall, the coral reefs in South Buton were found to be in relatively 'good' ecological condition (using coral cover as the primary indices where 51-75% as defined by Suharsono (1998) for Indonesian coral reefs), with one reef (Pulau Ular) exemplary in coral cover. In contrast, there were reefs (namely Nirwana) showing signs of substantial degradation with rubble and sand dominated habitats that hosted very few fish and invertebrates of importance to fishers. Furthermore, coral reefs in South Buton compared favorably to those in the neighboring region at Wakatobi National Park, where longer term management actions have ensured habitat protection, as well as food and livelihood security.

The fishing practices of South Buton communities were characterized by fishing focused on off shore pelagic fish rather than on reef associated species. Maintaining high diversity and abundance on South Buton reefs may therefore not require substantial interference with current fishing practices. In particular, my conclusions suggest that it is not necessary to designate the entire study area as a no-take marine park zone. For future reef management plans in the South Buton region, the work herein illustrates the benefits of evaluating local

community perceptions and needs early in the management-planning phase. Importantly, this thesis provides a reference point of socio-ecological data from which a fixed long-term monitoring program of reef health can build upon, and which should underpin any successful management actions.

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LIST OF ABBREVIATIONS

COTS	Crown of Thorns Starfish
EM	EventMeasure
FB	Fish Base
GBR	Great Barrier Reef
GIS	Geographic Information Systems
LIT	Line Intercept Transect
MDS	Multidimensional scaling
OPWALL	Operation Wallacea
SPSS	Statistical Package for the Social Sciences
SVS	Stereo Video System
SWD	Shannon-Weiner diversity index
UVC	Underwater Visual Census
WIO	Western Indian Ocean
WNP	Wakatobi National ParkWWF World Wildlife Fund

CHAPTER 1

GENERAL INTRODUCTION

Coral reefs are one of the most productive and diverse ecosystems on the planet, holding over 25% of marine life within only 0.2% of the ocean area (Hoegh-Guldberg 1999). They are home to a large variety of organisms and vary greatly in structure and composition. Tropical coral reefs contribute an estimated $375 billion in annual goods and services globally (Costanza et al. 1997), and have long been supporting the livelihood of millions of people; especially those engaged in fisheries activities. As a result, reef ecosystems are vulnerable to natural and anthropogenic stressors, such as overfishing (Jackson et al. 2001), climate change (Hoegh-Guldberg et al. 2007b), and disease (Hughes et al. 2003). These stressors can have lasting effects on reef health; however, high biodiversity has been shown to safeguard reefs from such threats by increasing redundancy and the way a functional group can respond to change (Nyström 2006, Cole et al. 2008). On the other hand, there is research to suggest that high-diversity systems in particular high diverse reef fish assemblages are actually more vulnerable to anthropogenic stressors (Mora et al. 2011). Unfortunately, cumulative impacts on the reefs over time have led to them becoming a threatened resource (Graham et al. 2006, Munday et al. 2008) and thus endangering an estimated 400 million people who rely on reef fisheries for their protein and mineral intake (Dulvy and Allison 2009). Defining the condition of global coral reefs remains a dearth of information in the last decade and the last world report was conducted in 2008. This 2008 world coral reef status report showed that 19% of coral reefs have effectively been lost and 35% more are seriously threatened with complete degradation (Wilkinson 2008). These figures however are likely worsened as reef systems such as the Great Barrier Reef (GBR) are experiencing threatening events as seen in 2016 - which showed <9% of reefs had no bleaching occurrence (Hughes et al. 2017a). In the Caribbean, the latest status report (2012) revealed that more than 50% of these regions reefs had declined since the 1970s (Network 2014). Across in the coral triangle, more than 85% of reefs are currently threatened by local stressors, which is substantially higher than the global average of 60% (Burke et al. 2012). All these decreasing reef condition reports will result in devastating consequences for local and global communities (Clifton and Majors 2012, Cinner 2014).

The Coral Triangle of South-East Asia is home to 75% of known coral species and over half of the world's reefs (Cesar et al. 2003). It is recognized primarily for its high global biological productivity and diversity in reef composition (Geider et al. 2001), which provides food security and livelihoods to millions of people (Cesar et al. 2003). Therefore, loss of reef can have serious socio-economic effects (Cesar et al. 2003). Countries situated within the Coral Triangle, such as Indonesia, are at threat from phase-shift phenomena such as changes from being coral-dominated to algal-dominated due to anthropogenic impacts (Done 1992, Bellwood et al. 2004, Hughes et al. 2010). Particularly, Indonesia is forecast to have reductions in fishery yields of 20% per annum, with subsequent loss of livelihoods under current predictions of climate change trends (Cheung et al. 2010). By understanding the ecological condition of coral reefs and their associated fisheries, the human communities that depend upon them may be better managed so that biological reductions in species catch yield are mitigated, which is essential for maintaining a sustainable economy.

Studying the ecological condition of reef communities can serve as an important tool for reef managers in distinguishing reefs and setting targeted, conservation-led initiatives for the protection of reef resources (Clifton et al. 2012). However, there is a dearth of information on the ecological condition of many coral reefs, particularly those situated within the Coral Triangle (Clifton et al. 2013). Furthermore, studies across the Coral Triangle - in particular those focusing on remote communities (i.e. South East Sulawesi, Indonesia) - reveal high dependence on fishing as a primary source of income, underscoring the need for healthy coral reefs and associated fisheries (Crabbe and Smith 2002, Exton and Smith 2012, McMellor and Smith 2013, Exton et al. 2014). There is a large body of information regarding social systems and fishing practices particularly in South

East Sulawesi and much of it has been conducted in the Wakatobi National Park (WNP) (Flint 2002, May 2005, Cullen 2007, Majors 2008). However, there is still research to be conducted in other neighbouring communities to the WNP. By doing so, it is possible to narrow the gap in our understanding towards the needs (i.e. livelihoods) of the communities associated to the reefs and how these are reflected in the way they use them (Hughes et al. 2005).

By investigating social dimensions, such as fishing practices, reef managers are able to increase the effectiveness of protecting the ecological condition of coral reefs (Bruner et al. 2001). However, social-ecological relationships are complex and often mismatch in our presumptions of how one affects the other (Liu et al. 2007). For example, a study in the Philippines found a positive relationship between high coral condition (i.e. health), and increase of fisher population density (Pollnac et al. 2000). More recently, it was discovered that fish biomass was higher in places with high population growth, however likely due to human migration to an area of better environmental quality (Wittemyer et al. 2008) which overtime could degrade the site (Cinner et al. 2016). Most studies would hypothesize the opposite to occur; when fisher population is low, coral condition is high (Birkeland 1997). These findings correlate with human-ecological theories: Higher populations are found where there is access to good resources. Fishers' usage of boats has for a long time allowed them to migrate to more fish abundant areas, as historically studied amongst Bajau communities in Indonesia (Shepherd and Terry 2004). However, in our ever-changing world where untouched resources are now scarce (WRI 2005), the reality is that coastal communities with high reliance on reef resources are less likely to have the option of migrating to areas with better resources (Piguet and Laczko 2013). This coupled with increasing populations leads to natural resources eventually reaching a maximum carrying capacity, consequently negatively impacting those resources and causing shifts in ecosystem functionality and overall condition (Birkeland 1997). Without first understanding the social, cultural, economic, political and ecological systems and the way they interact, effective resource management and conservation strategies may not be implemented (Bruner et al. 2001, Cinner et al. 2005, Ban et al. 2011).

To help balance conservation and livelihood needs a social-ecological approach is needed. Just understanding the ecological condition of coral reefs, and trying to manage it from only that perspective has been proven to be unreliable (Norström et al. 2016). By understanding human involvement managers can begin to safeguard a community's basic needs (i.e. livelihoods) and consequently increase compliance from local communities towards conservation incentives (Maslow and Lewis 1987). However, many studies have proven that compliance within reef fisheries is not determined by any single factor but by a combination of complex socio-economic conditions (Liu et al. 2007, Pollnac et al. 2010, Cinner et al. 2012). As such, there is no one perfect answer for reef management, but rather a combination of techniques should be used as tailored to that specific fishery. This was widely investigated in a recent study looking at the ecological performance of 56 marine reserves throughout the Philippines, Caribbean and Western Indian Ocean (WIO), as measured by comparing fish biomass in reserve and nearby non-reserve areas (Pollnac et al. 2010). It found that compliance and human population where the most influential factors on fish biomass, but not to the same degree for each region. The author's results specifically showed that population density effect on fish biomass was negatively correlated in the Caribbean, positive in the WIO, and uncertain in the Philippines. On the other hand, compliance by resource users was only positively correlated to the marine reserves ecological performance in the Caribbean (Pollnac et al. 2010). The high levels of compliance found within the Caribbean region were attributed to a variety of factors; notably, the involvement of the local community in the ecological monitoring program and regular consultation processes. This is a key socioeconomic principal for the success of a region's resource protection developed by Dr. Elinor Ostrom; stating the importance of *"ensuring that those affected by the rules can participate in modifying the rules"* (Ostrom 2015).

However, if done incorrectly, collaborations between resource users and decision makers can have negative outcomes (Cinner et al. 2012). Portrayal of fisheries as unmanaged, lacking in regulations or simply non-existing is a dangerous assumption. The degree of success in managing ecosystems depends on how external government systems supported by science-based management are introduced to collaborate with local resource users. In order to avoid a conflictive scenario both in large and small-scale fisheries a co-management approach is needed. Ideally, the already existing local management practices are used as a basis from which to build upon leading to less conflictive scenarios (Ferse et al. 2010). When this does not happen, there is a lack of participation and compliance from both parties (Turner et al. 2016). For example, in Northern Norway, Sami people struggled to secure fishing rights for their accessible in-shore waters. This came as a result of implementing regulations that did not incorporate local fisheries historical and cultural use of resources (Søreng 2013). Similarly, the conflict between EU management institutions on existing Spanish fishers regulations who have proven historical effective models (Symes and Phillipson 1999). Fishing is a historical industry, attached with generations of knowledge, resource management, and cultural significance, and overall provides security for millions. This historical value ought to be part of the conversation when addressing the needs of local communities usage of coral reefs.

The following study takes place in Sulawesi island, which is the fourth largest in Indonesia (area of 159,000 km^2) and lies between Borneo and the Moluccas Islands. Sulawesi is also situated on the Wallacea Line, which distinctly marks the transition of flora and fauna between Asia and Australia, and thus is of great importance in terms of biodiversity, evolutionary biology, and biogeography (Brodie et al. 2018). The present study was concentrated around South East Sulawesi in the southern Point of Buton Island (the most southerly point of mainland Sulawesi). South Buton contains three major regions; Bau Bau, Kadatua and Siompu, as well as a wide variety of fringing reefs (herein referred to as the "study area") covering 550 km^2 (Fig. 1.1). It encompasses 4,640 km^2 in land area, and hosts a human population of approximately 450,000 (Martin et al. 2012). This research was funded by James Cook University alongside in collaboration with multiple universities and high schools driven by the on-site research organisation, Operation Wallacea (OpWall), whose long-term presence in the region has resulted in the creation of a number of sustainability projects and community enforced nature parks.

The overarching aim of this thesis was to establish a reference point of ecological reef condition and associated fishing practices, which can then be used to inform and monitor future management efforts. The overall goal of Chapter 2 was to survey the diversity, abundance, and distribution of benthic habitats and fish, and invertebrate communities of the study area, with additional measurements on structural complexity. Subsequently, using these four ecological measures, this chapter aimed to explore spatial differences amongst the six studied reefs to understand the ecological drivers that dictate reef state in this region. Chapter 3 aimed to ascertain the fishing practices characteristics occurring in the same study area. This involved investigating: fisher's occupational diversity, fishing location, seasonality, gear use, frequency and targeted species. Chapter 4 discusses the implications of the previous two chapters to investigate the convergence between social and biophysical/ecological data, therefore presenting a series of discussion topics, which can be used to influence management decisions for local fisheries. It also uses data from the WNP as a benchmark of local reef management outputs in S.E. Sulawesi.

This region of S.E. Sulawesi remains to some degree understudied, with most research focused on terrestrial ecology of the local rainforest (Martin and Blackburn 2014). The marine ecosystems in South Buton have been previously surveyed through efforts by COREMAP (Coral Reef Rehabilitation and Management Program – Coral Triangle initiative); a $53 million program with the aim to develop a community-based approach to sustainable coastal resources planning and management (COREMAP 2014). Monitoring program leader Tri Aryono Hadi carried out a baseline study of South Buton coral reefs in June 2016, a year after this thesis study, and through personal communication with Mr Aryono Hadi, I was made aware of two additional baseline studies (Tuti 2013, Aryono Hadi et al. 2017). All three studies are not publicly available; however contain a large dataset of information regarding the condition of the reefs in South Buton and nearby areas. Whilst this is crucial for future survey efforts, the coral reefs surveyed under COREMAP were at times different to the ones in this study. Furthermore, personal communication with other local stakeholders in South Buton revealed that Pertamina (an Indonesian state-owned oil and natural gas corporation based in Jakarta) were conducting coral reef condition surveys on similarly located reefs to the ones presented in this study. Their aim is to investigate whether the presence of their oil and gas tanks in the region had a harmful effect on the reef. These studies likewise are unavailable publicly. If anything, the presence of studies in this region regarding the ecological condition of coral reefs demonstrates a necessity to consolidate data for future studies.

The research presented in this thesis will therefore generate novel information concerning marine resources in the region, namely the coral reef structure and composition as well as the fishing activities from the local fishing community. For the broader international scientific community, this research provides a reference point of ecological and social information about South Buton's coral reefs, which can be used to further advance our knowledge of reef state drivers or fishing activities. For local decision makers, this research will aid them with designing and implementing strategic reef management plans.

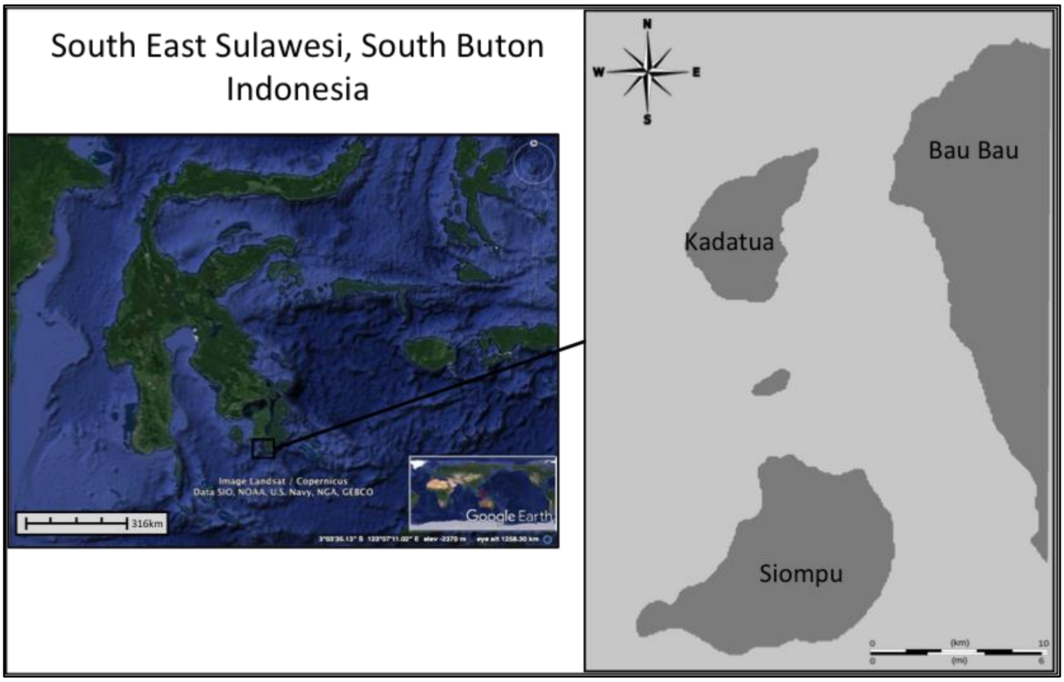


Fig. 1.1: Site location of South Buton Island in South East Sulawesi. Topographic location map created with Google Earth Maps and GIS (ArcMap).

CHAPTER 2

THE ECOLOGICAL STATE OF CORAL REEFS IN SOUTH BUTON, INDONESIA

2.1 Introduction

Before management implications and future research directions can be drawn, a reference point survey on the ecological condition (or state) of the reef is required. In order to do so, data on the condition of the reef's biota is needed. Reef state is characterized by the ecological condition of the biota. Pandolfi et al. (2003b) provided seven categories of biota on a reef (e.g. Corals, suspension feeders and large herbivores), which are assessed individually and then combined to characterize an overall reef status. Many reef evaluation studies have only focused their assessment of coral reef benthos, with scant attention to fish assemblages and mobile invertebrate richness (Fox and Bellwood 2007). However, in order to understand the ecological state of reefs and their associated communities all three groups of biota (benthos, fish and mobile invertebrates) as well as measures of topographic complexity are recommended (Hill and Wilkinson 2004). In my study I measure the biota in four ways: firstly, benthic community composition; secondly, the fish assemblage structure; thirdly, the non-coral invertebrate community structure; and lastly, an abiotic factor, which was the structural complexity of the reef. With this reference information, it will be possible to begin to evaluate reef change.

Studying the benthic composition of reefs primarily includes differentiating the percent cover of live biota to abiotic substrates. The key measure used to compare reef condition globally is percent cover of scleractinian coral cover or 'live hard coral' (Wilkinson 2006). Hermatypic corals provide reef growth through skeletal limestone formations (Hoegh-Guldberg et al. 2007a), which in turn create shelter and food security for thousands of non-coral invertebrate and fish species (Gardiner and Jones 2005, Vroom and Braun 2010). Studying not only the percentage cover coral habitats have across a reef, but also including inherent attributes such as growth form and / or species diversity can be fundamental. Reef fish are often dependent on particular species and / or morphologies of live corals (Jones and Syms 1998, Holbrook et al. 2003) such that accurate assessment of a reef's ecological function requires more detailed descriptors than just percent live coral cover. Furthermore, anthropogenic influences such as fishing can directly affect benthic composition and habitat structure (e.g. (Edinger et al. 1998). By monitoring the diversity and abundance of benthic taxa, changes in the condition of the substrate over time can be assessed and indicate the overall status of a reef's health. However for many reef regions this level of data remains unavailable.

When the type of benthic habitat is diverse (e.g. lots of different shelter sizes and shapes) a greater diversity of fish can ensue. This is largely attributed to the growth form of coral species. For example, large table top corals and overhangs of mounding corals provide shelter to larger bodied species (i.e. > 30cm in length species of Serranidae, Lutjanidae, Ephiphidae), while complex branching corals often host multiple species of smaller taxa (i.e. < 10cm in length species of Gobiidae, Pomacentridae, Apogonidae) (Wilson et al. 2007, Kerry and Bellwood 2012). In contrast reefs devoid of major architectural features, such as those on sandy or loose substrate slopes, or in heavily degraded areas where coral structures have been destroyed and not recovered, typically host depauperate fish assemblages. This was highlighted in a 1981 study across four fringing reefs in the Philippines. Results indicated that sandy substratum was always negatively correlated with fish abundance, which was correlated with greater complexity of substrate type, namely corals (Carpenter et al. 1981). Therefore, a diverse and complex benthic habitat clearly has direct benefits for the fish assemblages and thereby for overall reef state.

Assessing the abundance, diversity, biomass and size structure of reef fish assemblages provides detailed indicators of reef ecosystem resilience and the effects of fishing. Healthy fish assemblages are particularly important for maintaining reef state because they help control algal over-growth (Hughes et al. 2007) and outbreaks of corallivorous invertebrates (e.g. crown of thorns, (Cowan et al. 2016)). Maintaining reef state is largely attributed to the functional roles of certain species such as herbivores, which are able to increase the resilience of reefs to global climate change, and can reverse declining reefs back into more productive systems (Rasher et al. 2013, Rogers et al. 2014). A study by McClanahan et al. (2011) suggests that macroalgal-dominated sites may become more prevalent as fish biomass decreases; indicating early warning signs of change towards a more degraded reef system. Their results show that below 1,130 kg ha^{-1} of herbivorous fish, macro-algae to hard coral becomes more variable and that below 850 kg ha^{-1} the ratio of macro-algae to hard coral changes. In contrast, Seychelles reefs protected from fishing enhanced their herbivore biomass (2005 values: 279 kg ha^{-1} ± 21.5SE) compared to fished areas (mean 163 kg ha^{-1} ± 58.6SE) (Selig and Bruno 2010) with positive effects on overall reef state. Predicted reductions in fishery yields from global climate change and other anthropogenic impacts will have devastating effects on livelihoods if not managed appropriately and prevented where possible. Such a task requires accurate assessments of local fish populations, including targeted reef fish taxa. Where fishing activities have been reduced, there is evidence of less fish diversity loss (Russ et al. 2008), less composition shifts (Wilson et al. 2010), less size structure shifts (Dulvy et al. 2004a) but also many positive impacts of effective management regimes (Russ et al. 2003).

Studies assessing the status of non-coral invertebrate communities are rare, particularly compared to fish and coral community assessments. This is likely due to the inherent difficulty in assessing cryptic organisms (Bouchet et al. 2002). Nevertheless, invertebrate communities have strong symbiotic relationships with the reef benthos, which impact the overall health of reef ecosystems. Crown-of-thorns starfish (*Acanthaster plancii*) are renowned for their capacity to devastate coral assemblages (Moran 1986, Babcock et al. 2016), and henceforth cause declines in other reef communities (Kayal et al. 2012). Invertebrates are key prey items for many reef fish species. For example, crustaceans are consumed by invertebrate guild species such as squirrel fishes and wrasses (Shepherd and Clarkson 2001). Changes in invertebrate prey abundance have been shown to drive reef state transformations. For example, on reefs in Kenya, increase in the abundance of sea urchins (*Echinometra mathei*) due to fishing activities on their major predators; triggerfish and wrasse drove a decline in coralline algal cover. This then led to declines in coral recruitment followed by a reduction in net calcification, reef stability, growth and overall resilience (O'Leary and McClanahan 2010). Thus, measuring changes in the abundance and composition of invertebrate taxa is an important component for identifying, predicting and henceforth managing the drivers of coral reef ecosystem state.

Structural complexity as defined by Graham and Nash 2013, is the physical three-dimensional structure of an ecosystem (Graham and Nash 2013). The degree of a reef's structural complexity is largely formed by geological features and skeletal structures of organisms (Kleypas et al. 2001). It is important as it has been shown to create microhabitats that in turn increase diversity of associated organisms (Komyakova et al. 2013). Loss of structural complexity has been shown to have a wide impact on reef organisms such as fish (Graham et al. 2006), such that incorporating structural complexity into reef state surveys is highly encouraged (Feary et al. 2007).

Examples where complexity measures are incorporated into monitoring studies have demonstrated the value of including this variable. In the Caribbean, structural complexity loss over the last 40 years has had a profound effect on reef state (Alvarez-Filip et al. 2009). Anthropogenic pressures shifted reefs to less complex, stress-dominant coral species, which consequently forecast long-term declines in fish abundance affecting the food security for millions of people (Alvarez-Filip et al. 2009). While structural complexity is typically positively correlated with fish biomass and density (Graham and Nash 2013), for other taxa an increase in complexity can be detrimental. For example, in Puerto Rico, a study by Weil et al. (2005) showed that sea urchin (*Diadema antillarum*) abundance and aggregations were higher in low complexity habitats.

Incorporating reef complexity into status reports is therefore valuable for determining and modelling ecosystem condition in a more holistic way.

In order to evaluate the condition of a reef, and to begin establishment of a long term monitoring program a current reference point of ecological data is needed. To ascertain the reef condition, results of the current reef state can be compared to other benchmarks on reef health and to reefs nearby. Eventhough, COREMAP have carried out surveys in the region, the data remains largely inaccessible. For that reason this study uses another proximal area where substantive research and monitoring of reef condition has been carried out; Wakatobi National Park (WNP) for comparison (Clifton et al. 2013). The condition of WNP reefs can serve as a useful comparative benchmark for South Buton.

This chapter evaluates the ecological condition of fringing coral reefs in South Buton, South East Sulawesi, Indonesia. I compare reef condition spatially, investigating reef community differences among several fringing reefs. I investigate the relative abundance and composition of the benthic community (incl. Scleractinian taxa), the mobile non-coral invertebrate fauna, and the reef fish assemblage and the relationship between all three communities. By doing such, this work presents the first quantitative evaluation of reef ecosystems in the South Buton, which will form the basis of ongoing monitoring and reef management regimes in the region.

Specifically, I hypothesize that the ecological condition of South Buton reefs will be similar to that of neighboring regions where long-term reef assessments have been conducted, namely the Wakatobi region, South East Sulawesi. However, due to the higher population density and presumably higher fishing activities on South Buton reefs, overall reef state is expected to be somewhat poorer. Furthermore, within South Buton reef areas are expected to differ in benthic habitat composition due to pilot surveys conducted in June 2014, which will in turn drive much of the differences in fish community assemblage.

2.2 Materials and methods

2.2.1 Study site

Surveys were conducted at six fringing coral reef sites. Three of these were located along the coastline of the Bau Bau region (Pampanga, Nirwana and Moko reef), one on Kadatua island (Kadatua reef), one on Snake island (Pulau Ular reef) and one on Siompu island (Siompu reef) between June - August 2015. Hard coral cover and sandy/rubble patches dominated the area. The most prevalent coral genera were *Acropora* and *Porites*, and the most dominant fish were planktivorous pomacentrids. Pampanga, Kadatua and Pulau Ular reefs reach maximum depths of 50-70m whereas Nirwana, Moko and Siompu reach 30-40m where the seabed levels off (Fig 2.1).

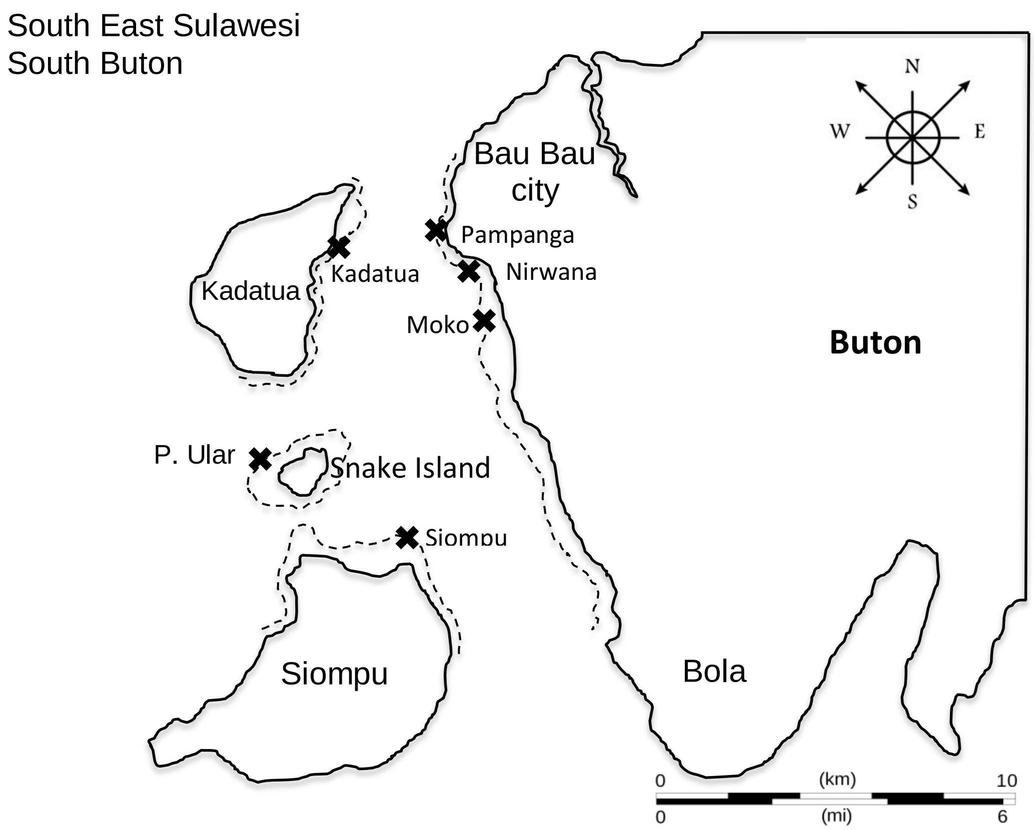


Fig. 2.1: South Buton map depicting reef location (marked **x**) created with Adobe Photoshop through trace and Google maps. Dotted lines represent reef crest.

Reef descriptions are as follows: Pampanga reef is characterized by large drop offs between the crest and slope and high currents during tidal periods. Nirwana reef is situated just offshore from Nirwana beach, characterized by large areas of sand and sea grass with patchy coral outcrops as well as two artificial reefs and a low depth gradient between reef zones. Moko reef follows typical reef contours with moderate transitions between zones and a large intertidal rocky shore. Siompu, likewise to Moko has a moderate gradient between zones, close proximity to the islands main harbor and a frequently exposed reef flat at low tides. Pulau Ular reef encircles Snake Island (uninhabited 1.5km^2), with deep reef slopes and several hundred-meter long coral reef ridges that extend out from the crest. Lastly, Kadatua reef located at the islands eastern 40m high cliffs has steep drop-offs mirroring those found in Pampanga. Figure 2.2 shows typical reef contour for the six surveyed reefs.

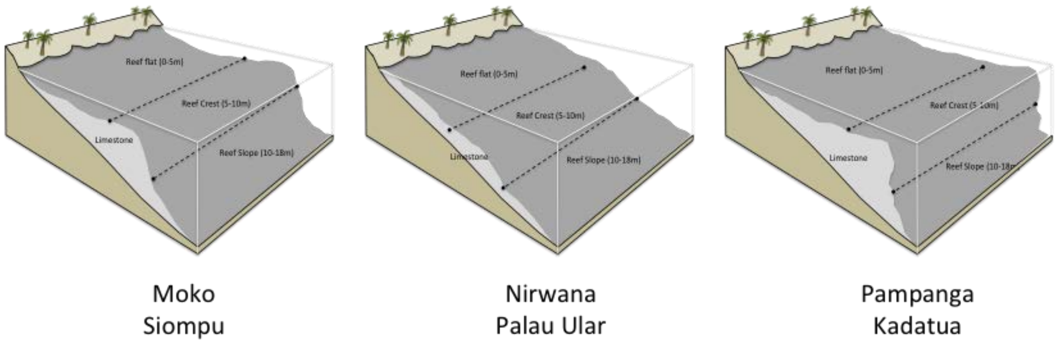


Fig. 2.2: Typical fringing reef zonation found across South Buton and associated surveyed reefs.

2.2.2 Sampling Design

It's important to survey a variable reef system as it provides a better representation of the area of interest methods (Hill and Wilkinson 2004). In order to do so, pilot surveys on Manta tow were conducted in June 2014 to provide rapid characterization of the reef habitats. This allowed for informed decisions to be made regarding the implementation of fixed reef monitoring sites. This pilot work revealed reefs along Northern points of South Buton had higher structural complexity than those found in the South (deep, overhanging reef systems). Furthermore, coral, invertebrate and fish community structures varied in diversity and abundance. As a consequence, from over 15 differing preliminary surveyed reefs, 6 were chosen that could illustrate the range of reef states and fulfill monitoring efforts. Figure 2.1 illustrates location and relative distance between sites.

Surveyed reefs represent a range in reef condition from healthy to moderately impacted reefs (based primarily on benthic composition and species indicators of reef health). Within the group, replication of typical reef zonation is included. 2 reefs are slowly sloping fringing reefs, 2 are moderately sloping with overhangs and 2 have sudden drop-offs (i.e. reef flat and walls, with high gradient slope zone) (Fig. 2.2). At each site surveys were be done on the reef flat (0-5m), reef crest (5-10m) and reef slope (10-18m) to ensure future survey efforts (after this thesis) can build upon and test the effects of depth on species composition over time. Belt transects (50m long x 5m high x 5m wide) were used to assess fish and invertebrate community indices, and 50m point-intercept transects were be used to assess the benthos. Four replicate 50m transects were conducted at each depth and location, with a 5-10m interval between replicates, and repeated annually (2015 and 2016). However, the lack of change seen, primarily due to insufficient temporal data, focuses results and findings in this thesis to be discussed on a spatial scale for only the 2015 data collection period.

Transects followed the reef contours and were surveyed simultaneously by teams of 4-6 members. Firstly, fish were surveyed by diver-operated stereo-video system (SVS; SeaGIS, Melbourne, Australia). Two or more other members of the survey team followed behind simultaneously surveying benthic habitats, invertebrate communities and abiotic factors. Second divers were responsible for distance measurement by giving a fin tug to indicate the start and end of transect. Cameras in SVS were set to record and synchronized prior to dive in order to minimize fish disturbance. Contrary to reef crest or slope, the reef flat zone for Moko and Siompu reef always had to be surveyed on mid-high tides in order to avoid reef exposure. Finally, surveying times where randomized throughout the study period to reduce bias via fish community changes by time of day through diurnal migrations and tidal cycles (Hobson 1972, Domm and Domm 1973).

2.2.3 Benthic community

The benthic variables counted included the abundance and diversity of: scleractinian corals (growth form and genera included), soft corals, dead coral, algae, sponges, rock, sand and rubble. Coral growth forms were classified within the following criteria (branching, encrusting, columnar, tabulate, massive, mushroom and foliose) whilst taxonomic identity was limited to genus using primarily the Russell Kelley coral finder ID book (Kelley 2016) (Annex 6a). Four 50m line-intercept transects (at 25cm intervals) with 5-10m separation between each transect was laid out across each reef zone for the surveyed reefs resulting in a total of 804 surveyed points per reef zone (14,472 total surveyed points per year). Points were photographed using GoPro Hero 3+ cameras at 1080p 60fps mid-Fov settings. Swimming speed was equal to the fish surveyor (aprox. 50m/8min) and the camera lens held 20cm from transect tape. Finally, results were collated into three major life forms; Total live coral, total other live cover and total abiotic cover, presented through percentage cover.

2.2.4 Fish assemblages

Fish community assemblages were surveyed along four-50x5m Belt transects using Stereo-video (SV) equipment (Fig. 2.3). SV equipment was used because it is quick, efficient and allows comparison among multiple surveys and surveyors with very low error estimates (mean error using SVS: 0.6cm, compared to mean error using Underwater Visual Censuses (UVC): 2.3cm (Harvey et al. 2001)). In addition SV provides an excellent archive of video data for long-term monitoring assessments. Stereo-Video surveys work by using two cameras operating independently, mounted on plates at fixed angles, ensuring correct alignment is maintained throughout the dive. A diode in the center of the apparatus helps synchronize the two images during later computer analysis. SV surveys were swum at speeds of approximately 50m/8min, following recommendations of Dominic Andradi-Brown. Studies have shown no significant differences in the survey results when transects are swum at 50m/2min and 50m/10min (Andradi-Brown et al. 2013). Both cameras used GoPro Hero 4 silver systems at 1080p 60fps mid-Fov settings. Fish identification was accomplished using Allen (2002).

After the footage was taken and extracted, 3D measurement software (EvenMeasure: SeaGIS) was used to collate the desired data. The software allows designations of transect boundaries (i.e. 5m width) and fish length (Standard length) and gives error estimates on all measurements. For each transect, the software was used to record these specific factors: Fish spp. ID (include all reef fish, including any associated marine mammal and reptile), abundance and length. All measurements within video frames are extracted and stored electronically in database format. Fish biomass estimates for each species were then extrapolated using species-specific weight constants from Fish Base (FB) (Froese and Pauly 2000). To allow for data analyses fishes where classified into six major trophic guilds: Piscivore, Invertivore, Planktivore, Herbivore, Omnivore and Corallivore (Annex 6c) determined by their feeding habits obtained through Fishbase (www.fishbase.org).

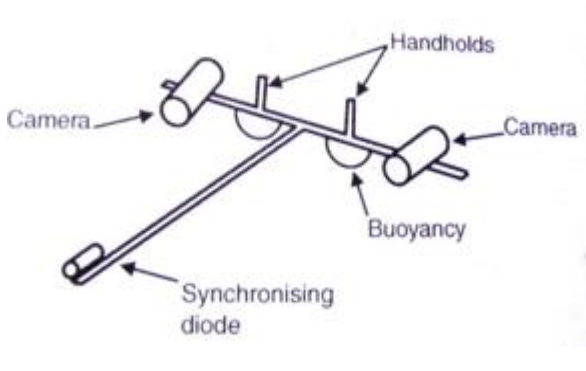


Fig. 2.3: Stereo-video apparatus uses two cameras mounted on either side of a metallic bar with a central diode extending in front of the cameras used to synchronize the video footage during analysis. *Img. From OpWall Cayos (2011) report.*

2.2.5 Non-coral invertebrate community

In-situ UVC documented the major invertebrate groups (Molluscs, Echinoderms, Crustaceans) and key predatory species (*Acanthaster planci* and *Drupella*) (Annex 6b). Divers swam along the same four 50x5m belt transects as fish and coral counts were done on, tallying sea cucumbers, lobsters, cleaner shrimps, giant clams, crown of thorns (COTs), nudibranchs, anemones, tritons and urchins. The tally system allowed for quick abundance counts; however, in exceptional cases where abundance of organisms exceeded 30+ within a $2m^2$ area (such as seen with urchins), surveyors estimated counts. This allowed for focus to be evenly distributed amongst all targeted species.

2.2.6 Abiotic factors and reef structural complexity

Secchi disc measurements were used in support of SV analysis in providing a semi-quantitative method of measuring light attenuation. Measurements were made through underwater diver census in buddy teams, in contrast to the typical deployment from the side of a boat. This way we reduce result bias that may arise from viewing the secchi disk above the water (from the boat) as light may reflect on the surface and distort the readings. Temperature was recorded from dive computers and tidal records collected (Annex 7A). Reef structural complexity was evaluated visually, based on 0-5 measurement scale where 0 = no vertical relief and 5 = exceptionally complex with numerous caves and overhangs (Polunin and Roberts 1993). Complexity, visibility, temperature and tidal records were collected for each replicate 50m transect.

2.2.7 Statistical analyses

SVS and benthic video analyses were begun on site by a team of research assistants (RAs) during the study period and finalized later by the principal researcher. RAs had to undergo extensive training prior to involvement in the monitoring team by completing a week long coral reef ecology course, with follow up in-water survey tests focused on identification of coral, invertebrate and fish taxa. Furthermore, RAs had to pass an Indo-Pacific marine fauna identification written exam at the end of the course (pass grade 80%) and all incorrect answers were discussed afterwards. RAs were also required to undergo training in the use of EventMeasure using sample transects and results later verified by the principal researcher. Whilst conducting fish analysis, RAs worked together in identifying fish with the use of a digital and hard copy of “Reef fish identification – Tropical pacific” (Allen 2002). All data were initially entered into Microsoft Excel spreadsheets with PRIMER software used for graphical and comparative analysis.

Fish length measurements were converted into biomass using equation 1.

$$(1)\ W = aL^b$$

Where *L* represents the fish length in millimeters, W the weight in grams and *a* and *b* published species-specific conversion constants from Fishbase.org. Where a direct conversion was not available (i.e. no data published), the next closest relative was used as a proxy, using taxonomy and making sure that species was also found in the same area of the world. Fish were then collated into feeding guilds and biomass weight calculated per hectare. Four 50 m long by 5 m wide by 5 m high belt transects were conducted at each zone separated by a 10 m interval giving a total of 1,250m^3 area per belt transect. This is equivalent to 0.125 hectares as per equation 2.

Transect area (m^3), was converted into hectares (ha^{-1}) using equation 2.

$$(2)\ 10{,}000\ m^3 = 1\ ha^{-1}$$

Species diversity, was calculated using the Shannon-Weiner index; equation 3.

$$(3)\ H = \Sigma i\ pi\ (\log pi)$$

I examined the diversity and evenness of fish species between reefs using the Shannon diversity index. Where *pi* represents the relative proportion of the number of species. This allowed me to compare species diversity among reef zones.

Multivariate analyses of variation in the fish community and benthic composition between reef zones was accomplished in the statistical software PRIMER-E (Plymouth Routines in Multivariate Ecological Research) v.6.7 (Clarke and Gorley 2006). For fish assemblage analysis, the four spatial replicates of each 50m transect were averaged to produce a single data point. Species biomass data as well as benthic composition cover was square root transformed to allow for normal distribution and to contribute to the determination of ranked similarities and a similar matrix was created using Bray-Curtis coefficients. Non-coral invertebrate community abundance was transformed ($\log^{10}$) to allow for both common and rare individuals to contribute to the determination of ranked similarities.

Biomass indices from the fish guilds and benthic cover across zones were visualized using two-dimensional non-metric Multi-Dimensional Scaling (MDS) plots and cluster analysis for determining group averages. MDS was used to investigate spatial differences of fish trophic guild composition at each reef zone using the Bray-Curtis similarity measure. Similarity profile (SIMPROF) permutation tests were used to underline at which point the cluster structure becomes different. BIO-ENV test in PRIMER was used to determine the most influential combination of environmental variables on the fish similarity matrix.

To examine patterns and describe relationships between fish biomass and other ecological measures, a regression approach (De'ath and Fabricius 2000) was used. Linear regression analyses were used to determine if fish biomass indices where associated (1) with hard coral cover, (2) structural complexity and (3) transformed non-coral invertebrate community abundance. Box plots were used to compare the mean biomass of individual planktivorous fish across reefs and reef zones. Individual planktivorous fish size records could potentially indicate whether in future studies, the size spectra was affected by anthropogenic disturbances such as fishing practices.

2.3 Results

2.3.1 Summary of ecological conditions

A total of 14,472 benthic life forms, 10,374 individual fish, 1,838 individual invertebrates and 72 structural complexity scores were derived from the 2015 reef surveys, presented as percentage cover, biomass, and abundance indices (Fig. 2.4).

Across the South Buton reef zones, live scleractinian coral cover averaged 49 ± 3SE%, 52 ± 4SE%, 45 ± 3SE% on the flat, crest and slope zones respectively (Fig 2.4). Other live cover averaged 16 ± 1SE%, 14 ± 1SE%, 16 ± 1SE% and abiotic cover averaged 35 ± 3SE%, 34 ± 3SE%, 40 ± 3SE% on the flat, crest and slope zones respectively (Fig. 2.4 and 2.6). Scleractinian coral growth forms were dominated by branching corals making up 23% of all coral cover (Fig. 2.6). Most branching corals were from species in the *Acropora* genus followed by foliose growth forms making up 8% of coral cover and led by species in the *Montipora* genus. Other live cover was mostly dominated by algae making up 9% of reef cover followed by soft corals accounting for 4% of reef cover (Fig. 2.7). Abiotic cover was dominated by sand making 18% of reef cover followed by 10% rubble (Fig. 2.4 and 2.8).

Across all reefs, accounting for all feeding guilds (Piscivore, Invertivore, Planktivore, Herbivore, Omnivore, Corallivore), the average reef fish abundance was made of 576 individuals ha^{-1} totaling 32.8 kg ha^{-1} of fish biomass (Fig. 2.4). Reefs were dominated by planktivorous fish (mostly damselfish, Pomacentridae), averaging 354 ± 112SE individuals ha^{-1} and a total biomass of 19.4 ± 4.1SE kg ha^{-1}, which represented 59.1% of average reef biomass (Fig. 2.4 and 2.10), followed by herbivores (mostly fish in the family Acanthuridae), which averaged 64 ± 4SE individuals ha^{-1} and a total biomass of 4.46 ± 0.56SE kg ha^{-1} (Fig. 2.4 and 2.10). However, omnivores had a higher average abundance of individuals; 82 ± 9SE ha^{-1}, but less overall biomass averaging 3.53 ± 0.47SE kg ha^{-1} (Fig. 2.4 and 2.10).

Non-coral invertebrates from nine targeted groups (sea cucumbers, lobsters, cleaner shrimps, giant clams, COTs, nudibranchs, anemones, triton and urchins) averaged a total of 102 individuals ha^{-1} across all reefs (Fig. 2.4). The most commonly found invertebrate were Diadema; sea urchins, which represented 32% of all found invertebrates followed by cleaner shrimp, which accounted for 22% (Fig. 2.4 and 2.12). Lobsters and tritons were the least common invertebrates, accounting for less than 1% of all invertebrate abundance across all reefs (Fig. 2.4 and 2.12).

Structural complexity scores (scale of 0-5) averaged 2.6 across all reefs (Fig. 2.4) representing reefs with numerous hiding holes for fish as well as overhangs and sudden drop offs. Surveys were done with average temperatures of 28°C, 12m visibility and medium tide heights (data not shown).

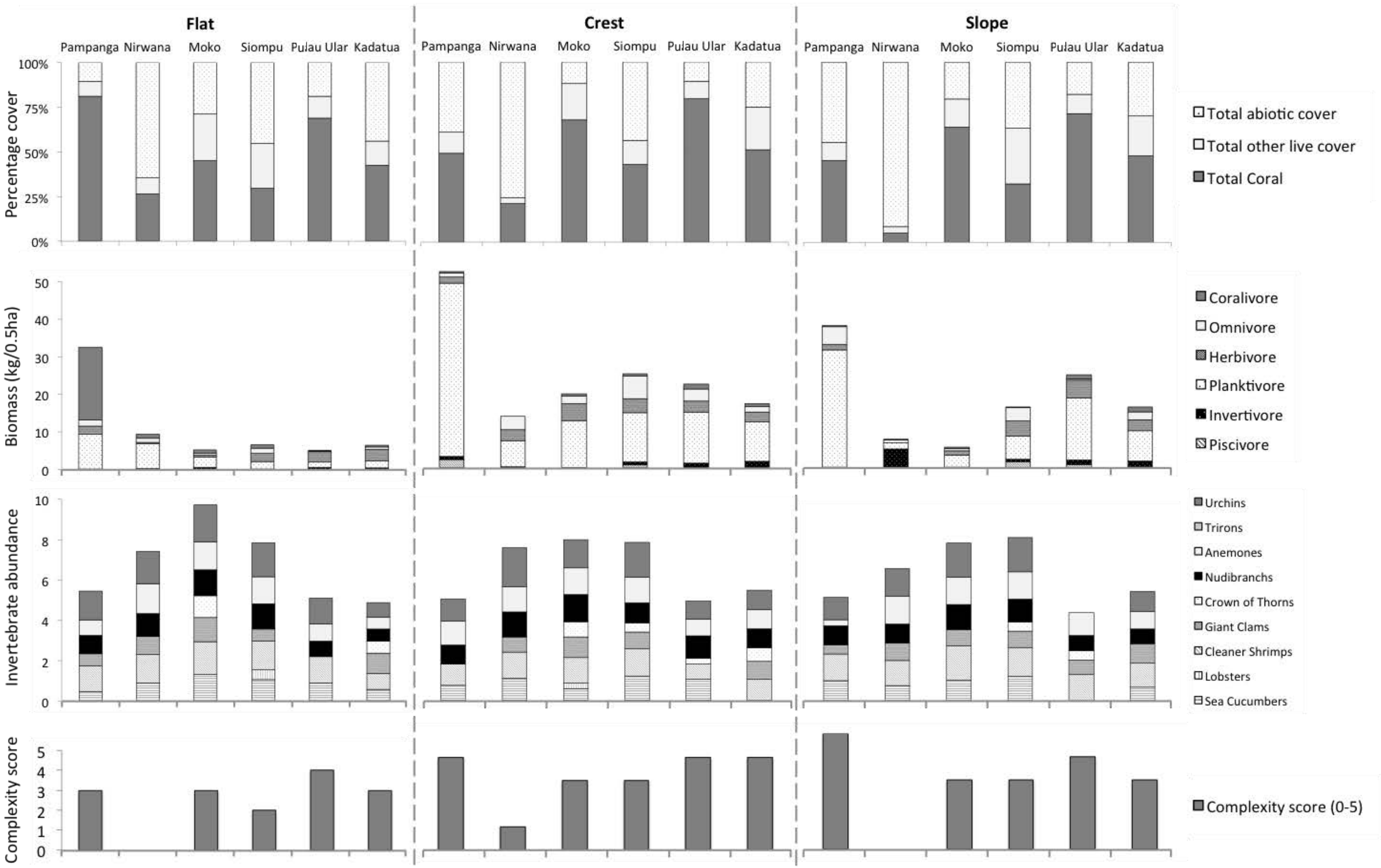


Fig 2.4. Reef ecological condition for six surveyed reefs (Pampanga, Nirwana, Moko, Siompu, Pulau Ular, Kadatua) across three reef zones (flat, crest, slope) evaluating four main ecological studies (benthic, fish, invertebrate and structural complexity) per 500m^3 during the 2015 study period.

2.3.2 Benthic community composition

CLUSTER analyses separated the surveyed reefs into 5 groups with a 75% boundary delimited (Fig. 2.5). The two-dimensional (2D) MDS plot had a stress level of 0.14, meaning that there is a moderate ordination fit and site differentiations or clusters should be interpreted with some caution (Clarke 2001). Nirwana reef flat, crest and slope comprised a single cluster with the slope being least similar to other zones (Fig. 2.5). Pulau Ular flat, crest and slope also comprised a single cluster and reef zones were most similarity to each other (Fig. 2.5). Kadatua flat and slope formed another single cluster as well as Pampanga's slope alongside Moko's flat and slope zones (Fig. 2.5). Lastly, all of Siompu's reef zones, along with Pampanga's flat and crest and Kadatua's and Moko's crest made for a single cluster (Fig. 2.5).

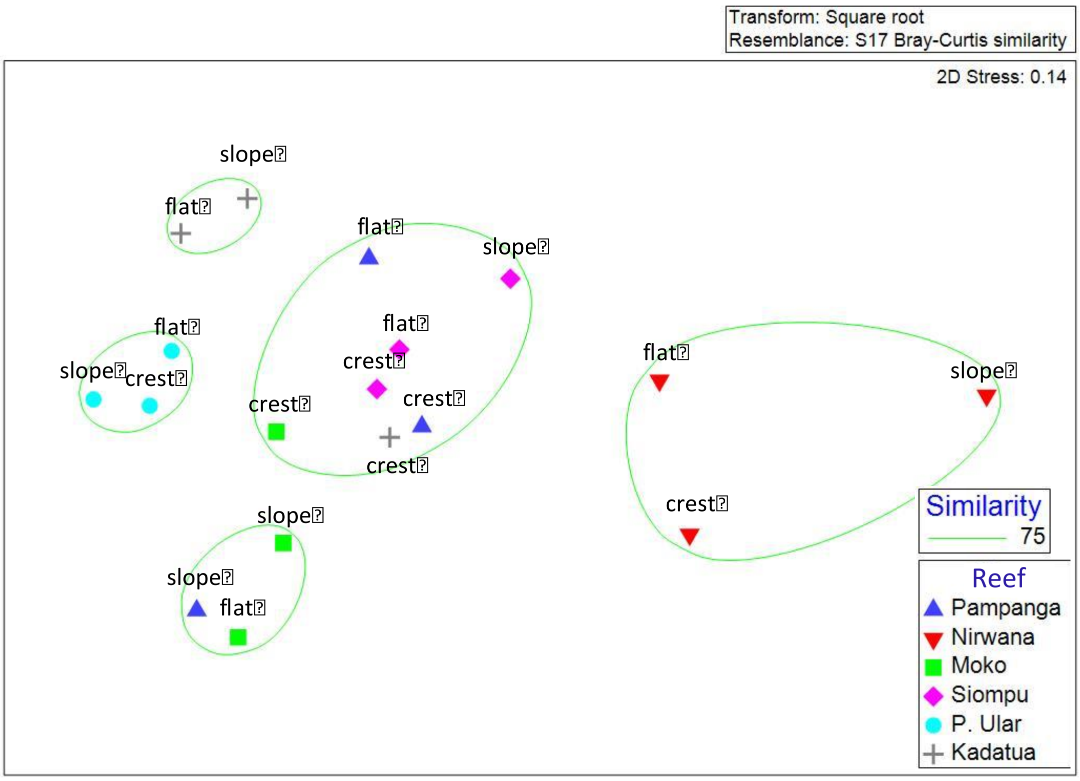


Fig. 2.5: 2-D Nonmetric multidimensional scaling analysis (MDS) plot based on Bray Curtis similarities between 15 variable benthic compositions (coral cover, other live cover, abiotic cover) across three reef zones (flat, crest, slope) at 6 reefs forming five groups based on 75% similarity (circles) distinguished by cluster analysis (symbols) in 2015 (n=4).

2.3.2.1 Scleractinian coral growth forms

Across all reefs, branching coral from the genus *Acropora* was the most prevalent growth form with columnar being the least made mostly by *Heliopora* genus corals (not shown). Moko reef had the highest percentage of branching coral making up ~41 of its 59% overall coral cover (Fig. 2.6). Pulau Ular had the highest and most diverse growth forms of all sites with Foliose coral from the genus *Montipora* being the most prevalent making ~29 of its 74% overall coral cover (Fig. 2.6).

Across the flat zone, Pampanga reef had the highest total coral cover with ~81% cover (Fig. 2.6). ~63% of that was from Branching growth forms and corals of the genus *Acropora*. Pulau Ular followed in second highest coral cover across the flat with ~69% cover and half as much Branching growth forms as Pampanga (~26%) (Fig. 2.6). Nirwana's flat had the least coral cover (~27%) (Fig. 2.6) mostly made from Branching *Acropora* genus growth forms (not shown).

Across the crest zones, Pampanga and Nirwana had the lowest coral cover among all reefs (Fig. 2.6). Pulau Ular crest had highest average coral cover of all sites, Foliose *Montipora* and *Turbinaria* genus growth forms being most prevalent making ~37 of ~80% overall cover (Fig. 2.6). Nirwana reef had the least coral cover of all reef crests with a ~22% cover, ~3% less than its flat, however a x2 increase in Massive (mostly *Porites*) growth form accounting for ~6% of total cover (Fig. 2.6).

Across the slope zones, branching growth forms decreased for all reefs by an average of ~10% from the reef crest (Fig. 2.6). Only Siompu and Nirwana reef experienced lowest scleractinian coral cover across the slope reef zone with ~33 and 5% cover respectively (Fig. 2.6). Likewise to the flat and crest, Pulau Ular had the highest cover and diversity of growth forms with Foliose *Montipora* and *Turbinaria* genus accounting for ~37 of ~72% overall cover (Fig. 2.6).

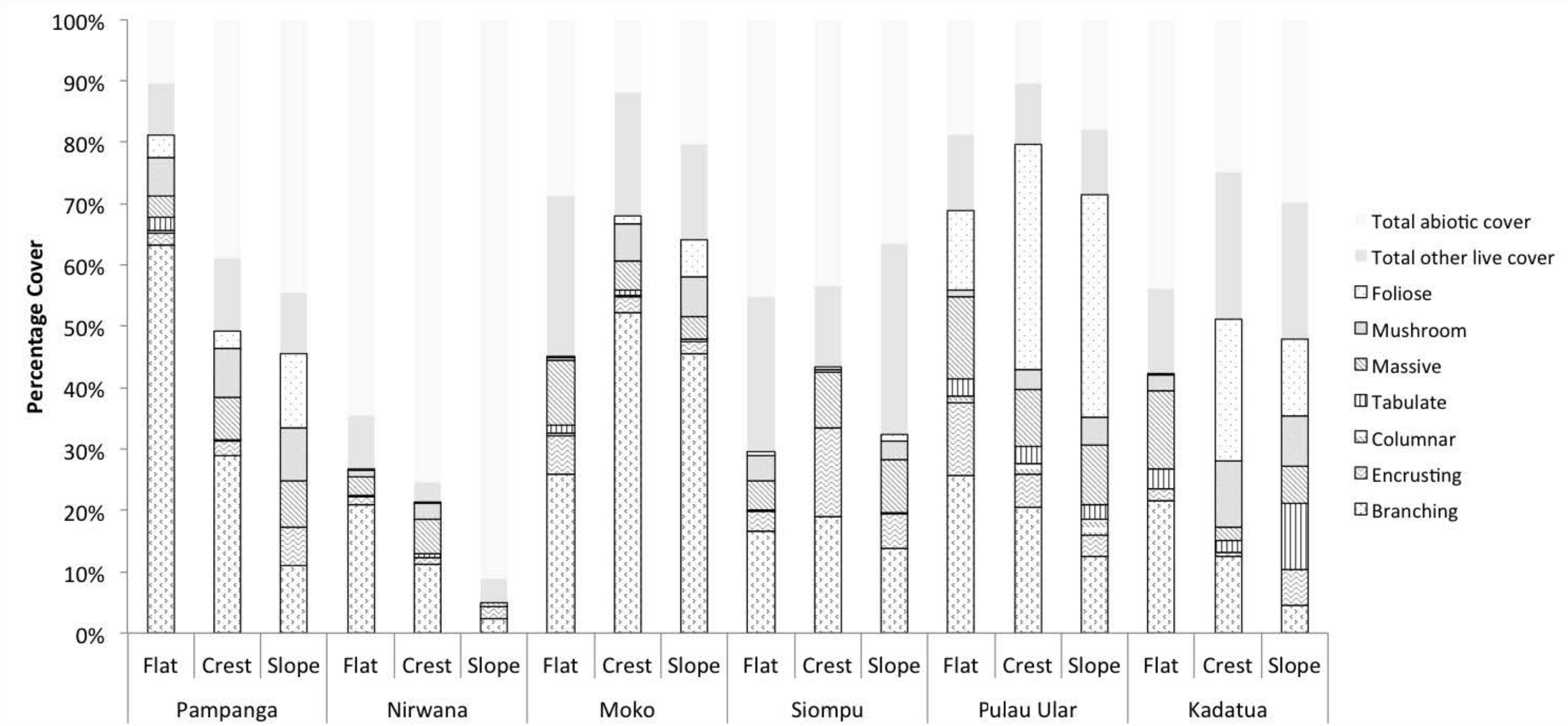


Fig. 2.6: The percentage cover of scleractinian coral cover represented by seven growth forms (branching, encrusting, columnar, tabulate, massive, mushroom, foliose) and other live cover and abiotic cover at 6 reef sites across three reef zones (n = 4 replicates per reef site and zone).

2.3.2.2 Other live cover groups

Across all reefs, algae was the most abundant other live cover averaging 9% of total reef cover (Fig. 2.4). Siompu reef had the highest average other live cover (~23%), of which algae represented ~10% (Fig. 2.7). In contrast, Nirwana had the lowest average other live cover (~5%), of which algae represented ~3%. Kadatua however, had the highest percentage cover of algae which accounted for ~17% of its overall ~20% other live cover (Fig. 2.7). Other and Sponge groups where the least prevalent other live covers making for < 2% of overall other live cover (Fig. 2.7).

Across the flat zone, Moko had the highest other live cover with overall ~26% cover of which ~21% was dominated by algae and ~5% soft corals (Fig. 2.7). Pampanga's reef flat had the lowest abundance of other live cover of all other reef flats with ~9% cover of which ~7% was algae (Fig. 2.7). Pulau Ular had the lowest percentage cover of algae on its reef flat compared to all other reefs, and highest soft coral cover, ~4 and ~8% respectively (Fig. 2.7).

Across the crest zone, Kadatua had the highest other live cover with overall ~24% of which ~23% was dominated by algae, also being the highest algae cover of any reefs zone (Fig. 2.7). Nirwana's crest had the lowest overall other live cover with ~3% of which soft coral was most dominating (Fig. 2.7). Sponge cover was most prevalent in Siompu's crest followed by Pampanga with ~4 and ~3% cover respectively (Fig. 2.7).

Across the slope zone, Siompu had the highest other live cover with overall ~31% and highest soft coral and sponge cover of all other reefs and zones with ~10 and ~6% cover respectively (Fig. 2.7). Kadatua's slope had the highest algae cover of all reef slopes with ~19% covered in algae of its ~22% overall other live cover (Fig. 2.7).

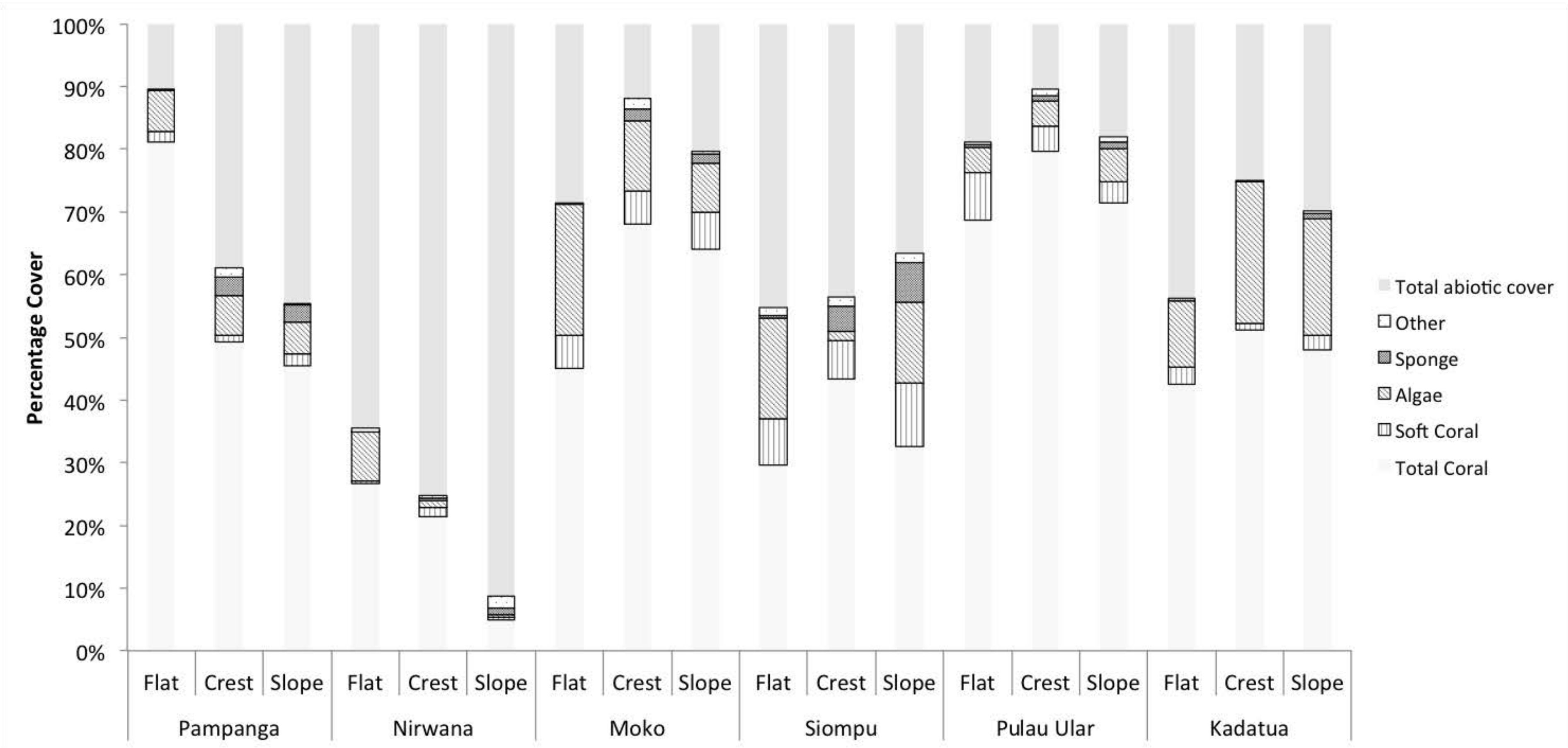


Fig. 2.7: The percentage cover of other live cover represented by four groups (soft coral, algae, sponge and other; i.e. ascidians) and total coral cover and abiotic cover at 6 reef sites across three reef zones (n = 4 replicates per reef site and zone).

2.3.2.3 Abiotic cover groups

Across all reefs, sand and rubble were the most abundant abiotic groups (Fig. 2.8). Nirwana reef had the highest percentage of sand with an average of ~67% across all its zones which was 17x more prevalent than the average of all other reefs sand cover (Fig. 2.8). Pulau Ular had the lowest abiotic cover averaging ~16% across zones of which rubble represented ~8% (Fig. 2.8). Dead coral was on average the most prevalent across zones in Moko reef accounting for ~7% of its overall ~20% abiotic cover (Fig. 2.8).

Across the flat zone, Nirwana had the highest abiotic cover and Pampanga the least with ~65 and ~10% cover respectively (Fig. 2.8). Siompu reef had the second highest abundance of abiotic cover ~45% of which rubble represented ~20% which was on average 2x more rubble content than any other reef flat (Fig. 2.8). Kadatua had the highest rock abundance with ~15% of its total ~44% abiotic cover (Fig. 2.8).

Across the crest zone, Nirwana had the highest abiotic cover and Pulau Ular the least with ~75 and ~11% cover respectively (Fig. 2.8). Pulau Ular's crest zone was the only reef section across all sites to have 0% sand, however, ~3% more dead coral than Nirwana (Fig. 2.8). Abiotic cover along Moko's crest was predominantly dominated by dead coral accounting for ~9% of its overall ~12% abiotic cover (Fig. 2.8).

Across the slope zone, likewise to the crest, Nirwana had the highest abiotic cover and Pulau Ular the least with ~91 and ~18% cover respectively (Fig. 2.8). Across all sites, except for Pampanga and Nirwana, the slope zone had the highest percentage cover of abiotic groups (Fig. 2.8). Sand was the most predominant abiotic cover across the slope of Pampanga and Nirwana, whereas rubble dominated along the slope of the other four reefs (Fig. 2.8).

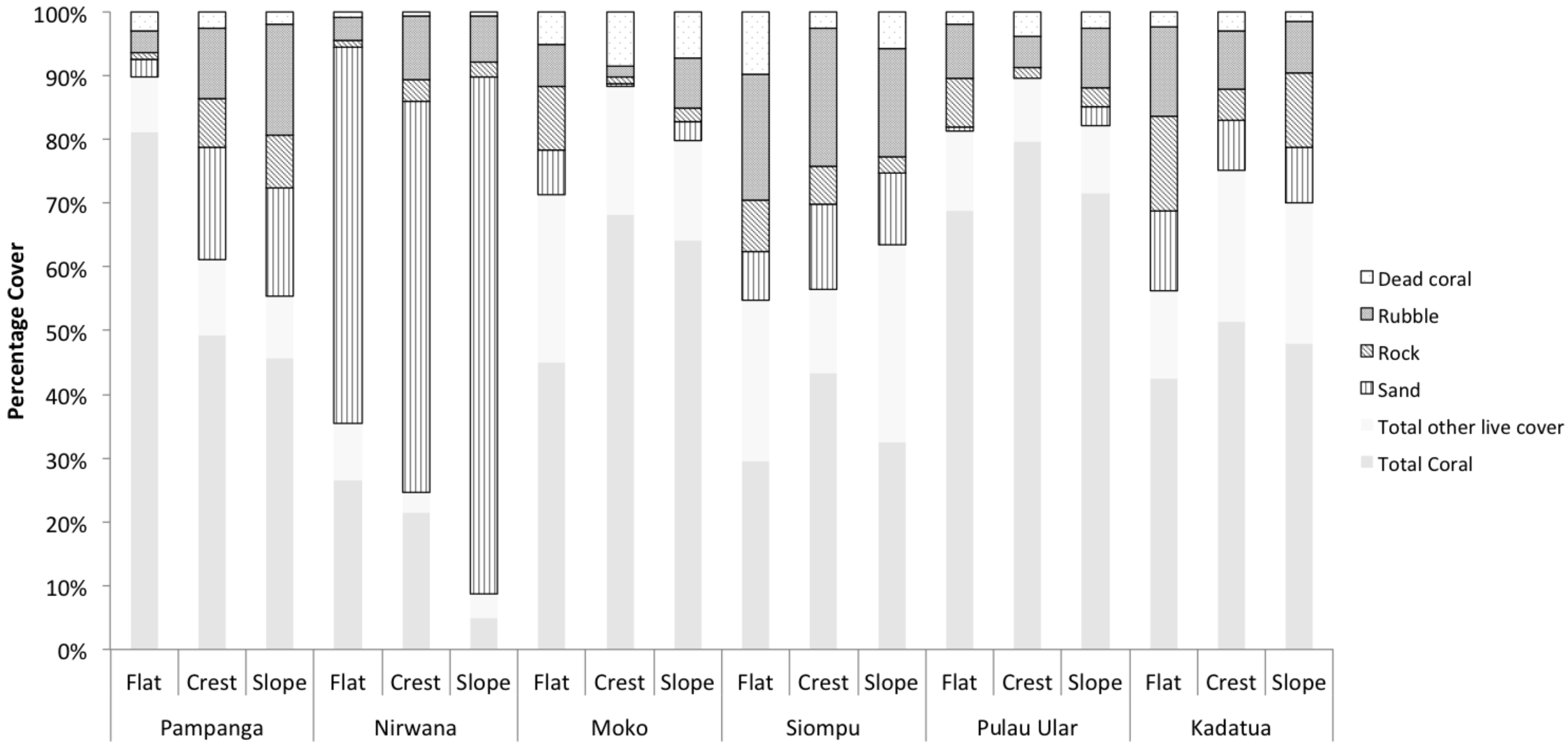


Fig. 2.8: The percentage cover of abiotic cover represented by four groups (dead coral, rubble, rock and sand) and total coral and total abiotic cover at 6 reef sites across three reef zones (n = 4 replicates per reef site and zone).

2.3.3 Fish assemblages

CLUSTER analyses separated the fish community on surveyed reefs into 5 groups with a 70% boundary delimited (Fig. 2.9). The two-dimensional (2D) MDS plot has a stress level of 0.13, meaning that there is a moderate ordination fit and site differentiations or clusters should be interpreted with some caution (Clarke 2001) The MDS plot revealed that fish assemblage composition did not differ consistently among reef zones, as the flat, crest and slope sites did not cluster together consistently (Fig. 2.9). The most distinct site was that of Nirwana slope. The Pampanga flat, crest and slope sites were also quite distinct from other locations. Nirwana reef slope dissimilarity was mostly driven by invertivorous fishes, whereas, on the Pampanga reef flat, corallivorous fishes where the primary driver indicating differences in community structure between the reefs (Fig. 2.9).

A global BEST (BIO-ENV) test revealed no significant match in fish assemblage composition and habitat composition (Fig 2.5) however the strongest single predictors of fish assemblage differences were the influence of massive coral growth form (R=0.348) and sponge cover (R=0.390).

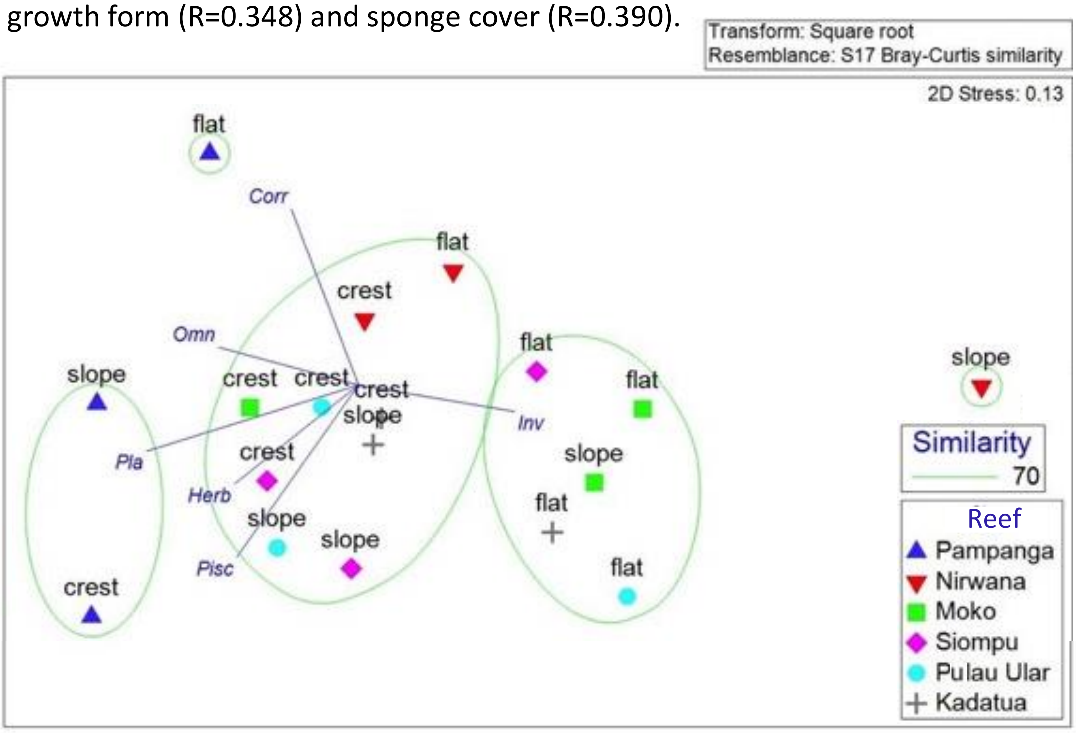


Fig. 2.9: 2-D Nonmetric multidimensional scaling analysis plot based on Bray Curtis similarities between fish assemblages based on seven feeding guilds across three reef zones at 6 reefs

depicting 5 groups based on 70% similarity (circles) distinguished by cluster analysis (symbols) in 2015 (n = 4 replicates per reef site and zone).

2.3.3.1 Fish assemblage biomass by functional feeding guilds

A total cumulative fish biomass across all 6 sites of 591.8 kg, from 10,374 individuals, 88 fish species (Annex 6d) were counted in the study site, South Buton (Annex 6, Section D). Across all reefs, planktivorous fish on average had the highest biomass indices (~19.4 ± 2.34 kg ha^{-1}), whilst piscivores represented the least (~0.6 ± 0.09 kg ha^{-1}) (Fig. 2.10). Of all reefs, Pampanga had on average the highest biomass of fish across all zones with ~75.4 ± 12.3 kg ha^{-1} compared to Moko reef which had the least; ~18.4 ± 2.3 kg ha^{-1} (Fig. 2.10). Fish communities were dominated by Planktivorous damselfishes (Pomacentridae), of which 6,369 individuals were counted, and invertivorous breams (Nemipteridae) were the least common with, 420 individuals (not shown). Shannon-Weiner diversity index (SWD) revealed along reef flats, crest and slope Pampanga had the highest index with 1.16, 0.92 and 0.95 respectively. Moko reef had the lowest SWD, along the flat and slope with 0.35 and 0.25 respectively whereas Nirwana had the lowest SWD along the crest with an index of 0.44 (not shown).

The reef crest had the highest indices of fish biomass; Pampanga being the highest ~92.9 kg ha^{-1} compared to Nirwana 24.4 kg ha^{-1} (Fig. 2.10). Planktivore fish represented 82.1 kg of the total 92.9 kg ha^{-1} fish biomass found in Pampanga's reef crest, which translates to 88.3% of the total biomass, compared to Nirwana, were planktivores represent 51.7% of the total 24.4 kg ha^{-1} (Fig. 2.10). Along the crest, Nirwana had a higher omnivore and herbivore fish biomass indice than Pampanga, however no presence of corallivores or piscivores (Fig. 2.10). With the exception of Pampanga, along the reef crest, Pulau Ular had the lowest proportion of herbivores to its total fish biomass; where herbivores accounted for 12% of the total 39.7 kg ha^{-1} (Fig. 2.10). Compared to Moko who had the highest proportion of herbivores to its total fish biomass; 23% of the total 35.0 kg ha^{-1} (Fig. 2.10). The highest biomass of corallivores was found on Pulau Ular's reef crest with 2.4 ± 0.3 kg ha^{-1}, and least in Nirwana (Fig. 2.10). Omnivore biomass was highest along Siompu's crest with 10.8 kg ha^{-1} compared to Pampanga's 1.8 kg ha^{-1} (Fig. 2.10).

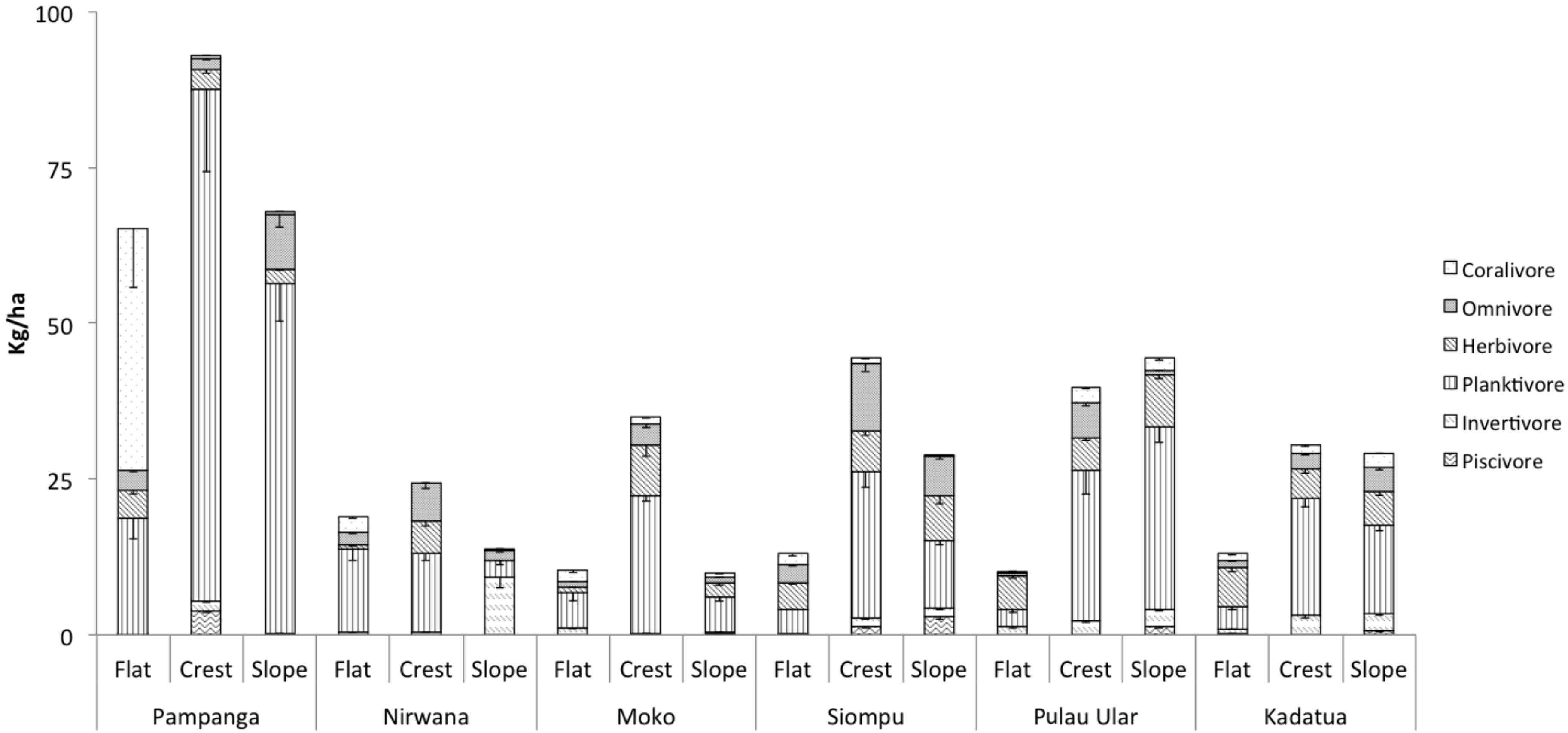


Fig. 2.10: The total biomass (kg ha^{-1}) represented by six functional feeding guilds (corallivore, omnivore, herbivore, planktivore, invertivore and piscivore) at six reef sites across three reef zones (n = 4 replicates per reef site and zone).

2.3.3.2 Individual planktivorous fish mean biomass

A total planktivorous fish biomass of 350.1 kg, from 6369 individuals was surveyed at 6 reefs in the study site (Fig. 2.10). Across all reefs, the reef flat had on average the lowest indices of individual planktivore biomass with 0.028 kg ha^{-1}. The reef crest had the highest with 0.0704 kg ha^{-1}, closely followed by the reef slope with 0.0697 kg ha^{-1} (not shown). On average individual planktivore biomass was highest on Pampanga reef (0.077 kg ha^{-1}), whereas the lowest was on Siompu reef with an average of 0.039 kg ha^{-1} (Fig. 2.11). Overall individual planktivore biomass across Pampanga reef was 0.025 kg ha^{-1} more than the average of all other reefs (Fig. 2.11). Generally the highest indices of individual planktivore biomass can be found along the crest of Pampanga and the lowest along the flat of Siompu (Fig. 2.11).

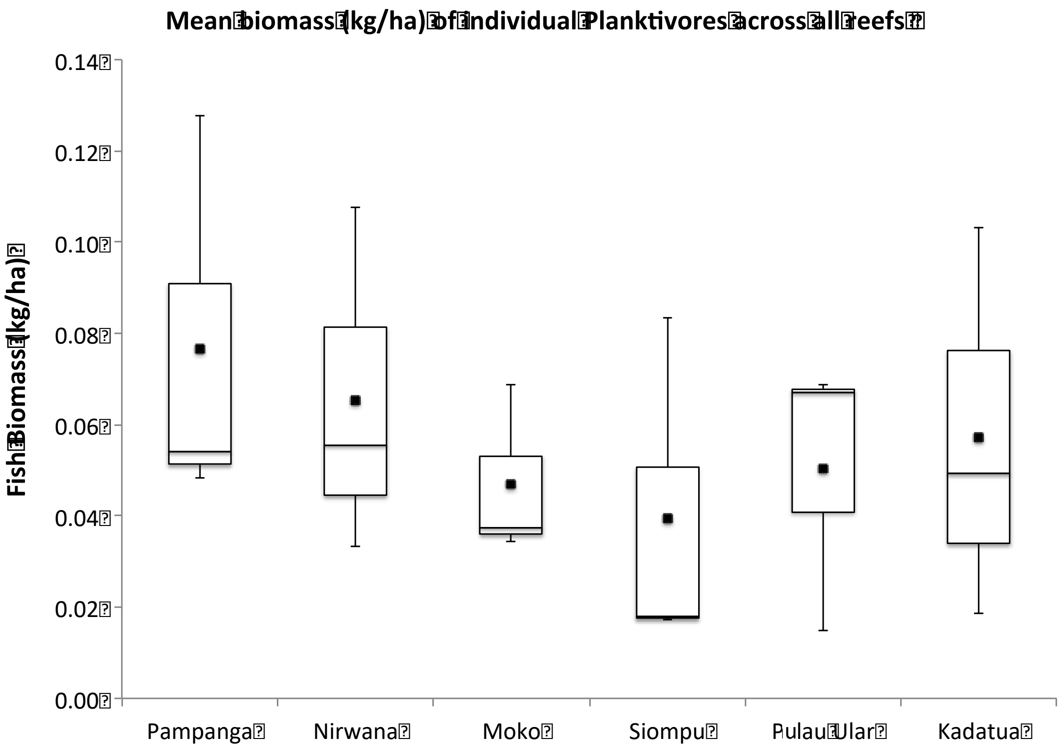


Fig. 2.11: Box plots for individual biomass (kg ha^{-1}) of planktivorous fish at six reef sites across three reef zones in South Buton. (n = 4 replicates per reef site and zone). Black squares represent average individual biomass values for planktvirores in that reef.

2.3.4 Non-coral invertebrate community structure

A total of 1,838 individual non-coral invertebrates were counted across all surveyed reefs (9 populations) or ,3,676 ha^{-1} of which urchins represented the highest abundance making up 32% of total counts; i.e. a total of 1,182 individuals ha^{-1} (Fig. 2.4). Tritons were the least abundant; total count of 2 followed by Lobsters (18) per ha^{-1}. Moko reef had the highest abundance of non-coral invertebrate individuals; 1,006 individuals ha^{-1} followed by Siompu reef; 866 individuals ha^{-1} (Fig. 2.12). Kadatua reef had the lowest abundance followed by Pulau Ular; 298 and 324 total individuals ha^{-1} respectively (Fig. 2.12). Urchins were the most abundant invertebrate were mostly found along Nirwana reef followed closely by Siompu, with 332 and 330 total individuals ha^{-1} respectively (Fig. 2.12). Likewise, sea cucumbers were most abundant in Siompu followed by Moko reef; 98 and 74 total individuals ha^{-1} respectively (Fig. 2.12). However, across all the reef zones, Invertebrate abundance was equally distributed with each zone holding ~33% of total invertebrate count (Fig. 2.12).

COT population abundance was found sporadically distributed amongst zones, with highest abundance on Moko's reef flat and crest; 36 individuals ha^{-1} (Fig. 2.12). Likewise, sea cucumber, cleaner shrimp, giant clam, nudibranch and anemone populations were most abundant along Moko's reef flat, making it the most ample reef zone of any site (Fig. 2.12). Kadatua's reef flat had the lowest overall abundance of sampled invertebrates followed by Pulau Ular's reef crest and slope (Fig. 2.12).

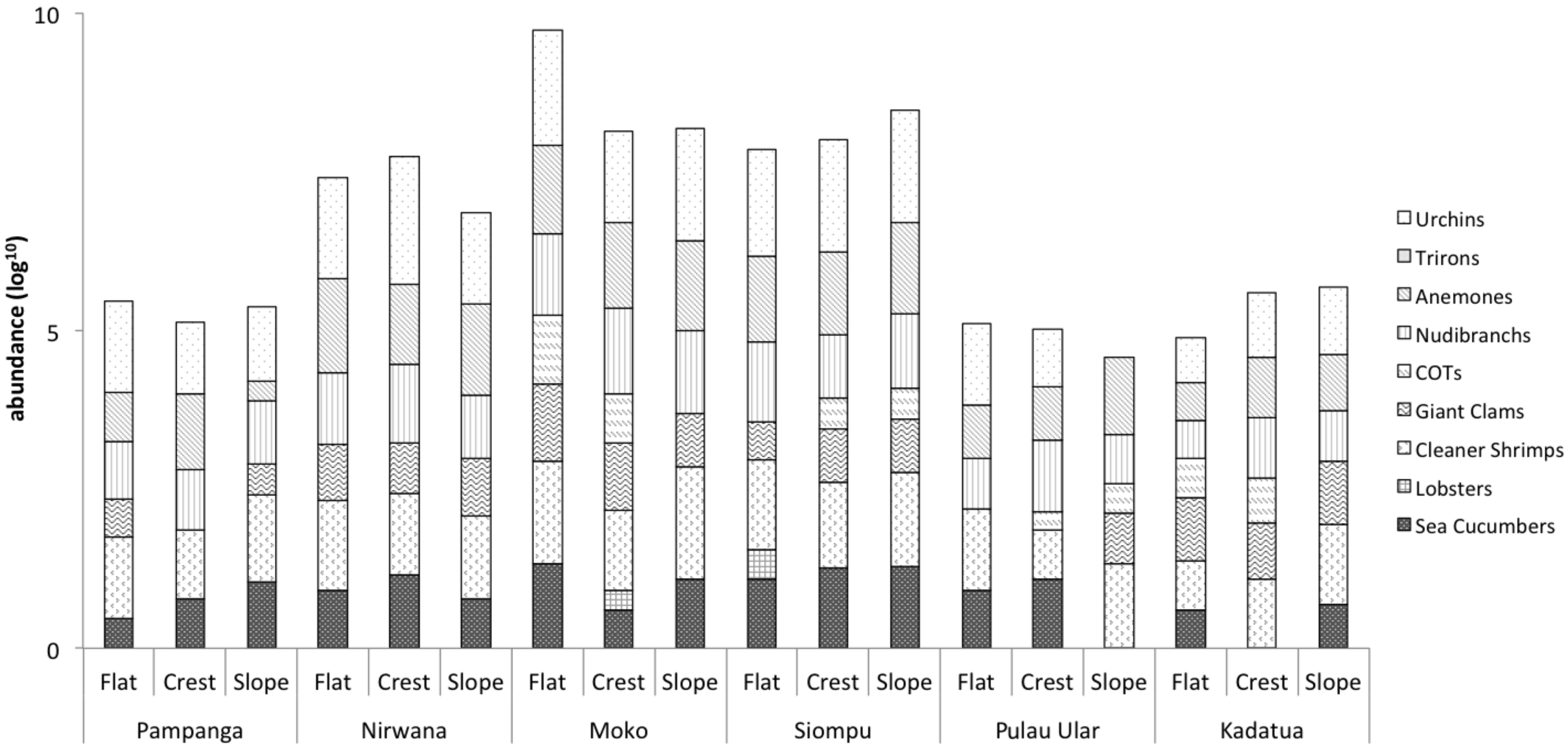


Fig. 2.12: The abundance (transformed – log[10]) of non-coral invertebrates represented by nine key reef dwelling individuals (sea cucumbers, lobsters, cleaner shrimps, giant clams, COTs, nudibranchs, anemones, triton and urchins) at six reef sites across three reef zones (n = 4 replicates per reef site and zone).

2.3.5 Reef structural complexity and abiotic factors

The reef crest, with the exception of Pampanga's slope, was the zone with equal to or higher structural complexity score for all reefs (Fig. 2.13). Pulau Ular and Pampanga reefs scored highest with an average of 4.0 ± 0.5SE, however, differ in that scleratinian growth forms drive structural complexity for Pulau Ular reef, whereas overhangs and cave systems are more representative of Pampanga (Fig. 2.13). Only within Nirwana's reef flat and slope, structural complexity is absent; dominated by benthic habitats with low structural support (i.e. sand) (Fig. 2.13).

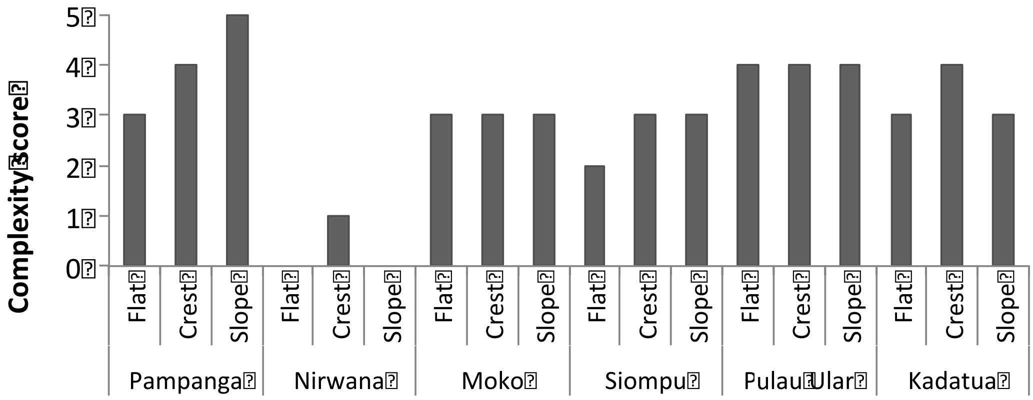
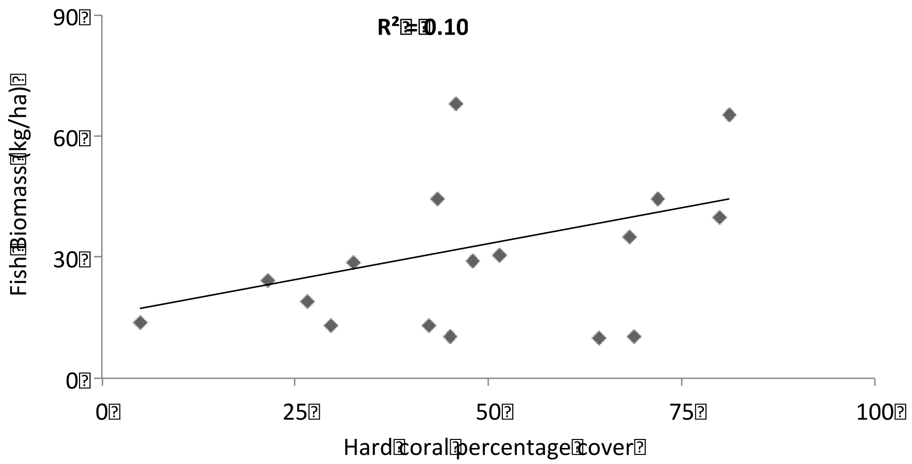


Fig. 2.13: The structural complexity of reef substratum, estimated on a 5 point scale: 0, no vertical relief; 1, low and sparse relief; 2, low but widespread relief; 3, moderately complex; 4, very complex with numerous caves and fissures; and 5, exceptionally complex with high coral cover and numerous caves and overhangs at six reef sites across three reef zones (n = 4).

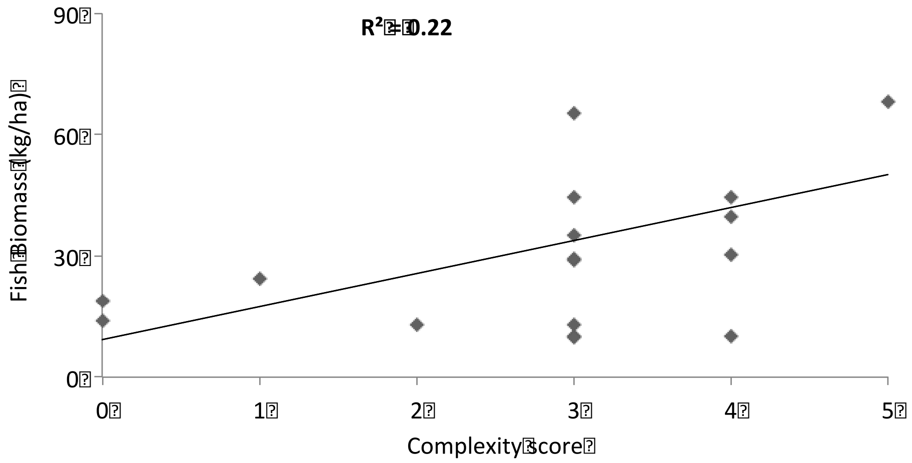
2.3.6 Relationship between fish biomass and habitat variables

The relationship between fish biomass and three habitat variables (coral cover, structural complexity and invertebrate abundance) explained a relatively small portion of the variance in fish biomass (R^2 = 0.10, 0.22, 0.24 respectively). Fish biomass showed the strongest positive linear relationship with structural complexity, which was statistically significant (Fig. 2.14b, r^2 = 0.22, $F_{(1,32)}$ = 26.215, $P < 0.001$). Fish biomass was also positively and statistically significantly correlated with hard coral percentage cover, but weaker than structural complexity (Fig. 2.14a, r^2 = 0.10, $F_{(1,32)}$ = 4.795, P = 0.03). Lastly, fish biomass showed a non-significant linear relationship but most strongly correlated with non-coral invertebrate abundance (Fig. 2.14 c, r^2= 0.24, $F_{(1,32)}$ =30.900, P = 3.91).

a) Hard coral cover (%)



b) Structural complexity



c) Non-coral invertebrate abundance (log^{10})

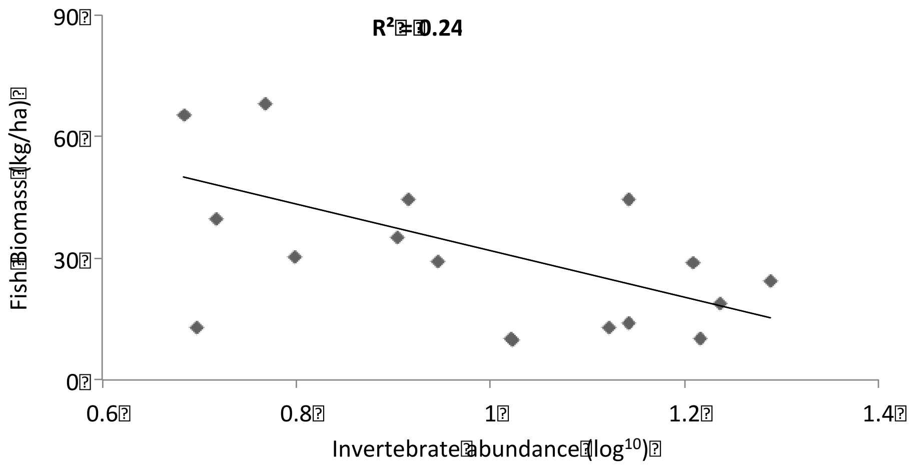


Fig. 2.14: Linear relationship between fish biomass (kg ha^{-1}) and habitat variables (a. Hard coral cover, b. structural complexity and c. log^{10} invertebrate abundance) across reefs in South Buton.

All relationships except for that with non-coral invertebrate abundance were statistically significant ($P<0.05$).

2.4 Discussion

The coral reefs of South Buton, Indonesia have received little scientific and management attention even though their geographical location is amongst some of the worlds more diverse and prominent coral reef areas (Geider et al. 2001, Cesar et al. 2003, Cruz-Trinidad et al. 2014). Nevertheless there are investigative bodies in Indonesia (COREMAP 2014) which have surveyed vast areas of coral reefs, namely those in South East Sulawesi. The work presented here evaluated the ecological condition of six different fringing reefs and reef zones across South Buton, by evaluating and comparing their ecological communities. Overall, using Suharsono (1998) scale place South Buton coral reefs in a fair to very good condition, in terms of live coral communities but less so in reef fish biomass (Pandolfi et al. 2003a). Hard coral cover (average 49%) and fish biomass values (average 32 kg ha^{-1}) put these reefs on par with those of the nearby Wakatobi National park which average 20% hard coral cover and 38 kg ha^{-1} of fish biomass (Smith et al. 2015 unpublished data). In fact, the fish biomass values presented here are extremely low in comparison to thresholds defined by McClanahan et al. (2011), were an estimated unfished reef fish biomass to be ≈ 1,200 kg ha^{-1} (± 110). The average value of 32 kg ha^{-1} across the studied reefs in South Buton is indicative of an overfished reef system (McClanahan et al. 2007). However, using live coral community indices place the condition of reefs in South Buton more closely to those in the WNP from 12 years ago, when the average coral cover was ~50% (Clifton et al. 2013). Furthermore, similar to the WNP; the most prevalent coral genus surveyed was *Acropora* and *Porites* and the most common fish family being Pomacentridae (Clifton et al. 2013).

Only coral reefs like Pulau Ular can be situated amongst the few that come close to a “pristine” condition (particularly in terms of live coral cover) as defined by literature (Suharsono 1998, Pandolfi et al. 2003b, Wilkinson 2006). However, more recent events, as seen through fishing practices and climate change endured bleaching are threatening this status from ever existing again. For that reason, the status of coral reefs in South Buton can only be generally considered to be on a global scale as in a relatively good condition (Wilkinson 2008). More specifically, according to a study carried out by Suharsono in 1998 that presented a large-scale coral reef survey of ecological condition in Indonesia, South Buton reefs would fall under the 'fair' condition category. Suharsono's report stated that only six per cent of coral reefs in Indonesia were in 'excellent' condition (75-100% coral cover), whilst the rest show various signs of impact, with around 40 percent in 'poor' condition (< 25% coral cover); 31 per cent in 'fair' condition (26-50% cover), and only 23 per cent in 'good' condition (51-75% cover) (Suharsono 1998). Suharsono's study and the coral reefs of the WNP are therefore likely the best benchmarks from which to categorize the coral reefs of South Buton. However, unlike the previously mentioned studies, it's important to consider other influential ecological conditions such as structural complexity or invertebrate abundance.

To begin with, Pampanga reef, which is the most closely situated reef to the main city of South Buton, Bau Bau would fall under the category of 'good' condition using hard coral cover as the primary index of reef condition as seen through Suharsono (1998) coral reef condition scale. The range of hard coral percentage cover on Pampanga reef was 46-81% with an average of 59%. Fish biomass ranged between 65 and 92 kg ha^{-1} with an average of 75.4 ± 12.3SE kg ha^{-1}. Globally, these fish biomass indices are representative of a poor condition reef (McClanahan et al. 2011). However, for the region itself, the results show that the highest fish biomass indices can be found along Pampanga reef, and therefore indicate that the best fish habitats are likely found here. This too is supported by the high hard coral percentage cover found which as many other studies have shown is key in providing fish with a wide range of habitats (Jones and Syms 1998, Holbrook et al. 2003). Furthermore, Pampanga's reef crest had the highest piscivorous fish biomass of any reefs zone which is also indicative of a healthy functioning ecosystem. Studies looking at the removal or lack of key predatory species such as those found in piscivorous guilds have frequently demonstrated their importance in avoiding negative ecosystem-wide shifts and maintaining trophic cascades (Babcock et al. 1999, Boaden and Kingsford 2015). Moreover, Pampanga reef had a relatively low urchin abundance, likely due to the presence of one of its major predators; triggerfish (McClanahan 1994). This top-down control effect of triggerfish on the urchin population is important, as other studies have shown that an increasing urchin population can result in bio-erosion of coral, and an increase in filamentous algae (McClanahan and Shafir 1990). In addition, the high structural complexity values found in Pampanga reef (likely shaped from strong underwater currents as bottle-neck effect occurs between Kadatua and Pampanga reef) may provide fish assemblages a dissimilar habitat to other reefs in which to thrive. These 'drop-offs' and 'cavernous' characteristics of Pampanga reef allow for more complex trophic systems were larger predators can be found (Almany 2004). Overall, Pampanga's reef relatively high coral cover, highest fish biomass indices within the study area, low presence of urchins and high structural complexity is indicative of a reef in 'good' condition within the study area.

Nirwana reef is situated along the public beach "Pantai Nirwana" where most boat traffic occurs due to a lack of coastal cliffs plus low wave action (pers. obvs.) and would therefore fall under the category of 'poor' condition (Suharsono 1998) due to its overall low hard coral cover. The range of hard coral percentage cover on Nirwana reef was 5-27% with an average of 18%. Fish Biomass ranged between 13 and 24 kg ha^{-1} with an average of 19.0 ± 2.7SE kg ha^{-1}. These results show that Nirwana reef had the lowest coral cover and second to last lowest fish biomass indices. However, the lack of coral in Nirwana reef was mostly due to the high percent cover of sandy substratum. This does not necessarily represent a degraded reef and more likely represents a naturally sandy coastal habitat. In addition this study is descriptive of a single-time 'snapshot' and therefore does not provide information on the process by which the reef benthos has changed over time. Therefore, any conclusions regarding the benthic condition of Nirwana reef in the past are not feasible. Furthermore, whilst sand does not provide as ample array of habitats for fish, it does create niche habitats for species such as goatfish and blue-spotted rays to thrive. This is represented in the higher invertivorous fish biomass index (compared to the other reefs in this study) of Nirwanas reef slope (average 2.3 ± 1.6SE kg ha^{-1}). The sandy substratum provides small non-coral invertebrates such as crustaceans with places to burrow, only to later be predated by higher trophic fish such as rays (Compagno et al. 1989). Another example is the Ringtail Surgeonfish *A. blochii*, which was a dominant herbivorous species in Nirwana. It feeds on algal films covering compacted sand, indirectly ingesting the sand (Randall 1985), of which Nirwana reef has plenty. However, with seasonal changes in wind, sand may become re-suspended which can lead to the suffocation of corals and to decreased calcification rates resulting from reduced light penetration (Crabbe and Smith 2002). Furthermore, Nirwana reef had the highest abundance of urchins, which in the low presence of coral may be beneficial as urchins have been reported as important controllers of macroalgae by mediating competition between coral and algae (Hughes 1989). Lastly, low structural complexity scores indicate that Nirwana reef had the lowest fish refuge availability of all sites. In such situations small fish and juveniles are more readily at risk from predation by piscivores (Almany 2004). Overall, Nirwana's reef low coral cover, low fish biomass indices, high presence of urchins and low structural complexity is indicative of a 'poor' condition reef within the study area, albeit that its sandy substratum is providing niches for species not seen in other reefs. However, as previously stated, this could naturally be a sandy coastal habitat and not the consequence of anthropogenic or natural degradation over time.

Moko reef has an extensive rocky intertidal zone frequently used by locals for gleaning and would fall under the category of 'good' condition according to Suharsono (1998) reef condition scale. The range of hard coral percentage cover on Moko reef was 45-68% with an average of 59%. Fish biomass ranged between 9 and 34 kg ha^{-1} with an average of 18.4 ± 2.3SE kg ha^{-1}. However, even though Moko reef had a relatively high percentage of coral cover, the vast majority was uniformly branching *Acropora* allowing for very little diversity in other growth forms. This low diversity in coral species and morphology predicts that larger bodied fish (i.e. > 30cm in length; coral trout) are less likely to find opportune refuge areas usually provided by large tabletop corals and overhangs of mounding corals (Kerry and Bellwood 2012). This is evidenced by Moko reef having the lowest average fish biomass indices of all reefs in the study area. In fact, Moko reef was the only reef with no recorded Invertivorous fish biomass (reef crest) as well as one of the lowest planktivorous fish biomass, and had overall the highest non-coral invertebrate abundance. Regression analyses depicted a trend of decreasing invertebrate abundance with higher fish biomass (Fig 2.14c). In the case of Moko reef, high COTs population abundance could be explained by the low presence of its predators; planktivorous damselfishes (i.e. *D. aruanus*) (Cowan et al. 2016) as well as the giant triton *Charonia tritonis*a (Hall et al. 2017). As such, Moko reef had a total of 19 COTs recorded compared to 2 in Pampanga, whilst the planktivorous damselfish biomass was 6.7 and 11.4 kg ha^{-1} and triton count was 1 and 0 respectively. Moko reef also had the highest abundance of cleaner shrimp populations, which are effective at removing ectoparasites and monogenean flatworms *Benedenia* sp. from fish (Becker and Grutter 2004). Whilst cleaner shrimp can therefore be helpful to individual fish, they did not correlate to higher fish biomass at Moko reef. Lastly, structural complexity in Moko, which scored mediocrely, was mostly due to the high percentage cover of branching *Acropora* coral species*,* which as previously discussed, may provide refuge for smaller bodied species but less for larger ones (Kerry and Bellwood 2012). Without diverse coral growth forms, structural complexity alone cannot provide the adequate habitat for fish to thrive. Overall, Moko's reef high coral cover yet low coral growth form diversity, low fish biomass indices, high abundance of non-coral invertebrates and mediocre structural complexity is indicative of a 'fair' condition reef within the study area.

Siompu reef is situated alongside the main harbor of Siompu island and similar to Moko reef, has an extended intertidal zone where locals frequently glean for sea cucumbers and snails (pers. obs.). Siompu's reef condition would also be classified as in 'fair' condition as per Suharsono (1998) reef condition scale. The range of hard coral percentage cover on Siompu reef was 30-44% with an average of 35%. Fish biomass ranged between 13 and 44 kg ha^{-1} with an average of 28.8 ± 3.3SE kg ha^{-1}. Siompu reef had the highest percentage of benthic rubble cover and one of the highest dead coral cover indices (20% and 6% respectively) yet maintained a relatively high fish biomass value in comparison to the other reef within the study area (28.8 ± 3.3SE kg ha^{-1}). The structure provided by dead coral may be enough to host higher fish biomass (e.g. Bellwood et al. (2004)). However, Siompu's reef was most notable for its high sponge cover (4x more than all other reefs). This is not necessarily a sign of an 'unhealthy' reef system as sponges have a number of important ecosystem functioning roles such as substrate stabilization (Wulff and Buss 1979), facilitating primary production (Wilkinson 1987) and even structural complexity (Van Soest et al. 2012) thus providing a suitable habitat for other marine species. More importantly, sponges provide food sources for many reef fish, turtles, echinoderms, crustaceans and nudibranchs (Dunlap and Pawlik 1996, Wulff 2006, Bell 2008). Therefore, the high presence of sponges in Siompu could possibly be one of the reasons for the relatively high fish biomass indices within the study area. In the future, sponges along Siompu reef may also play a key role in recovering reef condition to more coral dominated (Wulff 1984). At the time of this study, Siompu reef had the second lowest structural complexity scores, due to the high percentage cover of rubble habitats. However previous studies have demonstrated sponges ability in consolidating coral rubble and stabilizing it until colonization of corals occurs (which can be completed within 10 months) (Wulff 1984). However, this ability only occurs amongst certain species of sponge, which are frequently small in size and therefore have the tendency to glue pieces of rubble together (Becking 2012). In South Buton, the most frequently observed sponge is *Callyspongia samarensis*, which fits in with the description of Becking (2012) as a sponge capable of consolidating rubble. Therefore, even though Siompu reef had a low coral cover with a high rubble and dead coral cover, low structural complexity score, relatively high fish biomass indices within the study area but far less so globally and mediocre non-coral invertebrate abundance; the relatively high sponge cover could indicate a promising future for Siompu reef. Siompu's reef condition according to Suharsono (1998) scale in comparison to the other reefs within the study area would be considered as in ‘fair’ albeit far less globally.

Pulau Ular reef is the most isolated reef of South Buton, and surrounds the un-inhabited island (Snake Island). It is the only reef in South Buton that could be classified as in ‘excellent’ condition according to Suharsono (1998) reef condition scale. The range of hard coral percentage cover on Pulau Ular reef was 69-80% with an average of 74%. Fish Biomass ranged between 10 and 44 kg ha^{-1} with an average of 31.4 ± 3.5SE kg ha^{-1}. Most notably, Pulau Ular reef had the highest percentage of coral cover and highest diversity of growth forms. This is indicative of a reef with the ability to provide higher opportunity for various species to thrive across all fish guilds and therefore result in a lack of dominance by one particular assemblage (Roberts 1987). Foliose growth form corals from the genus *Montipora* dominated Pulau Ular, and whilst few studies have investigated its correlation with fish assemblages foliose corals may provide similar structural benefits to branching coral. Pulau Ular had the highest fish biomass of herbivorous fish as well as second highest of corallivorous fish, both of which are key guilds in maintaining healthy ecosystem function (Bellwood et al. 2004, Madduppa et al. 2014, Rogers et al. 2014). On the other hand, there are studies demonstrating that high presence of corallivorous chaetodontids can lead to an increase in coral disease spread due to their preferential feeding on physically damaged, stressed or diseased coral tissue (Raymundo et al. 2009). In fact, corallivorous fish such as Butterfly fish from the Chaetodontidae family group were most diversely present along Pulau Ular reef. These (mostly) obligate coral dwelling fishes benefit from the adequate space provided amongst the coral growth form variety in Pulau Ular for movement and feeding as well as protection from larger predators (Cox 1994). Furthermore, Pulau Ular reef was the only site where sharks can be found (although none appeared in the video analyses (pers. obvs.)). Non-coral invertebrate abundance was predominantly low in Pulau Ular’s reef, in particular; the COTs population (which was below the average number found across all reefs; 1.68 and 2.28 respectively). COTs are known for their ability to multiply in numbers are thereby decimate large areas of reef (Pratchett 2005). The low number of COTS predators (e.g. triton conch) seen on South Buton reefs may suggest that COTS abundance is being regulated by factors not assessed in this study. Overall, the very high coral cover, variety of coral growth forms, high structural complexity, high fish biomass indices and low non-coral invertebrate abundance within the study area makes Pulau Ular reef to be considered as a 'excellent' condition reef due primarily to its high hard coral cover (as per Suharsono (1998) reef condition scale).

The last surveyed reef was Kadatua reef which lies alongside a ~2km cliff range of Kadatua's Island east side and is characterized by large waves and strong currents. Overall, Kadatua's reef would be considered as in 'fair' condition according to Suharsono (1998) reef condition scale. The range of hard coral percentage cover on Kadatua reef was 42-52% with an average of 47%. Fish biomass ranged between 13 and 30kg ha^{-1} with an average of 24.2 ± 2.4SE kg ha^{-1}. The most notable feature of Kadatua's reef was the high percentage of rock cover (twice that of other reefs) and high structural complexity scores. Both factors have been positively correlated with high fish biodiversity indices elsewhere (Brokovich et al. 2006, Dominici-Arosemena and Wolff 2006). In future years rock cover may have a positive effect on reef growth, as the substrate provides coral polyps an adequate area for settlement and growth (Bellwood et al. 2003). This would subsequently increase fish species abundance. Kadatua's reef had relatively high coral cover; particularly of mushroom coral, which were twice as abundant compared to other nearby reefs. Whilst mushroom corals do not provide as adequate a range of habitats for fish or invertebrates, they are promising signs for future reef growth in certain environments such as sandy areas (Chadwick-Furman and Loya 1992). However, because Kadatua reef is predominantly a rocky area, the presence of mushroom corals is likely having the opposite effect. *Fungia* genus mushroom coral species which are the most commonly found in Kadatua reef (7 ± 2SE%) secret a mucus that can damage other corals tissue and thereby prevent the growth of nearby corals (Chadwick and Morrow 2011). In the future, an increase in mushroom coral cover could consequently lead to a reduction in other coral species.

Another key ecological condition of Kadatua's reef is the low abundance of non-coral invertebrates. This may be attributed to the small surface area of the reef flat and crest, where on average most invertebrates were found. Abundance of anemones were particularly low on Kadatua reef restricting the distribution and abundance of anemone fish. The average coral cover albeit by mostly mushroom coral growth forms, high structural complexity score, average fish biomass indices and low non-coral invertebrate abundance within the study area makes Kadatua's reef to be considered as a 'fair' condition reef under Suharsono (1998) reef condition scale. Nevertheless like the other reefs presented here, on a global scale, particularly in fish biomass indices,

The six surveyed reefs in South Buton therefore had relatively distinct physical and ecological characteristics that reflect the overall ecological condition of the region. Compared to other coral reef regions globally, using hard coral cover as the primary index of reef condition only Pulau Ular's reef can be categorized as a globally exemplary reef. However, this is not the case when considering fish biomass as the primary index of reef condition. In fact, across all reefs present here, the fish biomass values are indicative of a collapsed and overfished system (<100 kg ha^{-1}) (MacNeil et al. 2015). Yet, much of the low fish biomass values presented in this study can be attributed to constraints in the survey method as explained further on. Albeit not sufficient enough to explain these extremely low values. In any case, using hard coral cover as the primary representative index of the overall reef condition places reefs such as Pulau Ular in an overall 'excellent' condition and compares it favorably to other areas within the Coral Triangle such as the WNP or even Milne Bay in Papua. Both Nirwana and Siompu in particular were not good examples of a healthy functioning reef capable of providing fish with habitat security or on a larger scale, human populations with food security. A similar future could await Moko's reef if benthic coral diversity remains as uniform as surveyed here. Moko's reef would need to see a varied shift in benthic coral growth forms if it is to avoid a change into 'fair' or 'poor' condition. Lastly, Pampanga's and Kadatua's overall 'good' condition is likely to be maintained as their high structural complexity is the most resilient feature they have for avoiding negative future changes in their community composition.

A number of notable sampling limitations affect the results presented here. Firstly, small sized fish (i.e. < 10cm - as frequently surveyed in this study) respond to structural complexity at a finer smaller scale than the one used here (Wilson et al. 2007). Using the 0-5 scale (Roberts 1987), does not adequately reflect how structural complexity may drive smaller fish assemblages. A more precise account of structural complexity such as measuring hole size and species association as done in other studies (Gratwicke and Speight 2005b) could be encouraged in future surveys. Secondly, studies have shown the effects of depth on species distributions. My study does not do a fair job of exemplifying this effect, as the deepest surveys were capped at ~18m and reef systems such as Pampanga and Kadatua are as deep as ~40m. In the Red Sea, 80% of juvenile zebra angelfish (*Genicanthus caudovittatus*) are found at 30m (Brokovich et al. 2007). Thus some species will have been excluded due to depth restrictions. Thirdly, this study did not account for any seasonal differences because monitoring was only conducted at one time of year (dry season). With global coral reef trends indicating a shift towards sandy and rubble-dominated reefs, reefs such as Nirwana could be studied across multiple seasons and the effects on associated fish and invertebrate communities evaluated.

Without long-term monitoring programs, it is not possible to ascertain whether reef state of global and local reefs is as portrayed or in transition (Walker 1993, Hughes et al. 2010). Where long term studies are founded on strong scientific sampling regimes, they are able to underscore detailed accounts of change in reef systems, including stability, decline and recovery hence underpinning the success of management (de Bakker et al. 2017). However, whilst for many areas this vital work is carried out, there remain a large percentage of coral reefs where it is not, namely, in the Coral Triangle.

The Coral Triangle area has seen many studies, such as those carried out in Western Indonesia, where valuable reference points of ecological and social data have been collected but changes in the reef's condition and rate of degradation remains unknown because of the lack of follow up studies (Saila 1997). When this is done, via long-term investigations that also include social evaluations (i.e. fishing practices), the outcome can be beneficial for the longevity and conservation status of reefs. This has been demonstrated in various reef systems around the world. Most recognized of which, is the Great Barrier Reef (GBR) in Australia, which received its protected status in 1975 through the *Great Barrier Marine Park Act* (Lucas et al. 1997, Hutchings and Hoegh-Guldberg 2008). Likewise, in the Philippines across Apo Island, the long-term monitoring program showed that declines in fish populations where rapid in response to un-managed fishing practices that negatively affected the reef community dynamics and recovery was slow when enforced (Russ and Alcala 1996, 1999, Russ et al. 2008). Another study by Baird et al. (2005) recorded little change in coral assemblage after a tsunami struck Aceh, Indonesia in 2004 and concluded that anthropogenic impact had been much more destructive to the reef than the tsunami. Furthermore, because this study in Aceh had recorded reef condition pre and post the tsunami event, they where able to conclude that the modification of the reef did not contribute to the modification on land by the tsunami. By enacting a long-term reef monitoring program in South Buton, it may be possible to measure future impacts. More importantly, as shown by Cinner et al. (2012) a co-management approach where government and civil society groups engage resource users is needed so that both ecological and social goals are met. As their 2012 study showed, 54% of the resource users perceived a beneficial outcome by this co-management approach.

In conclusion, this chapter establishes a reference point of ecological data for areas once depauperate of it in South Buton. Henceforth the confluence between ecological and social community drivers and thereby the condition of the reefs overall can be evaluated. Herein I have established the state of the studied reefs and compared them to the nearby areas of the renowned

Wakatobi National Park. This data provides reef managers with the necessary information to evaluate ecologically appropriate conservation strategies.

CHAPTER 3

THE FISHING PRACTICES OF SOUTH BUTON, INDONESIA

3.1 Introduction

The most commonly occurring fishing practices across S.E. Sulawesi, and in particular South Buton, are typically defined as artisanal. They comprise low scale operations such as gleaning, spear fishing, and the use of fish traps (Nédélec and Prado 1990). In addition, trolling, seines, and hook and line are also commonly used but are typically associated with boat usage and high effort, which varies with the degree of motorization (i.e. whether a boat has an engine) (Jennings and Kaiser 1998b). However, these commonly used artisanal practices amongst small fishing communities can have harmful effects if not managed accordingly with respect to the biological thresholds of the associated reefs. They can directly affect targeted species by decreasing population and diversity indices (Russ et al. 2008) and may also indirectly affect fish assemblage structure through habitat alteration (Wilson et al. 2010). Such changes can decrease reef resilience towards additional anthropogenic disturbances (Worm et al. 2006). Therefore, investigating the scale of 'effort' via evaluation of fishing practice, catch targets, and location can provide insight of the level of fishing activity on local reefs.

Three commonly used fishing practices found across South Buton, S.E. Sulawesi are bubu traps, hook and line, and trolling (Fig. 3.1). However, the specific locations in which these particular practices are used have not been documented. Bubu traps are semi-permanent structures placed on the seafloor without bait to lure fish. They are designed to work without attendance, and are typically left to catch for 3-5 days. Their production cost (if made with bamboo) is approximately 400,000 IDR (i.e. 40 AUD). However, the impact of these traps on reef ecosystems and fishing assemblages is capable of modifying the structure of reef fish populations as shown by others (Pet-Soede et al. 2001, Campbell and Pardede 2006, Campbell et al. 2014). Campbell et al. (2014) demonstrated that the traps used in Karimunjawa, Indonesia tended to remove larger bodied fish and therefore more adversely impact overall reef fish structure. On the other hand, hook and line as well as trolling practices have been studied considerably more as they are more frequently employed across the globe. Unlike bubu traps, these methods require higher attendance and daily use for catch effort to yield fish. They also require boat usage, although hook and line can be operated with a simple canoe and paddle, whereas trolling requires motorized boats.

Fig. 3.1: From left to right (bubu trap (©Batang Manyang), hook and line (©Jurgen Freund), trolling (©Australian fisheries management authority)), three commonly used fishing methods across S.E. Sulawesi, in particular the studied area of South Buton.

Fishing location can be studied by spatially assessing where fishers frequent. However, assessing the practices they use can provide additional insight into how fishing practices alter fish community composition or the structure of the reef as well as if the effects will be long or short-term. For example, these two factors have been coupled and used to investigate the functionality on the 15-year old no-take zone of South El Ghargana, Egypt. It was discovered that the abundance of piscivorous fish increased with distance from fishing villages, while herbivorous fish showed the opposite trend. More importantly, occurrence of discarded gear was shown to increase closer to fishing villages (Advani et al. 2015). Likewise, Cinner et al. (2013) showed that fish biomass on reefs remained relatively low within a 14km radius but increased exponentially when that distance grew. This too coincides with the findings of Brewer et al. (2012) who reveal that access to market and population density also has an effect on reef diversity and function.

Understanding fishing practices and the effects they have on reef community composition or structure require long-term data. However, we can study the short-term effects on the associated reef biota by investigating their impact. For example, fishing traps placed on healthy branching corals can become easily entangled and either lost (continuing to catch via ghost fishing) or damaged when lifted back to the boat (pers. obs.). This breaking of coral outcrops has been documented (with practices such as gillnets and beach seines) and shown to have negative long-term habitat impacts (Burke et al. 2011). It has also been documented that coral branches have been broken of to cover and disguise the trap further (Pet-Soede and Erdmann 1998). Furthermore, the speed and breadth of physical changes to reef structure on whole reef fish assemblages is now relatively well known, with up to 62% fish species reduction within 3 years of reef disturbance (> 10% coral cover loss) (Wilson et al. 2006). Additionally, a lost or forgotten trap can damage the reef by continuously 'ghost fishing', thereby overfishing and consequently slowing the recovery of a reef (Matsuoka et al. 2005). This effect has also been well documented in the north coast of Jamaica after Hurricane Allen in 1980 lowered coral cover such that macro-algae dominated reef habitats (Hughes 1994). However, it is thought that the over-fishing of herbivorous fish is what most hindered reef recovery (Hughes 1994). This goes to show that fishing practices that affect fish assemblage structure can be a useful indicator of reef condition.

The literature shows that fish community assemblages encompass a variety of trophic guilds within the coral reef ecosystem, such as herbivores, corallivores, and piscivores (Froese 2006, Micheli et al. 2014). Whilst these guilds are important groupings in assessing a reef, they can also indicate the effects and targets of fishing practices. Largely, these are measured using biomass, abundance, diversity, and size spectra indices (Russ and Alcala 1989). Guilds of large predatory fish (primarily piscivores) comprise the dominant fisheries target group as their yield values are often higher than other guilds (Butler et al. 1993). This has been studied across areas where minimal or no fishing has been recorded to have larger piscivorous biomass than fished areas (O'Leary and McClanahan 2010). Furthermore, for lower trophic levels, impacts are usually less obvious but have been shown to include cascading effects of higher trophic level fishing on the abundance of lower prey species (Robertson 1987). Investigating the impacts of fishing on targeted catch composition can help forecast the assemblage structure of fish communities.

However, catch often fluctuates and fishers are often not able to distinguish short-term variation from long-term trends in stock abundance due to lack of available information (Densen 2001). Fishers typically have a range of strategies to deal with catch fluctuations (Allison and Ellis 2001). For instance they may: bear the losses and wait in hope of better future catch; increase fishing efforts by seeking new fishing grounds and/or changing fishing methods, include using destructive fishing practices; temporarily switch to alternative occupations; or seek a full occupational replacement (Pauly 1990, McClanahan et al. 2005). It has been documented that in Sulawesi fishers in response to overfishing and seasonality will for example, borrow from fishing patrons, migrate to other areas, and even create a local institution in order to regulate fishing activity (Ferse et al. 2014). These livelihood changes typically include occupations in agriculture, tourism, transportation, and trade (Pomeroy et al. 2006, Cinner et al. 2010). Investigating how fishers diversify their professions through multiple occupations is an important theme in understanding a community's dependence on fishing, and in turn, the identification of sustainable management strategies (Rigg 1998, Salafsky and Wollenberg 2000).

This chapter evaluates local fishing practices across South Buton, S.E. Sulawesi, Indonesia, and considers convergence between social and biophysical / ecological data. This involves characterizing fishing practices (fisher's occupations, fishing location, seasonality, gear use, frequency, targeted species) and evaluating emerging patterns from the overlap with reef ecological conditions. Holistically, this chapter provides an overview of fishing practices in relation to reef condition and state (Chapter 2) and may therefore set a reference point of social data in a region of the world with a dearth of information that can be used by community decision makers to design and implement future suitable reef management plans.

I hypothesized that (1) fishing efforts would be concentrated on reef zones with the highest ecological fish yields, namely the reef crest due to its high natural drivers for diversity and abundance; (2) when considering remote communities, it could be expected that reefs nearer to settlements would be more heavily fished since accessibility is likely to be a more important driver than overall high catch yields; and (3) fishing practices requiring daily attendance would target less variety of fish species than practices requiring low attendance as the former practice requires higher fishing effort so those fishers are more likely to concentrate their effort on high value catch.

3.2 Materials and methods

A face-to-face survey, which took approximately 15 minutes to complete, was implemented in June-August 2016 in three regions; Bau Bau, Siompu, and Kadatua. Fifty-two interviews were conducted throughout the region of Bau Bau, 32 in Siompu, and 39 in Kadatua, making a total of 123 surveys with a response rate of 100% (Fig. 3.2).

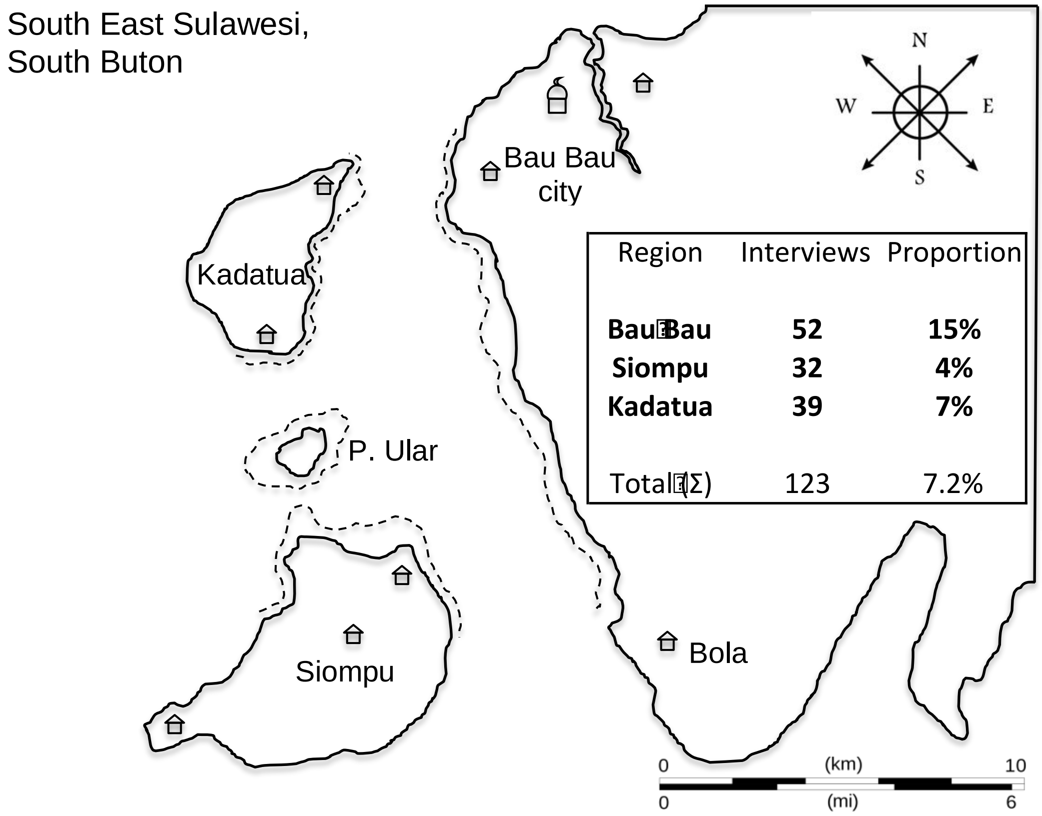


Fig. 3.2: South Buton map depicting survey sites. Dotted lines represent reef crest and small houses represent main village locations where fishers were surveyed. Table insert references the number of interviews conducted per sub-region and the proportion of total fishers in the area.

3.2.1 Sample

Overall population sizes of each region were in the proximity of 154,800 in Bau Bau, 16,872 in Siompu, and 7,703 in Kadatua (Badan Pusat Statistik - BPS, Annex 3B – 2010 and 2015). Triangulated estimates from key informants (unpublished and inaccessible to foreigners data from heads of villages) indicated a higher abundance of fishers throughout the Siompu region compared to Bau Bau and Kadatua with 836, 328, and 524 fishers respectively (fig. 3.2). In order to be classified as fishers, interviewees must have engaged in fishing as one of their livelihood occupations (classified by the extraction of a marine or related animal). Due to time constraints and accessibility to regions, a minimum quota sample of 30 was set for each region: Bau Bau, Siompu, and Kadatua. A higher sample was obtained from Bau Bau because it was the easiest location to target fishers. Although a convenience approach was taken to identifying respondents, efforts were made to survey fishers across all districts in each region.

3.2.2 Survey Instrument

The survey was tested in March 2016 and implemented by local research assistants from Operation Wallacea in June-August of the same year. Response rates for this study were particularly high due to the prior relationship of the surveyors and community members.

Survey questions were divided into three sections: demographics, fishing characteristics, and a mapping exercise (Annex 2A). These sections covered topics such as occupational diversity, geographical location, gear type, frequency and seasonality, and target catch composition. Interviewers asked fishers to locate on satellite imagery their typical fishing locations and identify frequency to those locations. They also asked fishers to state which sites they most frequently visited and identify which sites are the best for fishing and why. It is also important to note that this study focused on fishers whose fishing practices were carried out on a daily/weekly basis and whose fishing vessels were not equipped for overnight fishing. Furthermore, there were times when two or more fishers were present at the interview, which could have led to biased responses or lack thereof from fishers due to peer pressure. When possible, fishers were encouraged to wait and be interviewed individually. In cases where this was not possible, an ad-hoc group interview was carried out, allowing fishers to discuss topics such as which sites produce higher yields of fish and which are more difficult to access.

To begin the interview, fishers were asked demographic information. This served as an important first approach questionnaire and included the fishers' age, gender, residency, and occupational diversity. Occupational diversity in particular was measured by asking respondents to list all occupations that they have throughout the year, including fishing, and the associated months in which they were engaged in these activities. Furthermore, interviewees were asked which occupation they felt was most important for supporting their families (independent of time spent in each job). Occupations were individually noted and later grouped into the following categories: fishing, transport, trade, industry, agriculture, and government (Annex 1A). Furthermore I investigated fishers' residency for the possibility that interviewees may have come from other areas outside South Buton, for example from the nearby Wakatobi National park or the main capital of Sulawesi - Makassar. This was done in order to verify whether fishing activity was predominantly localized and to assess the portion of practices carried out by local communities.

Following the demographics section of the survey, fishers were asked about fishing characteristics linked to their practices. This covered boat uses, ownership, engines, and fishing gear availability. By doing so, I investigated fishers' range and therefore their reef accessibility. In the cases where a fisher may not own a boat, they were asked if he or she had access to one. The previous sections of the survey served as stepping-stones for the mapping exercise, which asked more 'personal' questions of the fishers. Engaging in 'softer' and less invasive questions at the start of an interview to make the interviewee more comfortable and open in their responses has been an important tool used by social scientists in other studies (Tourangeau and Smith 1996).

Lastly, the mapping exercise - in conjunction with a visual aid poster (Annex 2B) - aimed to investigate the areas that fishers targeted. Participants drew their fishing areas on an aerial map of the study site. These areas were given reference tags so they could later be analysed in terms of the gear used, reef zone targeted, species targeted, and temporal targeting for each area. A final open-ended question was asked regarding the fishers' opinion on which area (within or outside their usual fishing grounds) they perceived as being optimal for fishing.

3.2.3 Data Validity

The Research Assistants (RAs) were chosen for their strong ecological background as a consequence of many years surveying the reefs in S.E. Sulawesi. This allowed them to better understand the overall idea of the project that the fishing practice data would be overlapped with known ecological data. Furthermore, during the pilot testing, the principal researcher carried out practice runs and trained the RAs in the use of the survey instrument as agreed by the investigative team. Once fieldwork commenced, follow-up meetings were implemented daily to verify the number of achieved interviews, the scope of districts visited, and to verify the data were collected appropriately. This allowed for careful planning as to which district to target next and verify a representative spread of interviewees. Furthermore, the daily meetings were used to go over responses and briefly discuss their outcomes. By doing so, data inconsistencies could be addressed and digital backup copies made once the validity of the interviews confirmed. As an extra precaution, the incoming results of the interviews were discussed with an external local body (the on-site manager who has a scientific background and lived in the area for over 15 years). This allowed for external insight as to the validity of the results and further planning with regards to future randomization of interviewees.

3.2.4 Illiteracy

Illiteracy was an important issue to consider during data collection for this study. Some fishers may have trouble deciphering the names and view of the aerial map. Illiteracy is not uncommon in remote areas of Indonesia (Clifton et al. 2013) and so it was anticipated that some fishers could have trouble deciphering the names and understanding the aerial map. In order to overcome this, the three translators employed in this study had strong ecological backgrounds so that they could give detailed descriptions of the sites when necessary.

3.2.5 Data Analysis

Data processing and analysis was carried out after the field season. Firstly, interviews were translated into English with the aid of native Indonesian speakers. In cases where translations were difficult (primarily due to dialect barriers; Indonesia has more than 600 dialects (Lewis et al. 2009)), contact with a Butonese partnering scientist was made for clarification. Survey responses were then entered into Excel for digitization. Original copies where cataloged and organized by region into a binding folder. Thereafter, data collation and analysis was done through Microsoft Excel and geographic information system (ArcGIS). GIS was used to create fishing effort maps as seen through color gradients (representative of effort). This was done by transposing each map (n = 123) through a tally-based system of grids. Each participant's map was collectively overlaid onto a map with a grid. Each drawing was given an effort of 1, so when a different fisher draws his fishing area and it overlaps with another fisher's area, the value raises +1. So on and so forth is done with certain areas reaching values of 15+, meaning that specific locations were targeted by 15+ different fishers. This was done for each fishing method and then a final map was produced to show total fishing effort for all methods (Annex 4A).

Using the fishing survey results, this study explored trends and mismatches between targeted reef areas by fishing practice and reef condition of the same areas. A total of six reef sites were evaluated for their ecological condition across three reef zones (Chapter 2). Exploring trends and mismatches could not be done for reefs that were not monitored ecologically, regardless of whether fishing activities where present or not. Comparisons were made between fishing practices (area target, composition, frequency, and gear use) and the reef's complexity and community structure (benthic, invertebrate and fish composition). However, most notably, comparisons were made between fish targeted by fishers and fish observed on reefs during ecological surveys. This overlap was done by categorizing fish species into functional feeding guilds.

3.2.6 Ethics

Verbal consent was obtained from participants before conducting surveys. Each fisher was also provided with a survey, a verbal and written explanation of the purpose of the study (in Bahasa Indonesian) (Annex 2A), how the data would be utilized, and the contact details of associated scientist, managers, and organizations in case interviewees wanted more information. Participants' names were not recorded. Written consent was not obtained due to low literacy rates in many of the regions in order to avoid the possibility that participants may not have fully understood what they signed. This project and survey was given ethical approval by the James Cook University ethics board.

3.3 Results

3.3.1 Demographic Summaries

The average age of participants was early 40s with the youngest fisher aged 17 (interviewed in Kadatua) and the eldest aged 80 (interviewed in Siompu). On average, fishers spent 68% of the year fishing as their primary occupation, the least being those along the Bau Bau region (58%) and highest in the island region of Siompu (77%). Overall, Table 3.1 reveals that regions where fishers have on average higher occupational multiplicity tend to fish less. Furthermore, surveys indicated that fishers from Bau Bau on average spent more time of the year on secondary occupations than those in the island regions of Siompu and Kadatua. The only other occupation besides fishing, found across all regions was agriculture, which was found to be second to fishing in Siompu and Kadatua; taking up 8% and 13% of the year, respectively (Annex 1B). In contrast, fishers from the mainland (Bau Bau) prioritized occupations in trade and transport, 13% and 10% yearly occupation, respectively.

Table 3.1: Demographic characteristics of respondents from the three surveyed regions (Bau Bau, Siompu, Kadatua), focused on fishers' occupational multiplicity (i.e. number of jobs per fisher) and preference (i.e. whether or not, they perceive fishing to be their most important). [1]

Location			Occupation		
Area	N =	Avg. Age	Time spent fishing	Occupation Multiplicity	After fishing most important occupation
Bau Bau region	52	41	58 %	1.9	1. Trade (13%) 2. Transport (10%) 3. Agriculture (9%)
Siompu Region	32	45	77 %	1.5	1. Agriculture (8%) 2. Industry (6%) 3. Transport (4%)
Kadatua Region	39	43	69 %	1.7	1. Agriculture (13%) 2. Industry (12%) 3. Trade (6%)

[1] "Time spent fishing %" represents average fishers within region % of year-spent fishing. "After fishing most important occupation %" represents average fishers after fishing most time consuming occupations throughout the year.

3.3.2 Fishing Characteristics

3.3.2.1 Seasonality of fishing practices

Participant responses to fishing throughout the year showed a peak in fishing effort (90%) during the months of June – October (Fig. 3.3). This overlaps with the 'dry season', which ranges from May to September. In contrast, during the 'wet season' (October to April), average fishing effort by the three most common methods was reduced by 20%. This trend is most notable for the hook and line and trolling methods whose usage in the middle of the wet season fell as low as 55% and 50%, respectively. On the other hand, deployment of bubu traps remained fairly constant in comparison, ranging from 80 - 90% use across both seasons. However, it did show a small decline of use during the wettest months. Lastly, all three methods showed a steady rise in usage during the first few months of the year and a decline towards the end. Furthermore, findings showed that Kadatua fishers, whose use of trolling was the most prevalent amongst the three surveyed regions (> 60% of total trolling use in South Buton), associated most consistently with the above-mentioned trend. In contrast, Siompu region (30% of total trolling in South Buton) had least fluctuation in its seasonality, with 80 - 100% use across the year. Furthermore, surveys showed bubu trap practices were not used at all by fishers in Kadatua.

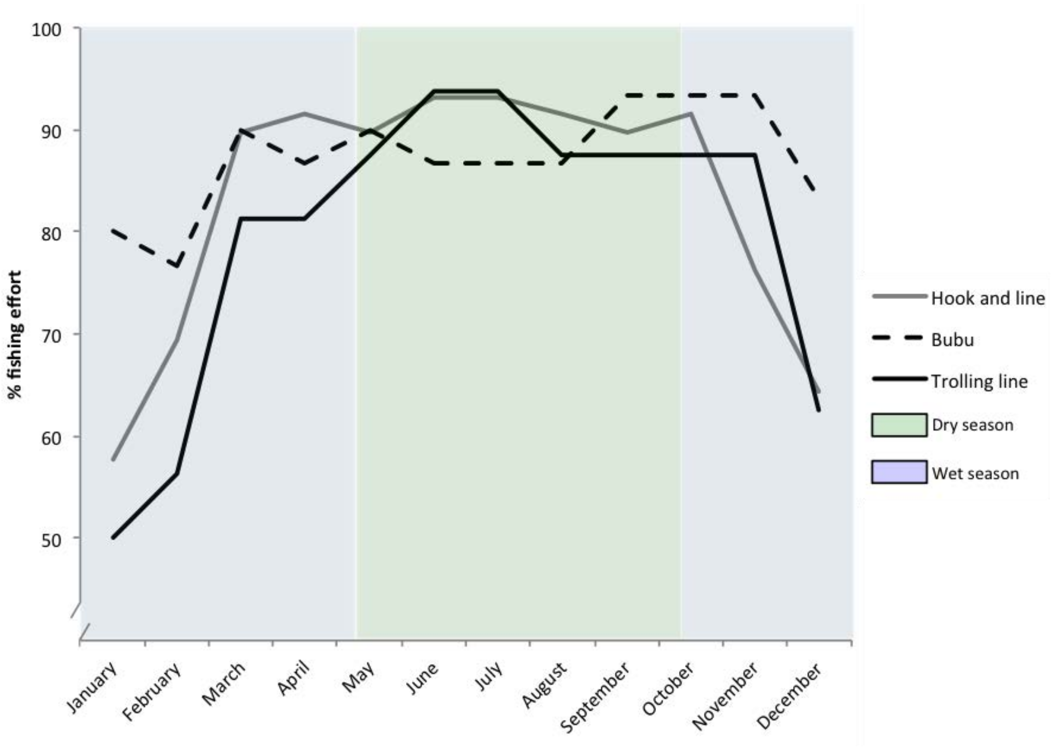


Fig. 3.3: Percentage of fishers interviewed that use each fishing method each month, with an indication of seasonality (n=123).

3.3.2.2 Reef zones targeted by fishing methods

Across the study area, the reef flat was the least fished zone, targeted by 18% of fishers (Fig. 3.4), the reef crest received one-third of total fishing effort, and 48% of effort was carried on out on reef slope. On the reef flat, bubu trapping was most the dominant method used (45% of all flat fishing), whereas hook and line fishing was much lower (9%). On the reef crest, bubu traps and hook and line fishing were similarly prevalent (40% use ± 5SE%). While all three fishing techniques were used on the reef slope, trolling and hook and line were the primary methods used, with bubu trap use only averaging 10% across South Buton. Hook and line and bubu trap methods were used throughout all reef zones but trolling had 100% effort on the slope (Fig. 3.4). Bubu traps were placed fairly evenly across flat and crest (45% use), whereas only 10% of all bubu traps were placed on the slope. Hook and line fishing showed a gradient in fishing effort, which related with increased depth; the shallow zone (reef flat) had 10% effort, which increased three-fold at medium depth (crest 30%), which then doubled in the deepest zone (reef slope 60%).

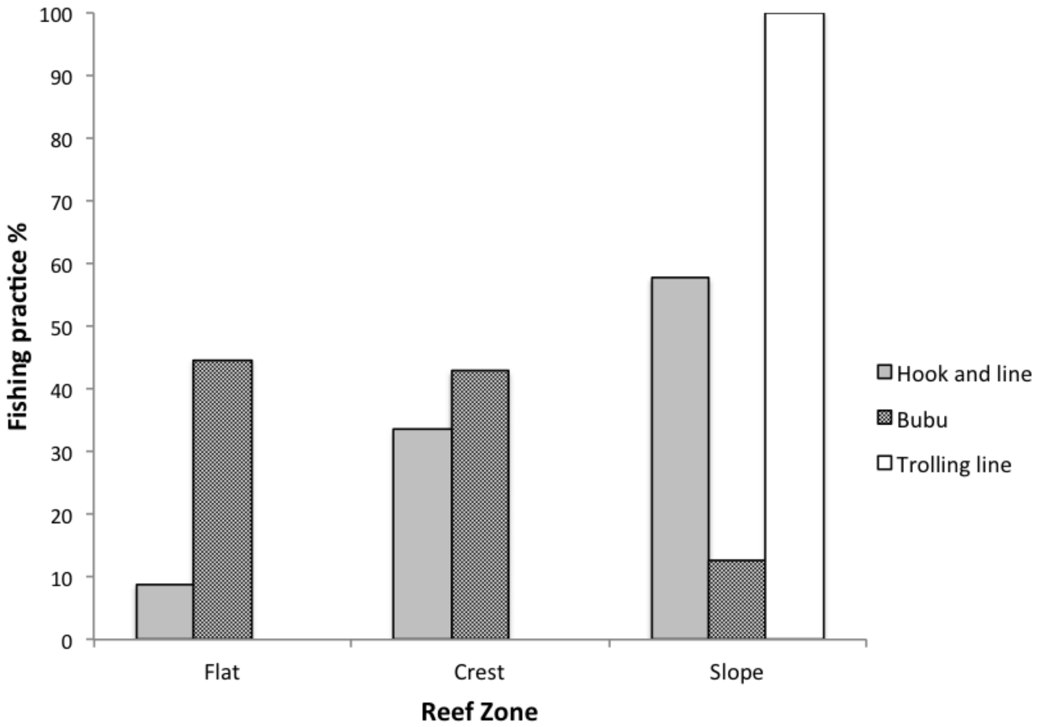


Fig. 3.4: Percentage of fishing effort (n=123) by reef zone (Flat: 0-5m, Crest: 5-10m, Slope: 10+m) for each of the three most commonly practiced fishing methods.

3.3.2.3 Structural complexity in relation to bubu trap placement

On average, fishers claimed to place the most bubu traps along the North West point of the Bau Bau region (n=12) where Nirwana and Pampanga reef are situated (Fig. 3.5). The reefs of Kadatua and Pulau Ular were exempt from any trap deployments whereas Moko and Siompu reefs had a few (4 and 1 fishers using the area with bubu traps respectively). This relates to the average complexity scores found on the reefs. With the exception of Pampanga, the reefs with the higher structural complexity scores where the least targeted by method of bubu trap.

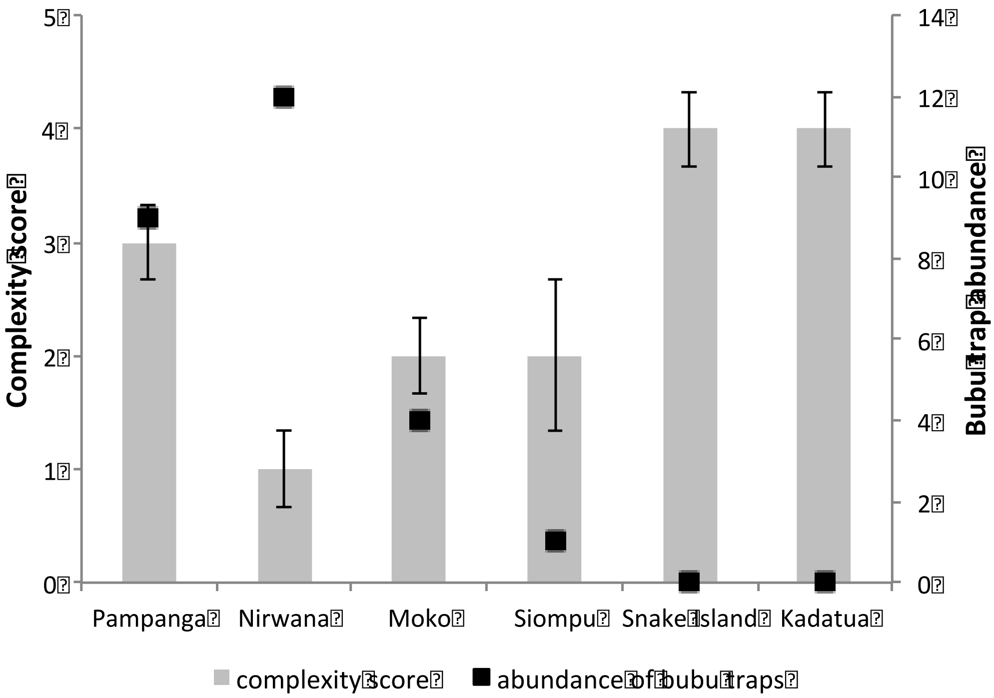


Fig. 3.5: Relationship between bubu trap abundance and structural complexity scores of six surveyed reefs and their associated crests.

3.3.3 Mapping Exercise

3.3.3.1 GIS Maps for the three most common fishing practices and sum of all practices

GIS maps (from participatory mapping exercises) show the effort and location of fishing methods used across South Buton as an aggregate of all surveyed regions (Fig. 3.6d). Overall, the highest activity values of fishing when all practices are combined is revealed to be along the North West corner of the Bau Bau region, where Pampanga, Nirwana and Moko reef are situated. The offshore pelagic areas and the South West corner of Pulau Ular reef are also being targeted, however, far less than the coastal reefs of mainland Buton. The extent of fishing practices within the study area reveals less than five percent is not subject to some sort of fishing practice.

Bubu trap fishing occurred in very specific locations, and most was practiced by fishers from the Bau Bau region (80% of practicers) (Fig. 3.6a). Surveys also revealed fishers using bubu traps often lacked engines for their boats/canoes. Moreover, GIS maps indicate that the second highest usage of trap deployment was in the South West corner of Siompu island (carried out by fishers from Siompu region), but with less usage than reefs along the Bau Bau coastline. Likewise to most practices surveyed, bubu traps were not deployed around reefs of Snake Island (Pulau Ular).

Hook and line was the most prevalent fishing practice and was used by fishers from all regions (Fig. 3.6b). Unlike trolling, hook and line had a higher target of hotspot usage. This was primarily concentrated on the North West point of the Bau Bau region. However, this practice was spread across all of South Buton, with few areas exempt from the practice (map reveals only 10% of ocean in the study area was exempt from this practice). Furthermore, hook and line was the only one of the three most common practices to be used around Snake Island (Pulau Ular) with mid-high levels of effort.

Trolling (commonly used to target piscivorous fish such as tuna, Table 3.2) was used primarily in outer reefs or pelagic ocean, with little to no practice near mainland areas (Fig. 3.6c). The only exception can be seen in minimal effort on the South West corner of Siompu Island. Furthermore, the respondents did not practice trolling at all in between the three surveyed regions or along the Bau Bau shoreline. Lastly, trolling usage differed vastly between regions, with more than 56% deployed by Kadatua fishers and as little as 12% by Bau Bau fishers.

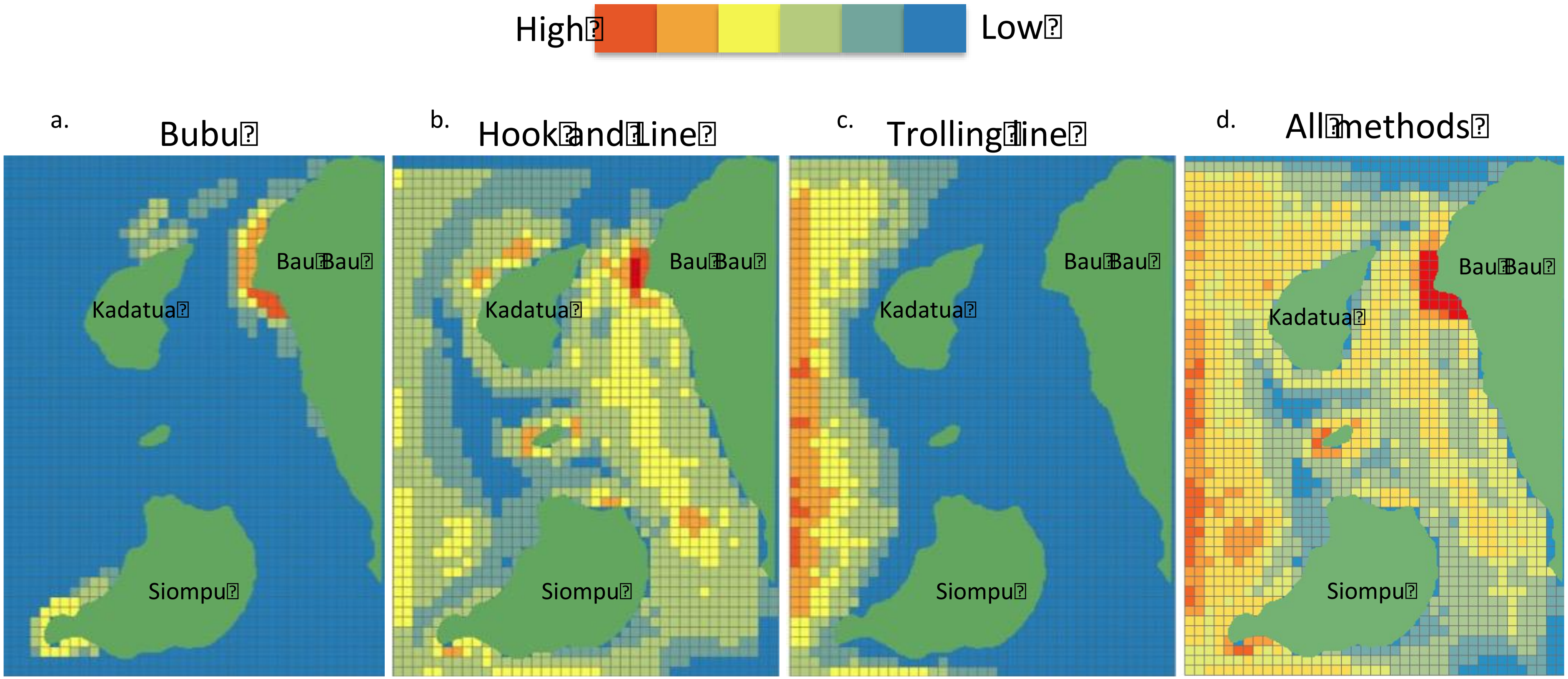


Fig. 3.6: GIS produced maps from participatory mapping (n=123) showing the three most common fishing practices and the locations in conjunction with effort where they are deployed. a: Bubu trap; b: Hook and line; c: trolling; d: all practices combined.

3.3.3.2 Catch target by trophic guild for each fishing practice

Overall, the 123 fishers across South Buton targeted 56 different marine species (fish and invertebrates) covering six different trophic guilds. Piscivorous fish were the most heavily targeted (36% by all practices), with tuna being the most sought after. Corallivores were the least sought fish guild, comprising only 0.4% of all targets, all of which were butterflyfish. Omnivorous fish such as groupers, tunas, emperors and snappers where the primary target by fishers (Table 3.2).

Fishers employing bubu traps targeted the largest variety of fish species, more notably being the only practice that targets omnivorous and corallivorous fish. In contrast, trolling was specifically used to target piscivorous fish in particular tuna. Moreover, it was the only practice that concentrated more than 60% of its effort on one fish guild (piscivores). In comparison, hook and line, which was the most utilized and widespread method (Fig. 3.6b) focused 50% of its effort on invertivores. Furthermore, bubu trap practices where relatively low in their target of piscivores compared to hook and line or trolling methods. Lastly, if not for bubu traps, herbivorous fish would be subject to less than one percent of the targeted fish guilds across the region.

Table 3.2: Percentage fishing effort on targeted fish species by the three most common fishing practices across all regions. The total percentage use of all fishing practices (n=12) across the 6 different guilds is also displayed.

	Invertivore		Piscivore		Planktivore		Herbivore		Omnivore		Coralivore	
Hook and line	**51%**	Grouper (14%)	**35%**	Bobara (12%)	**10%**	Scad (7%)	**1%**	Parrot fish (2%)	**0%**	/	**0%**	/
		Snapper (12%)		Tuna (10%)		Sardine (2%)		Mullet (1%)		/		/
		Emperor (11%)		Skipjack (4%)		Soldier fish (1%)		/		/		/
Bubu	**51%**	Emperor (13%)	**11%**	Bobara (4%)	**7%**	Soldier fish (4%)	**20%**	Surgeon (8%)	**7%**	Moorish idol (3%)	**3%**	Butterfly fish (3%)
		Goatfish (7%)		Shark (2%)		Fusilier (3%)		Parrot fish (4%)		Sergeants (2%)		/
		Triggerfish (5%)		Trumpet fish (1%)		/		angel fish (4%)		Catfish (1%)		/
Trolling line	**12%**	Emperor (2%)	**67%**	Tuna (31%)	**20%**	Scad (14%)	**0%**	/	**0%**	/	**0%**	/
		Snapper (2%)		Skipjack (18%)		Rainbow runner (4%)		/		/		/
		Grouper (2%)		Mackarel (8%)		Fusilier (2%)		/		/		/
All practices (n=12)	**26%**	Emperor (6%)	**36%**	Tuna (14%)	**11%**	Scad (8%)	**14%**	sea shell (5%)	**12%**	Sea cucumber (6%)	**0%**	/
		Grouper (4%)		Mackarel (6%)		Fusilier (2%)		surgeon fish (4%)		Urchin (5%)		/
		Snapper (2%)		Skipjack (5%)		Soldier fish (1%)		Parrot fish (3%)		Moorish idol (0.5%)		/

3.3.5 Overlap – Reef condition and fishing activity

Overall, reef condition scores (represented through percent hard coral cover (HC), and total fish biomass (kg ha^{-1})) and fishing activity scores (represented by locations of fishing practice targets) were not well matched (Fig 3.7). Pampanga reef, which is one of the highest scoring HC and fish biomass locations, was also one of the highest targeted reefs. In contrast, Nirwana reef, which scored the lowest of all reefs in HC and fish biomass indices, was the second most targeted by fishers. P. Ular reef; with the highest overall HC, and second highest fish biomass indices, had similar reef condition scores to Pampanga, and was not proportionally targeted by fishers as per Pampanga. Kadatua reef had medium HC and fish biomass scores, and one of the lowest fishing practice indices. Lastly, Siompu and Moko reef with mid-low HC and fish biomass scores, had proportionally mid-low fishing practice indices. Overall, reef condition scores and fishing practice revealed no clear trends.

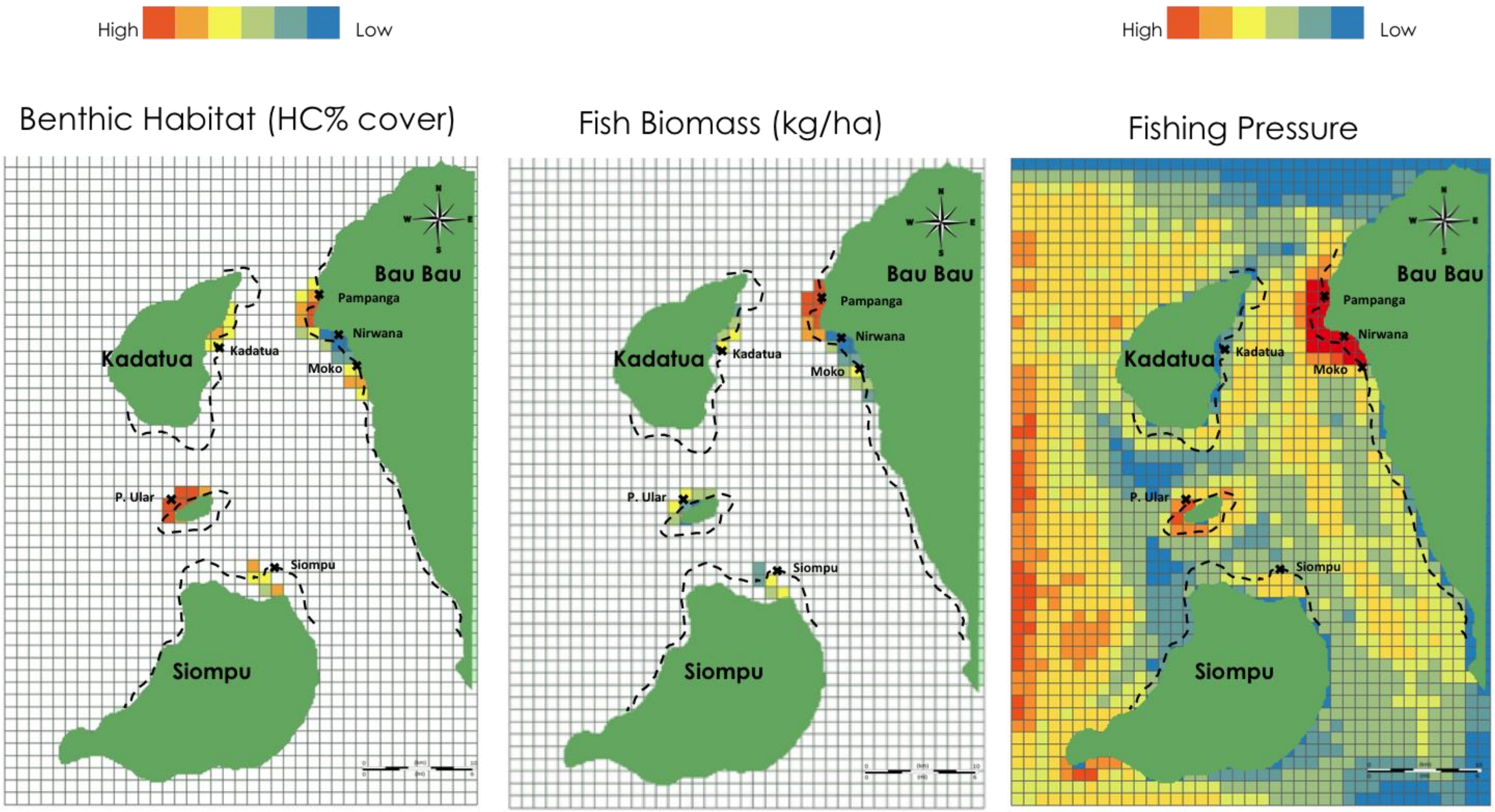


Fig. 3.7: Mean hard coral% cover (left), fish biomass (kg ha^{-1}) (middle), fishing activity (all practices) (right) across reefs in three regions of S.E. Sulawesi.

3.3.6 Overlap – Proportion (%) of targeted fish and observed fish biomass

Overall, no obvious trend or pattern can be observed between targeted fish guilds (Fig. 3.8a) and observed fish biomass (Fig. 3.8b) of the same guild. The most targeted guild using all practices in the study area were piscivores (Fig. 3.8a), which were the lowest recorded (kg ha^{-1}) guild in Chapter 2 (Fig. 3.8b). This similar trend was observed for fish within the invertivorous guild, which was the second most targeted guild by fishers, and the second least observed by fish surveys. Inversely, planktivorous fish were second least targeted guild by fishers (accounting for 12% of all targeted guilds) and the highest recorded guild (biomass indice of 350 kg ha^{-1}) (Fig. 3.8b). Lastly, corallivore, omnivore and herbivore fish guilds showed no relation between being targeted and observed biomass. Findings reveal herbivorous fish for example were the third most targeted guild (< 15% of fishing target) and the second most abundant (75 kg ha^{-1}). Together, these three guilds make up as much effort of fishers catch target as invertivores alone (26%), which were 10% less than piscivores (36%).

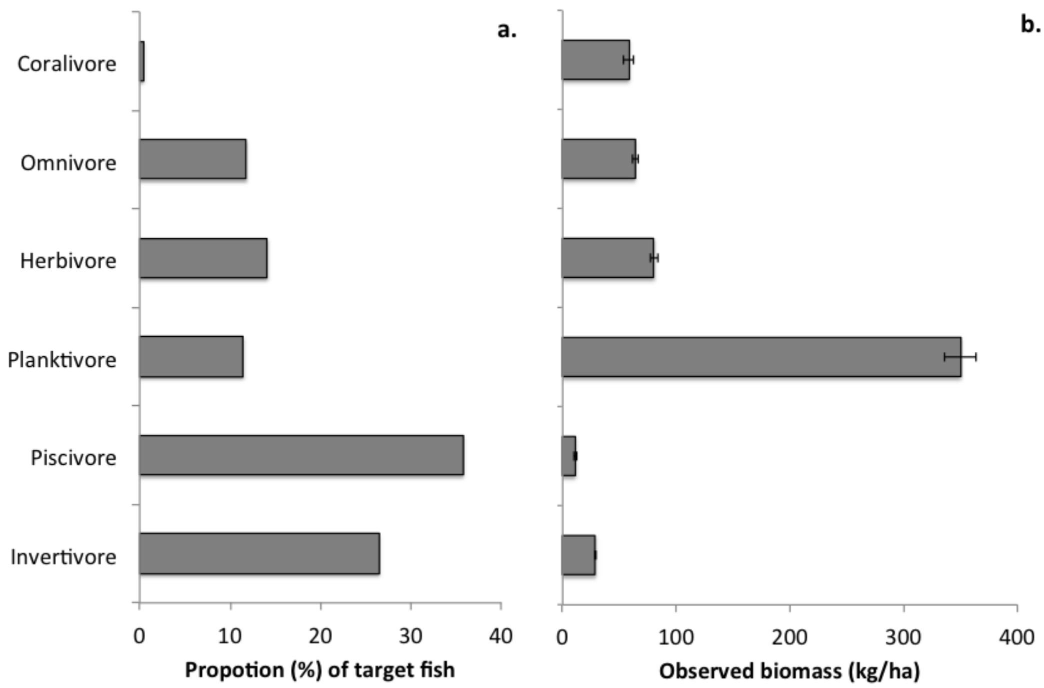


Fig. 3.8: Overall summative graph depicting (a) proportion (%) of targeted fish guilds by all fishing practices, (n = 123 interviews) in comparison to (b) mean observed biomass (± 4.4 st. error) of each fish guild in the study area (Chapter 2, n = 4 replicates per reef site and zone)

3.3.7 Overlap – Proportion (%) of targeted fish families within ~500m of surveyed reefs and observed fish family biomass.

Similar to the overlapping the proportion (%) of targeted fish guilds to observed fish guilds (Fig 3.8), no obvious trend or pattern can be observed between targeted fish (Fig. 3.9a) and observed fish biomass (Fig. 3.8b) of the same family. Figure 3.9 reveals the top five most targeted fish families by all fishing methods within ~500m of the surveyed reefs. Only two families (Scombridae and Lutjanidae) were observed during the underwater surveys (Fig 3.9b) and overlap with the proportion (%) of targeted fish families by fishers (Fig 3.9a). The most targeted fish family using all practices and within a ~500m distance of surveyed reef was Carangidae (Fig. 3.9a), however not recorded during underwater surveys (Fig. 3.9b). The same outcome can be observed for fish in the family Lehtrinidae and Serranidae. The families of Scombridae and Lutjanidae (second and fifth most targeted families) were observed during the underwater surveys, albeit in very low numbers (5 ± 0.4SE kg ha^{-1} and 4 ± 0.3SE kg ha^{-1} respectively). The top five most targeted fish families (Fig. 3.9a) accounted for 58% of fishing targets within ~500m of surveyed reefs however underwater surveys only overlap amongst two families (Fig. 3.9b) accounting for < 1% of observed fish during underwater surveys.

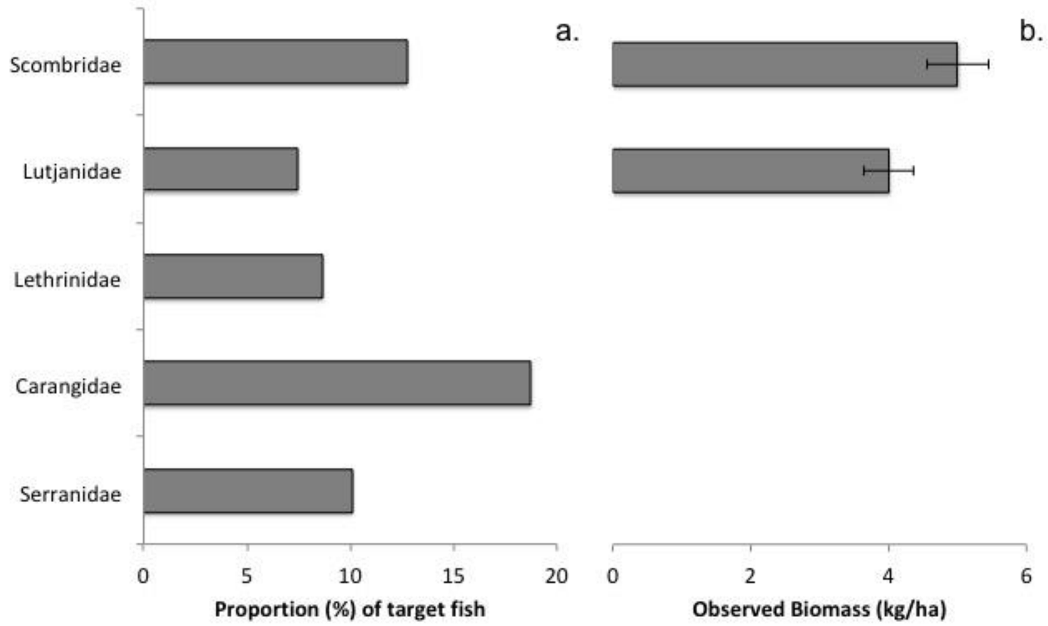


Fig. 3.9: Overall summative graph depicting (a) proportion (%) of the five most targeted fish families by all fishing practices, (n = 123 interviews) in comparison to (b) mean observed biomass (± 0.4 st. error) of the same observed fish families within the study area (Chapter 2, n = 4 replicates per reef site and zone).

3.4 Discussion

Results showed that fishing effort and method varied both temporally and spatially across the South Buton study area. The demographic information does not ascertain the level of dependence on fishing of the study communities, but broader census data from other studies in nearby regions have shown there is high dependence on fishing as a primary source of income in this area of S.E. Sulawesi (Crabbe and Smith 2002, Exton and Smith 2012, Exton et al. 2014). This may infer that the communities in the study area have high levels of dependence on fishing. Moreover, fishing characteristics revealed fishers overall target the reef slope and not the reef crest as hypothesised. This could significantly help future conservation efforts in maintaining diversity and abundance of reef fish, due to their high ecological dependence on the reef crest. Furthermore, fishers revealed high preference towards piscivorous fish, mostly found on offshore pelagic areas, with the exception of practices requiring close to shore deployment. This indicates communities may be extending their fishing range away from inshore reefs as predicted. Lastly, in reference to the third hypothesis, results revealed accordingly that practices with daily attendance requirements were more specific in catch targets than those able to catch without direct involvement, therefore targeting a wider array of fish species.

3.4.1 Demographics and occupational diversity

Occupational diversity was relatively high across the study site as a whole, but was highest across fishers in the Bau Bau region and lowest across fishers in the Siompu region. This is important, as Buton is a relatively small island, isolated from other parts of Indonesia making as other studies have shown, the size of the domestic market small and accessibility to outside goods more difficult (Baldacchino 2002). However, there are small island cases where “exclusive island identities” and overall good condition result in the attraction of external markets such as tourism (King 1993) thus providing new occupational opportunities for communities. Furthermore, given that fish is the primary source of protein in the Indonesian diet, the supply and demand from local fishers is high (Dey et al. 2008) thereby not only increasing pressures on local resources but also expanding fishing occupations. Moreover, fishing is a trade that can be learnt with little formal education, which is particularly advantageous for those families living on the smaller and more remote islands of Kadatua and Siompu. All these factors would contribute to the high occupational demand in fishing. Furthermore, given that Kadatua and more so, Siompu are so small and isolated, there are less opportunities for occupational diversification. On the other hand, Bau Bau, with a population 9.6 fold and 22 fold higher than Siompu and Kadatua, respectively, has more infrastructure (hospital, university, shopping centre), and therefore offers more opportunities to fishers to have greater occupational diversity, as this study showed.

Greater occupational opportunity would also explain why fishers from Bau Bau were found to spend more time of the year in secondary jobs than those on Kadatua or Siompu. More in-depth analyses on secondary occupations revealed that fishers from both Siompu and Kadatua valued agricultural occupations as second most important (8% and 13% time spent per year, respectively). In contrast, the Bau Bau region valued trade as their second most important source of income, occupying 13% of the year. This is likely due to land constraints, making fishers' availability to mainland markets more difficult. This might suggest therefore that growing crops on the island is a viable and cheaper option than travelling to the mainland. Studies on other islands in the Indo-Pacific (e.g. Ahus island, Papua New Guinea) have found that poor soil quality led to minimal engagement in agriculture (Cinner et al. 2005) and terrestrial resources such as firewood, timber, and vegetables were dependent on good trade relations with neighboring mainland villages (Carrier and Carrier 1989). These issues could be the case for South Buton, where Bau Bau region fishers had a high level of participation in trade (business) related jobs. Indeed, Bau Bau fishers surveyed were the only participants to own shop stalls.

Fisheries related studies in other developing countries, such as those in Africa, have found that lack of support for new institutions and dismantling of community led governance to be a primary cause in the ecological collapse of the fishery (Béné et al. 2010), thereby underscoring the need to support occupational diversification. These studies show communities with high development, and thus wealth, tend to consume more and often this leads to negative impacts for ecosystems at larger scales (Arrow et al. 1996, York et al. 2003, Cinner et al. 2009). If this is the case for communities in the Bau Bau region, precautionary measures such as occupational diversification and catch quota policies need to be implemented in order to prevent future negative impacts that could result in the local small-scale fishery collapse. Thus, further studying the scope of fishers' occupations is crucial for developing management policies with high compliance and success, and also for referencing the social-economic status of local communities.

3.4.2 Effects of seasonality of fishing effort

For South Buton, fishing practice trends followed the seasons, wet season (October to May) and dry season (June to September). That is, fishing effort was highest in the dry season and lowest in the wet season. This was particularly true for hook and line and trolling methods. This can likely be attributed directly to heavy rainfall, whereby fishers utilizing hooks and trolling are somewhat impeded by the rain (pers. obvs.). An annual rainfall average of 2,000 – 3,000mm (Fig. 3.10) can be an inhibiting factor to fishers on canoes or boats without cover, as is typical in these communities. Nevertheless, fishers continued to practice fishing during the wet season, likely due to the incessant demand for fish from local communities and even international markets. This similar trend of fishers and season can be found in the neighboring Wakatobi National park (von Heland et al. 2014). Additional support for this idea is that the use of bubu traps was less affected by seasonality because they do not require constant attendance. This means, that fishers can wait for the right opportunity to yield their catch and deploy their traps independent of weather related pressures.

Seasonality typically has a very strong influence on spawning periods, which in some cases has led to fishing regulations being made around spawning models (van Overzee and Rijnsdorp 2015). It may be possible therefore, that fishers across South Buton are aware of spawning seasonality, and that could be causing the observed changes in fishing effort rather than, or in addition to, direct effects of the wet season. Alternatively, ecological effects of seasonality have been shown to differ amongst varying reef structures. For example, a study in Northwestern Moorea (French Polynesia) on fish community structure across diurnal, nocturnal, and crepuscular communities amongst fringing, barrier, and outer slope reefs showed that amongst fringing reefs (as per those studied in South Buton), fish abundance decreased from March to August (Galzin 1987). This coincides with the increased fishing effort observed in Bau Bau between April and August. Therefore, it could be that due to continuous demands for fish from the community, the fishers are required to increase their effort in order to maintain yields in some seasons.

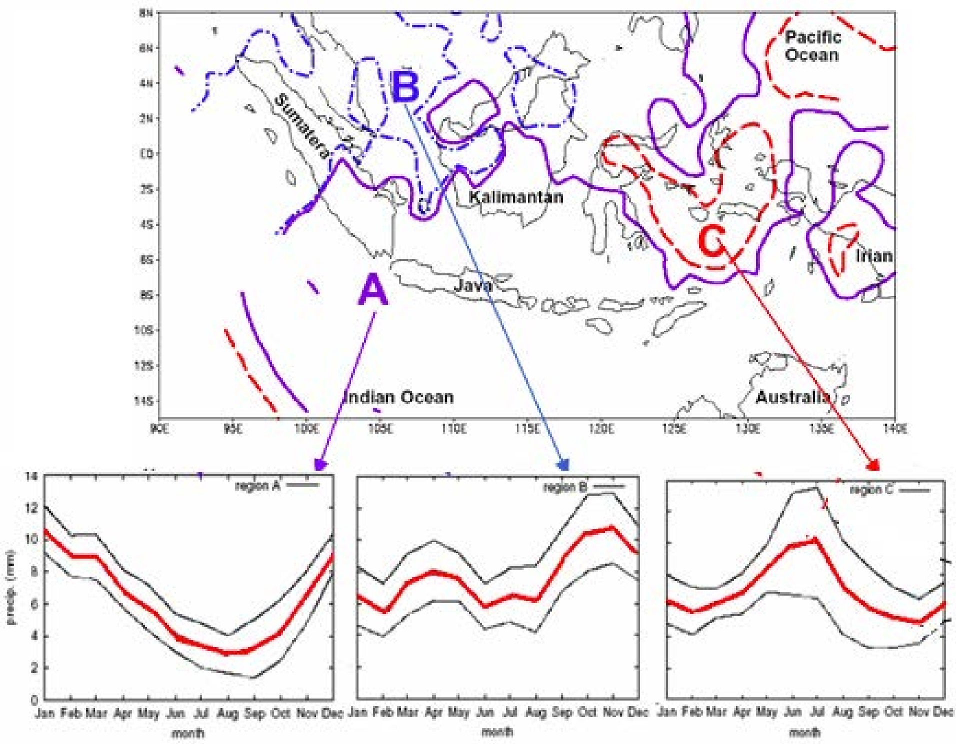


Fig. 3.10: Seasonality map of rainfall patterns across Indonesia (Kardasah (2007)).

3.4.3 Reef zones targeted by fishing practice

Different fishing practices were found to target different reef zones in South Buton. For example, bubu trap fishing was targeting the reef flat, while hook and line was most practiced on the reef slope, and both were used on the reef crest. Difference in fishing zone preferences can be explained, in part, by the differential structure of biotic assemblages on each reef zone (McManus et al. 1981, Meekan et al. 1995, Adjeroud et al. 1998). Many of the biotic differences are related to depth gradients (Brokovich et al. 2006) and habitat structure (Lara and González 1998). Reef crests and slopes are frequently correlated with higher abundance of fish as their higher structural complexity offers considerable refuge for smaller fish (Almany 2004). South Buton fishers working reef slopes typically targeted depths of 20m – 50m. However reef fish surveys were conducted between 2 and 18m, indicating any linkage herein between fishing practice and the ecological state of reef slopes should be taken cautiously.

In addition to different reef zones providing advantages, each practice is also coupled with a degree of risk in the form of loss or breakage. Fishers using hook and line are mostly carrying out this practice on small boats, without engines, with more than one crewmember, and targeting the reef slope. Perhaps fishers target the reef slope because average fish size increases with depth (Andradi-Brown et al. 2016). However, the reason for slope fishing could also be related to avoiding equipment loss. Hook and line materials (nylon and led) can be expensive to replace for impoverished fishers if frequent loss occurs from entanglement on coral branches at shallower depths.

Similar conclusions can be derived for the second most frequented practice in South Buton - trolling, which was primarily located on offshore (non-reef) areas. This practice, however, differs in that it is mostly used in a commercial context rather than subsistence (Majkowski 2003, Bugoni et al. 2008). Furthermore, the commercial attribute requires elevated capital investment and thus a fishery production of high catch yields suitable for export (Bugoni et al. 2008). All interviewees utilizing this practice responded to deploying their lines along the reef slope. However, the survey refers to the slope as depths of 10+ meters thereby including outer reef slopes of 40+ meters from which little ecological data are available. This is important when discussing the use of trolling because even though pelagic fish size may be significantly larger than reef fish targets (Andradi-Brown et al. 2016), the catch diversity is low and therefore less likely to impact overall ecosystem services (Worm et al. 2006). Furthermore, most pelagic species have a higher reproductive and growth potential than reef fish, thereby increasing their vulnerability to fishing, but so long as fishing activities and fish recruitment are in time, they may be fished sustainably (Jennings and Kaiser 1998a). The effect of fishing on the slope can therefore be argued as a preferable area of fishing practice, as the consequential effects are less than those on a highly diverse coral reef crest.

In the context of biodiversity reduction, bubu traps are potentially one of the most harmful practices because of the diverse and non-specific guilds they capture. For this fishing practice, 36 fishers responded to using them 45% of the time on the reef flat and 40% on the reef crest. However, physical changes on a reef are noticeable with varying depths, such as wave action, which bring about potential risks for fishers using traps seeking diverse catch yields (Matsuoka et al. 2005). Ironically, wave action has been shown to increase biodiversity along Hawaiian exposed reef crests (Huston 1985). Bubu trap placement would therefore seem optimal along reef crests where the likelihood of catch was highest. South Buton fishers, however, indicated that they placed the highest amount of traps on reef flats.

The placement of traps on reef flats could be due to several reasons, one of which relates to the substrate on which traps are placed. If fishers place traps on sandy areas, retrieval is easier as they are less exposed to breakage from entanglement on coral outcrops (Matsuoka et al. 2005). Secondly, fishers run the risk of traps falling down the reef slope, where retrieval is significantly more difficult. Replacing these traps can be costly as previously stated, but more so, it is time consuming as their construction (for bamboo traps) takes approximately one week from start to finish. This then creates a risk-reward scenario (Fig. 3.11), whereby a fisher must decide whether the risk of losing their trap is worth the potentially higher fish catch yield from the slope placement. This risk-reward scenario for fishers using trap practices was reflected in the results of this study, which showed that fishers generally avoid reefs with high complexity scores (which are likely to yield highest catch) such as Pulau Ular reef. In contrast, they appear to place traps on low structural complexity reefs such as Nirwana, where the catch yield is lower but the chance of retrieval much higher. Furthermore, fish tend to be attracted to artificial structures in low-complexity environments (Beets 1989, Gratwicke and Speight 2005a) such as the ones found in Nirwana reef. Therefore catch can be quite high due to this aggregation of fish in one spot.

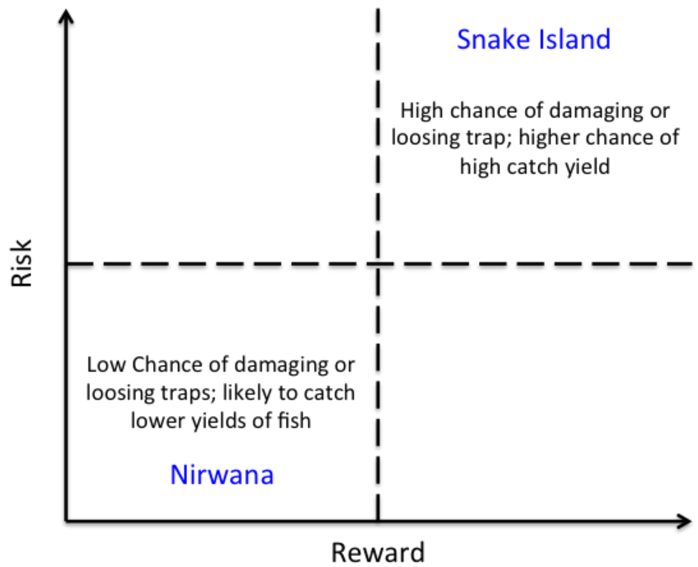


Fig. 3.11: Risk-reward scenario concept for fishers using fish trap practices in South Buton.

Ecologically, however, the loss of these traps can pose a severe threat. Mainly, in the form of 'ghost fishing'; a term used to describe derelict fishing gear, either lost or abandoned, which continues to function in the water by inducing mortality of aquatic organisms without human control (Matsuoka et al. 2005). For example, studies of crab traps in Japan revealed cages in shallow waters (such as those found along reef crests and flats in South Buton), were able to maintain capture function for 3-year periods (T. Matsuoka & T. Nakashima, unpublished data, 2002). Arguably, trap material for surveyed crab traps in Japan was made from non-biodegradable sources such as metal wire (Matsuoka et al. 1997). Bubu traps deployed along reefs in South Buton were mostly made of bamboo, with the exception of a couple that were made from metal wires. The lifespan therefore of bamboo traps would be considerably lower than that of metal wire. Consequentially, loss of bubu trap, and more specifically those made from metal materials, will have the highest long-term damage on a reef crest (Fig. 3.11).

Fig. 3.12: Bamboo (left) and metal (right) bubu traps lost, with ghost fishing characteristics.

3.4.4 Mapping exercise

My mapping exercise identified the areas of South Buton where fishing practices are carried out and the range of practices used per site. Trolling for example was reported as being used in pelagic regions, far from any inner reefs (mostly along the S.W. area of South Buton). This practice involves the use of deploying lines on the water with attached hooks and a moving vessel, and as such entanglement on a coral reef crest can be a risk. Results herein corroborated this as 100% of participants using trolling methods indicated offshore pelagic areas were targeted. However, no trolling was reported within the offshore area covered by Siompu, Kadatua and along the shoreline of the Bau Bau region (Fig. 3.6c). This may be due to two reasons. Firstly, there is a high traffic of commercial vessels (i.e. transport of goods and people) utilizing these waters (pers. obs.). This traffic could be disturbing the targeted pelagic fish population and / or pose a high risk of line entanglement for fishers. Secondly, it could be attributed to the low currents present in the area (pers. obs.). The three areas are relatively sheltered, and have weak current activity (pers. obs). High current areas typically bring in additional nutrients that in turn attract baitfish and predatory pelagic fish like tuna (Lewis 1990). Current lines (created by two bodies of differing temperature water) are also used by tuna fish in order to aggregate their prey against the thermocline (Lewis 1990). Weak currents would therefore host less of the targeted fish. These factors therefore provide possible explanations for the lack of trolling activity on the inner area of the three regions. Should further surveys be done on these methods, interviewers may consider asking the reason for the heavy fishing activity in the pelagic zone, and extend the boundaries of the participatory map to include a larger area to the west so as to best identify the 'range' of fishing activity.

Hook and line was by far the most used fishing practice across all regions with a total of 64% fishers using this method. Likely due to its cheap replacement, ease of use, and basic characteristics, fishers can employ this practice regardless of their vessel availability, access to reef or even expertise. However, the GIS maps revealed that hook and line not only covered most of the surveyed area, but also heavily targeted certain places. One such area is in the North Western point of Bau Bau region. This area is heavily surrounded by fishing communities and the main city of Bau Bau, so fishers need not travel far for daily catch. This translates to more time spent on secondary occupations and/or lower costs in the form of travel (i.e. fuel). Furthermore, the island of Pulau Ular was only targeted by this practice in comparison to the other two (trolling and bubu traps). This demonstrates that hook and line has the least restrictions as a fishing practice as Pulau Ular is known across South Buton for its rich reefs.

Fishing practices in Pulau Ular reef would therefore improve chances of high catch yields. Bubu trap practices were used by 23% interviewed fishers, of which > 90% were residents of the Bau Bau region. This might be an indication as to why the range of use by bubu trap method was mostly centered on the North Western corner of the mainland coastline. Likewise to hook and line practices, reef accessibility plays an important role and especially when the item is as bulky as bubu traps. However, the construction of bubu traps requires local knowledge. Knowledge for which the district of Sulaa (Annex 3 Section A), located a few miles north of Pantai Nirwana (where Bubu traps are kept when not in use), is well known. This local knowledge is likely to influence the abundance of bubu traps found in the area, more specifically, on the reefs near beach “Pantai Nirwana”. This beach provides fishers an easy way to load their canoes with the traps and paddle out to their desired reef location as well as an area in which to sort through their catch. Likewise, the distance to neighboring communities reveals a lack of fishing activity in the highly biodiverse reefs surrounding Pulau Ular. Bubu trap fishers from Bau Bau would need to paddle 9 km to reach these reefs and would risk losing their catch or trap in transit, which could negate the efforts.

Lastly, the GIS map revealed fishers using bubu traps were doing so close to the shoreline (in comparison to other methods). Moreover, this is verified by the findings in figure 3.4, which showed the highest fishing activity to be on the reef flat by bubu trap practice. The risk-reward concept therefore can help explain why the highest placement of bubu traps is found along Nirwana reef. This reef is characteristic of a slow gradient between the flat and slope, which in turn ensures fishers a low chance of bubu trap loss via falling down the reef slope. However, GIS maps also indicated a small fishing effort in the S.W. corner of the Siompu region. This means that if bubu trap practices were a proxy of reef structural complexity, we would likely find those reefs to mirror that of Pantai Nirwana’s reef.

Overlapping the observed fish biomass and percentage target of the same guild by fishers revealed mismatches and limitations in the data collection process. For example, piscivorous fish were the most targeted guild by fishers but they were one of the least recorded fish in underwater surveys. This could infer that fishing activity is driving piscivorous fish biomass down. However, fishers targeting piscivores claim to target them in offshore pelagic regions far from where fish surveys were conducted (Fig 3.6c). These pelagic areas were not included in ecological surveys due to diving limitations. For this reason I cannot fully confirm if there is a direct relation between observed biomass (kg ha^{-1}) levels on the reefs and the percentage target of the same guilds by fishers. The same trend appears amongst invertivorous fish (such as snappers), and likewise, collecting data on species in these guilds is difficult due to their low presence on coral-associated substratum.

To further investigate how these two surveys overlapped we also compared the top five most targeted fish families (%) by fishers within ~500m of surveyed reefs with the same observed fish family biomass (Fig 3.9). This too revealed mismatches and presented even further the limitations in the data collection. In fact, of the five most targeted fish families, three (Lethrinidae, Carangidae and Serranidae) where not observed during the underwater surveys. The two that did appear in the surveys accounted for very little of the overall observed biomass (< 1%). The fish families targeted by fishers within ~500m of the surveyed reef where largely made of fish such as scad, tuna and emperor which rarely if ever appeared in the underwater surveys.

Perhaps, a more comparable trend would appear when analyzing the fishing practices more closely related with targeting reef fish such as Bubu traps. However, as seen in Annex 7b which accounts for the five most targeted fish families within ~500m of a surveyed reef using Bubu traps, only two fish families (Acanthuridae and Siganidae) overlap with the five highest recorded fish family biomass (Annex 7c) thus showing even further mismatch and limitations in the survey method. Perhaps, the only trend these results reveal is that the most targeted fish family by Bubu trap within ~500m of the surveyed reef was the herbivorous rabbitfish (Siganidae) (Annex 7b) which was also was the lowest observed fish family biomass amongst the top five most observed during the underwater surveys (Annex 7c). Ultimately, whether overlapping the data through feeding guild, family or even a particular reef associated fishing practice to the observed fish biomass during the underwater surveys explains very little of the cause and effect between fishing and reef condition. Therefore this study cannot draw any substantive conclusions as to their relation. However, it can help discuss why that might be that case and how any future surveys could avoid this.

The invertivore fish guild was also not commonly recorded via methods used in underwater surveys. This guild is mostly made up by species such as groupers, emperors, and snappers, which likely due to the unprotected status of South Buton reefs are experiencing high levels of fishing activity. This has been proven to influence the 'flight' response of fish when surveyed (141cm increase on average in fished areas compared to no-take marine reserves) (Januchowski-Hartley et al. 2012). This can result in low observations of fish within this guild and therefore account for the low-recorded biomass indices of this guild. A similar problem may occur with some of the targeted planktivorous fish (e.g. Scad) that were rarely observed in ecological surveys, simply because the UVC methods used here are not well suited to determining their presence.

While the corallivore, herbivore, and omnivore fish guilds together made up as much fishing effort target as piscivores alone (36%), these guilds are comprised of fish species less desirable to fishers such as butterfly fish and moorish idols. This is important because low target effort by fishers towards these guilds is likely to benefit the overall health of the reef. Species within these guilds have lower trophic levels and therefore serve as food sources for the more commonly targeted species such as tuna and mackerel (Majkowski 2003). Maintaining species of lower trophic guilds (Holt 2009) and avoiding removal of top predators (Dulvy et al. 2004b) is pivotal for the overall health of the reef. Furthermore, the fact that they are not targeted as much within the study area suggests that these reef fish guilds are likely to continue thriving.

The reef areas most highly targeted by fishers were also the areas richest in fish biomass (namely Pampanga reef). This suggests that reefs across the study area, in particular Pampanga are healthy enough to withstand fishing activities. However, I cannot state that the fishing activities the reefs are subjected to is high or low in comparison to reefs across the globe, primarily because fishing activity in this study was measured through fishers' responses and not directly through observed testing. To further investigate mismatches between observed ecological condition and fishers fishing practice responses, this study uses the nearby Wakatobi national park as a benchmark of reef ecological condition and fishing practice use. This is discussed in the following chapter, were management implications and future research direction as well as limitations in this study are examined in more depth.

CHAPTER 4

GENERAL DISCUSSION

Key Findings:

Overall, this thesis provides a reference point of ecological and social data for a region of the world that was previously understudied. This will serve to advance understanding of these reef systems as well as aid decision-makers in the design and implementation of suitable reef management plans. This thesis also demonstrates the value of a social-ecological approach to evaluating how people interact and use the reefs; which ultimately underpins any successful environmental management plan.

In Chapter Two, findings on the combination of high and diverse scleractinian coral cover indicated that reef benthos is in good condition overall. Simultaneously, the region had low fish biomass indices, indicating that the overall condition of the reef was indeed poor and particularly when compared to reefs in nearby regions. Non-coral invertebrate community abundance, such as the presence of COTs, was helpful in comparing reefs to one another however, less indicative of overall condition. Likewise, structural complexity differed greatly between reefs and remains an important measurement, but more in depth analysis is required to understand the correlations it has with other ecological variables such as fish and invertebrate communities (Chapter 2).

In Chapter Three, overlapping this ecological information with fishing practices in the same area revealed uncertainties whether the reefs in South Buton are healthy enough to withstand local fishing activities. In fact, the presented data would suggest that the reefs across South Buton are overfished, but due to limitations in the study, this cannot be certain. More so, the fishing practices carried out were focused on outer-reef areas and not generally targeting the more closely coral-associated species (Chapter 3). Both are promising signs for future reef health. However, I cannot conclude that the ecological condition of coral reefs in South Buton will remain in its overall 'good condition'. I can only suggest that future research directions build upon the ecological reference point created here and cover more in depth the impact of fishing practices by direct measurements.

Emerging hypotheses:

Coral reefs in South Buton varied greatly in ecological condition, likely determined by the composition of the biota living within them. Hermatypic corals provide shelter and food security for thousands of coral-associated species (Gardiner and Jones 2005, Vroom and Braun 2010) thus can be used for evaluative processes in overall reef condition from which a reef can be categorized (Suharsono 1998, Pandolfi et al. 2003b, Wilkinson 2008). High coral cover and growth form appears to be a common feature in driving overall favorable reef conditions as was evident across reefs such as Pulau Ular and Pampanga. In contrast, when both or one lacks, the associated reef community composition showed poor overall condition as was evident across Nirwana and Siompu reef. Comparative to reefs in the nearby areas, such as the WNP, the reefs of South Buton were more reflective of the condition present at WNP 12 years ago prior to management intervention (Clifton et al. 2013). At South Buton, a program of long-term monitoring and evaluation of reef condition is necessary to ascertain the trajectory of reef state and underpin future management initiatives. Additionaly, socio-ecological approach to management is essential, whereby the ecological condition of a reef is overlaid with social priorities of local communities (i.e. fishing practices).

The high population density of South Buton and presumed reflective fishing activity was expected to negatively impact the reefs. However, this was not certain to be the case. This may be explained by a recent migration of fishers to reefs in better condition. More likely perhaps, it could be explained by the fact that fishers in South Buton were targeting outer-reef areas and therefore, direct impact on reef-associated biota (i.e. 'lower trophic' guild species) was less evident on overall reef condition. This is promising as these usually 'lower trophic' guild species are essential prey for the more sought after 'higher trophic' guild species such as tuna (Lewis 1990). This finding was made even more confounding as fishing practices in nearby areas such as the WNP (Clifton et al. 2013), would suggest fishing of coral associated species such as herbivorous parrotfish (Scaridae) or planktivorous damselfish (Pomacentridae) are a key food source for human population of S.E. Sulawesi. It may be possible that South Buton's highly developed industries (in comparison to more remote Indonesian locations) have as a consequence a more capable fishing fleet for outer reef fishing that in effect limits the human impact on fringing reef systems.

Nevertheless, there still remain a few coral-associated fishing practices on the rise in South Buton (i.e. Bubu traps) that may in the long-term have harmful effects on the condition of the reef as have many other destructive fishing methods (Pet-Soede and Erdmann 2003). A direct measurement of all fishing practices studied here would detail the level of impact on reef condition and may provide evidence of favorable and non-favorable reef associated fishing practices. However, the outcome of this evaluation may be hindered if the local community is not part of the evaluative process. In conclusion, for the time being in this study area, my findings imply that conservation plans to protect coral-associated species would not likely interrupt the majority of fishers.

Implications for ecological theory:

Ecological evaluation regarding the overall condition of a coral reef are driven primarily by the benthos with scant attention to fish assemblages and invertebrate richness (Fox and Bellwood 2007). Studies focusing on one or few ecological traits of a reef do not adequately explain the overall condition of the reef (Vroom 2010) which is why this study aimed to cast a wide net of ecological valuations in reef associated biota and structural form. High coral cover theories are predicted to result in ‘good’ to ‘very good’ overall reef condition over time and space in most evaluative studies (Connell et al. 1997, Gardner et al. 2003). Whilst this is true to a certain extent, this thesis implies that high structural complexity is also needed with the addition of varied growth forms and low abundance of harmful non-coral invertebrate species. When this is not the case, low indices of associated fish assemblages are evident (Chapter 2). As a consequence, the low diversity of fish communities who hold key roles such as herbivory (Hughes et al. 2007) can be lost. That loss contributes to degraded reef state such as seen across Nirwana and Siompu reefs. As other studies have shown, coral cover may fluctuate and therefore as a measure does not adequately reflect the potential resilience or recovery of a reef (Diaz-Pulido et al. 2009). Here we saw, over a wide range of differing fringing reefs, that the theories behind the evaluation of coral reef condition are largely more complicated.

Whilst other studies have shown the relationship between size spectra and fishing pressure to be positively correlated (Dulvy et al. 2004a), my findings do not as fishing pressure was not ultimately investigated. I found that the area with highest fishing activity (Pampanga reef) had on average the highest individual biomass of the most common guild; planktivorous fish. However, this study does not investigate size spectra and therefore cannot ascertain wether fishing activities are directly impacting fish. However, in this study, catch information was mostly associated to targeting piscivorous fish. Ultimately, to properly ascertain if fishing activity is having an effect on the size spectra of fish, analyses for piscivorous fish guilds need to be conducted. However, as previously mentioned, my methodology for assessing fish within this guild did not allow us to correctly quantify them. Furthermore, piscivorous fish in this study were almost exclusively made by pelagic species. Future studies should explore new ways of assessing fish, namely fisheries data. Moreover, because I did not directly measure fishing activity through catch composition but rather via what species fishers target, I can neither declare nor can I examine the change in metric over time and therefore the direct impact of fishing on the fish assemblage remains inconclusive.

Implications for social theory:

If management was required regarding how fishing practices effect outer-pelagic piscivorous fish; additional surveying methodologies of fisheries should be implemented. This would help regulate and assess the impacts of pelagic fishing. For example, I suggest that future work conducts triangulation of fish assemblages from catch yields of fishers. This is likely best achieved by visits to the fish markets such as the main one of Bau Bau city: Wameo market. By doing so, and interconnecting fisheries data with reef census data, future work would create better depictions of reef fish assemblage in the area.

Not knowing the elapsed fishing time on a reef mitigates any conclusions that fishing activity has on impacting the reef. Potentially, although this thesis shows no evidence of such, fishers' replies to the survey instrument were in accordance with movement of fishers to "high fish biomass" reefs from a degraded ones. The concept of moving to an area with more resources is in accordance with many human-ecological theories: higher populations are found where there is access to good resources. Similar trends were found in Philippine coral reefs where high coral condition correlated with high fisher populations (Pollnac et al. 2000). However, likewise to this study, temporal movement of fishers was not investigated and therefore we cannot determine causality of fishing on reef condition. Future monitoring programs should seek to employ fishers in studying their movement of fishing locations and test whether it correlates with the reef's overall ecological state. By involving the fishers in the study process it is possible to ensure that both fishers and supporting policymakers cooperate for mutual benefits. Otherwise, various problems may arise such as a lack of enthusiasm from the community, which ultimately leads to a lack of compliance with any new legislations (Christie et al. 2009).

Future directions:

Whilst my study has not shown that reef accessibility is a likely strong driver for the location of fishing, I encourage future studies to investigate this. If (as per pers. obvs.) fishers were determining the area of fishing mostly based on distance from their homes, then reefs such as Pulau Ular would be ideal to initiate a no-take zone. Currently, no one lives on this remote island, and my data revealed that the reefs around it are in the best overall condition. Furthermore, I discovered this area to be second to Pampanga reef in hosting the highest reef associated fishes such as the above-mentioned planktivores. In conclusion, if these 'lower trophic' guild species are helping replenish the more sought after 'higher trophic' piscivorous fish, then all reefs around Pulau Ular should be considered as a no-take zone. However, other studies have proven that areas under protection policies are commonly treated as open-access by local communities (Dixon and Sherman 1991). Furthermore the degree to which a conservation area is accepted or not, highly depends on factors such as participation by local users and stakeholders (Ferse et al. 2010). Without the appropriate level of participation it is possible that differing and conflicting views be overlooked regarding natural resources (Bennett et al. 2006). In order to mitigate this effect, future studies should investigate programs that allow local communities to realize the economic and financial value of maintaining a healthy coral reef as well as to understand the potential loss that will result from the overexploitation of their reefs (Cesar 1996).

For this reason, and in accordance with my findings of seasonality, I suggest that fishers during the low fishing seasons be trained and encouraged to partake in tourism-related activities. This would primarily involve occupations in the diving sector (which can be stimulated by the overall good condition of reefs in South Buton), such as boat driving and island tours. Long-term, this could potentially aid the local population transition to a much less fishing-dependent community. However, future studies must also regulate and record the effects that divers and tourism can potentially have on the overall health of the reef (Barker and

Roberts 2004). For this, educational programs, likely driven by local community members, would aid in educating foreign divers to the values and security that coral reefs provide.

Conclusion:

To the best of my knowledge, this is one of the first studies to evaluate the ecological state and fishing practices of coral reefs in South Buton. Whilst other surveying bodies such as COREMAP have conducted outstanding research in the area, their data remains largely inaccessible underpinning a necessity to collaborate in future endeavors. This research makes an important contribution to the on-going monitoring program, by providing one of the first holistic reference points for ecological conditions of the reefs and the corresponding social dependence on these resources. I urge that annual ecological survey efforts are continued and extended, along with fisheries catch monitoring surveys. Furthermore, as discussed across this chapter, any future reef management plans for the area must involve local community's perceptions and needs as part of the evaluative process. By valuing a socio-ecological approach, implementing conservation plans for the health of the reef will be more successful. Studying the fishing practices of South Buton is therefore an important first step towards this goal. However, these future studies and management plans for the study area may be unsuccessful if our global leaders do not address the wider issues facing coral reefs such as climate change and pollution. With over 19% of global reefs already lost and more than half showing signs of degradation (Wilkinson 2008) – excluding the recent 2016 mass bleaching event in the Great Barrier Reef (GBR) (Hughes et al. 2017b). Reefs like the ones found across South Buton may serve as hotspots and sources for future reef growth and replenishment.

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ANNEX

Annex 1

Section A (Occupation summaries)

	Fishing	Transport	Trade	Industry	Government	Agriculture
Bau Bau	58	10	13	7	3	9
Siompu	77	4	2	6	2	8
Kadatua	69	1	6	12	0	13

Occupation

Name	Pool together name
Motorbike taxi	Transport
boat taxi	
car taxi	
Boat Driver	
Porter	

Name	Pool together name
trader	Trade
Selling fish	
Shop stall	
Waterbottle filler	
shop owner	
Monger	
vendor groceries	
Weaving	

Name	Pool together name
Handyman	Industry
construction labour	
Mechanic	
Builder	
tire fixer	
Mining	

Name	Pool together name
Fisherman	Fishing
international fishing	

Name	Pool together name
ex-civil service police	Government
civil cervant	

Name	Pool together name
Farmer	Agriculture
Livestock	
seaweed farmer	

Section B

		FISH	TRADE	TRADE	TRADE	TRANSP	TRADE	INDUS	GOVER	AGRIC	TRADE	TRANSP	TRANSP	INDUS	INDUS	INDUS	TRADE	AGRIC	TRANSP	INDUS	INDUS	GOVER	TRANSP	INDUS	TRADE	AGRIC	TRADE	FISH	
	District	Fisher man	Selling fish	Shop stall	Waterb ottle	Motor bike	trader	constru ction	ex-civil service	seawee d	vendor groceri	boat taxi	car taxi	mecha nic	Builder	tire fixer	shop owner	Farmer	Porter	Mining	Mecha nic	civil cervant	Boat Driver	Handy man	Weavin g	Livesto ck	Monge r	interna tional	Total
BAUBAU	Wale																												/
	Wameo	75	25																										100
	Lipu	63		13	13	13																							102
	Bone-Bone	63	13			13	13																						102
	Betoambari	34				14		12	21						19														100
	Sulaa	70		2		12				1	5	2	2	2		2													98
	Labalawa	53				3	3										3	37											99
	Batuaga	52								15								10	11	13									101
SIOMPU	Katampe	100																											100
	Molona	70																12			6	6	6						100
	Lalole	100																											100
	Biwinapada	100																											100
	Kaimbulawa																												/
	Lontoi																												/
	Karae	53	9				10								15			13											100
	Tongali	55																13				13		20					101
	Wakinamboro	96													4														100
	Nggulanggula	40				27												27											94
	Batuawa																												/
KADATUA	Banabungi	61				5	5											3						18	8				100
	Lipu	50																50											100
	Uwemaasi	60																						9	6	11	14		100
	Kaofe	51																10						14	10	14			99
	Marawali	75																						25					100
	Waonu	85																										15	100
	Kapoa	85													15														100

Annex 2

Section A (Survey instrument)

This survey instrument is targeted at **only** fishermen within the surveyed region.

When fishermen are asked **"where do you fish"** during the mapping exercise.

Answer: "The student (Uso) wants to know the lvl of fishermen dependence in this area. This will help understand the balance point between people's needs and conservation. We are also talking to all the fishermen".

The ecological state and fishing practices of coral reefs in South Buton, Indonesia.

You are invited to take part in a research project that investigates the regions' reef ecological state and the link to them through fishing practices in South East Sulawesi, Indonesia. The study is being conducted by Alejandro Usobiaga in partnership with Operation Wallacea and will contribute to the completion of his Masters by research degree at James Cook University.

The study will be carried out in two distinct formats:

1) Ecological Assessment: Underwater visual and stereo-video methodologies are used to assess ecological state across 6 reefs in South Buton, Indonesia. The 6 reefs cover the area of Palau Ular, Kadatua, Siumpu and Buton Island.

2) Social Assessment: To compliment ecological state, a survey instrument is used to assess the fishing demographics and characteristics of the fishermen in South Buton. This study will also cover the area of the mentioned above four islands.

If you agree to be involved in the study, you will be invited to be interviewed. The interview, with your consent, will be annotated on a paper held by the interviewer and will include a mapping exercise. The interview will take approximately 15 minutes of your time. The mapping exercise will be used to compliment the ecological data in order to best understand how the reefs are responding to fishing.

Taking part in this study is completely voluntary and you can stop taking part in the study at any time without explanation or prejudice.

If you know of others that might be interested in this study, can you please pass on our interest to interview them for the study.

Your responses and contact details will be strictly confidential. The data from the study will be used in research publications and reports. You will not be identified in any way in these publications.

If you have any questions about the study, please contact - Alejandro Usobiaga and Mohini Johnson at Nirwana pantai Villa.

Questionnaire

DEMOGRAPHICS

Age: ____ Gender: ____

Where are you residing? Bau Bau ____ Siompu ____ Kadatua ____

1) Are you based there permanently? ____

If no (to permanently there);

2.1) Where are you from? ____

2.2) How many years have you been here? ____

2.3) How many months a year do you spend here? ____

2.4) What months? ____

3)

What activities do you do to support yourself and your family?	Months per year	Which is the most important for supporting your family?

FISHING CHARACTERISTICS

4) What gear do you use to fish?

Hook and Line	Lamba net	Gaff	Lift net	Fish trap	Drag net
Compressor	Gilnett	Purse siene	Blast/poison	Trolling line	Other gear

5) Do you have access to a boat? (Y/N) ____

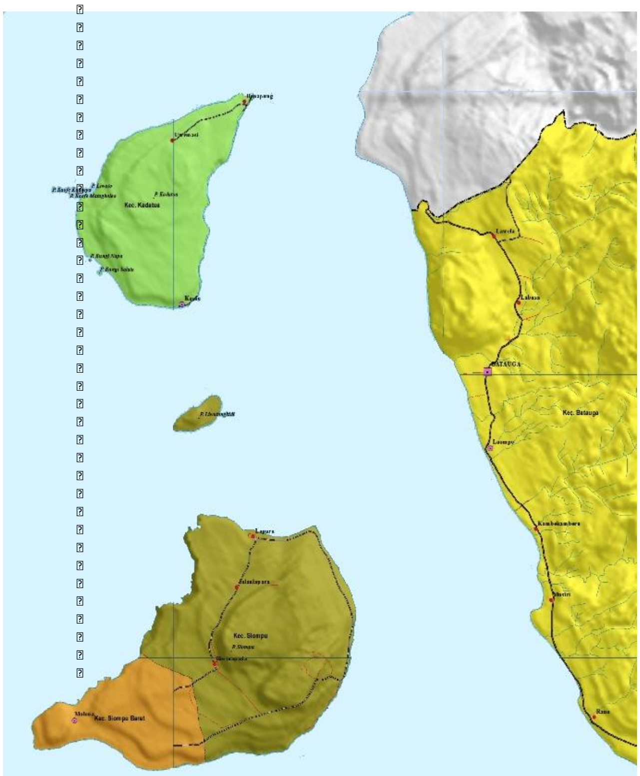
5.1) Do you own it? ____

5.2) How many people use the boat? ____

5.3) Does it have a motor? (Y/N) ____

6) Using the map provided below, annotate the answers to the following questions;

- **Where do you fish**? Mark (O) on map and write letter (A,B,C etc..) inside (O) for further annotation.
- **Where do you fish the most**? Mark (X on O) on map

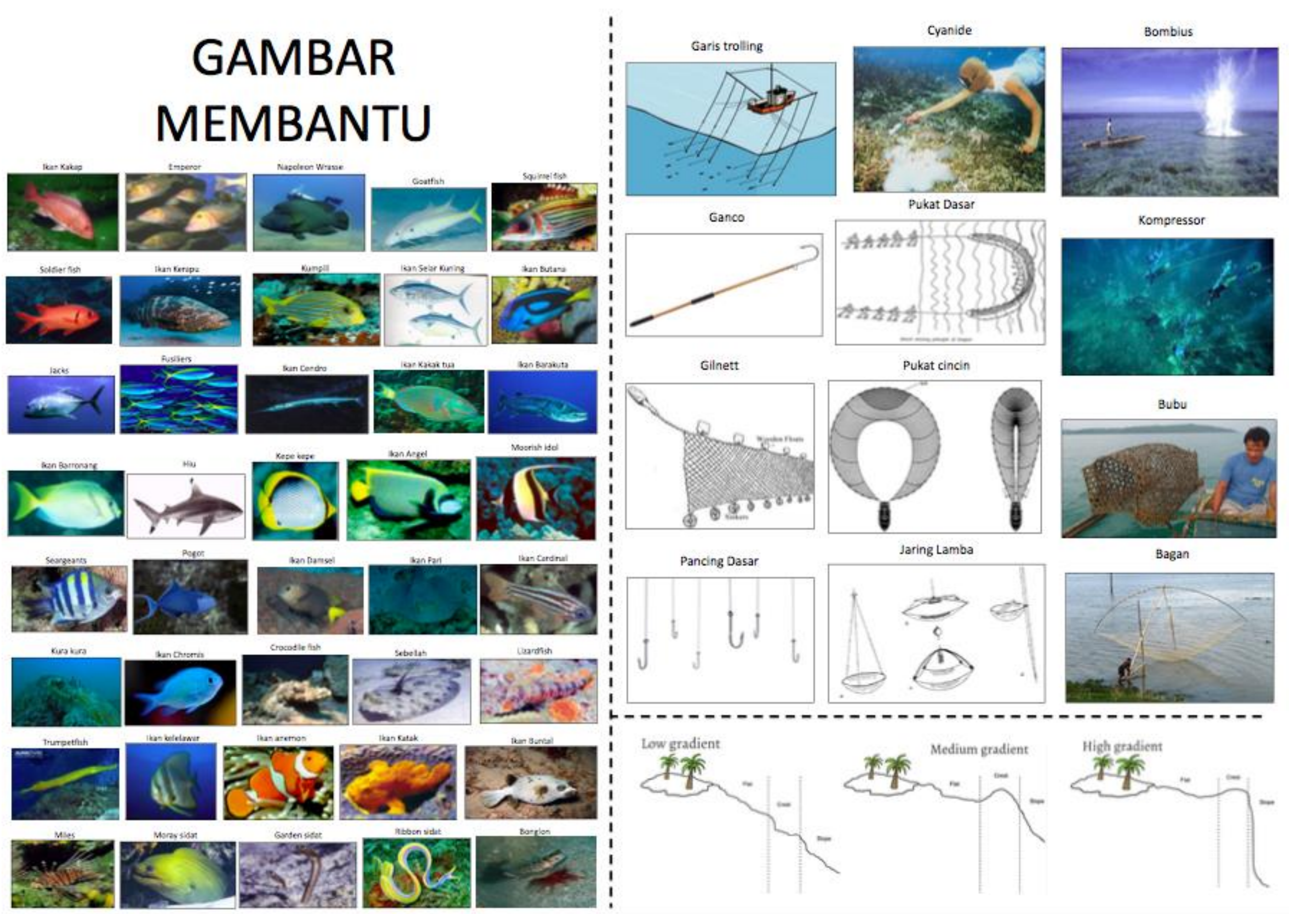


Site	What gear do you use? (Any not on list?)	If stationary gear, how much do you place?	Where on the reef do you place it (F,C,S)	What spp. do you catch? (Any not on list?)	What Months?

7) Which is the best place to fish and Why? (Symbol Δ inside O)

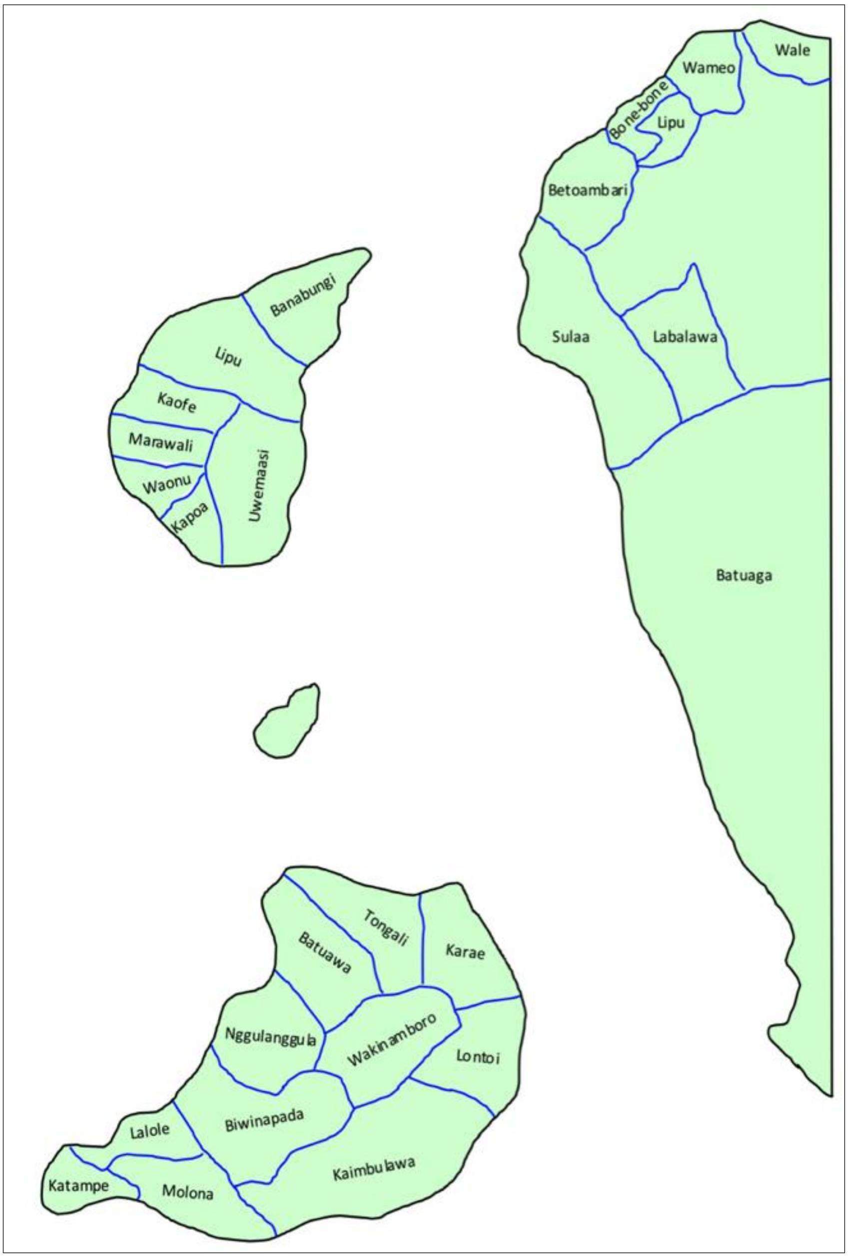
____

Section B (visual aid sheet provided)



Annex 3

Section A (Districts in South Buton)

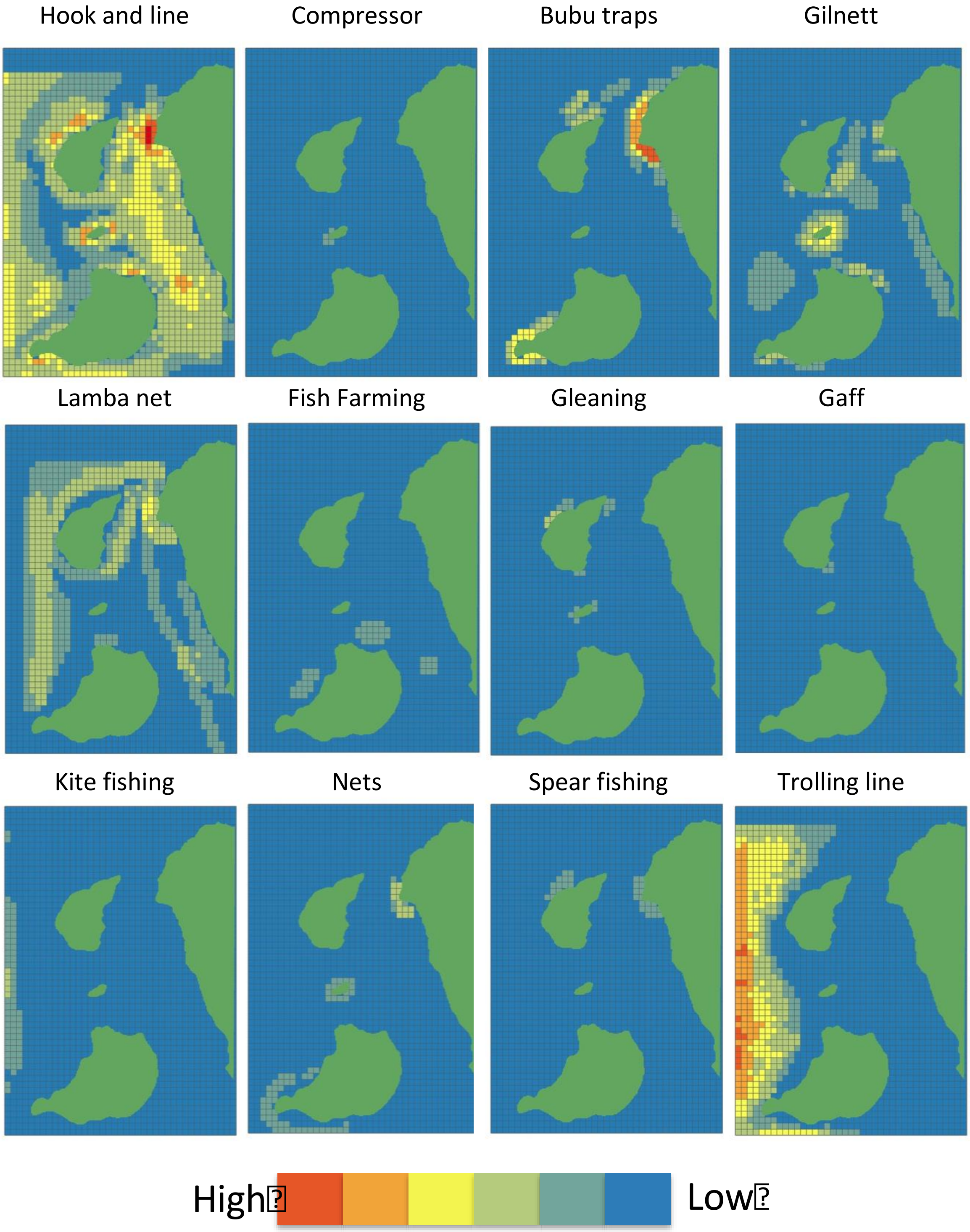


Section B (Links to Census for population size)

Interviews	Source		District names	
Area	census year	Link	Name (Bahasa)	Surveyed
Bau Bau region	2015	https://baubaukota.bps.go.id/index.php/Publikasi/view/id/82	Wale, Wameo, Bone-Bone, Lipu, Beteombari, Sulaa, Labalawa, Batauga	7 of 8
Siompu Island	2010	https://www.citypopulation.de/php/indonesia-sulawesi-admin.php	Katampe, Molona, Lalole, Biwinapada, Kaimbulawa, Lontoi, Karae, Tongali, Batuawa, Nggulanggula, Wakinamboro	8 of 11
Kadatua Island	2010	https://www.citypopulation.de/php/indonesia-sulawesi-admin.php	Banabungi, Lipu, Kaofe, Marawali, Waonu, Kapoa, Uwemaasi	7 of 7

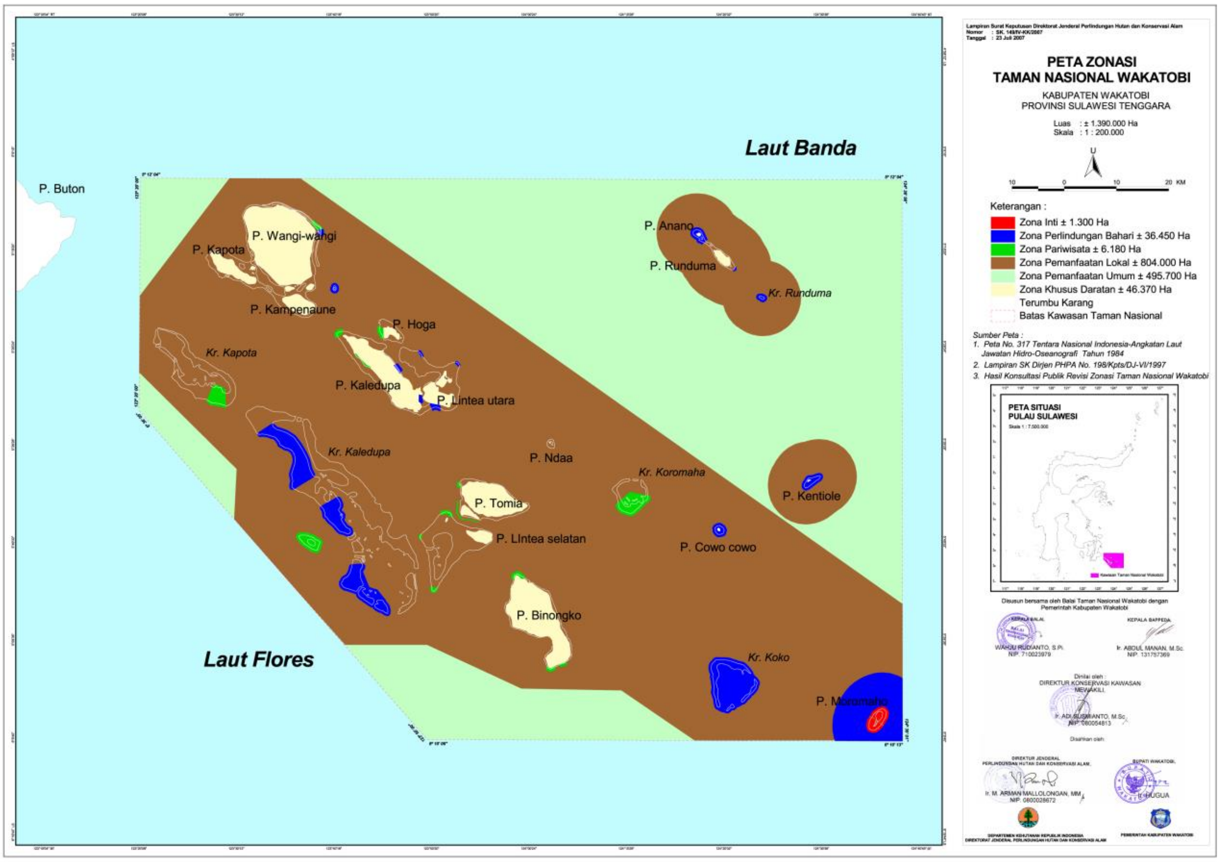
Annex 4

Section A (Fishing practices GIS maps)

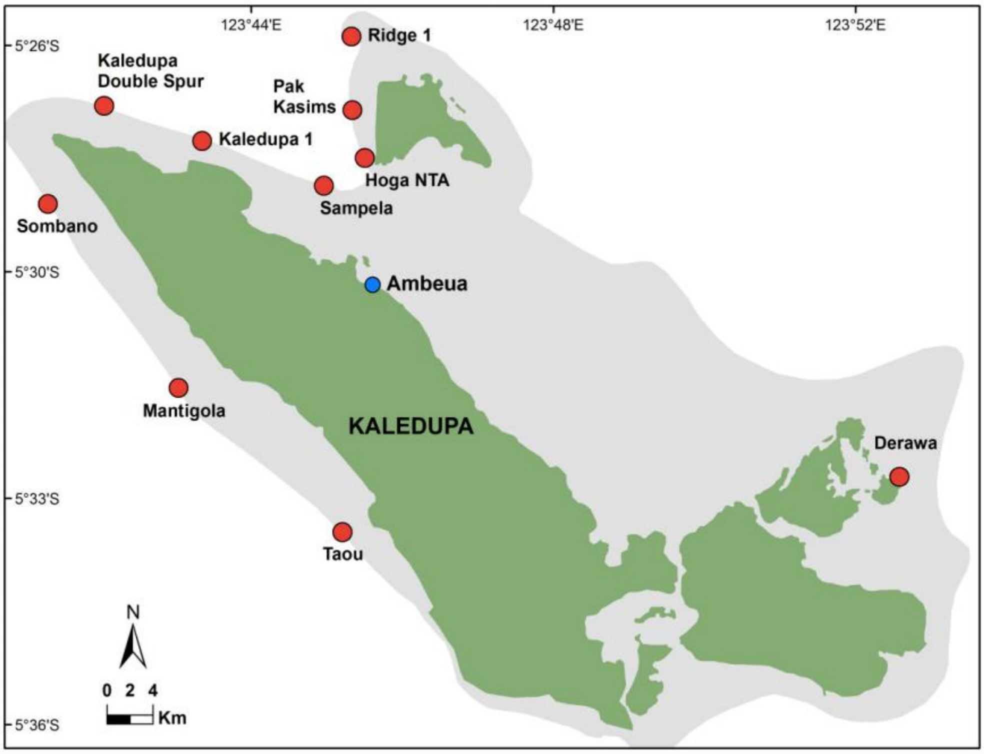


Annex 5

Section A (WNP) (source: (Clifton et al. 2013))



Section B (OpWall monitoring sites) (source: (Clifton et al. 2013))



Section C (Map of two regions (South Buton – blue and Wakatobi – red))

Annex 6

Section A (Benthic habitat categories)

Benthic Survey (50m LIT)

Abrv.	Benthic Substrate	Definition	Growth Form
HC	Hard Coral	**HC**: All living coral; includes fire, blue and organ pipe corals	Branching, Encrusting, Columnar, Tabulate, Massive, Mushroom, Foliose
SC	Soft Coral	**SC**: Include zoanthids but not anemones (OT)	
DC	Dead Coral	**DC**: Coral that has died within the past year; appears bleached and white or with corallite structures still recognizable	
AL	Algae	**AL**: Coralline, calcareous, turf etc..	
SP	Sponge	**SP**: All erect and encrusting sponges (but no tunicates)	
RC	Rock	**RC**: Any hard substrate; includes dead coral more than 1 yr old and may be covered by barnacles, etc.	
RB	Rubble	**RB**: Reef rocks between 0.5 and 15cm in diameter	
SD	Sand	**SD**: Sediment less than 0.5cm in diameter; in water, falls quickly to the bottom when dropped	
OT	Other	**OT**: Any other sessile organism including sea anemones, tunicates, gorgonians or non-living substrate	

Section B (non-coral invertebrate community groups)

Invert. Survey (50x5m Belt Trns.)
Sea cucumbers (all species)
Lobsters (all species)
Cleaner Shrimps (all species)
Giant Clams (all *Tridacna* spp.)
Crown of Thorns (*Acanthaster planci*)
Nudibranchs (all species)
Anemones (all species)
Tritons (*Charonia tritonis*)
Urchins (all *Diadema* spp.)

Section C (Fish assemblage feeding guild groups)

Stereo Video Survey (4 (50x5x5m) Belt transect)

Feeding guild	Definition
Piscivore	Primarily feeds on fish
Invertivore	Primarily feeds on invertebrates, regardless of size (Nudibranchs to sponges)
Planktivore	Primarily feeds on small planktonic organisms in the water column
Herbivore	Primarily feeds on fleshy algae
Omnivore	Has a bi-feeding strategy, divided between feeding on algae and live organisms
Coralivore	Primarily feeds on coral species

Section D (All surveyed species of fish)

Abudefduf sexfasciatus	Chaetodon trifasciatus	Heniochus chrysostomus	Rastrelliger kanagurta
Abudefduf vaigiensis	Chaetodon vagabundus	Heniocus varius	Rhinecanthus rectangulu
Acanthochromis polyacanthus	Cheilinus fasciatus	Hologymnosus annulatus	Scarus chameleon
Acanthurus auranticavus	Cheilio inermis	Lutjanus decussatus	Scarus dimidiatus
Acanthurus blochii	Chlorurus bleekeri	Macolor macularis	Scarus flavipectoralis
Acanthurus pyroferus	Chlorurus sordidus	Melichthys vidua	Scarus globiceps
Amblyglyphidodon curacao	Chromis alpha	Naso caeruleacauda	Scarus niger
Amphiprion clarkii	Chromis analis	Neoglyphidodon crossi	Scarus psittacus
Amphiprion frenatus	Chromis eleare	Neoglyphidodon melas	Scolopsis bilineata
Anampses meleagrides	Chromis pura	Neoglyphidodon nigroris	Scolopsis ciliata
Arothron hispidus	Chromis yamakawai	Neoniphon sammara	Scolopsis temporalis
Arothron nigropunctatus	Chrysiptera cyanea	Neotrygon kuhlii	Scolopsis trilineata
Balistapus undulatus	Chrysiptera glauca	Odonus niger	Siganus argenteus
Caesio cuning	Chrysiptera parasema	Parapercis cylidrica	Siganus corallinus
Caesio teres	Coris aygula	Pomacentrus chrysurus	Siganus doliatus
Cantherhines pardalis	Coris gaimard	Pomacentrus lepidogenys	Siganus guttatus
Centropyge bicolor	Ctenochaetus striatus	Pomacentrus moluccensis	Siganus vulpinus
Chaetodon kleinii	Dascylus aruanus	Pomacentrus pavo	Sufflamen bursa
Chaetodon lunulatus	Dascylus melanurus	Pomacentrus tripunctatus	Thalassoma hardwickei
Chaetodon melannotus	Dascylus reticulatus	Pterocaesio lativittata	Thalassoma jansenii
Chaetodon meyeri	Dascylus trimaculatus	Pterocaesio tile	Zanclus cornutus
Chaetodon ocellicaudus	grammatorcynus bilineatus	Pygoplites diacanthus	Zebrasoma scopas

Annex 7

Section A (Abiotic factors)

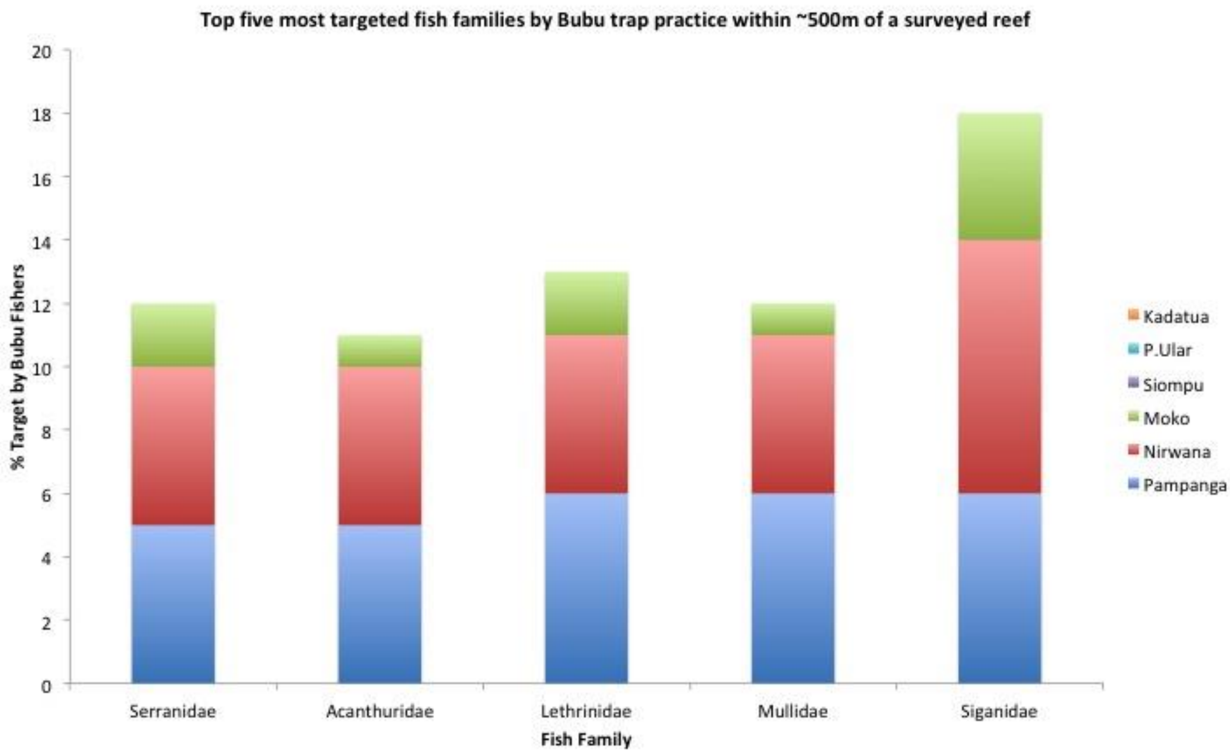
	Complexity Scores			
	Flat	Crest	Slope	Avg.
Pampanga	3	4	5	4
Nirwana	0	1	0	0
Moko	3	3	3	3
Siompu	2	3	3	3
Snake Island	4	4	4	4
Kadatua	3	4	3	3

Temperature (C°)			
Flat	Crest	Slope	Avg.
28	28	28	28
28	28	28	28
28	28	28	28
28	28	27	28
29	28	28	28
27	28	28	28

	Light attenuation (m)			
	Flat	Crest	Slope	Avg.
Pampanga	13	10	13	12
Nirwana	13	11	13	12
Moko	12	13	13	13
Siompu	13	13	9	12
Snake Island	13	10	9	11
Kadatua	13	14	13	13

Tide			
Flat	Crest	Slope	Avg.
H	M	M	M
M	H	H	H
H	H	M	H
M	M	L	M
H	H	H	H
H	L	L	M

Section B (Top five most targeted fish families by Bubu trap practice within ~500m of a surveyed reef)



Section C (Top 5 most recorded fish family biomass during underwater surveys)