Towards a better understanding of small-scale fishing decisions and their consequences in Northern Mozambique

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Abstract

This study investigates the relationship between the interacting social and ecological systems within the Pemba Bay fishery, in Northern Mozambique, as mediated by fishing decisions. All ecosystems in the world are affected by human behaviours in some way. In many cases, human effects on ecosystems are detrimental to many other species and can cause shifts in the entire system. In fisheries, the connections between human behaviours and ecosystems are obvious, as fishers extract wild populations of marine species. Human behavioural plasticity and sometimes rapid cultural evolution allow human behaviours to change and adapt faster than many other species can respond which often allows fishers to overexploit marine ecosystems. Many fisheries in the world are fully, or over exploited. Managing these fisheries often focuses on changing those highly adaptable human behaviours. Fishers' motivations for making different fishing decisions as well as attitudes towards the fishery can be used to understand human interactions with ecosystems when the dependence between the two is direct, as well as allowing managers to tailor interventions that account for fishers' motivations and attitudes.

Most fisheries' management projects assume that behaviours are motivated by profit maximization. This study investigates this assumption by comparing the compatibility of interview responses and fishing behaviours with rational actor theory, which assumes profit maximization is the only goal. Responses are also compared with prospect theory, which emphasizes reliability of outcomes; descriptive norms, which focuses on social interactions; habitual behaviour, which assumes most decision are automatic based on habit; and theory of planned behaviour, which allows attitudes to be shaped by economic or non-economic motivations, as well as peer opinion and incorporates perceived behavioural control in making decisions. These behavioural theories span a variety of potential fisher motivations which could affect fishing decisions. The study then investigates the state of the social and ecological systems which have resulted, at least in part, from those fishing decisions, and makes recommendations on possible interventions to improve the system based on better understanding of fishers' attitudes and motivations.

The study tests the hypothesis that fishers are motivated primarily by profit maximization and, therefore, rational actor theory is most compatible with fishers' stated motivations for fishing, or alternatively, that one of the other behavioural theories better explains fisher responses. This section used categorized interview responses based on their agreement, or not, with assumed responses if a particular behavioural theory were compatible. The results indicate that four of the five theories are most compatible with responses for at least one fisher, but that the theory of planned behaviour is the most consistent with the data overall, not rational actor theory. Specifically, fishers seem concerned with behavioural control as well as some non-catch related characteristics of the fishery, such as collective action and sustainability.

The second hypothesis is that prospect theory is more compatible with current fishing behaviours than rational actor theory. Prospect theory states that people prefer more reliable outcomes, even if slightly less profitable, than outcomes which are more profitable on average, but also more variable. This section used catch data, and changes in relative use of different fishing methods to address this hypothesis. This hypothesis is confirmed for some aspects of fishery data, but not all. Fishers prefer methods which are more reliable and these methods are increasing in relative use. However, neither catch value nor reliability increases fishers’ opinions of their fishing method, but fisher characteristics which increase options do. This again indicates that behavioural control is important in determining fishers’ attitudes towards fishing.

The third question addresses the social system within the fishery. It investigates whether fishing in Pemba Bay is a chosen profession or a livelihood of desperation from the poorest individuals. The study hypothesizes that fishers are as well-off as their non-fishing neighbours, and fishers who use more reliable or profitable methods are better off than those using less reliable/profitable methods and, as such, are more committed to fishing as a way of life. This section used fisher interview responses and household surveys to compare subjective and material wellbeing of fishers and non-fishers around Pemba Bay. The first part of the hypothesis is partly supported. Fishers using most methods have material standards of living comparable to non-fishers. However, they report lower subjective well-beings. Most measures of wellbeing are not affected by the reliability or profitability of the fishing method used, which does not support the second part of the hypothesis. Additionally, fishers using more profitable or reliable methods do not indicate more commitment to fishing as a way of life.

The fourth and final section investigates the marine ecosystem. Based on conversations with fishers and local researchers, it is assumed that the Pemba fishery is overexploited. As such, the study hypothesizes that marine biomass, individual size of marine species, and functional diversity are lower in Pemba Bay than in other sites around Northern Mozambique, Vamizi Island, Situ Island, and Nuarro, due to high fishing pressure, and that direct removal of species by fishing has a dominant effect. This final section used baited remote underwater videos (BRUVs) to compare species composition and indices of abundance from the different locations. Again, there is support for part of this hypothesis. Marine species biomass and sizes are lower in Pemba Bay than other sites in Northern Mozambique; however, functional diversity is not different. In these data, changes in biomass and size are not correlated with amount of catch, so direct removal by fishing may not be the dominant source of change in the Pemba fishery.

Together, these data indicate that the Pemba fishery may be unsustainable based on social and ecological indications. The importance of behavioural control in understanding fishing decisions indicates that any interventions to mitigate problems in the fishery will need to work with fishers to increase empowerment and allow experimentation to find locally relevant solutions to problems.

Keywords

Human behaviour, Social-ecological systems, Fisheries, Fishery management, Ecosystem functional diversity, Case study, Collective action

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List of Abbreviations

AICc	Akaike Information Criterion corrected for small sample size for model comparison
BRUV	Baited Remote Underwater Video systems
CAP	Constrained Analysis of Principle components with cross-validation
CATAMI	Collaborative and Automated Tools for Analysis of Marine Imagery
CCP	Coselho Comunitaria da Pesca, local fishing collective
CPUE	Catch Per Unit Effort
CV	Coefficient of Variation
DN	Descriptive Norms
ECDF	Empirical Cumulative Distribution Function
ELPD	Expected Log Predictive Density
ESS	Effective Sample Size
FAO	Food and Agriculture Organization
FD	Functional Diversity, a library in R used to measure functional diversity
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
HB	Habitual Behaviors
l-95% CI	lower 95 % Confidence Interval
LOO	Leave-One-Out comparisons of model fit
MaxN	Maximum number of individuals from a species/stage within a single frame of video
MCMC	Markov Chain Monte Carlo
MetaMDS	function in R to run NMDS analyses
MMAIP	Ministério do Mar, Águas Interiores e Pescas; Ministry of ocean, inland waters, and fisheries
MSL	Material Standard of Living
NGO	Non-Governmental Organization
NMDS	Non-metric Multidimensional Scaling
OSOL	Our Seas Our Lives fishery monitoring project
PERMANOVA	Permutational Multivariate Analysis of Variance
PT	Prospect Theory
RAT	Rational Actor Theory
RDA	Redundancy Analysis
SAIAB	South African Institute of Aquatic Biodiversity
SAU	Sea Around Us
SD	Standard Deviation
SE	Standard Error
SES	Social-Ecological System
SG	Sea Grass
TPB	Theory of Planned Behavior

u-95% CI	upper 95% Confidence Interval
USD	United States Dollar

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Chapter 1 Introduction

Abstract

This chapter focuses on the scientific context of human environment interactions in which this study is embedded, the behavioural theories used to understand fishing decisions, the social context within which those decisions are made, and the framework used to understand the social and ecological effects of communal decisions. It is argued that due to humans' history of, and accelerating, modification of natural systems, the need to understand human decision-making is urgent. Five possible behavioural theories are proposed to better understand fishing decisions. Rational actor theory is used as the baseline theory, as purely economic motivations are most often used to understand fishing decisions. This is compared with prosect theory, the theory of planned behaviour, habitual behaviour, and descriptive norms. These theories encompass a range of other possible motivations and priorities when making decisions. The Ostrom groups framework for understanding social-ecological systems is used to understand the Pemba fishery.

Introduction

Understanding the interactions between human and natural systems is a growing area of research (Biggs *et. al.*, 2022). Ellis (2015) argued that all ecosystems are socially and culturally constructed and, therefore, ecology cannot be understood without understanding humans' interactions with it. This understanding is made more urgent by environmental degradation experienced all over the world from local to global scales (e.g., Halpern *et. al.*, 2008; Hughes et al., 2003; Hughes *et. al.*, 2013 ; Rockström *et. al.*, 2009). Individual human decisions affect the relationship between social and ecological systems and can change faster than other aspects of these systems. Therefore, a better understanding of the causes and consequences of human decision making can facilitate better understanding of how current social-ecological system (SES) came to exist, as well as informing incentives to create positive interactions in the future.

This dissertation uses the small-scale fishery around Pemba Bay in Northern Mozambique as a case study to understand human interactions with their environments. Small-scale fisheries are good study systems for looking at human interactions with natural systems because fishers' livelihoods are directly influenced by the fluctuating numbers of wild stocks. Their decisions on when, where, and how to fish affect not only fishers' wellbeing, but also the marine ecosystem on which they depend. Also, small-scale fisheries, by necessity, are often managed at the local level (e.g., Arceo *et. al.*, 2013; Cinner & McClanahan, 2015; Léopold *et. al.*, 2013). This means rules are established based on the local condition and incentives, although these conditions and incentives can include external forces such as climate change and global markets (e.g., Cinner *et. al.*, 2013; Díaz *et. al.*, 2015; McClanahan *et. al.*, 2015). Together, these characteristics of small-scale fisheries allow understanding of human decisions based mostly on local conditions and interactions. This dissertation investigates fishing decisions, a few potential behavioural theories which could be used to understand these decisions, and the consequences of the decisions for fishers and the marine ecosystems on which they depend. This study adds to the growing number of case studies of social-ecological systems to facilitate future meta-analyses to determine universal characteristics of these systems (e.g., Frey & Rusch, 2013; Hinkel *et. al.*, 2015; Ostrom, 2009).

This introduction is divided into the following sections:

1. An overview of contemporary and historical use and modification of ecosystems by society;
2. An overview of the human behavioural theories considered and how these might be used to understand fishing decisions;
3. An overview of small-scale fisheries in the Western Indian Ocean and Pemba Bay;
4. Ostrom's social-ecological systems (SES) framework;
5. Background on methods used in the dissertation and how these interact within Ostrom's SES framework;
6. And the questions, hypotheses, and structure of the dissertation.

Humans in the Anthropocene

Humans have had a dramatic effect on the ecosystems in which we live since prehistoric times (Ellis, 2015). Indigenous people in Australia modified fire regimes to promote hunting which also increased abundances of their preferred prey (Codding *et. al.*, 2014). Codding *et. al.* (2014) argued that this was a matter of co-evolution on the part of Aboriginal society and their prey rather than intentional conservation. Jackson *et. al.* (2001) found many examples of historic and prehistoric overfishing causing detrimental changes to coastal ecosystems. Johannes (2002) argued that these examples of overexploitation do not preclude indigenous conservation, as many indigenous peoples learned conservation ethics after depleting their resources. Berkes and Turner (2006) agreed that living through resources crisis was one way that people learned about the limits of their environment and learned sustainable practices. However, there were occasions when cultures did not learn to manage their resources and their civilizations declined as a result (e.g., Diamond, 1994; Snyder, 2020). The most famous potential cultural collapse is most likely Rapa Nui. Diamond (1994) posited the deforestation of this island as the major cause of cultural collapse; however, Rull (2020) argued that, although humans most likely contributed to the complete deforestation of the island which caused declines in the population, the culture survived. So, while there is ample evidence that humans have, and continue to change our environments, sometimes to our detriment, our ability to adapt to these changes is more contentious. Even if survival is possible, avoiding the probable human suffering and irreversible ecological losses caused by detrimental environmental modifications is desirable.

The acknowledgement that humans can and have caused detrimental effects on our environments has led to concern about overexploitation. Starting with Malthus's essay in 1798 on population growth and continuing through Hardin's "tragedy of the commons" (Hardin, 1968) to the present, there has been an argument that without external regulation, due to the immediate benefit to a person from overexploiting a common resource, this will occur to the detriment of all. Ostrom (1990) countered that many communities have found ways of instituting collective action strategies to protect their common pool resources. These institutions may develop following resource crises as mentioned above. Or Turner and Berkes (2006) argued that through gradual accumulation of knowledge about their environments, some communities learned the environment's limits without having to suffer a crisis. Community management is complicated when access cannot be controlled, i.e., excludability is low, as is the case in many marine fisheries. For example, Marschke and Berkes (2005) talked about a local fishing community which voluntarily increased the mesh size of their crab traps until they realized they could not prevent fishers from neighbouring villages for catching the smaller individuals they were foregoing. This example shows the importance of conservation work at multiple levels due to the degree of connection which exists within human society.

While humans have been modifying our local environments for millennia, these modifications have grown in speed and scale since the industrial revolution (Ellis, 2015; Gowdy, 2007). All marine ecosystems are experiencing detrimental human impacts, and 41% suffer from multiple impacts at once (Halpern *et. al.*, 2008). Coral reefs, the most biodiverse ecosystem in the oceans, are in decline globally, being affected by climate change, ocean acidification, overfishing, terrestrial runoff sedimentation, and other detrimental processes (Bellwood *et. al.*, 2004; Hughes *et. al.*, 2017). Many fisheries are in decline globally (Watson *et. al.*, 2013; Pauly & Zeller, 2016), including small-scale artisanal fisheries (e.g., Cinner & McClanahan, 2006; Johnson *et. al.*, 2013; McClanahan *et. al.*, 2008). Many other global systems are near or beyond safe ranges for human wellbeing according to Rockström *et. al.* (2009). Ellis (2015) argued that all ecosystems are to some extent socially and culturally constructed by humans due to our unprecedented ability to modify our environments, and that promoting cultural norms that allow the coexistence of non-human species is the only way forward for conservation for the foreseeable future. Understanding the links between human decision making at the individual level, what motivates people's choices, and the consequences of those choices in contemporary social-ecological systems can be used to determine how coexistence is being facilitated. It can also highlight situations in which changes need to be made to allow continued coexistence. Behavioural frameworks are necessary to understand these systems and links. A few possibilities are addressed in the next section.

Considered human behavioural theories as related to fishing decisions

In fisheries, the exploitative nature of the interaction between fishers and aquatic ecosystems leads many to assume that humans are attempting to maximize their gains, whether monetary, caloric, or for other reasons. For example, in a review of fishery models which define fishing behaviour, van Putten *et. al.* (2012) found that the most commonly used theories were economic or foraging theories, which assumed that maximization of profit or foraging efficiency, respectively, was the ultimate goal. However, foraging theories and economic utility theories predict different decisions based on the differences in the "currency" being maximized. Schlüter *et. al.* (2017) mentioned that most fisheries' models used rational actor theory or bounded rationality to model fishers, both of which assume that some form of maximization (e.g., monetary, caloric, nutritional, etc., but most often monetary) is the ultimate goal.

Using economic and foraging theories to understand human fishing behaviours has been important in understanding fisheries. For example, Aswani (1998) found the optimal foraging theory explained seasonal changes in fishing sites in the Solomon Islands. Prellezo *et. al.* (2012) reviewed several bio-economic models used in European Union fisheries to understand different aspects of the fishery. Also, in model simulations, Wilen *et. al.* (2002) found different fishery states if fisher movements aimed to maximize their profits compared to scenarios where movements resulted in a uniform distribution of fishers. However, these theories may still be too simplistic to capture real human decision-making. There are many examples of fishers making decisions which are not expected based on purely economic considerations. Salas *et. al.* (2004) found that economics only explained part of fishers' decisions on which species to target. When studying small-scale fisheries, researchers often find sub-optimal behaviours based on economic theories, indicating that other factors are involved in the decisions making process (e.g., Guest, 2003; Holland, 2008; Lopes & Begossi, 2011; Naranjo-Madrigal *et. al.*, 2015; Salas & Gaertner, 2004). The consequences of making inaccurate assumption about human decision making can be important. Fulton *et. al.* (2011) argued that many fishery management strategies have been unsuccessful because their assumptions about human behaviour were too simple.

In order to better understand human decision making and avoid detrimental surprises when managing fisheries, it may be necessary to consider behavioural theories which allow for motivations other than profit maximization. Boudon (1998) argued that while the simplicity of economic profit maximization cost-benefit analyses can be helpful to explain some behaviours, they do not apply in all, or even most, situations. And Herrnstein (1990) argued that in situations where the outcome of a decision depends on the frequency of use, such as the amount to which certain species or habitats are targeted, animals instinctively equalize the profits from the different choices, rather maximizing the profits. In a review, Kwon and Silva (2019) found 62 different behavioural theories which have been used to explain human behaviour. Schlüter *et. al.* (2017) mentioned that despite the wide array of behavioural theories available to explain human decision making, almost all fishery models used rational actor theory or bounded rationality to explain fishing behaviours based on cost-benefit analyses. They expand on six potential theories to explain fishing decision, although they acknowledge that other theories may also prove useful. The behavioural theories suggested by Schlüter *et al*. (2017) provide a reasonable starting point to understand fishing behaviours which are not completely predictable based on profit maximization, because they cover many other possible motivations. Combining rational actor theory with bounded rationality, this becomes the standard economic theory for comparison which assumes profit maximization is the ultimate goal, although it allows different ways of reaching this goal, such as “rules-of-thumb”. Four other behavioural theories are assessed. Prospect theory points out the importance of perceptions of risk in achieving the goal when making decisions. The theory of planned behaviour posits that intention to perform an action is influenced by attitudes, perceived ability to control a behaviour, and social pressure. Descriptive norms identifies social copying as a major source of behaviours. And habitual behaviour posits that behaviours which have been successful in the past are repeated without considering other alternatives. A limitation in using these theories to explain fishing behaviours is that they do not allow an explicit comparison of short-term versus long-term goals and trade-offs. However, both prospect theory and the theory of planned behaviour allow for perceptions of, or attitudes towards, future conditions to influence current behaviours. The five theories addressed are briefly described below.

Rational actor theory

Rational actor theory (RAT) assumes that the subject is attempting to maximize some utility, generally economic returns. This is achieved by computing the odds of an outcome multiplied by the utility gained or lost if it occurs, which equates to the mean value achieved from the choice. The action with the highest expected utility should be selected. It assumes perfect knowledge of the system as well as unlimited cognitive abilities to distinguish between options; physical resources, however, can be limited (Simon, 1955). These unrealistic assumptions can be relaxed with actors able to use rules-of-thumb and limited knowledge and computational ability which, over time, develop to maximize their returns (Simon, 1956). Due to its mathematical simplicity, it is favoured in most fisheries models (Hilborn, 2007; Schlüter *et. al.*, 2017).

Prospect theory

Prospect theory (PT) holds that humans rarely make choices which maximize their expected returns and that more complicated evaluations of risks and rewards are needed to understand decision making (Kahneman & Tversky, 1979). Kahneman and Tversky (1979) argued that people prefer less profitable but more certain outcomes when assessing potential gains. Interestingly, decisions reverse when avoiding losses rather than making gains. In other words, people choose an improbable, large loss over a probable smaller loss. However, humans weight highly improbable outcomes with large costs or benefits higher than the probability of the outcome would suggest, which explains playing the lottery and buying insurance (Kahneman & Tversky, 1979). Within fishing context, this theory indicates a preference for more reliable catches over, on average, more profitable but less reliable catches. However, it is also compatible with fishers gambling on extremely high profits occasionally, even if the odds of success are very low. In interviews with fishermen in New England, Holland (2008) found that many who chose not to switch to more profitable methods mentioned the risk as most of the reason for their choice, despite many believing that it would have been more profitable overall, consistent with PT but not RAT.

Theory of planned behaviour

The theory of planned behaviour (TPB) acknowledges first, that our intentions to act are influenced by more than just our perceived benefit from an action, and secondly, that an intention to act does not necessarily indicate the behaviour being successfully accomplished even if the required assets are available. The three main aspects affecting intention are one's attitude towards the behaviour, subjective norms, and perceived behavioural control (Ajzen, 1991; Figure 1-1). This theory varies from the first two in that it allows for aspects of the behaviour itself, as well as outcomes other than monetary or caloric value or reliability, to be incorporated into attitudes. The actor considers how the action will be received by his or her social group as well as the perceived ease or difficulty of the action when deciding whether to attempt the action. This theory allows a framework for investigating how issues of empowerment and marginalization can affect fishing decisions. It also allows for attitudes toward fishing which go beyond utility maximization.

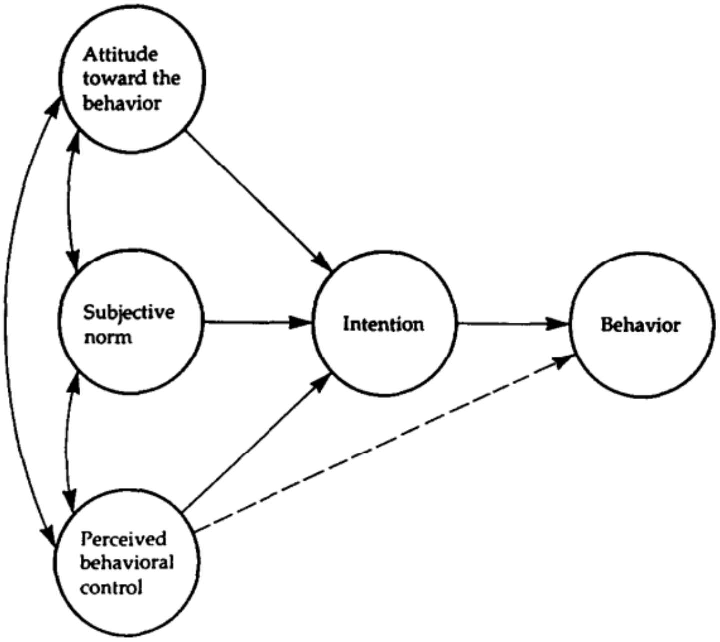

Figure 1-1: A representation from Ajzen (1991) on the interactions between aspects of the theory of planned behaviour.

Habitual behaviour/ reinforced learning

Habitual behaviour (HB) assumes that most actions are based on habits formed through positive feedbacks between an action and its consequence. In a stable environment, a subject can save time and energy making decisions based on habit rather than weighing each decision (Boureau *et. al.*, 2015). So long as the outcomes are within what the subject considers acceptable, it is unlikely that he or she will use the time and energy needed to evaluate other options. Deliberative decision making only occurs if the consequences of their decisions consistently fail to meet their expectations (Schlüter *et. al.* 2017).

Once deliberative decision making is engaged, it can follow any number of decision-making paradigms such as rational actor, prospect, or planned behaviour theories.

Descriptive norms

Descriptive norms (DN) assumes that the subject is motivated primarily by the behaviours around him and, therefore, will tend to adopt the behaviours most common in his community. Imitation of others, starting with parents and other elders, is the basis for much learning and allows the acquisition of knowledge at low costs (Henrich, 2001). Additionally, conforming to group behaviours can be an important indication of group membership which can be beneficial beyond access to resources (Tyler & Blader, 2001). Within this theory, cultural norms and current practices are the most important drivers of decision making and people will resist changing until a majority of those around them have done so. Schlüter *et. al.* (2017) pointed out that people within a society had varying levels of conformity which affected the strength of majority behaviour on the behaviour of the subject. The extent to which a society chooses to copy a new behaviour depends to some extent on the prestige of the person promoting the behaviour (Henrich 2001).

Whichever behavioural theory is used as a framework to explain fishing decisions, these occur within a social context. The next section reviews the social context of small-scale fishing in general and in Pemba Bay specifically.

The social context of small-scale fishing

Fishing and identity

The importance of fishing for fisher identity is contentious with some arguing that fishing is a livelihood of last resort and others arguing that it is an identity and source of power for fishers. Béné (2003) reviewed the argument that fishing is a sink absorbing excess labour until catches are equivalent to the profit made from other employment opportunities, when they exist. In this case, fishing is most likely not a major part of fisher identity. However, Pollnac and Poggie (2008) posited that many fishers chose the profession because it allowed them to meet a psychological desire for adventure. Holland *et. al.* (2020) found that many vessel owners stated an unwillingness to stop fishing due to the non-monetary benefits they got from fishing. However, both these previous studies assumed that other high-paying jobs were available to those without this intrinsic desire to fish, which is not the case in Northern Mozambique. In poorer communities, fishing may also be a form of identity. The Vezo people in

Madagascar define their cultural identity based on the practice of fishing rather than any genetic heritage (Astuti, 1995). Béné *et. al.* (2016) mentioned the importance of fishing in not only individual, but in group identity and its ability to contribute to collective action. In India, fish are associated with a person's power and lack of fish can cause lack of self-esteem (Nayak *et. al.*, 2014).

Another indication that fishing is more than a job is the unwillingness of many fishers to stop fishing. Blythe (2015) found that fishers in central Mozambique were unwilling to stop fishing and they encourage their children to fish as well, stating that in the case of fishery collapse, they would move rather than change occupations. Daw *et. al.* (2012) found that only about half of the fishers they interviewed indicated a willingness to exit the fishery even facing a hypothetical consistent 50% decline in catch. Yet both Daw *et. al.* (2012) and Blythe (2015) acknowledged that fishers' willingness to exit the fishery was determined in part by availability of alternatives, indicating that these responses may have been due more to lack of expectation about viable alternatives rather than commitment to fishing. In situations with consistent declines in fishing catches but a lack of alternatives to exit the fishery, the possibility exists for entering a poverty trap. As the resource declines, people perceive even less ability to innovate and exit the fishery and human suffering and resource degradation enters a positive feedback loop (e.g., Carpenter & Brock, 2008). This is addressed in more detail in the final discussion. Surprisingly, both Daw *et. al.* (2012) and Blythe (2015) found that poorer fishers may be better able to exit the fishery than richer ones due to the amount of wealth invested in fishing equipment. Wealthier fishers may also have better access to new technologies which allows them to continue to make profits in the fishery even after it starts to decline, further dis-incentivizing them from exiting the fishery (Finkbeiner *et. al.*, 2017). Wealthier fishers could have more alternatives before deciding to be fishers, meaning they may have chosen fishing for the non-monetary benefits they get from the activity, although no study looking at this in developing countries has been found. Irrespective of fishers' commitment to fishing, the importance of their catches to themselves and their communities is high, and this is not controversial.

Small-scale fishing and food security

In coastal communities all over the world, seafood is an important source of protein and micronutrients. For example, Fonseca and Pezuti (2013) found that 60% of meals in the Amazon River basin included fish and Makela (2016) found that families in Northern Mozambique were 10 times more likely to eat seafood than land-based animal protein. And in Madagascar, Barnes-Mauthe *et. al.* (2013) found that fish made up 99% of the protein in meals. In these communities, most calories come from staple crops, such as rice or casava, but the protein, fat, and micronutrients from seafood are essential for health and development (e.g., Black, 2003; McClanahan *et. al.*, 2015; Moreau & Garaway, 2018).

In many coastal communities, most seafood is provided by small-scale fishing operations. In Mozambique, small-scale fishing catches represent 75 to 90% of the total catch (Doherty *et. al.*, 2015; Jacquet *et. al.*, 2010; Pereira *et. al.*, 2014). Also, small-scale fishing catches are generally consumed locally or regionally (Arton & Crona, 2017; Jacquet *et. al.*, 2010). Based on the assumption that all small-scale catches are consumed in the country, total catch, and population size, Jacquet *et. al.* (2010) estimated that seafood consumption in Mozambique declined substantially between the 1950s and the early 2000s. Makela (2016) found that over 70% of households in Northern Mozambique were food insecure, so any decreases in food availability could affect the health and wellbeing of everyone in the community but particularly fishers. Along with its importance for food security, fishing is a small, but important part of the Mozambican economy.

Fishing and the Mozambican economy

Fishing makes up three to four percent of Mozambique's GDP, and as discussed above, most of this is small-scale catch (Benkenstein, 2013). Little of the small-scale catch is exported, but it is important for food security and subsistence within coastal communities in Mozambique (Benkenstein, 2013). Based on the 2017 census in Mozambique, 27% of people in urban areas and 82% in rural ones in Mozambique depend on fishing or agriculture for their livelihoods (Maunze *et. al.*, 2019). Unfortunately, these results do not distinguish between agriculture and fishing. However, Benkenstein (2013) mentioned that an increasing number of Mozambicans transitioned from agriculture to fishing due to increased droughts. There are at least 30,000 fishers in Cabo Delgado and 90% of them use fishing as their primary source of income (Jone & Malate, 2013). Other economic activities are limited in most of Mozambique.

The Mozambican economy has had consistent economic growth since the end of the civil war in 1992, averaging 7% annually. However, this economic growth has occurred almost exclusively around Maputo and through mega-projects such as oil and gas exploration and extraction, which provide little employment for local communities (Castel-Branco *et. al.*, 2015 and Mahdi *et. al.*, 2017). The Mozambican government has few resources available for small to medium scale economic activities, so these remain very limited throughout the country (Castel-Branco *et. al.*, 2015). This trend is especially apparent as you move north away from Maputo. Castel-Branco *et. al.* (2015) mentioned that tourism was one aspect of development which was present outside of Maputo, and Pemba Bay has some tourist infrastructure (personal observation). However, these tourism companies provide limited employment opportunities and Madhi *et. al.* (2017) found that the Mozambican tourism industry has been shrinking nationally since 2012. British Petroleum oil also began operating out of Pemba in 2017 due to instability farther north in Cabo Delgado. However, this provided few local jobs and was not yet established during data collection (Seminar with oil company executives).

Access to formal employment is also limited by lack of education. Fox *et. al.* (2012) found that lack of education limited Mozambicans' ability to start small businesses. They noted that education reform in 2004 had started to ameliorate some of the education gaps, but that illiteracy and lack of basic education was still a problem in most of the country. An adult literacy program intended to decrease poverty by allowing increased employment opportunities did not achieve this goal, although it did increase self-esteem, allow for better social interactions, and increased health and education for participants' children due to increased monitoring by parents (Buque, 2013). So, these adult literacy programs may have long-term benefits which are not yet apparent. Due to lack of education and limited government support for small and medium-sized businesses, employment opportunities outside fishing and farming are limited around Pemba Bay. The fishing economy includes more than active fishers. A census of Artisanal fishing in Mozambique found that across the country, there were two people working in the periphery of the fishery for every fisher (Jone & Malate, 2013). This includes boat builders, fish merchants, net makers, mechanics, etc. Understanding fishing decisions within the above social context which exists in Pemba Bay requires a framework for how different aspects interact. This study uses Ostrom's social-ecological systems (SES) framework.

Ostrom's SES framework

Investigating social-ecological systems (SESs) is interdisciplinary, which has led to problems of terminology and methodology between academic disciplines. To address these issues, Ostrom and her colleagues looked at case studies of SES research and established a framework to allow these case studies to be compared to understand social rules leading to successful management of natural resources (Ostrom, 2009). Ostrom's framework focuses on understanding common-pool resource problems (Biggs *et. al.*, 2022). It is ideal for the current study which is attempting to diagnose current interactions within the fishery to make recommendations on management to increase social and ecological wellbeing of the system. Other frameworks exist, but are less suitable to the current problem. For example, Gunderson and Holling's (2002) panarchy framework focuses on different spatial and temporal scales of change, which is not the focus of the current research. Likewise, the 'coupled human and natural systems' framework (Liu *et. al.*, 2007) focuses on interactions at different scales. Other frameworks provide focus on different aspects of the SES, but the predominance of Ostrom's framework for looking at case-studies of common pool resources management allows results from this study to potentially be included in meta-analyses of these systems to determine universal patterns (Biggs *et. al.,* 2022).

Ostrom's framework discusses the importance of the environment in which the SES exists, resource users, resource systems, resource units, and government systems. Ostrom talks about how these aspects of the system interact in what she calls "action situations" to allow successful, or not, outcomes. While this basic framework is helpful for comparing different SESs, Hinkel *et al*. (2014) pointed out some difficulty in determining how, and where in the system, to include new variables. They proposed formalization of the Ostrom framework to explicitly include different types of relationships between levels of the framework and including action situations as specific processes in which the state of some of the variables of the SES affect the future state. This study uses the Hinkel *et. al.* (2014) formalized version of Ostrom's framework to understand the factors of the Pemba fishery which are affecting fishing decisions and outcomes for fishers and the marine ecosystem.

The Pemba Bay small-scale fishery is embedded within the economic and social context described above. Resource users are fishermen and women with individual characteristics who make fishing choices within this context, which lead to catches which can be summarized into mean and variance characteristics from fishing trips. Finally, the marine ecosystem is composed of a sessile and mobile community which is in turn composed of species which can be harvested by fishers. All of this is embedded within environmental and governance systems, which are considered invariable at the scale of this study (Figure 1-2).

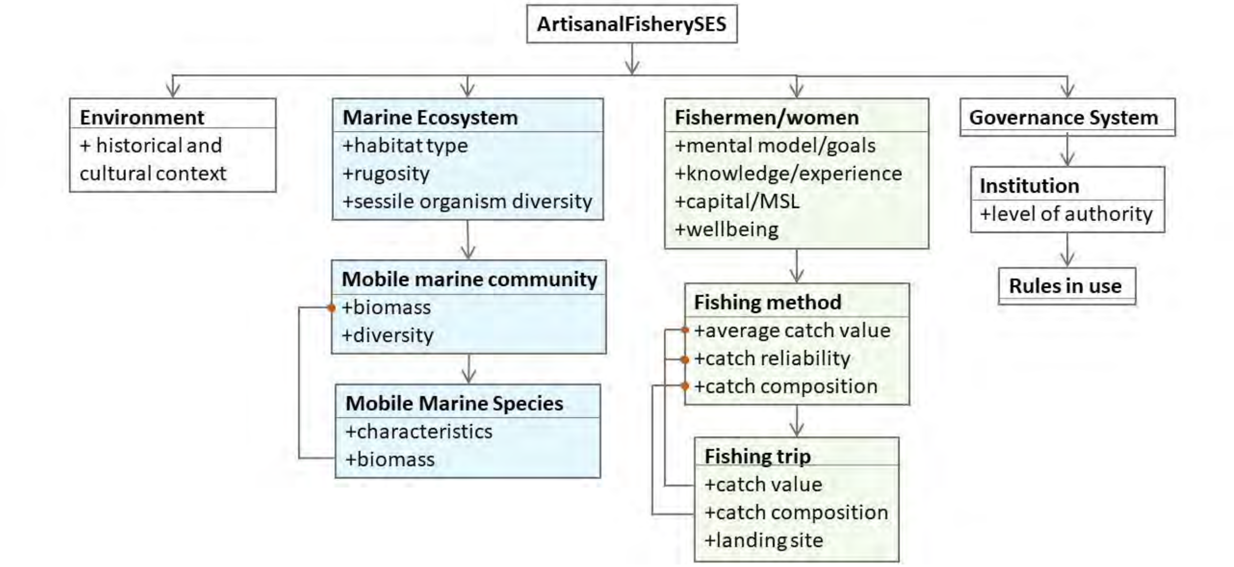

Figure 1-2: A schematic of the formalized framework of the Pemba Bay fishery SES adapted from Hinkel *et. al.* (2014). Arrows indicate attribution relationships, meaning they are attributes of the level above, and rust dots indicate aggregation relationships, meaning the combination of the characteristic at the lower level determines the characteristic at higher levels. The middle columns represent the focus of this study on the marine and social systems. The column in blue represents the resource system, the column in green represents the resources users. MSL here refers to the fisherman/woman's material standard of living. Environment and Governance systems represent external contexts within the scope of this study.

This study focuses on fishing decisions and the consequences of those decisions (Figure 1-3). In Ostrom's framework, these are denoted as actions situations. Hinkel *et. al.* (2015) specified them as appropriation action situations, as they directly exploit the resource for some benefit. This study addresses how fisher characteristics, motivations and goals, and knowledge, affect these actions and how the different behavioural frameworks above can be used to understand these actions. These actions influence the characteristics of the resource system as a whole. If fishing harvest is high, then fish are a zero-sum resource and removal by one fisher noticeably affects the availability of fish to another. The fishery is subtractable. If harvest levels are significantly lower than growth and reproduction rates, removal by one fisher may not noticeably affect availability to another, making fish non-subtractable in this case. When a resource is subtractable, as are many fish stocks, there is risk of overexploitation and degradation of the resource system, as is the case in many fisheries (e.g., Worm *et. al.*, 2009). In this case, Hinkel *et. al.* (2015) mentioned the possible existence of provisioning action situations, in which maintenance or improvement of the resource system is the goal rather than exploitation. They contended that in open access systems, this requires governance or collective action to be successful. In order to understand the different aspects of the Pemba fishery SES, this study uses several different types of data and analyses these using qualitative and quantitative techniques. An overview of the background on some of these methods is described below when necessary to understand the protocols in the methods section.

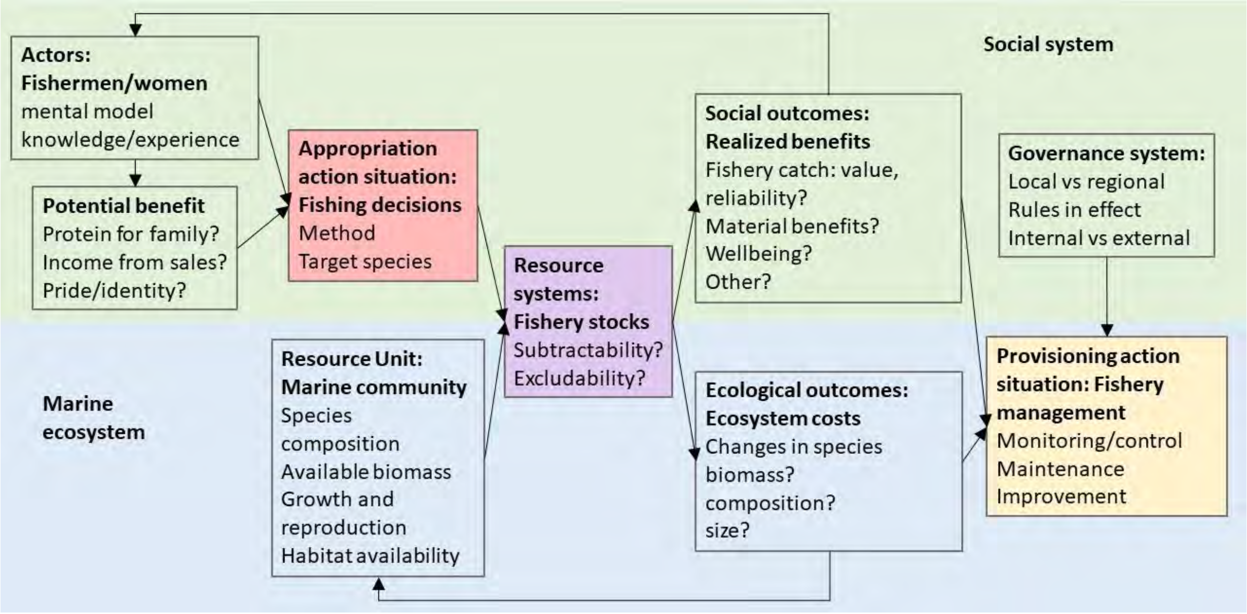

Figure 1-3: A schematic of the parts of the Pemba fishery social-ecological system which are addressed in this study. The green box encompasses social aspects, and the blue box ecological aspects of the system. Action situations are in the red box, appropriation situation, and yellow box, provisioning situation. The resource system is in the purple box as its characteristics are directly affected by the resource units of which is it composed, and the appropriation actions used to exploit those resource units. The social and ecological systems are assumed to interact based on action situations that affect fishery stocks and fishery management.

Background on methods used in the dissertation and how they interact with Ostrom's framework

Transdisciplinary research to understand fisher characteristics and behaviours

Transdisciplinary research is research which is envisioned and conducted using a combination of academic and non-academic sources. Brown *et. al.* (2010) discussed the need for transdisciplinary imagination to tackle the wicked problems facing society. Dyball (2010) discussed transdisciplinary research specifically in relation to human ecology and understanding human and nature interactions. Transdisciplinary research focuses on the fact that no single perspective accurately encompasses "truth" and, therefore, there is a need to interact with different perspectives about a social-ecological system if it is to be understood (Parissi, 2010; Russell, 2010). This study uses a combination of workshops, interviews, household surveys, and informal communications to start to understand the social context of the Pemba fishery from different perspectives and the behaviours and motivations of resource users.

Workshops provide a way for groups of people to interact with a research project and identify the scope of the system and problems. Brewer (2013) found that through workshops, fishers in New England gained valuable connections with managers and other fishers, and managers benefited from the experiential knowledge and perspectives that fishers provided. Paterson *et. al.* (2010) used workshops to understand the scope of the sardine fishery in South Africa based on ecology, social science, industry, and management, thus allowing a more complete picture of the fishery to emerge. By having initial workshops early in the research process, this study attempts to allow for a more transdisciplinary research focus where fishers and local managers can be involved in the formation of the questions as well as possible solutions. It addresses the ideal situation for the fishery as well as ways to approach this ideal following Brown *et. al.* (2010). These ideas are addressed at the individual level as part of the individual interviews which follow.

Workshops are a good way to start conversations about a problem and allow discussion, however, individual perspectives may be lost in a group forum (DiCicco-Bloom & Crabtree, 2006). To address this possibility, individual interviews can be used. Semi-structured interviews allow the interviewee to discuss the topic without being limited by the assumptions of the interviewer (DiCicco-Bloom and Crabtree, 2006). This method of interviewing can further the ideal of transdisciplinary research by allowing a discussion to develop between interviewee and interviewer. However, this is limited in this study due to necessity of translators to conduct interviews limiting these interactions. Along with social data, this study uses ecological data to understand the SES, which is discussed below.

Functional diversity to simplify marine ecosystems affected by fishing

The ecological and fishing data collected from Pemba Bay and other areas in Northern Mozambique for this study contained over 600 species. When trying to understand how fishing or other disturbances affect ecosystems, it is essential to find ways to simplify these complex communities so that their overall functions can be addressed. Increasingly, researchers are looking at functional diversity as a way to understand basic differences in the functioning of ecosystems and changes following disturbance (Villéger *et. al.*, 2017), in this case, intensive fishing. Villéger *et. al.* (2008) suggested using functional richness, evenness, and divergence to simplify functional diversity into three independent measures. Functional richness is measured as the size of the n-dimensional functional space that a site inhabits. Evenness varies between 0 and 1 and indicates the extent to which the biomass of a system is evenly distributed within the functional space. Divergence is a value between 0 and 1 indicating the distribution of biomass within the functional space. Lower values indicate greater proportions of biomass near the centre of the functional space. Together, Villéger *et. al.* (2008) argued, these characteristics allow the functional diversity to be quantified to start to see how disturbances change that diversity. Using functional diversity also allows researchers to compare systems with different compositions of species with similar functions (e.g., Villéger *et. al.*, 2010). Changes in functional diversity are likely to cause changes in the functioning of an ecosystem, which has important implications, both for ecosystems themselves and human populations who depend on them. For example, Graham *et. al.* (2011) mentioned reefs with higher functional diversity are thought to recover faster from disturbance, although they admitted that current research is lacking to confirm this assumption.

Along with possible changes in functional indices, grouping species into functional groups allows for better understanding of differences between samples. As Díaz *et. al.* (2011) pointed out, resource users do not extract resources from the ecosystem at random. They select resources based on their functional characteristics. By grouping species into functional groups, this study can determine how groups which are targeted by humans are affected compared to those which are not. Using functional groups, rather than individual species when comparing community composition between sites allows this study to address where specific functions are lost or less prevalent and the possible consequences of these differences for the entire system. Functional diversity is used to simplify the resource system around Pemba Bay and compare it to ecosystems in other parts of Northern Mozambique.

Data collection and Ostrom's SES framework

This study uses different types of data to address different aspects of the SES. Aspects of the SES which are seen as unchanging within the temporal and social scale of this study, such as governance systems and social context of fishing, are addressed through literature searches and summarized in the previous section or addressed in the discussion. Social aspects of the SES (in green box in Figure 1-3) are addressed through workshops and interviews with fishermen and women, as well as household surveys with random members of the communities in which these fishers live. These social data were collected within a transdisciplinary context, meaning that the researcher attempted to interact with stakeholders in all aspects of the research. However, the research goals were established without stakeholder involvement. Ecological aspects of the SES (in blue box in Figure 1-3) are addressed through in-water data collected in Pemba Bay and other sites in Northern Mozambique and analysed through functional groups and functional diversity. Understanding the resource system (in purple box in Figure 1-3), uses a combination of the above data, as well as catch data from a variety of sources: the Mozambican fishery ministry, observations of fishing trips and creel surveys, and data from the Our Seas Our Lives project.

Finally, the action situations (in red and yellow boxes in Figure 1-3) are addressed by looking at all the above data. The appropriation action situations of fishing based on a particular method are addressed using interview responses and catch characteristics to compare the compatibility of the data with the different behavioural theories which could be used to understand that data. The provisioning action situation of fishery management uses results from all aspects of the study, in the final discussion, to address current mitigations and possible future interventions to improve the fishery. These data are analysed using a variety of techniques, including multinomial analyses and Bayesian statistics.

Bayesian models and complex systems

Analyses in this study revolve around multinomial analyses to understand how communities of factors, including functional groups and interview responses, vary based on different predictors; and Bayesian linear models are used to understand how different factors affect complicated outcome data. The complication of the resulting data structure, namely inflated number of zeroes compared to what is expected from common statistical data structures, made Bayesian methods best for this analysis (Zuur & Ieno, 2016).

Bayesian statistics was first proposed by Thomas Bayes in the mid-1700s. His seminal work, “An essay towards solving a problem in the doctrine of chances”, was published by the Royal Society of London post-humorously in 1763 (Bayes, 1763). Wide-spread use of Bayes’s theorem didn’t start until the mid-20th century (Dale, 2005).

The essence of Bayes’s theory is that, given unknown probabilities, humans iteratively incorporate prior beliefs, prior distribution, with new data to determine the new belief, posterior distribution (Pearl, 1988). Realizing this relatively simple idea requires use of techniques such as Markov chain Monte Carlo (MCMC). This requires significant computing power which only became widely available in the last few decades (Wagenmakers *et. al.*, 2008). MCMC creates parameter distributions rather than a single value as occurs in frequentist statistics (Congdon, 2006). These posterior distributions have the benefit of being intuitively interpreted, in that the 95% confidence interval is the odds that the true value is found within that interval, rather than an indication of type 2 error in frequentist statistics (Wagenmakers *et. al.,* 2008). The complex nature of the data and the models needed to incorporate social, catch, and ecological characteristics make Bayesian models a good choice for analyses.

Study goals, questions, and hypotheses

The goal of this study is to better understand what motivates fishing decisions within the small-scale fishery around Pemba Bay, Mozambique. Fishers are expected to make fishing decisions based on their motivations and attitudes, and these decisions, through the fishing catch achieved, are expected to affect their wellbeing and the fishery ecosystem. Better understanding of fishing decisions promotes understanding of human ecosystem interactions in a system where these interactions are direct. Better understanding of fishing decisions can also be used by fishery managers to design interventions to promote more sustainable fisheries. These overall goals are addressed through the following questions and hypotheses.

Q1) What behavioural paradigms best explain fishing decisions around Pemba Bay?

- h1) Fishers are motivated primarily by economic concerns, and therefore, rational actor theory is consistent with fisher responses, or alternatively, fishers are not always economically rational, and one of the other four theories investigated is at least as consistent with fisher responses as RAT;
- h2) The catches resulting from fishers' decisions more closely correspond with expectations from prospect theory than rational actor theory in that catch reliability is as important to fishers as catch value.

Q2) What are the social impacts of fishing decisions?

- h1) Fishing is a chosen profession and, as such, fishers are as well off financially and subjectively as non-fishers within their community;
- h2) Fishers' wellbeing is correlated with the reliability of their fishing method, or alternatively with the profitability of their fishing method;
- h3) Fishers using more reliable, alternatively more profitable, methods are more committed to fishing as a way of life/identity.

Q3) What are the ecological impacts of fishing decisions?

- h1) The fishing pressure around Pemba Bay causes lower marine biomass, functional diversity, and maximum fish size around Pemba Bay than other areas in Northern Mozambique with less fishing pressure;

h2) Direct removal by fishing is the primary cause of declines, and as such, catch is more negatively correlated with biomass or size in Pemba Bay than in other sites.

The rest of the thesis first discusses the general methods, including the study site and data collection and manipulation (Chapter 2). This is followed by three data chapters addressing the three questions above. Chapter 3 looks at the compatibility of interview data with the five behavioural theories mentioned above (rational actor theory, prospect theory, theory of planned behaviour, habitual behaviour, and descriptive norms). Chapter 3 also investigates the relationship between mean catch value and reliability in explaining changes in relative use of different methods to determine the extent to which PT allows a better understanding of fishing behaviours than RAT. Chapter 4 addresses the social outcomes from fishing. Specifically, it investigates the differences between fishers and non-fishers, and between fishers using different methods, with regards to their material and subjective wellbeing. Chapter 5 investigates the ecological effects of fishing around Pemba Bay by comparing in water marine communities around Pemba Bay with other sites in Northern Mozambique. The final chapter, Chapter 6, is the final discussion combining data from decision making paradigms, social outcomes, and ecological outcomes to determine the state of the fishery and address management interventions.

Chapter 2 General methods

Abstract

This chapter discusses general data collection and analysis used in the data chapters. These include study sites, social data such as interviews and workshops, and ecological data such as in-water surveys and catch surveys. Basic data analysis is included such as the calculation of weather data and the formation of marine functional groups, but specific analyses for each chapter are included in the data chapters themselves.

Study sites

The primary study site was around Pemba Bay in Northern Mozambique (Figure 2-1, GoogleEarth 2018, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO).

Figure 2-1: Map of primary study area with communities from which interview or catch survey data was gathered. (Google Earth Pro, 2019)

Pemba Bay is a large, deep-water bay (Siyabona Africa (Pty) Ltd, 2022). The provincial capital is on the southern peninsula of the bay, with an estimated population of 200,000 people, just under 10% of the provincial population (INE, 2019). The main economic activities in the area are farming and fishing. There have been various shrimp, clam, and seaweed farming projects in the area (Personal communication with locals). However, during data collection, from 2017 to 2019, none of these were operational. Some small-scale Tilapia farming continues in one community and, during data collection, the government was in the process of creating more tilapia tanks to allow more fishers to engage in fish farming.

Pemba Bay includes a variety of marine environments, including coral reefs, seagrass beds, and deep channels. On the coast are intact mangrove forests and many small rivers and stream enter the bay. The soil around Pemba Bay is sandy, with little organic matter in areas without vegetation. The climate is generally dry, but rains are monsoonal and heavy rain during the rainy season, November to March, is not uncommon. Cyclone Kenneth hit Pemba during data collection on April 23rd, 2019, causing significant flooding and some structural damage to the city.

Many different fishing methods are used in the area, including purse-seine nets on relatively large (8-12m) motor or sail boats; beach-seine nets from row boats; gillnets from small motor boats or canoes; traps, spear guns, and hand lines from canoes or shore; and hand spears and mosquito nets from shore. Purse and beach-seine nets require larger boats and crews with profits being split with half to vessel owners and the other half divided between the crew members. A few vessel owners also operate gillnets with a small crew. Motor boats only operate out of the fishing centre within Pemba City, Ruela, and that is where all purse-seine fishing occurs. Other methods, such as gillnet fishing, handline fishing, spearfishing, and trap fishing are generally practiced from small, one or two person canoes, sometimes with a sail. Handline, gillnet, spearfishing, mosquito net fishing, hand-spear fishing, and gleaning occur from shore as well. Note that what is referred to as handline fishing by local fishers and in data from the provincial fishery ministry is a combination of different techniques using a hook and line, including trolling and jigging, and can target pelagic or demersal species in the deep-water channel or reef or seagrass species in shallow waters. Fishers who target demersal or pelagic species often hedge-their-bets by allowing time in a fishing trip to fish the reef if unsuccessful in deeper water. Likewise, what is referred to as gillnet fishing includes both active gillnet fishing which attempts to encircle a school of fish midwater and scare them into the nets, and passive gillnet fishing in which the nets are set, usually overnight near the reef, and checked in the morning. Finally, purse-seine fishing includes more typical purse-seine nets which can be used in deep water and in which the purse is cinched from on the boat, and hybrid nets with a sack in the middle. The bottom edge of these net depends on making contact with the substrate to corral fish, and divers create the “purse” by sewing the bottom of the net near the sack closed just before the net is raised (See Figure I-1 in Appendix I). The typical purse-seine nets are used day and night, while the hybrid ones are only used during the day.

There are seven fishing centres around the bay. Fisher interviews and community surveys were conducted in three of these fishing centres. Ruela was within Pemba City. As mentioned above, it was the only community in which motor boats were in operation. There was a local fishing collective (locally referred to as a CCP); however, a very small percentage of fishers were members. One CCP member estimated that 0.1% of local fishers were members. Despite the small number of participants, the CCP had some power to influence management, as addressed in the final discussion. The neighbourhood consisted mostly of mud houses, however, most had electricity and there were many faucets with city water throughout the neighbourhood with most people getting their water from a faucet either at their home or at a neighbour’s house. They had a fish market with cement stalls and an ice maker; however, this was not in use at the time of data collection, although fish were sold off the boats near the market to fish vendors. There was no farmland in the vicinity. The second community, Chuiba, was on the ocean side of the Pemba peninsula, about eight kilometres from the city centre. They did not have a CCP. Again, most houses were made of mud, about half the residents had electricity, and water came mostly from communal wells. They did not have an organized fish market; however, fishers would sell on the beach or take catches directly home. There was farmland in the area. The last community, Metuge/Bandar, was across the bay from Pemba city. They had an active CCP with membership estimated at around 2% of active fishers in the area. The houses were almost entirely mud, there was electricity, but less than half of the residents had it. Even fewer had access to a faucet nearby, and most people depend on city wells for water. Most fishers landed on the beach near the community, and much of the catch was sold on the beach or in town near the minibus stop. There was ample farmland in the area.

This study used several types of data from around Pemba Bay. Interviews and household surveys at the three communities described above were conducted and fishery catch data from five sites around Pemba Bay was acquired and collected (Figure 2-1, GoogleEarth 2018, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO). Marine community data from four locations around Northern Mozambique, Pemba Bay, Vamizi Island, Situ Island, and Nuarro, were collected (Figure 2-2, GoogleEarth 2019, Data SIO, NOAA, U.S. Navy, NGA, and GEBCO). The other three sites have smaller populations than Pemba Bay. Two of the three sites, Vamizi and Situ, had marine protected areas in their vicinity. Situ Island is in the southern edge of Quirimbas National Park, which has been recently designated and UNESCO biosphere reserve which manages the area for sustainable use by local populations (UNESCO, 2018). All sites had a combination of coral habitat, seagrass, and sandy bottoms. Coral habitats were sampled at all locations, even though seagrass and sand dominated habitats were also present at all sites, most non-coral samples came from Pemba Bay. Artisanal fishing occurred at all locations. A previous study in the area found that maximum size of individuals in catch increased with increased distance from Pemba City (Da Silva, 2015). Based on this study, and decreasing human population, it was assumed that Pemba Bay had the greatest fishing pressure. However, fishery catch data was only obtained for Pemba Bay.

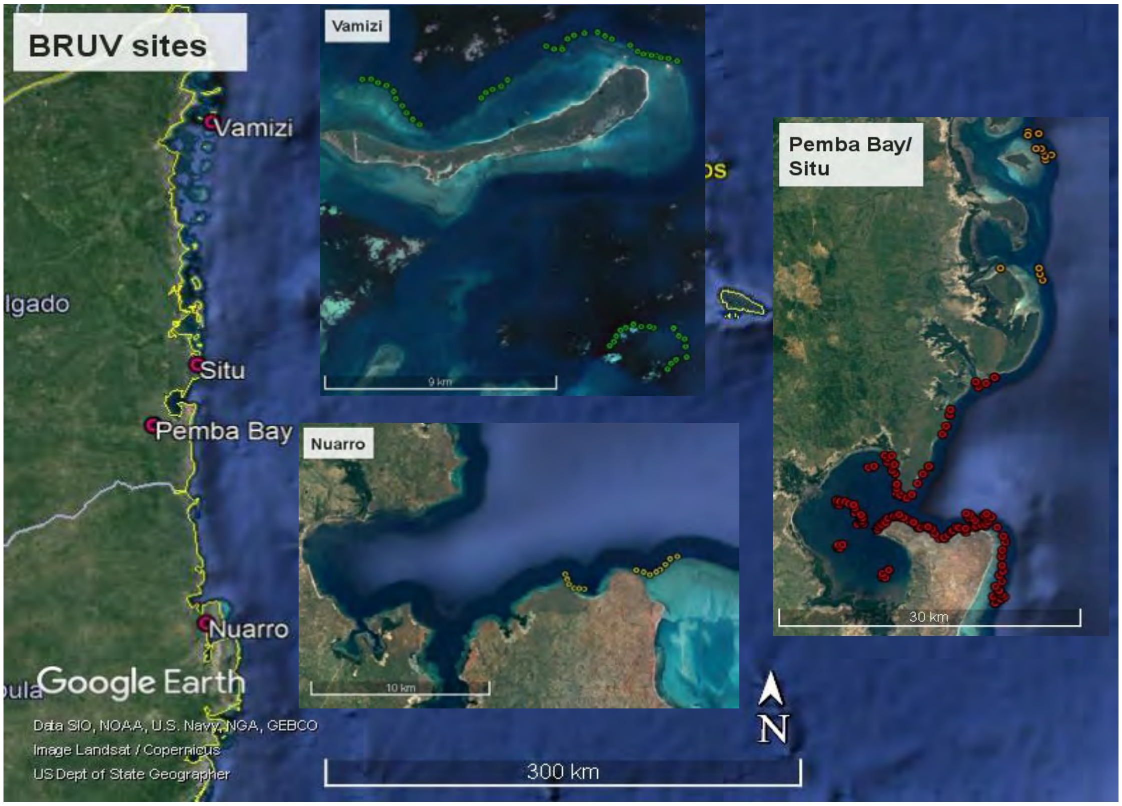

Figure 2-2: Map of study sites where BRUVs were deployed. (Google Earth Pro, 2019)

Data collection

Fisher interviews

Semi-structured interviews were conducted with 143 fishers from three communities around Pemba Bay, at least 40 from each community. Fluent speakers conducted interviews in Macua, the local language. A copy of the interview form can be found in Appendix I (Table I-1 to I-4). Questions were workshopped with local teachers and fishery managers in Portuguese. English translations by the author are in Appendix I (page 174). The Macua translations were done by a local translator. Interviewers often elaborated on the questions when conducting the interviews to make themselves clear, so the exact wording was not always used. Interviewees were asked if the interviews could be recorded, and if they agreed, interviews were recorded for posterity and saved under a random code, as were all responses. The recordings had not been translated as of the writing of this thesis. Interviews were conducted opportunistically. Initial interviewees were encountered through connections with the local CCPs and other community leaders. Recommendations from these fishers about other potential interviewees allowed snowball sampling to identify many interviewees (e.g., Aswani & Lauer, 2006). In Chuiba and Metuge, these interviewees were supplemented by opportunistically asking fishers on the beach if an interview could be conduct. These occurred either on the beach or at their homes. Finally, remaining interviews were conducted at random houses throughout the community while doing household surveys. Starting positions were chosen at random on a street not yet sampled and, if a willing fisher was encountered, an interview was conducted. The process was repeated five houses down the street. In Ruela, fishers were less willing to do interviews, so after interviewing CCP members and a few other willing fishers with which fishing observations were conducted, a local fish vendor was hired to help encounter willing fishers who were returning from fishing trips on the beach. All interviews in Ruela were conducted on the beach, as many fishers did not live nearby. Interview times varied from 20 minutes to an hour depending on the interviewees. Most interviews were conducted between August and December 2018, however 27 were done in August 2017.

Household surveys were conducted in the three communities in which fisher interviews were conducted, between August and December 2018, at the same time as most interviews were being conducted. This provided information on an additional 267 households between the three communities so that each community had at least 130 sampled houses. The exact percentage of houses sampled is unknown, however, within fishing neighbourhoods, surveys were conducted on most streets, so surveyed households are likely to represent about 10% of the houses within those neighbourhoods, but were a very small percentage of the population of the entire town/city. Household surveys were conducted by choosing a random house on a street within the community to start and conducting the survey with a willing resident of the house then moving five houses down and attempting to conduct another survey. Random starting houses encompassed all parts of the fishing neighbourhood. However, this did not lead to every fifth house being sampled in a regular grid. The sampling protocol was semi-random. As a thank you to participants and interviewees, they were given a photo of themselves if they chose, but no other compensation was provided. Household surveys and interviews addressed livelihoods, MSL, subjective wellbeing, and demographic information.

Questions about livelihoods included all the livelihood activities practised by the household and if these were different between the seasons, physical resources used for the different activities and how they were acquired, etc. Subjective wellbeing was measured on a three-point scale and included overall life satisfaction as well as satisfaction with family, social, and work life, feeling of security within the community, perception of access to help within the community, and overall health of the family. Respondents were asked what makes a good life. A wealth index for each household was based on the type of house, roof, floor and toilet, source of water and energy, and ownership of material goods such as cell phones and other electronics, ovens or stoves, refrigerators, and motorcycles or cars. Direct questions about income were considered inappropriate, so not included.

A wealth index and ordinal wellbeing variables were created for each respondent. Wealth indices used data on material possessions, housing materials, etc. A Redundancy Analysis (RDA) was used to compress the data into a single metric (Pollnac & Crawford, 2000) using package vegan (Oksanen *et. al.*, 2020) in R studio (R Core Team, 2020). The primary axis was associated with wealth, as higher scores correlated with having multiple houses, having more material possessions, etc. Outside financial resources were categorized as: none, family/friends, outside loan, or personal savings. Subjective wellbeing responses were ordered from one, negative perception, to three, positive perception for each aspect of their wellbeing. Responses about what makes a good life were grouped into a few general categories: fishing, working in general, wealth, health, and social relationships.

Along with the general information collected in household surveys, fisher interview questions addressed perceptions of the fishery in general and personal fishing behaviours. Questions on the fishery in general included the current state of the fishery, changes in the fishery since the interviewee began fishing, when they noted changes and what they believe caused the changes, how the fishery was managed, how they think it should be managed, ecological knowledge, etc. Questions about their fishing behaviours included why they fished, why they used a particular method, what method they would have preferred and why, what species they would have preferred to catch, how they had changed their fishing practices to account for the changes noted above, what they liked and disliked about fishing, what methods they knew how to use, fishing gears to which they had access, if they would have preferred a different type of work, and if they wanted their children to be fishers.

From the answers to a few of the interview questions, fisher adaptation and ecological knowledge scores were calculated. Adaptation scores were based on substantive answers to six questions on how fishers had responded to previous changes, what might occur in the future and ideas for how to deal with those changes, and ways to improve the fishery. It was assumed that the ability to think about future possibilities increased the chances of being able to adapt to changes in a positive way, which has been mentioned by others (e.g., Chapin *et. al.*, 2009; McClanahan *et. al.*, 2008). Adaptation scores ranged between zero, with no substantive answers, and six, with all questions answered in a substantive way. Ecological knowledge scores varied from negative one to four based on the question of when, where, and how a marine species reproduces and its time to maturity. Fishers could choose any marine species and all reasonable answers were considered valid. The only answers given that were considered invalid were maturity times of a month or less, which were given negative score, and maturities between one and three months given a zero score. The effect of the way fish maturity time was scored was checked by re-running the models below with no negative scores and positive one starting at two months rather than three, and the other way by making responses below two months negative scores and only positive scores when above four months. Very few fishers gave maturity times above six months, so larger cut-offs were not considered useful. Maturity times from fishbase.org and sealifebase.org were never less than eight months for any local species for which the data existed. This indicated that most fishers vastly underestimated true maturity times.

Fisher workshops

Workshops were conducted twice with fishers at each of the three communities where interviews were conducted to understand the cultural and historical context of fishing in Pemba Bay, and to explore the fishery and resources use in a more interactive way than interviews. Workshops occurred in May or June, 2017 and October to December 2018. In Chuiba and Bandar, the workshops in 2018 were separated with men and women coming on separate days. In Ruela, workshops were only conducted with men. In the first workshops, the current state of the fishery, how it was changing and ways to potentially improve it were discussed. Fishers were asked to draw the fishery and, if willing, explain what the fishery meant to them. Smaller groups of fishers discussed how the fishery had changed with the group presenting their recollections and creating a consensus about those changes. Ways that the fishery could be improved were then discussed. In the second workshops, fishers mapped fishing locations and the methods used at each which were compared to locations on a bathymetric map of the bay. Fishers as a group were asked to indicate how fishing catches had changed using tick-marks to indicate the proportional size of catches. They were also asked about important marine species groups or habitats and how these had changed. Workshops were led by the primary researcher and local fishery managers. Local translators were used to move between the local language and Portuguese in workshops. Workshops generally lasted a morning, and participants were given a meal at the end of them, but no other compensation was given. Comments from workshops were used anecdotally to help support or contradict patterns found in the interview data and understand the cultural context of fishing in the area. Additionally, in order to conform to the transdisciplinary objectives of this study, workshops allowed local fishers and managers to influence the forming of the fishery conceptual model introduced above and provided a framework for understanding the fishery interventions attempted and proposed in the final discussion of this thesis.

Interview and workshop data were used to understand fisher motivations and attitudes about fishing as well as their perceptions on their own wellbeing and that of the fishery. These data were combined with the catch and ecological data to understand how these attitudes and perceptions compare with objective catch characteristics and ecological data.

Catch surveys

Catch data was obtained from the national fishery ministry, Ministério do Mar, Águas Interiores e Pescas (MMAIP), from 2012 through 2018 for the fishing centres around Pemba Bay (n=9639). These data were obtained directly from the Ministry's database with the help of Arone Salenca. These data were supplemented with data from the Our Seas Our Lives (OSOL) project for catches from Bandar on the west side of Pemba Bay from 2018 and 2019, (n=132), and personal fishing trip observations (n=37) and creel surveys (n=35) from Bandar (n=28 personal fishing trip observations and creel surveys), Ruela (n=26), and Chuiba (n=18) from 2017 and 2018. In total, catch data from 9,843 fishing trips were used. All data included the fishing method based on local name of the method grouped as mentioned above, number of fishers, landing site, date, and total catch in kilograms. For the fishery ministry data, catch species composition was provided as monthly totals (n=686). The other data sets provided catch species composition for each trip.

Personal fishing observations occurred mostly with fishers encountered through the local CCPs and allowed the researcher to observe fishing on board the fishing vessel when a larger boat was used. A local fisher was hired in Chuiba and Metuge to transport the researcher following willing fishers during their fishing trips when they used a canoe, and assisting in finding willing fishers. In Ruela, the president of the local CCP or a friendly vessel owner provided transportation to observe fishers using canoes. Personal fishing observations included: observing fishers during a complete fishing trip, recording distances and locations using a handheld GPS, and collecting catch data. Catch was identified to species; fork length, mantel length, or carapace length or width measured to the nearest millimetre; and individuals were weighed to the nearest 0.1 grams using a digital scale. Weights were obtained on board the boat while in motion, so weights were less reliable than the accuracy of the scale would suggest. These were compared with calculated weights, based on length-weight relationships from the literature, which were always similar. When large catches were made (several hundred fish or more), several individuals (at least 10) from highly abundant species were measured, taking care to get a representative sample of sizes. All individuals of species with less than 10 individuals were measured. Photos of total catch and very small individuals/species were taken to assure that all species were identified and, occasionally, a species was encountered in photos which was not noted at the time. In these cases, lengths of the individual specimen were estimated based on known lengths of boat or crate structures for calibration using digimizer image analysis software trial version (digimizer.com). For large catches, the total catch was estimated based on the number of crates filled when selling the catch at the end of the trip. Estimated weights of crates varied between 15 and 25kg based on species group.

Creel surveys were conducted at landing sites or on the water. These did not always represent the entire catch for the day. When time permitted, catch was weighed and measured as above. More often, so as not to inconvenience fishers, catches were photographed and weights determined based on length-weight relationships. Lengths were determined from photos again using digimizer image analysis software (digimizer.com) with items of known length for calibration.

Determining catch characteristics

The take-home value of catch depended on the species of catch, costs of supplies, and division of the catch. Large crews, at least five fishers, indicated the presence of a vessel owner who received half of the net catch. The rest of the catch was divided between the fishers (personal observations and communications with fishers and managers). Negligible losses of fishing materials during a trip were assumed except when a motor boat was used and were based on lack of observed gear losses during fishing observations. From observations and conversations with local fishery managers, gillnet boats with more than 5 person crews and purse-seine boats with more than 10 person crews were assumed to use a motor boat in the fishery data. This led to almost 5% of gillnet trips and nearly 98% of purse-seine trips being classified as using a motor boat. In these cases, net catch was estimated as 64.5% and 66.4% respectively of total catch to account for the proportion of the catch that covered fuel costs. These estimates were based on the gross to net profits from fishing observations in Pemba (n=14). Despite this very small sample size, the proportions agreed well with estimates of proportion between net and gross profit for small-scale fishers from Daw *et. al.* (2009).

Catch caloric values were estimated based on catch composition and species estimates of caloric value from FAO and supplemented with outside literature when necessary. For each species, the proportion of wet weight of the fish that is protein or fat was multiplied by 4.27 or 9.02 kilocalories per gram respectively. The sum of these was multiplied by the proportion of the species which was edible to get total kilocalories per gram of total weight. This was multiplied by 1000 to get kilocalories per kilogram. Estimates of protein content, fat content and proportion edible came from Food and Agriculture Organization (Leung *et. al.*, 1972; Torrey Research Station, 1989). These were supplemented by other sources, when necessary, see references in Appendix I (Table I-5 and I-6), for each species. Total caloric value of the catch was the weighted average of caloric value per species multiplied by total catch amount in kilograms. For the fishery data, all fishing trips within a month, fishing centre, and method group had the same species composition and, therefore, mean kilocalories/kilogram measure.

Catch monetary value was estimated based on catch composition and estimates of the value per kilogram of fish from different locally defined species groups. Common names were acquired through conversations with a local fishery manager, a database from Isabel Marques da Silva, and conversations with local fishers. Locally defined species groups generally indicated a scientific family. However, some names indicated either subfamily groupings, such as Scombridae being divided into tunas and mackerels, or super-family groupings, such as Aristeidae and Penaeidae being combined into shrimp. Local fishery managers conducted meetings with fishers in Metuge and Ruela to determine the average value per kilogram of different fisher defined species groups. The mean value from the two meetings were used to calculate the value of each species in the catch, total value of the catch, and value per fisher. Unidentified species were given the minimum value based on the assumption that more valuable species were better known by fishery managers. Species not included in locally defined species groups were assumed to have zero value and be “bycatch” based on observations and conversations with local managers.

Two estimates of catch reliability were calculated for the different fishing methods: catch coefficient of variation (CV) and if a catch was “sufficient”. Catch CV was based on the weight of catch in kg per fisher for each month, method, and fishing centre to allow enough samples for CV computation (945 CV measures). One hundred fifty-seven combinations did not have enough catches for a CV measurement. In these cases, CV was recalculated based on year, season, centre and fishing method. Seventeen combinations still did not have enough sampled catches to allow CV calculations, in these cases, year, season and fishing method were used. This gave a total of 886 unique CV measurements.

A sufficient catch was defined as at least 1.75kg per fisher. This amount was estimated as sufficient based on protein requirements for an average fisher family. The average size of fisher families based on the data was 7 members. This was multiplied by daily protein requirements. Protein requirements for a healthy diet were estimated as 0.75g/kg body weight (National Research Council, 1989). Based on an average weight of about 70kg, this meant 52.5g of protein a day. FAO estimated about 20% of fish is protein (Torrey Research Station, 1989). Taken together, this meant each person needed a little more than 250 grams of fish a day to meet their protein requirements, so just over 1.75kg for a family of 7. It was assumed that dietary energy was obtained primarily through plant sources, so getting enough protein was the main necessity from fish.

Estimating total catch for Pemba Bay

To estimate the average total monthly catch of each species by each method and landing site, the proportion of the catch the species represented was multiplied by fishery estimates of total catch for the month, landing site, and method. All data for which species composition data existed were used in this estimate: fishery ministry monthly totals, personal observations, and OSOL data. Total catch was calculated by the fishery ministry based on days sampled extrapolated to days not sampled. Using all data in these estimates weighted individual trips from OSOL and personal observations the same as combined monthly composition data from the fishery ministry. This incorrectly assumed that a single trip represented an entire month’s catch, giving more weight to these individual trips than they deserved. However, based on the number of species which were only found in personal fishing observations and the observation that many fishery managers ignored small individuals when rare in catches, it was likely that many species were in catches from the fishery ministry but were ignored.

Therefore, using OSOL and personal observation data allowed an estimate of the catch of these species which would otherwise not be counted.

The mean monthly catch for each method, landing site, and year was calculated either with or without months with zero catch data. Zero catch data was complicated because, based on conversations with fishers, it was highly unlikely that any fishing method was not used in a month and, therefore, that the catch for the month was really zero. On the other hand, fishery managers were less likely to count a method when it was rare, meaning that months with zero catch values probably indicated that catch from that method was lower than in other months, and ignoring the zeros overestimated catch for the species by the method above the likely true value and including them underestimated it. The two measures gave the range of possible catches for each species by each method at each fishing centre. Due to interest in total catch for Pemba Bay, the total catch from the bay was estimated as the sum of the monthly averaged catches from all fishing centres. This assumed that catches from fishing centres were independent, or at least positively correlated. If whenever catches from one fishing centre increased, it caused decreases in other centres, then summing the averages would not be valid. However, as mentioned above, many fishing centres did not have data from all months, so finding a monthly total for all fishing centres and then taking the average was not possible.

Fishery catch data and fisher interviews and workshops were used to understand the social aspects of the fishery and the general outcomes from fishing activities. Ecological data were also collected to determine the ecological impacts of these decisions.

BRUV samples

Baited remote underwater stereo-video systems (stereo-BRUVs) were used to sample marine communities around Pemba Bay (n=99), Situ (n=11), Vamizi (n=53), and Nuarro (n=14) (Figure 2-2). Data collection occurred in September 2017 and April 2018 in Pemba Bay, September 2017 at Situ, December 2017 at Vamizi, and January 2018 at Nuarro. In Pemba and Situ, stereo-BRUV sampling attempted to represent nearly all habitats available for fishing. However, the visibility for many shallow water samples was too low to allow analysis. Additionally, this study did not attempt to sample in mid-water or deep demersal habitats with the stereo-BRUVs depending on catch data to give an estimate of these marine communities. In Vamizi and Nuarro, samples were set in an attempt to view sharks and rays, if present in the area, rather than trying to sample all available habitats. However, there was still habitat variability within samples at all sites.

Four stereo-BRUV systems were used, on loan from the South African Institute of Aquatic Biodiversity (SAIAB). These systems used two GoPro cameras mounted in a waterproof housing about 70 cm apart and angled toward each other by 7° to allow an overlapping view field. A bait arm was attached between the cameras, holding the bait canister 1.5 metres from the cameras. Stereo-BRUVs were deployed from motorboats with all four deployed at a time, at least 200 m apart (Griffin *et. al.*, 2016). On average, 10 stereo-BRUV samples were collected in a day, but this varied from 3 to 18 samples. All stereo-BRUV samples used imported horse mackerel, *Trachurus capensis*, as bait due to its high fat content and consistent availability (Dorman *et. al.*, 2012). Bait was crushed using a large stick into a heterogeneous fish mush to facilitate bait dispersion into the water to attract fish while still having chunks of fish too large to be washed out of the bait canister underwater. About 800 grams of whole mushed fish was added to the bait canister just before deployment. Soak times of at least 1 hour were used for all samples (De Vos *et. al.*, 2014).

Video samples were analysed in EventMeasure (SeaGIS, 2020a) following the standard operating procedures from SAIAB. All individuals were identified to species and stage (sex and age) when possible. The maximum number of individuals from a species/stage within a single frame of the video (MaxN) was used to determine abundance (Taylor *et. al.*, 2013). The left camera was generally used to determine MaxN, however, if this video was damaged, or the visibility impaired compared to the right camera, the right camera was used.

The use of stereo videos allowed length measurements of many individuals. Stereo videos were calibrated using specialized calibration software from SeaGIS. Lengths were measured for all individuals which could be reliably identified on both videos and were definitely not measured previously. For large schools, fewer individuals were measured when they were closer and gave more accurate measurements rather than more individuals when they were farther away and gave less accurate measurements. Different lengths were measured for different species based on what could be most reliably measured. Fork length was measured for fish whenever possible. When not possible, fork length was estimated based on morphometric ratios from fishbase.org. Different lengths were measured for invertebrates depending on the species, including mantel length for octopus and squid, carapace length or width for most crustaceans, and even claw length for hermit crabs. Individual lengths were used to estimate weights based on length-weight equations from fishbase.org and sealifebase.org and supplemented with the literature when necessary (see supplementary material for details on supplemental literature and weight/length equations used). Biomass of each species/stage was estimated by multiplying maxN by the mean weight of the measured individuals. For 30 samples, one of the two videos could not be used for various reasons. On these occasions, lengths were estimated for any individuals which interacted with the bait canister using its known length to calibrate the estimate. Species which did not interact with the canister were given the average weight for that species/stage in nearby samples.

BRUV habitat characteristics

Habitat characteristics were determined for each stereo-BRUV sample using TransectMeasure (SeaGIS, 2020b). Again, using SAIAB standard operating procedures, a 5-by-7-point grid on a single frame from the stereo-BRUV video with few fish obscuring the habitat features was used with the substrate at the centre of each grid mark identified using the Collaborative and Automated Tools for Analysis of Marine Imagery (CATAMI) classification scheme (Althaus *et. al.*, 2013). This scheme included identifying any immobile organisms to morphotype and classifying the amount of relief within the cell. Open water grid points were removed from the analysis, then percent cover for each morphotype and average relief for the site were estimated. Similar morphotypes with very small numbers of occurrences were combined, e.g., all seagrasses were combined as there was only one occurrence of seagrasses with elliptical leaves. This led to 34 morphotype groups. MetaMDS in the vegan library in R (Oksanen *et. al.,* 2020) was used to consolidate these groups into four habitat variables.

Percent water column in videos was calculated using vidana software (Hedley, 2003) which allowed the water and substrate portions of the photo used above to be highlighted in different colours and the percentage by area of each calculated. Water temperatures were collected during stereo-BRUV deployments using Onset temperature loggers set to record temperatures every five minutes. HOBOware software (onsetcomp.com) was used to view these data and calculate the mean temperature during the final 40 minutes of stereo-BRUV deployments. Visibility for each video was calculated using the stereo function in EventMeasure to calculate distances. The farthest distance at which an individual fish or habitat feature could be identified was used as the visibility. For samples without stereo videos, this was estimated based on movement of fish after interacting with the bait canister.

Mobile marine functional groups

In total, over 600 species were found in the combined catch and stereo-BRUV data used in this study. As many of these species perform similar functions within the ecosystem and have similar value in the fishery, they were combined into functional groups. Combining species into functional groups dampens variability of abundances and biomasses, based on somewhat redundant species being likely to have negative correlations in abundance, while still keeping the important information about how these species function within the fishery and their value to the fishery. To determine functional groups, a trait matrix for each species was compiled with its trophic guild, reproductive guild, mobility, habitat use of corals and/or seagrass, phylum, and standardized maximum weight and caloric and monetary value per kg (see Appendix I, Table I-5 for the full list of species and traits used). These traits were chosen because they directly related to fisher ability and assumed desire to catch and consume different species. Phylum was included since it seemed likely that at that phylogenetic level, fishers would respond to species differently. Traits on defences to predation were not included due to the large number of traits already in use and the fact that these characteristics were not generally important for fishing vulnerability, except to spearfishing. However, defences could be important in fishers' desires to target certain species which was not addressed here. Traits were obtained from fishbase.org and sealifebase.org using the rfishbase library in R-studio (Boettiger et al., 2012) as well as outside literature (see Appendix I Table I-6 for more information). Monetary value and caloric value per kilogram were calculated as above.

The FD library (Laliberté *et. al.*, 2014) in R studio was used to determine functional groups. The proportional biomass of each species for each sample was used. Since catch and stereo-BRUV data do not sample in the same way, these data can only be directly compared using proportional biomasses. Since some data included unidentified specimens, not all samples had proportions that added to one. The dbFD function used the trait matrix and sample species composition to determine functional groups. Traits were weighted such that groups always represented a single trophic group. Trophic groups are often important in determining species function and, therefore, no functional groups were allowed to have mixed trophic groups. A tree branch height of 0.8 was used which created 51 functional groups averaging 13 species per group. This tree branch height was suggested as a rule of thumb by a colleague at SAIAB. The effects of different functional grouping choices based on characteristics used and tree branch length will be explored further in a future publication.

Weather

Weather conditions associated with the different samples were determined using modelled weather data purchased from Meteoblue for Pemba Bay. These data included average, maximum, and minimum temperature, rain in mm, wind speed and direction, etc. from 1979 through 2019, but only data from 2012 to 2019 were used. Daily mean temperature, wind speed, and cloud cover were calculated as the mean value for hourly measures from predawn to late afternoon. Rainfall was the sum of hourly rainfall from predawn to evening. If any rain fell, a day was classified as rainy. Monthly average weather characteristics were used to determine the season, dry or rainy, for the month. Since the season that a month belonged to could be slightly different each year, a cluster analysis with two clusters was used to determine the seasonal identity that best described each month. Mean temperature, rainfall, wind speed, pressure, cloud cover, humidity, uv index, and number of rainy days for the month were used in the cluster analysis. All variables were standardized using scale in R. The analysis was run in R using kmeans in the base library (R Core Team, 2020) which uses the algorithm from Hartigan and Wong (1979) to calculate group membership.

Chapter 3 Behavioural paradigms for fishing decisions

Abstract

This chapter challenges the common assumption that fishers are rational actors who make decisions to maximize their utilitarian gains. Rational actor theory is compared with prospect theory, which assumes catch reliability was important, theory or planned behaviour, which assumes that perceived behavioural control is important as well as allowing for non-utilitarian priorities, habitual behaviour, which assumes choices are not consciously made until expectations are consistently unmet, and descriptive norms, which assumes that social pressures cause most behaviours. Interview data suggest that the theory of planned behaviour is most consistent with responses. However, heterogeneity of responses requires understanding different motivations for different people. Catch data and changes in relative use of different methods are used to compare rational actor theory with prospect theory based on observed changes in behaviour. Rational actor theory is found to explain changes in fishing method use worse than prospect theory in that the method with the highest average utility is decreasing in relative use. Overall, these data indicate that heterogeneity within fishing communities precludes a simple metric to understand fishing decisions, monetary utility of catch is not a good simplifying metric to understand fishing decisions in the area, and fisheries managers need to consider fishers motivations in more detail if they are to accurately predict reactions to management interventions.

Introduction

In the Anthropocene, our collective human behaviours have become a dominant force in shaping the earth’s systems (Ellis, 2015). This human modification of ecosystems makes it impossible to study most ecosystems without considering the human systems which are modifying them (Ellis, 2015). The reverse is also true, in that human systems are affected by the natural systems on which they depend (Collins *et. al.*, 2000). The combination of economic and ecological models has allowed the bridging of human and natural systems and fostered advancements in economics and ecology (e.g., Inkpen & DesRoches, 2020). In fisheries, where humans are provisioned from fluctuating wild stocks, economic models have been successfully used to understand fishing behaviours (e.g., Prellezo *et. al.*, 2012; Wilen *et. al.*, 2002). Yet, these economic models may still be too simplistic to accurately understand human decision making in many situations (Boudon, 1998) and many studies of small-scale fishers find suboptimal behaviours based on economic model assumptions (e.g., Guest, 2003; Holland, 2008; Lopes & Begossi, 2011; Naranjo-Madrigal *et. al.*, 2015; Salas & Gaertner, 2004).

In light of the inaccuracy of economic behavioural theories to explain fishing decisions in many cases, the aim of this chapter is to investigate several other behavioural theories which could be useful in explaining fishing decisions, adopted from Schlüter *et. al.* (2017). It compares purely economic incentives used in rational actor theory (RAT), with:

- prospect theory (PT), which allows reliability of outcomes to affect decisions;
- theory of planned behaviour (TPB), which incorporates attitudes which are not necessarily economically motivated, expected opinions of peers, as well as perceived behavioural control in decision making;
- descriptive norms (DN), which assumes that behaviours mostly aim to conform with majority behaviours within a person's social group;
- and habitual behaviour (HB), which assumes that most decisions are automatic and contemplative decision making only occurs if the outcome from the habit consistently falls below expectations.

Comparing the consistency of these five behavioural theories with fisher responses allows consideration of economic, social, intrinsic, and agency-based motivations when making decisions. However, many other behavioural theories exist which could fit fisher attitudes and behaviours better than any of the behaviours analysed here. This chapter addresses the question concerning which of the five analysed behavioural theories can be best used to explain fishing decisions in Pemba Bay. The first hypothesis is that:

h1) Fishers are motivated primarily by economic considerations; therefore, RAT is consistent with most fisher response, or alternatively, fishers are better understood through lenses other than economics, and one or more of the other four theories investigated is more consistent with fisher responses than RAT.

Current catch data is used to explain the consistency of the data to the expectations from RAT or PT, as these make predictions about the characteristics of fishing methods which should be preferred. The other three behavioural theories do not make specific predictions about what catch characteristics should be preferred. The second hypothesis is that:

h2) The catches resulting from fishers' decisions more closely correspond with the expectations of PT than RAT in that catch reliability is as important to fishers as catch value when deciding which method to use and determining method preferences.

From the conceptual model of the SES, hypothesis 1 addresses the mental model which fishers use and potential benefits fishers consider when making fishing decisions. The second hypothesis addresses how fishers use feedbacks from average outcomes from fishing in the mean value and reliability of catch to make fishing decisions (Figure 3-1).

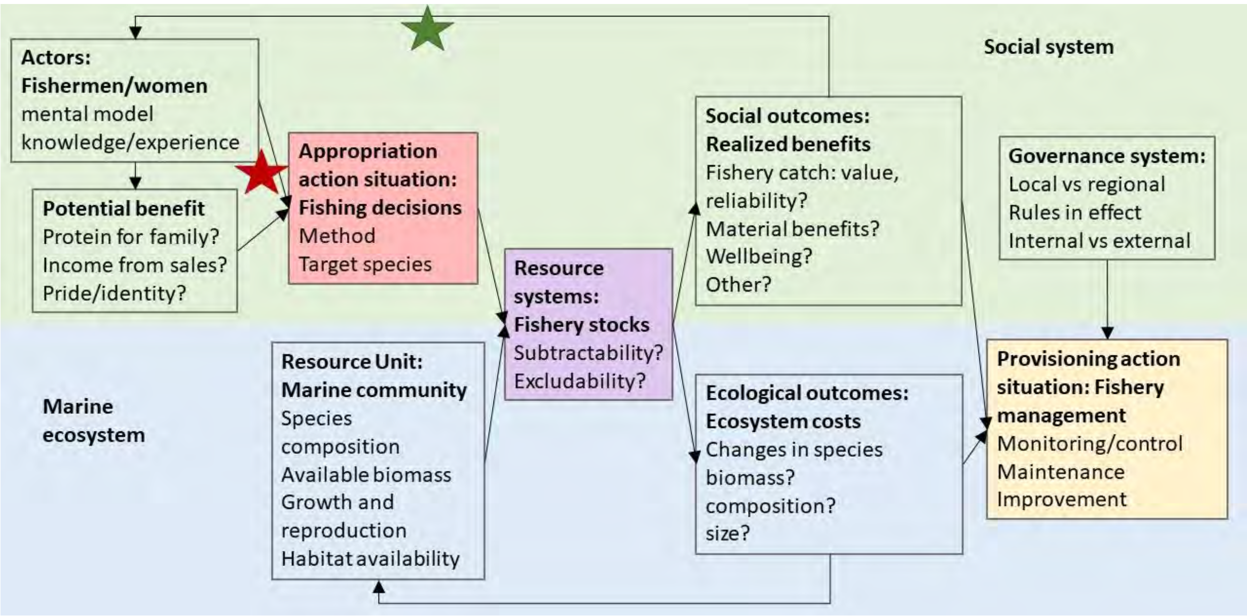

Figure 3-1: The conceptual model of the SES from above. The red star indicates the part of the model hypothesis 1 addresses and the green star the part of the model hypothesis 2 addresses.

Methods

Fisher responses and behavioural theories

This chapter used fisher responses to 11 questions on the state of the fishery, reasons for making fishing decisions, and values of the fishery to determine the consistency of the five behavioural theories in explaining these responses. This was used to address the hypothesis that RAT best explains fishing attitudes and decisions for all fishers or to determine which alternative explains these responses better. Interview protocols were explained above in the general methods section (page 24). For each fisher interviewed, a thematic analysis was done, categorizing their responses to the 11 questions as indicating the importance of profit, reliability, behavioural control, sustainability, social interactions, intrinsic value, and/or habit. Each of these categories of responses were consistent with at least one of the behavioural theories being analysed. Not all categories could reasonably be expected from all questions, and responses could fall into more than one category. Complex responses occasionally indicated several different motivations and considerations when making fishing decisions. In these cases, the response was categorised into several groups. Intrinsic value, in particular, encompassed different ideas for different questions, i.e., when asking about fishing method choice, it indicated an individual preference, but when talking about the state of the fishery it generally indicated habitat value. See Table 3-1 for the questions and type of responses used to determine category membership. Some responses could reasonably be considered indicating the importance of profit or reliability. Since profit was the baseline motivation tested, the analyses were run first with the authors best estimation of whether a response indicated profit or reliability, then rerun with all responses which could potentially indicate profit categorized as profit. This prevented underestimating rational actor theory's ability to explain fishers' responses.

Table 3-1: The 11 questions used to assess the importance of seven fishery concepts.

Objective	ID	Questions	Profit	Reliability	Behavioural control	Sustainability	Social interactions	Intrinsic value	Habit
condition	Q1	current state of fishery	makes money	consistently catch	can access resources	it is sustainable	allows social interactions	identity through fishing	go despite lack of catch
condition	Q2	changes in fishery	improved/still better than alternatives	consistent resources*	availability of gears/possible decisions	sustainable	interaction with others/ copying	improved	keep going despite little benefit
reason	Q3	why fish	makes money	reliable food/income	control the action	it is a sustainable livelihood	to be with people/started with family	personal enjoyment	habit
reason	Q4	why use method	profit	reliability	within control	sustainable	follows norms	personal preference	habit
reason	Q5	why want different method	profit	reliability	allows greater control	protect the resources	follows norms	enjoyment	NA
values	Q6	Importance of ocean	lots of resources	consistent resources	source of power	resources for future	recreational/ cultural activities	valuable through existence	NA
values	Q7	likes/dislikes of fishing beyond catching fish	other resources	reliability of resources	gets to make decisions	protecting the resources	being with people	personal enjoyment	NA
values	Q8	concern for future	profits	resource reliability	empowerment	sustainability	Social interactions	personal enjoyment	NA
values	Q9	what would a perfect fishery be like	high catch and/or with gears to allow it	high catch limited by other concerns	have access to gears and options in fishing	protect the resources	collective action/social change	protect habitat	NA
values	Q10	importance of rules	only in relation to fines	to stabilize catches	to allow more choice	to protect the resource	to protect fishers	for habitat protection	NA
values	Q11	suggested management	technology to increase catch	technology for reliable catch	increase choices	protect the resource	protect fishers/social cohesion	for habitat protection	NA

*Most people said the fishery no longer had much catch. This was considered as an indication that reliability had decreased, but one could say it is a decrease in profit. The analysis was run using both assumptions about the agreement of the response with profit or reliability.

The consistency of a fisher's responses with a particular behavioural theory was determined based on the proportion of responses which indicated the importance of: profit for RAT, reliability for PT, habit for HB, social interactions for DN, and behavioural control, social interactions, sustainability, and intrinsic value all for TPB. For TPB, a response was given a 1, marked as consistent. If any of the factors applied, this meant it was highly likely to be indicated more often than DN, as responses indicating the importance of social interactions to condition and value questions were considered consistent with TPB and DN. Due to the many thematic categories consistent with TPB, the proportion of responses in each category was calculated as well. As habit was not a reasonable response for many of the questions, the proportion of responses consistent with HB was out of only four of the 11 questions. All other behavioural theories could be consistent with all questions, so it is the proportion of 11 used for these theories. For each fisher, which behavioural theory was the most consistent with their individual responses was determined. The proportion of responses across all fishers which were consistent with the different behavioural theories based on the type of question, state of the fishery, reason for fishing, or value of the fishery, was calculated to determine if different behavioural theories were more relevant for attitudes towards certain aspects of the fishery.

It was possible that fishers with different characteristics gave responses which could best be understood through different behavioural theories. To address the possibility that differences in the best framework to explain fishing behaviours could be explained by obvious categorizations of fishers, such as gender, community, or dominant fishing method, multivariate analyses were used. Non-metric multidimensional scaling (NMDS), permutational multivariate analysis of variance (PERMANOVA), and constrained analyses of principle components with cross-validation (CAP) were run on the binomial variable indicating the presence of a specific categorical responses for each fisher/question combination. This led to 9,009 binomial response measures (63 question/response combinations which occurred multiplied by 143 fishers). This allowed the determination of similarities between fishers based on the responses to individual questions rather than assuming fishers with responses which were similarly consistent with different behavioural paradigms had similar responses to all aspects of the fishery.

The combination of NMDS, PERMANOVA, and CAP permitted visual assessment of the overall distribution of the data, determination of significant variables in distinguishing between fisher response samples, and finally, determination of the ability to correctly group individuals based on their responses. All analyses were run in R studio (R Core Team, 2020). NMDS was run using metaMDS in package vegan (Oksanen *et. al.,* 2020). Initially, as few dimensions as possible were used, and dimensions were added to the analysis until a convergent solution emerged. Bray-Curtis distance measures (Bray & Curtis, 1957) and shortest path estimates for sites without any shared species were used (Bradfield & Kenkel, 1987; Williamson, 1978). PERMANOVA used the adonis function also in package vegan. Predictors included fishing community, fishing method, and gender. CAPs were run on the differences in responses based on community, method, or gender using CAPdiscrim in package BiodiversityR (Kindt & Coe, 2005). CAPs used 999 permutations to allow significance testing. To analyse the possibility that fisher types existed based on responses to questions but which were not determined by community, gender, or fishing method, a cluster analysis was run using hclust in the base library in R (R Core Team, 2020). A gap statistic was used to determine the optimal number of groups using clusGap in the cluster package in R (Maechler *et. al.*, 2019). This method compared within group variance with expected variance based on random group assignment for different numbers of groups. Fisher characteristics in each group were determined as the mean values for members in the different groups and proportional representation of different communities, genders, and fishing methods. Calculated groups were compared to demographic grouping based on their ability to predict fisher response consistency with the different behavioural theories below.

To further understand the circumstances in which different behavioural theories might be relevant in predicting fisher attitudes and motivations, the categorical variables above were used as well as individual fisher attributes to determine the proportion of fisher responses consistent with the different behavioural theories. A series of Bayesian models were run using brm in the brms package in R (Bürkner, 2017). The proportion of responses consistent with each theory for each fisher was used as the response and an interaction between the behavioural theory and either community, method, gender, or group from the cluster analysis were used as predictors. A model with additive fishing community, fishing method, and gender was compared with the model using calculated groups to determine the extent to which the combination of obvious fisher groups could account for differences in consistency with different behavioural theories. Models were compared using expected log predictive densities (ELPD, Vehtari *et. al.*, 2017) which used leave-one-out (LOO) estimates of fit to compare models. Two models were similar in ELPD, so a combination model was run with the variables from both these models and the resultant combined model was compared to its sub-models using ELPD. Fisher characteristics were added to the model with the highest ELPD from above, and variables which increased the ELPD were kept. The full model with all predictor variables, categorical and numerical, was not run due to a relatively small sample size (142 fishers and 710 fisher/behavioural theory combinations, one fisher had to leave before giving all demographic data, so was dropped from this part of the analysis). Mypairs

(Zuur *et. al.*, 2009) was used to determine any correlations between potential numeric predictors and, if the correlation was above 0.7, both variables were never used together in the same model. Numerical variables were standardized using scale in R (R Core Team, 2020). Models were validated using R-hat equal to 1, bulk and tail effective sample sizes (ESS) of at least 1000, and visually assessing the fit of the model to the data using various posterior predictive check plots including empirical cumulative distribution function overlay or plots of mean and variance values for the model compared to the data (Bürkner, 2019) using pp_check in the brms library in R (Bürkner 2017).

Method catch characteristics and fisher preferences

This study used catch characteristics and fisher responses to address the second hypothesis that PT better explained recent fishing behaviours than RAT. This study used three lines of evidence to address this hypothesis: that more reliable methods would increase in relative use through time, fishers would prefer methods with more reliable catches, and fishers using more reliable methods would have a more positive perception of their method. Together, these sources of evidence indicated when or if RAT was sufficient to understand fishing decisions, when PT allowed for an improvement in that understanding, and potentially when neither provided insight. These supplemented the previous section by allowing greater understanding of the consistency of these two behavioural theories, including the one most often used in fishery models, with realized fishing behaviours. Addressing these three types of evidence required interview (page 24), catch (page 27), and weather data (page 34). Data collection for all these sources was addressed in the general methods section above (Chapter 2).

The first part of hypothesis 2 investigated how use of methods with different average profitabilities and reliabilities had changed from 2012 through 2018 using Bayesian generalized models. This part used catch data exclusively based on the calculated monetary and caloric values of catches, if a catch was sufficient for household consumption, and the coefficient of variation in catch from a method in a fishing centre in a month. All models were run in R studio using the brms library, as above. First, net monetary value of catch, CV of catch weight, and whether it was a sufficient catch were used as response variables. Net caloric value was highly correlated with net monetary value (cor= 0.97) in this data set, so only monetary value was used for the following analyses. These models allowed determination of which weather variables correlated with different catch characteristics so that these could be included in later models looking at how use had changed. It was likely that fishers were aware of how weather would affect their catch and that they adjusted their fishing behaviours based on weather cues (personal communication with fishers). Using generalized linear models allowed varied statistical distributions of the response variables. Monetary value had a hurdle-gamma distribution, CV of catch a Gaussian distribution, and if a sufficient catch a Bernoulli distribution. Two outliers in catch value of questionable validity were found during data exploration, and these samples were removed from all analyses. Numeric predictor variables were standardized using the scale function in R. Correlations between predictor variables were assessed using Mypairs as above. Predictor variables included weather variables of mean temperature, cloud cover, wind speed, and if a rainy day, season, and an interaction between year and fishing method. Fishing centre was included as a grouping variable, which functions similarly to a random variable in frequentist statistics. The expectation from later models was that the odds of using a method would increase with time if it had relatively high profitability or reliability. If the profitability or reliability of the catch characteristic were also changing, it could confound these results and, therefore, needed to be considered. The fishing centre could have been masking real correlations between fishing methods and catch characteristics because not all methods were used in all fishing centres. Therefore, models with and without fishing centre were compared using LOO comparisons in R. No other variables were dropped from the model following the recommendations of Zuur and Ieno (2016) that, in Bayesian analyses, there is no need to drop non-significant variables from a model to correctly interpret the effects of the other coefficients as long as the predictors are not correlated. Potential temporal autocorrelation was assessed using model residuals with the acf function in the stats library in R (R Core Team, 2020). If found, the model was rerun with an autoregressive correlation term, or a smoothed date term grouped by each fishing method when autoregressive correlations terms were computationally infeasible. Models were validated as above using R-hat, ESS, and posterior predictive plots.

To address whether fishers switched to fishing methods that were more profitable or reliable, the odds of using a method were modelled with net monetary value, catch CV, if the catch was sufficient, and year as predictors. Methods associated with more reliable catches, lower CV, were expected to increase in relative use through time. Weather and season predictor variables were only included in this model if they were significant for at least one of the catch characteristics models above. All numeric predictor variables were standardized using scale as above. Fishing method was a categorical variable, with handline fishing as the reference category because this was the most common fishing method and occurred in all fishing centres. As above, models with and without a grouping fishing centre variable were compared using LOO to determine ELPD in case the grouping variable was masking real correlations. Also, as above, R-hat, ESS, and posterior predictions were used to validate the model.

To address the second component of hypothesis 2 that fishers prefer methods which are more reliable or profitable required fisher interview and catch data. Fishers' preferred methods from interviews were analysed and their profitability and reliability from catch data were qualitatively compared with the percentage of the time they were chosen as preferred. Since preferred methods were given mean values, each method had one to three catch characteristic values based on the fishing centre in which it was mentioned. This precluded using a linear model to determine the relationship between average catch characteristic and the odds of choosing a method. It was possible that some fishers were more driven by economic profits and others, by catch reliability. To determine if fisher preferences for a profitable or reliable method were affected by their individual characteristics, a multivariate model was run using brm in package brms (Bürkner, 2017) with the average monetary value and CV of biomass of preferred method as the response variables. Predictors included fishers' years fishing, education, number of methods known, adaptation score, ecological knowledge score, wealth index, and gender. All variables were standardized using scale (R Core Team, 2020) and correlations addressed using Mypairs (Zuur *et. al.,* 2009) as above. Community was used as a grouping variable. Variables were added to the model one by one and only kept if they improved the model based on ELPD comparisons or if they had similar ELPD scores and the variable was significant in the model. Again, the final model was validated using R-hat, ESS, and posterior predictive plots. Lastly, fishers' reasons for preferring a method were qualitatively compared to the characteristics of their preferred method.

To address the final component of hypothesis 2 that fishers using more reliable or profitable methods had more positive opinions of their fishing method, fisher interviews and catch profitability or reliability, as calculated from the catch data, were used. Fishers' reasons for choosing a method were made ordinal such that responses like preference, profit, or reliability were considered positive; responses such as lack of knowledge or resources to switch were considered negative; and responses such as because it is individual, it is appropriate for women, or habit were considered neutral. An ordinal Bayesian model was used to determine the likelihood of a fisher giving a positive, neutral, or negative reason for their method based on catch and fisher characteristics. The adjacent category model distribution (acat) taken from Bürkner (2019) was used because it allowed for the predictors to affect the transition between levels differently, i.e., the change in the odds that a fisher gave a neutral to negative response did not have the be the same as the change in odds they gave a positive to neutral one. Predictors included mean catch monetary value and CV of catch. The odds that a catch was sufficient was negatively correlated with the CV of catch (cor=-0.76) and caloric value was still highly correlated with monetary value (cor=0.94) when data were grouped as mean values for a method/fishing community combination, so they were dropped from the model. Note, monetary value to owners was used for vessel owners, i.e., half of the total net profit from the trip, which was not used in any of the above analyses due to the small number of vessel owners around Pemba Bay. Standardized fisher characteristics such as education, years fishing, number of fishing methods known, ecological knowledge score, adaptation score, wealth index, and fishing centre as a grouping variable were added one by one and only kept in the final model if they improved the ELPD of the model based on LOO comparisons (Vehtari *et. al.,* 2017). Category specific variables were compared with general variables using LOO comparisons and only included as category specific if they improved the model. All variables were not included in the initial model due to the small sample size (n=140). As above models were validated using R-hat, bulk and tail ESS, and posterior predictive plots.

Results

Hypothesis 1: interview responses are consistent with RAT or other theories are more consistent with responses

This hypothesis addressed fishers' motivations for making fishing decisions and possible behavioural theories to understand those decisions based on those motivations. This section started with the types of responses given to questions on the condition of the fishery, reasons for fishing, and value given to the fishery. It then assessed the proportion of responses which were categorized as indicating the importance of seven properties of the fishery: profit, reliability, behavioural control, sustainability, social interactions, intrinsic value, and habit, for each question. Then the seven properties of the fishery were used to determine the consistency of the five behavioural theories with interview responses.

Condition of the fishery

The majority of fishers indicated that the fishery was in bad condition (75% of responses). Based on this low opinion of the condition of the fishery, most fishers seemed to be part of the fishery out of habit (70%). For example, one handline fisher from Ruela said, "Now the fishery is not good, not like before. Now there aren't fish and Tanzanians are fishing at night with lights. I fish out of habit and would stop fishing if there were other options." Reliability was indicated as an important aspect in determining the condition of the fishery for 34% of fishers, however most of this was indicated by the negative effects that lack of reliability was having on the condition (20%). For example, a gillnet fisher from Ruela observed, "[The fishery] is not good, sometimes I catch fish, sometimes not." Sixteen percent of fishers stated the importance of profit in determining the conditions of the fishery. A purse-seine fisher in Ruela commented, “Now the fishery is OK. There are not fish, but if you can catch fish, they are valuable. There used to be more fish but they were worth less.”

In total, 89% of fishers stated that the fishery was worse than when they started fishing. Most fishers said that catch had decreased. As a beach-seine fisher in Metuge put it, “now I don’t catch a lot of fish. When I started, I caught a lot of fish and there were lots of fish in the bay.” Most responses were attributed to a decline in the reliability of catch (93%); however, one could argue that this indicated decline in the profitability of catch, re-evaluating these responses as indicating the importance of profit did not change the overall conclusions below. Responses were only used as indicating a decline in profitability when money was mentioned. For example, a gillnet fisher in Ruela said, “When I started, [fishing] made money. I could fill two canoes. Now I only catch enough to eat.” Additionally, a few fishers mentioned that while catch amount has declined, the value of catch had increased which was assumed to indicate of the importance of profit in determining the condition of the fishery. Fifteen percent of responses indicated the importance of profit.

After reliability, comments about the change in the fishery indicated the importance of behavioural control (50%), habit (46%) and, mostly negative, social interactions (46%). In response to perceived declines in the fishery, most fishers adjusted their behaviours in ways they knew they could control, without changing their fishing methods. These adaptations demonstrated the importance of behavioural control in influencing how fishers interact with their fishery. The majority stated that they increased fishing effort in some way (44%), usually increased time. Although, one hand-spear fisher in Chuiba spread a local herb in the water near her home to feed the fish and “tempt them closer to shore”, showing some creativity in fishing responses. A large percentage (46%) of fishers said that despite the bad and worsening condition of the fishery, they continued to fish as before, which was attributed to habit. As a spear fisher in Ruela said, “When I started [fishing] there were fish in the sea. Now there aren’t and I just go out of stubbornness.” Many respondents attributed declines in the fishery to increased night fishing and fishing in general, this was categorized as a negative consequence of people adopting the practices of those around them, which indicated the importance of social interactions in causing fishing behaviours. As a spear fisher in Chuiba put it, “now all kids born go fishing.” This last comment also alluded to a lack of perceived control to realize other activities; however, the collective nature of the comment fits better with social controls than strictly behavioural ones.

Reasons for fishing

The majority of fishers (90%) stated that they fish because it was a behaviour they could control and they don’t have other options. As a trap fisher in Ruela put it, “I am a carpenter, but I can go months without selling anything, so I go out fishing out of necessity.” Many respondents also alluded to a social reason for being a fisher (16%) such as it being appropriate for them or following their families’ example. For a few respondents, being a fisher appeared to be an intrinsic part of their identity (5%). A dragnet fisher in Metuge commented, “it depends on what you are good at, and I learned to fish a long time ago.” Or as a gillnet fisher in Ruela said “It is what I have always done. God made me a fisher, and fishing is good.”

When it comes to reasons to use a particular method, behavioural control was still the predominant reason (60%). Eighteen percent of fishers indicated they used a method primarily out of habit. While 13% each ascribed the motivations to profit from the method and personal preference. Social expectations were mentioned by 9% of respondents. One young gillnet fisher mentioned “…the government prohibits spearguns and trap are for old men…”, as part of the reason he used a gillnet. This response indicated the importance of social perceptions on who should be using certain methods. Socially appropriate behaviours were also apparent in gender differences, with several women mentioning that they used mosquito nets and hand spears because they were appropriate for women. Only 5% of respondents suggested the importance of catch reliability in method choices. A purse-seine fisher in Ruela stated that he used purse-seine nets because they “…catch the small fish that come into the bay and it is always possible to fish in the bay, even when the weather is bad.”

Fishers indicated they prefer a method because of its perceived profitability most often (64%). Beyond profit, 29% of fishers suggested they preferred methods that allowed them increased control over their fishing activities, some indicating they would like methods which were independent and did not require a boss. Sixteen percent of fishers mentioned a preference for a method for intrinsic reasons. Generally, these fishers stated they were already using their preferred method. Nine percent of responses were attributed to being because of the reliability of the catch. However, fishers stating that they wanted a method because it caught a lot of fish could have been an indication of reliability or profitability. These responses were only counted as indicating reliability if they also mentioned some limitation of the catch, such as avoiding small fish, or specifically mention decreasing variation in catches.

Attitudes towards values of the fishery

Nearly all fishers said that the fishery was important for their survival and to feed their families (98%). The other 2% stated that due to the poor condition of the fishery it was no longer important. These responses indicated the importance of reliability of catch to fishers. Thirteen percent suggested that the fishery was also important for its profitability, either referring specifically to income from fishing or through related sources, such as tourism. Nine percent of fishers mentioned intrinsic value of marine ecosystems, indicating they enjoy being on the water or mentioning curative effects of salt water. Only two fishers mentioned the importance of the fishery for resources sustainability. A beach-seine fisher in Ruela said that the fishery was “the basis for my survival and a resource for future generations, if managed.”

In response to likes and dislikes about fishing beyond catching fish, only 34% of respondents noted other aspects of fishing. Of those who mentioned other likes or dislikes, 40% suggested an intrinsic appreciation of fishing. For example, a beach-seine fisher in Ruela described the excitement of seeing a fish in the net or feeling a fish on the line. Seventeen percent mentioned disliking the discomfort of fishing, such as the cold and stinging animals which was also seen as an intrinsic consideration. Seventeen percent also mentioned disliking the social imitation of some fishing methods, specifically night fishing. Thirteen percent indicated they do not like how unpredictable fishing can be indicating the importance of reliability, and 10% dislike that they felt limited options about how to fish due to lack of fishing materials, indicating lack of behavioural control.

In total, 45% of fishers answered the question about what might happen in the future. Of these, 8% predicted a positive change in the future, while the other 92% assumed things would get worse within the fishery. Seventy-five percent of responses were attributed to concerns about resource reliability. For example, a gillnet fisher in Chuiba posited, “In the ocean, there won’t be fish in the future, and I will have to go to different places to fish.” Responses to expected problems mostly focused on things that could increase the sustainability of the resource (69% of responses), often through social change (38% of responses). As a purse-seine fisher in Ruela mentioned, “Fish will disappear and there will be a lot of hunger and suffering because a lot of people depend on fishing. We need to find alternative ways of fishing that do not destroy the fishery.”

Some fishers focused more on expanding choices. Most commonly this was expressed as a desire for projects that would provide fishing materials. However, a handline fisher in Chuiba stated that “climate change, lack of fish, and more thieves will occur in the future [and that] young people need more opportunities to combat these problems.” The focus on opportunity rather than material resources was not common, but indicated that some fishers were thinking about change in broader terms. A gillnet fisher in Ruela commented, “I have hope to have good things in the future, like more schools and farms. To get this we need to convince the population to depend more on farms and send their kids to school.” This focus on education again echoed concern about opportunities beyond access to physical resources. A beach-seine fisher in Metuge stated the importance of “[getting] children used to different activities,” indicating the need for social change and education to improve the future.

Most responses from the questions about a perfect fishery related to behavioural control (53%). This was the most common response category partly because the catch motivations were divided between focus on maximizing catch and profit (46%), having high profits while limiting the catch in some way to increase reliability (24%), and limiting catch for sustainability with or without a focus on large catches (31%). For example, a trap fisher in Metuge defined a perfect fishery as, “…having recommended materials to catch big fish. But since there aren’t large fish, material to capture small fish to bring something home, is necessary.” This indicated the importance of behavioural control, desire for reliable catch, and desire for sustainability. It did not particularly indicate a desire for maximized profits because they stated that catch should actively exclude small fish even though, within the fishery, they had value. A gillnet fisher in Chuiba focused on having better methods to avoid catching small fish because, “…it hurts the fishery when you catch fish that are for tomorrow.” So, while more fishers indicated that maximizing catch was their main priority, a significant portion stated a willingness to limit that profit somewhat for the sake of fishery reliability and/or sustainability.

Only 66% of fishers gave at least one rule or norm for the fishery. Most common responses were rules that affect potential profits, specifically paying for fishing licenses to avoid fines (58%). Also important were rules targeted at increasing catch reliability and the sustainability of the fishery, e.g., limiting mosquito net fishing (51%). Twenty-two percent of respondents suggested that the rules and norms exist to control fishers, indicating some level of social control. However, knowing the rules did not mean they were internalized or obeyed. As one mosquito nets fisher said, “Don’t use mosquito nets [is a rule], but we insist because we don’t have other options and depend on the fishery for survival.”

Forty-five percent of interviewees gave an idea about possible fishery management options. Fishers mostly suggested temporary closures of part of the fishery and community reserves. These responses indicated a focus on community action (86%) and resource sustainability (77%). Some others focused on increasing the availability of gears to increase catches (9%). A few people also suggested alternative livelihood projects to decrease the communities' reliance on the fishery (6%).

Overall importance of the different factors

Different factors were important for describing different parts of the fishery. Reliability and habit were the factors most associated with the current condition of the fishery, being indicated in 64 and 58% of responses respectively. Reasons for making specific fishing decisions focused most on behavioural control, or lack thereof, with 60% or responses. The questions alluding to fishers' attitudes towards the value of the fishery indicated that reliability and sustainability of the fishery were important (45 and 42% of responses respectively). Social interactions appeared to be important to how fishers thought about the fishery (34% of responses), especially in the ways that they thought about dealing with current and future crises in the fishery (Table 3-2).

Table 3-2: The proportion of interviewees with responses which indicate the importance of the various concepts to their attitudes toward the fishery. Green cells indicate questions about the condition of the fishery. Yellow cells indicate questions about reasons for making fishing decisions, and purple cells indicate questions relating to attitudes about the value of the fishery. Darker bars indicate proportion of responses in each category.

Question	Profit	Reliability	Behavioral control	Sustainability	Social interactions	Intrinsic value	Habit	proprotion responded
Q01	0.18	0.34	0.11	0.08	0.06	0.04	0.70	0.99
Q02	0.15	0.93	0.50	0.21	0.50	0.05	0.46	0.96
condition	0.16	0.64	0.30	0.14	0.28	0.04	0.58	--
Q03	0.05	0.08	0.90	--	0.16	0.05	0.10	1.00
Q04	0.13	0.05	0.60	0.04	0.09	0.13	0.18	0.99
Q05	0.64	0.09	0.29	0.02	0.09	0.16	--	0.82
reason	0.27	0.07	0.60	0.03	0.12	0.12	0.14	--
Q06	0.13	0.98	0.00	0.02	0.05	0.09	--	0.87
Q07	0.02	0.15	0.15	0.15	0.19	0.56	--	0.34
Q08	0.23	0.75	0.34	0.69	0.38	0.05	--	0.45
Q09	0.46	0.24	0.53	0.41	0.31	0.09	--	0.97
Q10	0.58	0.51	0.07	0.51	0.22	0.06	--	0.66
Q11	0.09	0.09	0.06	0.77	0.86	0.09	--	0.45
values	0.25	0.45	0.19	0.42	0.34	0.16	--	--

Consistency of behavioural theories with fisher responses

Consistency of a behavioural theory was the percentage of questions for which a fisher gave importance to an aspect of the fishery which was consistent with the expectations of that behavioural theory, e.g., profit for rational actor theory. Overall, the theory of planned behaviour (TPB) was the most consistent with fisher responses (48%), however prospect theory was most consistent based on the condition of the fishery (62% of responses), and TPB was relatively inconsistent with responses from this category with only 44% of responses being consistent. If each category of questions was given equal weight despite being determined by a different number of questions, TPB was still the most consistent with responses overall. In terms of theories which most consistently explain the responses of an individual fisher, TPB was most consistent for 51% of fishers. Habitual behaviour was the most consistent theory for 36% of fishers with rational actor and prosect theory only being the most consistent for 8% and 4% of fishers respectively (Table 3-3). When determining if RAT was most consistent with a fisher's responses, all responses which could have indicated profit, even if generally considered a better fit for reliability, were categorizes as profit, meaning this was the maximum percentage of fishers for which RAT was the most consistent with responses.

Within TPB: behavioural control was indicated in 28% of responses, sustainability in 18% of responses, social interaction in 17% of responses, and intrinsic value/motivation in 8% of responses. This indicated that the dominance of TPB was determined most by perceived behavioural control, although the other factors were also important.

Table 3-3: The proportion of responses which are consistent with each behavioral theory based on all questions as well as for just the questions on condition of the fishery, reason for making fishing decisions, and attitudes towards the value of the fishery. The penultimate column gives proportion of responses consistent with each theory if each category is weighted evenly. The last column gives the proportion of fishers for which the theory is the most consistent with their responses.

Behavioural theory	Universal mean	Condition mean	Reason mean	Value mean	Equally weighted mean	Proportion of fishers
Rational actor	0.266	0.563	0.235	0.313	0.371	0.084
Prospect	0.298	0.615	0.065	0.167	0.282	0.042
Habitual	0.355	0.570	0.140	--	0.355	0.364
Descriptive norms	0.170	0.269	0.110	0.186	0.188	0.000
Planned behaviour	0.481	0.441	0.580	0.408	0.476	0.510

Fishers grouped by responses

There was a lot of overlap between different methods based on the initial NMDS of fisher responses, but some separation based on community and gender was apparent. The NMDS only required 2 axes to converge and had a non-metric R^2 of 0.93. The PERMANOVA showed that gender, method, and community were significant factors. The CAP showed differences between responses based on: gender, which led to the correct identification of 88% of respondents (p=0.001001, Appendix II, Figure II-1); community allowed 69% of respondents to be correctly identified, although this varied form 38% for Ruela to 85% for Chuiba (p=0.001001, Appendix II, Figure II-2); and fishing method led to 41% of respondents being correctly identified to their method, although the percent correctly identified was zero for purse-seine workers and trap fishers compared to 57 and 54% for handline and mosquito net fishers respectively (p=0.001001, Appendix II, Figure II-3). The gap statistic of the cluster analysis estimated seven groups in the data. Plotting these groups on the original NMDS indicated fairly good separation between groups, as expected (Figure 3-2). There were differences in fisher characteristics in the different cluster groups (Table 3-4), such as, all fishers in groups 6 and 7 were from Chuiba and all fishers in group 4 were from Bandar. Fishers from Ruela were spread fairly evenly between groups 1, 2, and 5. Fisherwomen were overrepresented in groups 3, 6, and 7. Vessel owners were overrepresented in groups 4 and 5. These groupings indicated that fisher group identity based on fishing method, gender, or community affected responses. But none of these classifications could be used to completely explain differences in interview responses.

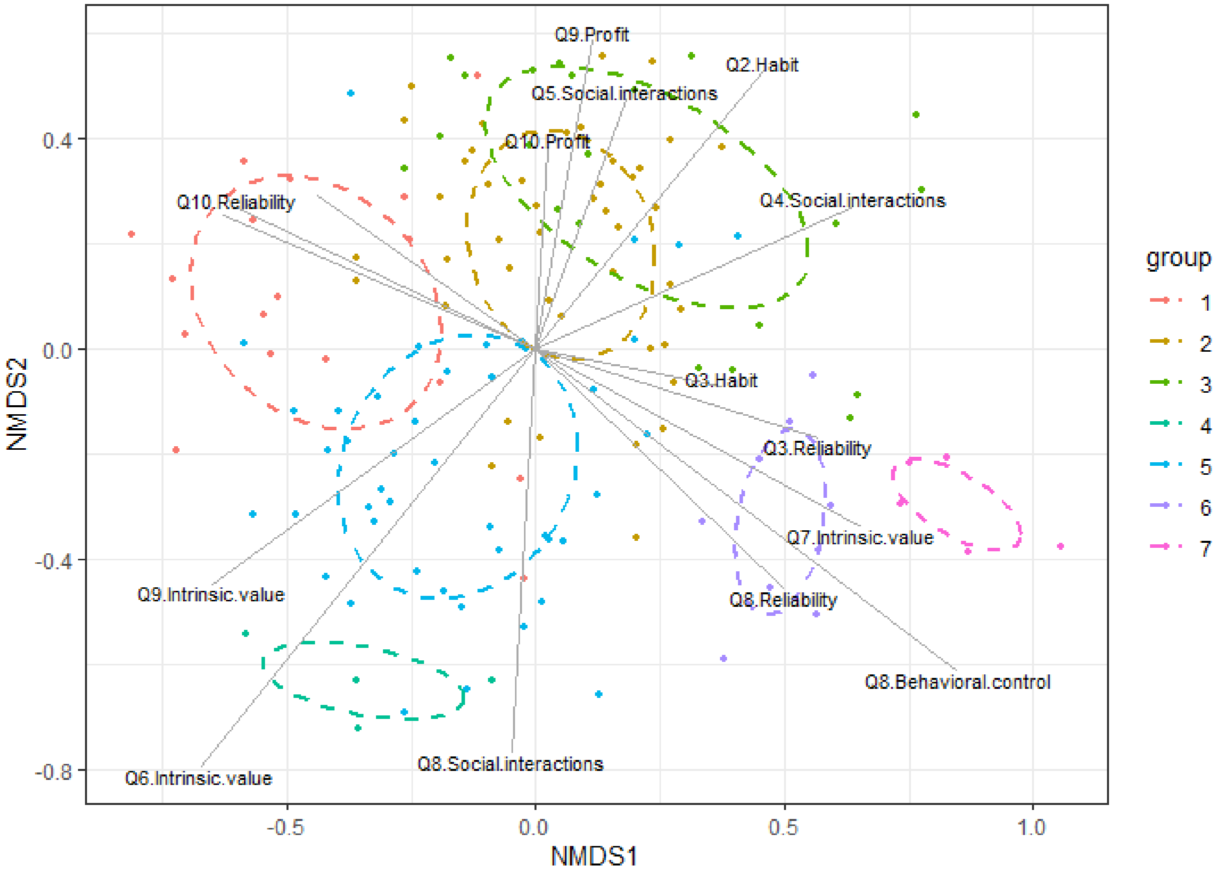

Figure 3-2: Interviewee locations on the first two NMDS axes based on fisher responses grouped by the optimal number of groups from the cluster analysis. Ellipses are based on covariance within groups.

Table 3-4: The proportional representation of the different communities (blue), women (yellow), and fishing methods (green) within each cluster group as well as mean consistency (±SE) of responses with the behavioral theories (salmon). Darker colors indicate that the characteristic is over represented in the cluster group compared to the global mean. Note that in the last group none of the behavioral theories are very consistent with responses, this indicates that many questions were not answered.

Cluster group	Ruela	Chuiba	Bandar	female	gill	hand	mos. net	other. own	purse	purse. own	spear	trap	RAT	PT	HB	DN	TPB
1	0.29	0.35	0.35	0.18	0.18	0.24	0.18	0.06	0.12	0.00	0.24	0.00	0.24 ± .03	0.36 ± .02	0.28 ± .08	0.12 ± .02	0.44 ± .03
2	0.39	0.43	0.18	0.07	0.27	0.32	0.07	0.02	0.07	0.05	0.11	0.09	0.26 ± .01	0.24 ± .01	0.43 ± .03	0.13 ± .01	0.42 ± .03
3	0.05	0.81	0.14	0.57	0.05	0.10	0.57	0.00	0.05	0.00	0.19	0.05	0.11 ± .02	0.31 ± .02	0.48 ± .02	0.12 ± .02	0.40 ± .02
4	0.00	0.00	1.00	0.00	0.50	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.32 ± .09	0.23 ± .50	0.00	0.32 ± .06	0.73 ± 04
5	0.40	0.12	0.49	0.05	0.16	0.35	0.05	0.14	0.00	0.12	0.14	0.05	0.19 ± .02	0.37 ± .02	0.26 ± .03	0.27 ± .02	0.59 ± .02
6	0.00	1.00	0.00	0.33	0.00	0.22	0.44	0.00	0.00	0.00	0.33	0.00	0.06 ± .03	0.24 ± .03	0.44 ± .12	0.11 +.03	0.45 ± .04
7	0.00	1.00	0.00	0.80	0.00	0.00	0.80	0.00	0.00	0.00	0.20	0.00	0.00	0.09 ± .00	0.35 ± .06	0.02 ± .02	0.4 ± .04
Total	0.28	0.43	0.29	0.19	0.17	0.26	0.20	0.07	0.04	0.05	0.16	0.05	0.19 ± .01	0.3 ± .01	0.35 ± .02	0.17 ± .01	0.48 ± .01

Bayesian models of proportion of questions consistent with each theory for each fisher were run using a single categorical fisher variable: gender, community, fishing method, or cluster group, grouped by behavioural theory. These models indicated that cluster group best explained differences in proportional support for the different theories. It had the highest ELPD, however, the model with community was barely significantly different than this model (ΔELPD= -38.6, SE=37.1). A model with both community and cluster group was therefore run. This model had the highest ELPD, although not significantly different from the model with only cluster group (ΔELPD= 5.5, SE=9.6). Compared to the model using just group, the additive model of fisher gender, community, and fishing method was significantly worse (ΔELPD= -49.0, SE=28.5). Adding individual fisher's adaptation score to the model using cluster groups and community increased the ELPD (ΔELPD= 42.4, SE=14.1), no other fisher characteristics did. The grouped density overlay plots do not show a great fit when grouped by community, cluster group, or behavioural theory (Appendix II, Figure II-4). However, the empirical cumulative distribution function plots show fairly good fits (Appendix II, Figure II-5). Mean support for the different groups showed good fit for some groups, but less so for others (Appendix II, Figure II-6). Specifically, the model overestimated the proportion of fishers' responses which were consistent with prospect theory by about the same amount as it underestimated the consistency with habitual behaviour. Overall, the model predicted that TPB was most consistent with responses for all groups (Figure 3-3). The relative consistency with the other behavioural theories varied based on cluster group. There were also some differences between consistencies with behavioural theories based on community. TPB was highest in all communities, but RAT, in particular, was more consistent with responses in Ruela than the other communities. Finally, as adaptation scores increased responses became less consistent with HB. Looking at the means and standard errors in consistency with the five behavioural theories from different clusters (Table 3-4) confirms the patterns seen in Figure 3-3.

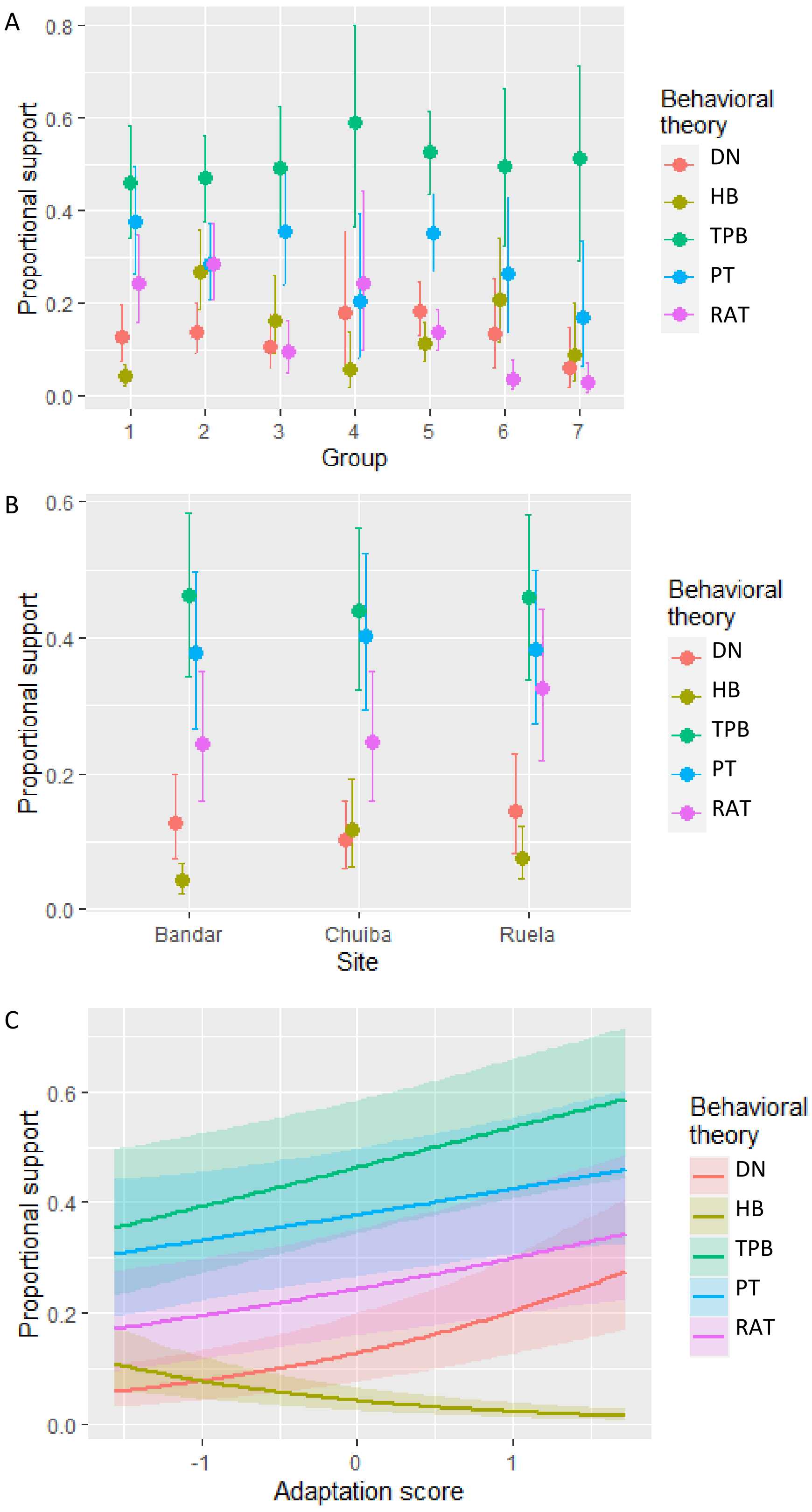

Figure 3-3: The conditional effect of Cluster group (A), community (B), and adaptation score (C) on proportion of responses consistent with different behavioural theories based on the Bayesian model.

Hypothesis 2: Prospect theory explains current fishing behaviours better than rational actor theory

Recent catch characteristics and fishers' opinions about methods with different mean catch values and reliabilities were analysed to address the consistency of PT or RAT in explaining recent fishing decisions. A preference for catch reliability when it came at the expense of catch value could be explained by PT, but would run counter to RAT. Fishing methods which were more reliable, were expected to increase in relative use through time and be preferred by fishers, and fishers using more reliable methods were expected to have more positive opinions of their methods. This section addressed how the feedback between the outcomes from fishing method choice, based on the average profitability and reliability of the catch, affected fishers' subsequent choices of fishing methods.

Catch characteristics

In general, there were differences in catch per unit effort (CPUE) between methods no matter what is used to measure catch. Calculating catch per fisher as weight in kilograms, monetary value in meticais, or caloric value in kilocalories resulted in highly correlated catch variables (cor>0.9 for all comparisons). Using monetary value, handline fishing was the most profitable on average (mean 1,888 meticais/person/trip ± 2,844, about 31 USD) and beach-seine fishing was the least profitable (mean 143 meticais/person/trip ± 215, about 2.30 USD), variability was standard deviation. Gillnet fishing was the second most profitable on average (1,704 meticais/person/trip ± 2,091, about 28 USD). The difference between gillnet and handline value per fisher was significant based on a student t-test (t=2.6723, df=4,193.2, p=0.0076). However, in Metuge handline fishing catches had lower average value than gillnet fishing, spearfishing, or trap fishing and in Maringanha, with habitat closest to Chuiba, trap fishing was the most profitable followed by handline fishing (Table 3-5). Part of the reason for these differences in the profitability of handline fishing may have had to do with access to the potentially more profitable deep-water channel. It also might have been caused by fishers taking their catch to Ruela for the higher prices when they made a large catch (personal communication with fishers). Purse-seine vessel owners on average made 13,980 meticais/trip ± 15,938, about 233 USD, while beach-seine vessel owners only made 1,426 meticais/trip ± 1,882, about 24 USD.

If caloric value rather than monetary value was used to determine catch, the relative value of methods did not change, however, if weight in kg per fisher was used, gillnet fishing made the largest catches overall. As this did not equate to larger amounts of useable food nor money, this study considered it a worse indication of the value of the catch than using monetary or caloric value.

The coefficient of variation in catch based on fishing centre and month showed that spear fishing was the least variable, with median CV of 0.39 and handline and beach-seine fishing the most variable with a median CV of 0.88 and 0.84 respectively. All methods were likely to make a sufficient catch for family consumption except beach-seine fishing (proportion sufficient=0.16). Spearfishing catches were the most likely to be sufficient (88% of trips), but all other methods had more than 75% of catches sufficient for family consumption based on fishery data. However, if fishers did not make a catch or made very little catch, they were likely to spend little time at the landing site and therefore were less likely to be sampled.

Table 3-5: Mean and standard deviation of monetary value of catch per fisher per trip based on fishing method and landing site. All landing sites can be accessed from any community, but this requires more effort if not living in that community.

Method	Maringanha	Metuge	Muxara	Ruela	Wimbe	Total
Beach-seine	NA	130.76 +/- 225.75	149.01 +/- 144.93	113.83 +/- 320.08	404.16 +/- 479.82	143.29 +/- 215.29
Gillnet	668.25 +/- 665.05	1187.99 +/- 1077.64	391.91 +/- 425.38	2753.39 +/- 2436.68	370.10 +/- 364.33	1704.28 +/- 2091.44
Handline	820.10 +/- 789.59	738.32 +/- 1320.02	699.53 +/- 1461.66	3660.37 +/- 3757.46	1426.02 +/- 2112.00	1887.8 +/- 2844.46
Purse-seine	NA	NA	520.83 +/- NA	901.05 +/- 1234.27	NA	900.81 +/- 1233.92
Spear	537.70 +/- 310.36	1135.73 +/- 1658.90	729.99 +/- 727.90	1122.00 +/- 689.08	500.20 +/- 422.18	607.83 +/- 623.84
Trap	1147.43 +/- 560.13	812.69 +/- 715.08	288.33 +/- 143.67	925.68 +/- 1001.91	3005.08 +/- 1530.58	979.30 +/- 975.28

Changes in catch characteristics

Models of catch characteristics were used to determine which confounding weather variables correlated with catch characteristics. These were included as possible influences on the odds of using a method on a particular day in the next section. These models also allowed understanding of how catch characteristics were changing through time for the different methods. Changes in catch characteristics through time needed to be considered when analysing changes in the odds of using a method below. If a characteristic was changing, there was a possible confounding effect on changes in relative method use.

All the models of catch characteristics were significantly better with the random fishing centre effect than without it (e.g., for the monetary value model without a fishing centre variable ΔELPD = -1,683, SE = 72.1), therefore only results from the models with fishing centre were presented below. The final model of monetary value was an ok fit for the data (Appendix II, Figure II-7), but failed to capture all the variation in value for some methods. The models of catch CV and odds of making a sufficient catch showed good fit with the data (Appendix II, Figure II-7). Note the CV model has year/month as a grouping variable as all trips within a month, method, landing site group had the same CV. Catch caloric value was highly correlated with monetary value (cor=0.97), so caloric value was not used in any of the following models.

The model of monetary value showed correlations with fishing method, being highest for handline fishing and lowest for beach-seine and purse-seine fishing (Appendix II, Table II-1 and Figure 3-4 A). The model indicated that being a purse-seine fisher was worse than the mean value per fisher would suggest. This was because purse-seine fishing only occurred in Ruela, where most methods had higher than average catch values compared to other landing sites. Therefore, compared to the high catch values possible in Ruela, purse-seine fishing had a very negative effect even though the actual income was significantly higher than for beach-seine fishing. Monetary value of catches had increased over time for gillnet, spear, and trap fishing and decreased nearly significantly for handline catches based on combined year and method specific year effects, i.e., the negative effects of year on handline and purse-seine catch value cancelled out the overall positive effect of year (Figure 3-4 B). Value to vessel owners was not included in the models of catch value because few fishers around Pemba Bay were vessel owners, and purse-seine vessel owner mean profit was more than seven times higher than handline profits, the next highest. Based on the difference in catch values and vessel owner estimates of costs of purchasing vessel and gear (about 500,000 meticais, 8,300 USD), after 50 fishing days, being a purse-seine owner should become the most profitable choice assuming no other essential maintenance nor interest payments.

CV of biomass also showed differences between fishing methods, with spearfishing, purse-seine, and gillnet fishing having the lowest CV measures and beach-seine and handline fishing the highest (Appendix II, Table II-2 and Figure 3-4 C). Year had a positive correlation with CV for beach-seine, gillnet, purse-seine, and spearfishing, and a negative correlation with handline and trap fishing CVs (Figure 3-4 D). Finally, the probability that a catch was sufficient, at least 1.75kg per fisher, was highest for purse-seine catches and lowest for beach-seine catches (Appendix II, Table II-3 and Figure 3-4 E). For purse-seine and spearfishing catches, year had a negative effect on the probability that a catch was sufficient, the effect was positive for trap fishing (Figure 3-4 F). From the three models of catch characteristics, cloud cover and average temperature were significant predictors of at least one of the characteristics (Appendix II, Tables II-1 to II-3), so these variables were included in the model of the odds of using a method below. Fishers may have used these weather signals in deciding which method to use on a given day, so they needed to be included in the model on the odds of using a method. Surprisingly, season did not affect any of the calculated catch characteristics.

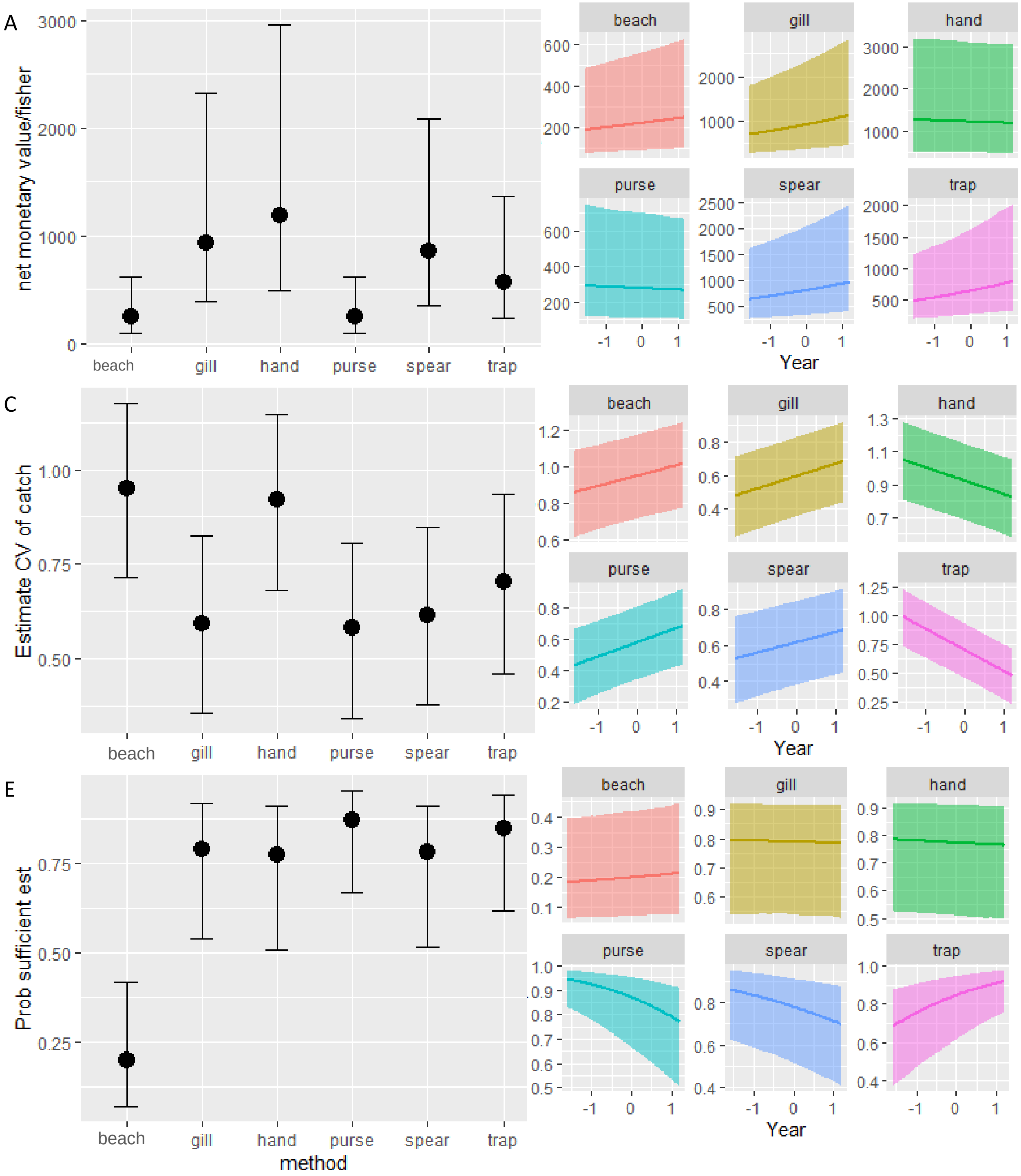

Figure 3-4: The conditional effect of fishing method (A, C, and E) and year by method (B, D, and F) on the model of net monetary value of catch per fisher (A and B), CV of catch weight (C and D), and probability that a catch is sufficient (E and F).

Changes in relative use of fishing methods

In all the data, handline fishing was the most commonly used method, comprising 39.5% of trips. Gillnet fishing and purse-seine fishing were also widely used, accounting for 17% and 16.2% of fishing trips respectively. Beach-seine fishing represented 13.9% of fishing trips. Trap and spearfishing represented a fairly small percentage of fishing trips from the data (4.3 and 9.1% respectively).

The model of odds that a fishing trip used a particular fishing method showed a good fit to the data (Appendix II, Figure II-8). A catch being sufficient increased the probability that the trip was using purse-seine nets or traps and decreased the probability that it was using beach-seine nets (Table 3-6 and 3-7 and Figure 3-5 A). Increasing monetary values increased the odds that the fishing trip was using handlines compared to all other fishing methods (Table 3-6 and Figure 3-5 C). Having a low CV of catch increased the odds that a fishing trip was using gillnets, spears, or traps (Figure 3-5 D). Gillnet, spear, and trap fishing also increased in relative use through time compared to handline, purse-seine, and beach-seine fishing (Table 3-7 and Figure 3-5 B).

When comparing each fishing method to all others, methods which were increasing in relative use were associated with lower CVs and often, but not always, higher monetary values. Because the model used standardized predictors, the importance of each coefficient in determining the odds of being from a specific method's catch could be compared. The largest effects were monetary value almost two-thirds of the time, sufficient catch was most important the other third, and CV was the most important variable only in differentiating between handline and gillnet catches (Table 3-7). When the coefficients for CV and monetary value were both significant, they were usually in the same direction, indicating that for these comparisons more profitable methods were less reliable. The exception was beach-seine catches which were both less profitable and less reliable than most other methods (Table 3-7 and Figure 3-5 C and D). So, while monetary value was important in distinguishing between methods, it did not necessarily indicate that the method with the higher value was increasing in use.

Table 3-6: The coefficient of predictor variables on the odds of a fishing trip using a particular method compared to the base group which is set to handline fishing. All variables are standardized.

Variable	Estimate	l-95% CI	u-95% CI	sig
Beach Intercept	-2.58	-6.01	1.16	
Gill Intercept	-1.18	-2.41	0.18	
Purse Intercept	-6.89	-13.9	-0.69	*
Spear Intercept	-2.66	-4.02	-1.04	*
Trap Intercept	-4.00	-5.72	-1.85	*
Beach cloud cover	0.05	-0.03	0.13	
Beach ave. temperature	0.09	0.02	0.17	*
Beach sufficient	-1.39	-1.64	-1.12	*
Beach Year	-0.05	-0.14	0.04	
Beach monetary value	-4.57	-5.71	-3.54	*
Beach CV of catch	-0.34	-0.42	-0.27	*
Gill cloud cover	0.05	-0.02	0.11	
Gill ave. temperature	0.00	-0.07	0.06	
Gill sufficient	0.09	-0.08	0.27	
Gill Year	0.14	0.07	0.20	*
Gill monetary value	-0.28	-0.35	-0.21	*
Gill CV of catch	-0.87	-0.95	-0.79	*
Purse cloud cover	0.09	0.00	0.17	.
Purse ave. temperature	0.15	0.07	0.24	*
Purse sufficient	1.95	1.72	2.17	*
Purse Year	0.02	-0.06	0.10	
Purse monetary value	-2.13	-2.30	-1.97	*
Purse CV of catch	-0.79	-0.90	-0.70	*
Spear cloud cover	0.09	-0.01	0.18	
Spear ave. temperature	0.07	-0.01	0.16	
Spear sufficient	0.24	-0.04	0.52	
Spear Year	0.14	0.04	0.23	*
Spear monetary value	-1.32	-1.76	-0.90	*
Spear CV of catch	-0.95	-1.08	-0.82	*
Trap cloud cover	0.15	0.04	0.25	*
Trap ave. temperature	0.09	-0.02	0.20	
Trap sufficient	1.35	1.03	1.69	*
Trap Year	0.06	-0.04	0.17	
Trap monetary value	-1.55	-1.78	-1.33	*
Trap CV of catch	-0.80	-0.95	-0.65	*

Table 3-7: Model coefficients from the categorical model of relative method use comparing each method to all others. The coefficients indicate how the odds of using the method in the row change in comparison to the method from the column with changes in the variable, i.e., positive values indicate that the method in the row increases in probability. Coefficients are calculated as the difference between the coefficient for the column method and the row method. Confidence intervals are 1.96 multiplied by the standard error of the difference variable. Asterisks indicate 95% confidence intervals that do not overlap zero.

		handline				beach-seine				gillnet				purse-seine				spear			
	Variable	Est.	l-95% CI	u-95% CI	sig	Est.	l-95% CI	u-95% CI	sig	Est.	l-95% CI	u-95% CI	sig	Est.	l-95% CI	u-95% CI	sig	Est.	l-95% CI	u-95% CI	sig
beach-seine	sufficient	-1.39	-1.64	-1.12	*																
	year	-0.05	-0.14	0.04																	
	monetary value	-4.57	-5.71	-3.54	*																
	CV of catch	-0.34	-0.42	-0.27	*																
gillnet	sufficient	0.09	-0.08	0.27		1.48	1.17	1.79	*												
	year	0.14	0.07	0.20	*	0.19	0.09	0.29	*												
	monetary value	-0.28	-0.35	-0.21	*	4.29	3.21	5.37	*												
	CV of catch	-0.87	-0.95	-0.79	*	-0.53	-0.64	-0.42	*												
purse-seine	sufficient	1.95	1.72	2.17	*	3.34	2.99	3.69	*	1.86	1.57	2.15	*								
	year	0.02	-0.06	0.10		0.07	-0.04	0.18		-0.12	-0.22	-0.02	*								
	monetary value	-2.13	-2.3	-1.97	*	2.44	1.35	3.53	*	-1.85	-2.03	-1.67	*								
	CV of catch	-0.79	-0.9	-0.7	*	-0.45	-0.58	-0.32	*	0.08	-0.05	0.21									
spear	sufficient	0.24	-0.04	0.52		1.63	1.26	2.00	*	0.15	-0.18	0.48		-1.71	-2.07	-1.35	*				
	year	0.14	0.04	0.23	*	0.19	0.06	0.32	*	0.00	-0.11	0.11		0.12	-0.01	0.25					
	monetary value	-1.32	-1.76	-0.9	*	3.25	2.09	4.41	*	-1.04	-1.48	-0.60	*	0.81	0.35	1.27	*				
	CV of catch	-0.95	-1.08	-0.82	*	-0.61	-0.77	-0.45	*	-0.08	-0.24	0.08		-0.16	-0.33	0.01					
trap	sufficient	1.35	1.03	1.69	*	2.74	2.32	3.16	*	1.26	0.88	1.64	*	-0.6	-1.01	-0.19	*	1.11	0.68	1.54	*
	year	0.06	-0.04	0.17		0.11	-0.02	0.24		-0.08	-0.19	0.03		0.04	-0.09	0.17		-0.08	-0.22	0.06	
	monetary value	-1.55	-1.78	-1.33	*	3.02	1.92	4.12	*	-1.27	-1.52	-1.02	*	0.58	0.30	0.86	*	-0.23	-0.72	0.26	
	CV of catch	-0.8	-0.95	-0.65	*	-0.46	-0.64	-0.28	*	0.07	-0.11	0.25		-0.01	-0.19	0.17		0.15	-0.06	0.36	

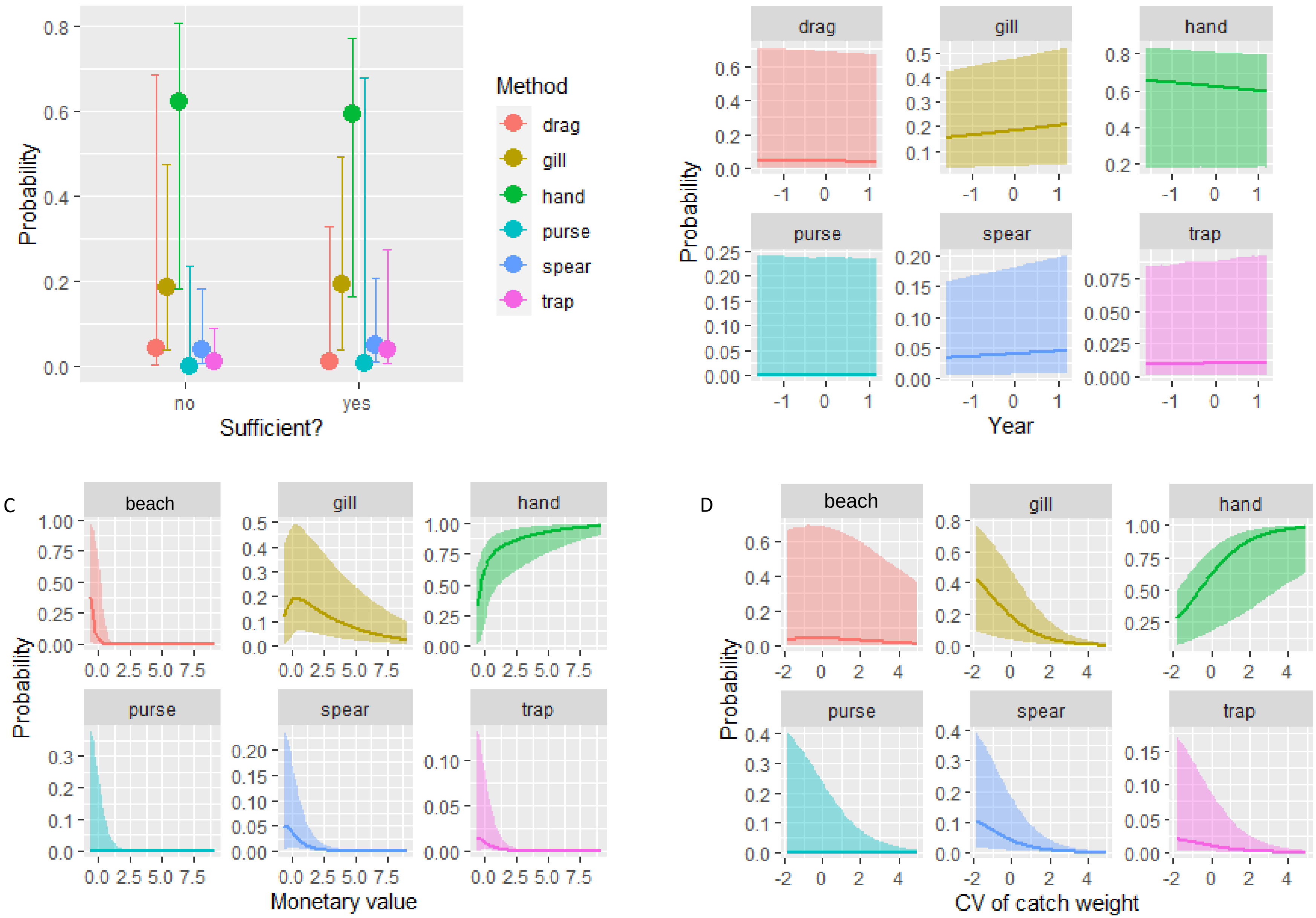

Figure 3-5: The conditional effects of whether a catch was sufficient (A), standardized year (B), standardized monetary value (C), and standardized CV of catch weight (D) on the odds that a fishing trip used a particular method. Note the different y axis scales for the different methods.

Preferred fishing methods

Changes in relative use of different methods could have been caused by factors other than fisher preference. To address this possibility, the characteristics of fishing methods which were stated as preferred were qualitatively compared. Of the 118 fishers who responded to the question on which method they would prefer to use, 36% said they would continue using the same method they currently use. The most common preferred method was gillnet fishing, with a total of 39% of respondents when including gillnet fishers who would not switch. The least common response was to prefer to be a purse-seine vessel owner. Only 3 respondents wanted to switch to this method, but half the current owners preferred not to switch. Being a purse-seine vessel owner was by far the most profitable method on average, however, all the excess profits were expected to go to paying off the vessel and gear for at least the first 50 fishing trips without accounting for interest payments for loans, or maintenance. Handline fishing, which was associated with the highest monetary values after being a purse-seine vessel owner, accounted for 17% of fisher stated preferred methods (Table 3-8).

Table 3-8: Percentage of fishers who stated a preference for each method in interviews based on their community, this includes the 36% of fishers who said they would not change methods.

Preferred method	Chuiba	Metuge	Ruela	Total
Beach	17.5	19.5	8.1	15.3
Gill	42.5	46.3	27.0	39.0
Hand	12.5	12.2	27.0	16.9
Purse	0.0	4.9	32.4	11.9
Purse owner	0.0	4.9	2.7	2.5
Spear	17.5	7.3	0.0	8.5
Trap	10.0	4.9	2.7	5.9
N	40	41	37	118

There were differences in preferred methods based on fishing centre. In Ruela, where purse-seine fishing occurs, most fisher (32%) preferred purse-seine fishing, followed by handline and gillnet fishing being preferred equally (27%). The most common reason given for choosing a method that was different from the current method was because it catches a lot of fish: 60% of responses, 80% of reasons for switching to gillnet fishing, 87.5% of reasons to switch to beach-seine fishing, and 57% of reasons to switch to purse-seine fishing. The second most common reason was to catch more valuable or larger fish, 15% of responses and 100% of the reason for fishers to switch to spearfishing. Other reasons included: to do something different, because it was individual or because it was in a group, and because a method was seen as easy to use.

Using individual fisher characteristics to explain differences in preferred method showed some correlations. The best categorical model to explain the odds that a fisher gives a particular method as preferred included fishing centre as a grouping variable and gender, ecological knowledge score, and number of methods known (Table 3-9). Most model runs fitted the data well, but some runs do not (Appendix II, Figure II-9). Women were more likely to say they would prefer to use beach-seine nets than men (Figure 3-6 A). Ecological knowledge scores were positively correlated with the odds of preferring gillnet fishing and negatively correlated with the probability of preferring beach-seine fishing (Figure 3-6 B). The opposite occurred with number of methods known, increased number of methods known increased the odds of preferring beach-seine fishing and decreases the odds of preferring gillnet fishing (Figure 3-6 C).

Table 3-9: Model coefficients from the categorical model on preferred method. * Indicates 95% confidence intervals which do not include zero.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Gill Intercept	-2.12	1.01	-4.34	-0.36	*
Hand Intercept	-1.89	1.25	-4.49	0.54	
Purse.owner Intercept	-27.65	33.86	-94.98	-5.19	*
Purse Intercept	-24.16	20.83	-80.49	-2.88	*
Spear Intercept	-2.99	1.65	-6.52	-0.05	*
Trap Intercept	-25.19	31.8	-91.76	-3.41	*
Gill male	4.12	1.05	2.15	6.34	*
Gill ecological know	1.03	0.42	0.23	1.88	*
Gill # methods known	-1.34	0.45	-2.24	-0.48	*
Hand male	2.91	1.25	0.58	5.47	*
Hand ecological know	0.51	0.45	-0.37	1.40	
Hand # methods known	-0.61	0.47	-1.55	0.28	
Purse.owner male	25.23	33.84	2.91	92.31	*
Purse.owner ecological know	2.44	0.92	0.76	4.38	*
Purse.owner # methods known	-2.79	1.10	-5.25	-0.94	*
Purse male	24.65	21.25	2.87	81.52	*
Purse ecological know	1.28	0.51	0.30	2.30	*
Purse # methods known	-1.13	0.54	-2.21	-0.10	*
Spear male	2.74	1.32	0.28	5.45	*
Spear ecological know	0.66	0.55	-0.42	1.77	
Spear # methods known	-0.55	0.57	-1.68	0.58	
Trap male	25.45	31.88	3.43	91.93	*
Trap ecological know	0.33	0.57	-0.80	1.42	
Trap # methods known	-0.69	0.60	-1.87	0.47	

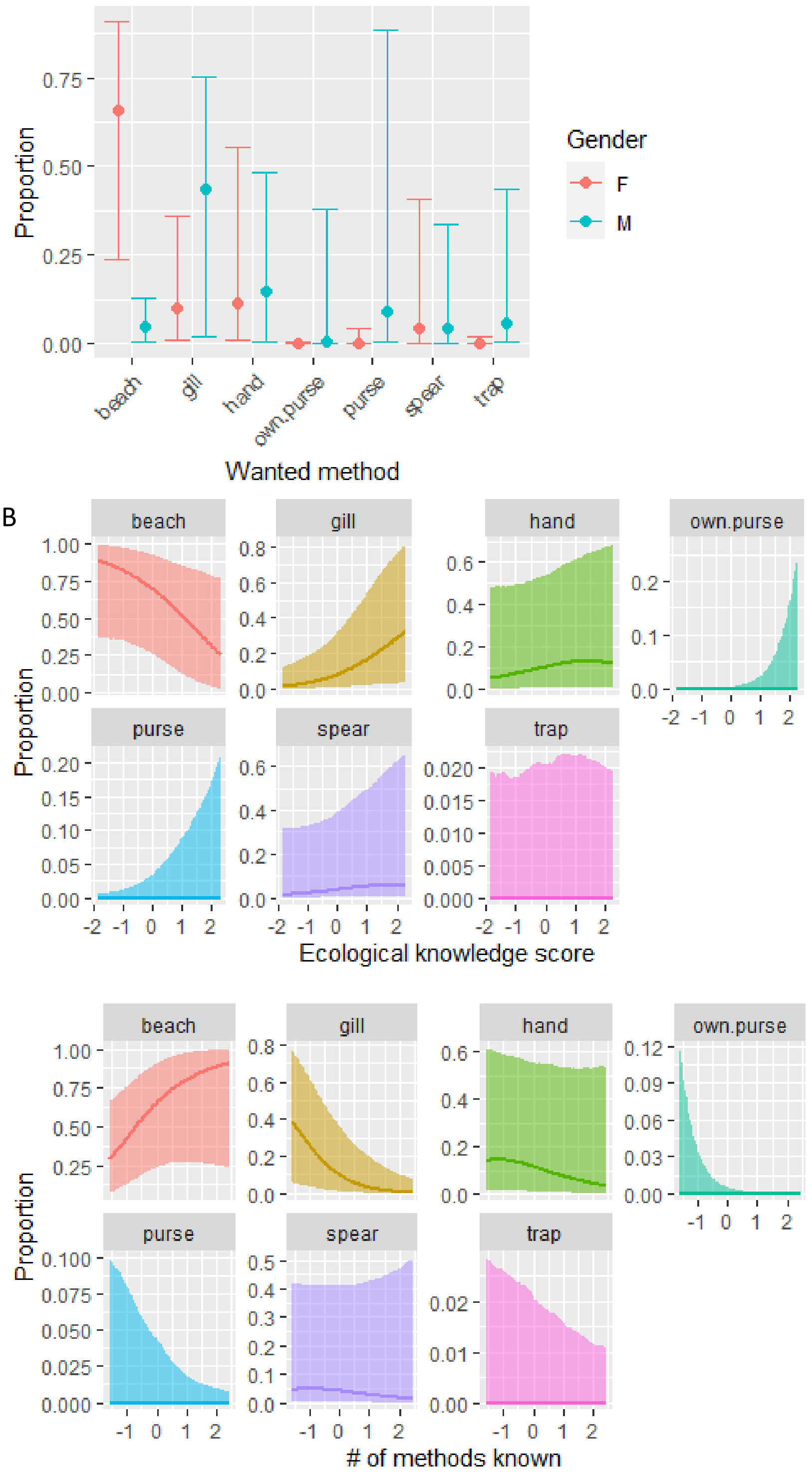

Figure 3-6: The conditional effect of gender (A), ecological knowledge score (B), and number of methods known (C) on preferred method. Note the different y axis scales in B and C.

The model using fisher characteristics to explain the monetary value and CV of catch weight of preferred methods did not fit the data well based on posterior prediction plots, but its plots show that mean and standard deviation values from the models surround the data values well (Appendix II, Figure II-10). Caloric value was highly correlated with monetary value in these data (cor=0.99) and proportion of catches which were sufficient for family consumption was negatively correlated with CV of catch (cor= -0.78). Ecological knowledge score and education were both positively correlated with the average monetary value of fishers' preferred methods (Table 3-10 and Figure 3-7).

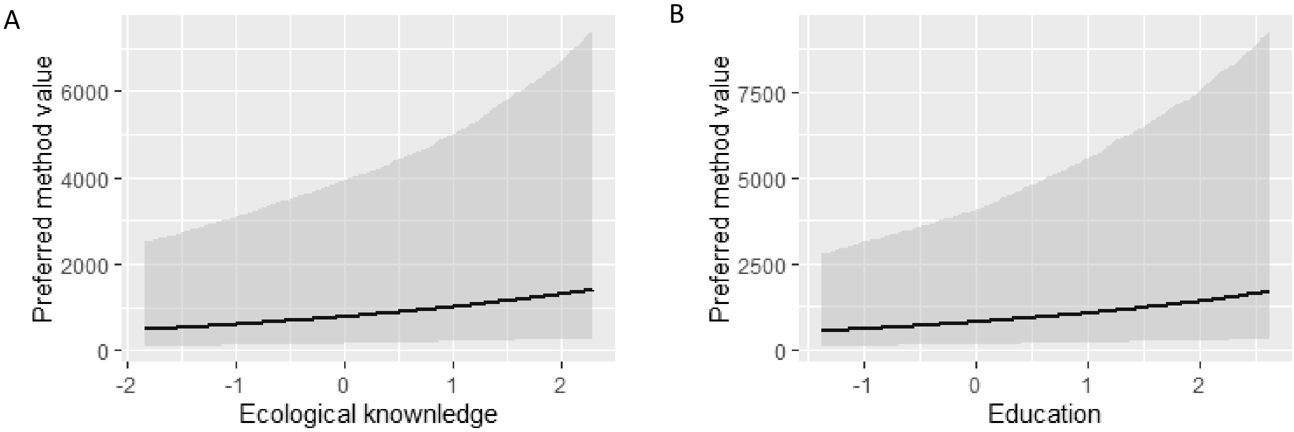

Figure 3-7: Conditional effects of standardized ecological knowledge scores (A) and standardized education (B) on the average monetary value of fishers preferred methods.

Gender was the only variable with a significant effect on CV of catch with men preferring methods which were more reliable (Table 3-10 and Figure 3-8). However, these gender differences in CV of preferred method were entirely created by women in Chuiba choosing mosquito nets despite their low reliability. Many of these women mentioned using mosquito nets because they were appropriate for women, indicating a possible cultural reason for this relationship.

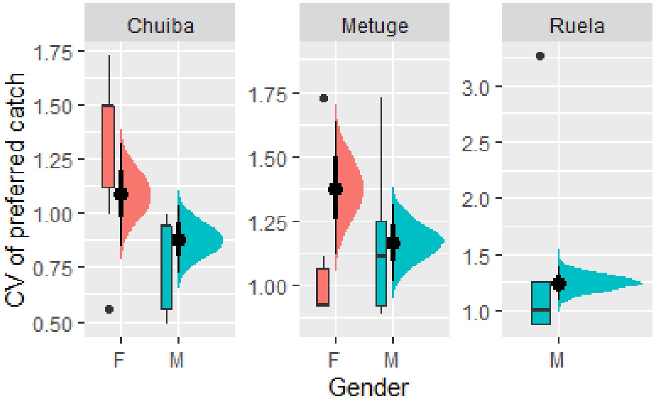

Figure 3-8: Model estimates (half-eye plots) and data (boxplots) of CV of preferred method catch weight based on gender and fishing centre.

Table 3-10: Model coefficients from the multivariate model of preferred fishing method characteristics explained by fisher characteristics. * Indicate 95% confidence intervals which do not overlay zero. The first part of the "response predictor variables" indicates the response and the second part the predictor.

Response predictor variables	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Monetary value: Intercept	6.65	0.79	5.02	8.27	*
CVcatch: Intercept	1.25	0.34	0.60	1.97	*
Monetary value: ecological knowledge	0.26	0.10	0.06	0.46	*
Monetary value: education	0.28	0.10	0.08	0.47	*
Monetary value: male	0.55	0.29	-0.02	1.10	
CVcatch: ecological knowledge	-0.02	0.03	-0.08	0.03	
CVcatch: education	-0.04	0.03	-0.10	0.01	
CVcatch: male	-0.23	0.08	-0.38	-0.08	*

Opinions of fishing methods

Finally, to understand the Pemba fishery SES, it was essential to understand fishers' motivations for fishing. Their opinions on different fishing methods combined with the characteristics of these methods alluded to these motivations. This section assessed fishers' attitudes towards different methods and stated preferences. Of the 140 fishers who answered the question on why they used a particular method, 29% gave a positive reason, 27% a neutral one, and 44% a negative reason. The model of responses to why fishers used particular methods fitted the data fairly well (Appendix II, Figure II-11. Both average monetary value and CV of catch showed positive correlations with the odds of giving a neutral reason for a method but negative correlations with the odds of giving a negative or positive reason (Table 3-11 and Figure 3-9 A and B). Positive reasons for the method were expected to be positively correlated with average value and negatively correlated with catch CV and negative responses to have the opposite correlations, so neither variable behaved as expected. Fisher attributes which should allow them more fishing choices were associated with more positive reasons for their methods. Fishers with higher wealth indices, more education, who had been fishing longer, and knew more methods were more likely to give positive reasons for their methods (Table 3-11 and Figure 3-9 C through F). Adaptation score was positively correlated with giving a positive reason for the method, but more strongly positively correlated with giving a negative reason for the method (Figure 3-9 G).

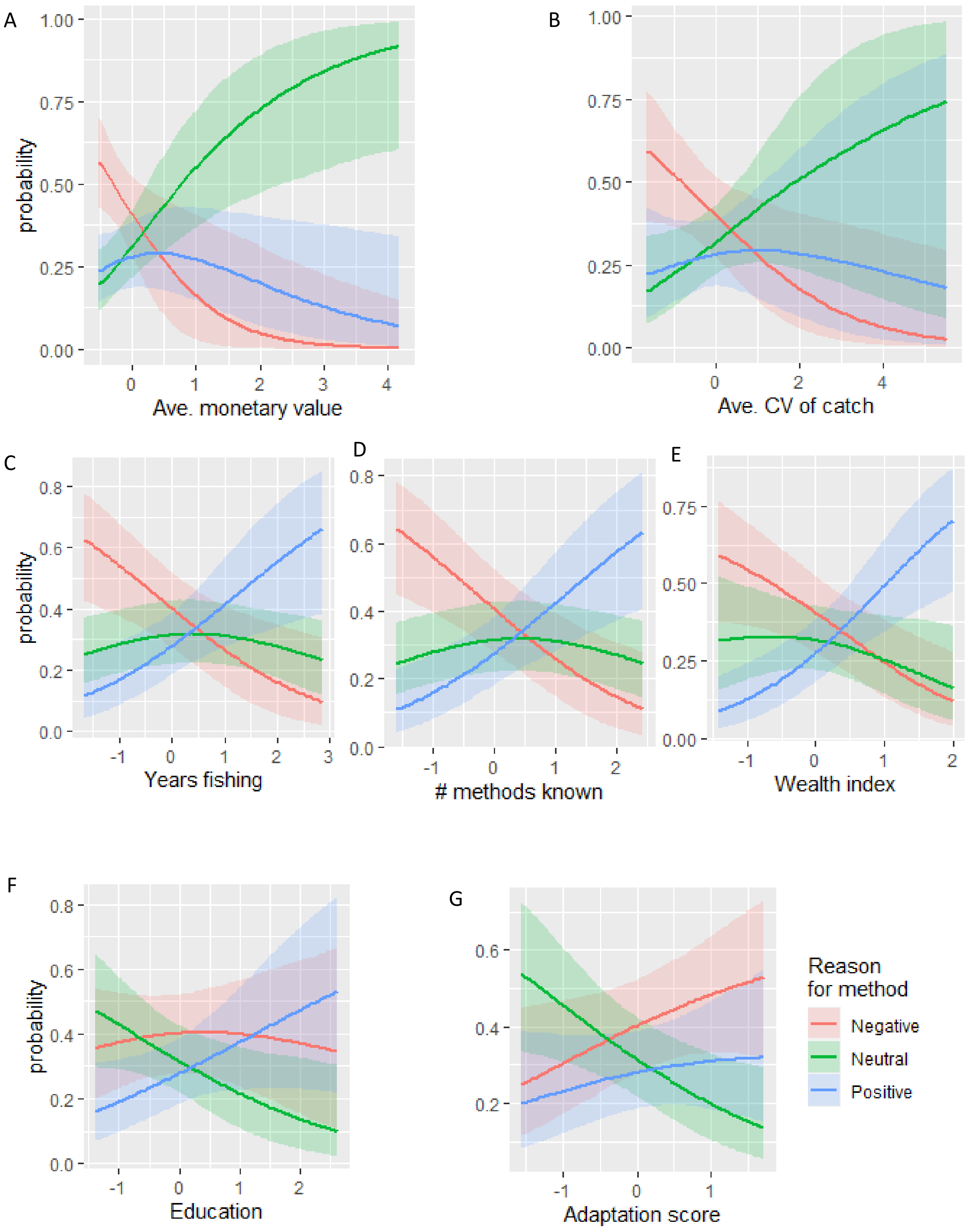

Figure 3-9: Conditional effects of average monetary value (A), CV of catch (B), years fishing (C), number of fishing methods known (D), fisher wealth index (E), fisher education (F), and adaptation score (G) on the odds of giving a negative, neutral, or positive reason for their method.

Table 3-11: Model coefficients of catch characteristics of fishers' current method and fisher characteristics on fisher stated reasons for choosing a method being positive, neutral, or negative. [1] indicates the variable affects the odds that a response is negative versus neutral, [2] indicates it affects the odds the response is neutral vs positive. Variables without a number indicate that the variable with the same value for each transition is in the model with the highest ELPD score. All variables are standardized.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept [1]	0.26	0.29	-0.33	0.82	
Intercept [2]	0.15	0.29	-0.41	0.73	
Years fishing	0.40	0.14	0.12	0.70	*
# Methods known	0.44	0.14	0.18	0.72	*
Monetary value [1]	1.58	0.65	0.50	3.02	*
Monetary value [2]	-0.60	0.25	-1.11	-0.12	*
CV of catch [1]	0.63	0.28	0.09	1.18	*
CV of catch [2]	-0.23	0.33	-0.87	0.43	
Wealth index [1]	0.28	0.28	-0.27	0.85	
Wealth index [2]	0.81	0.30	0.24	1.41	*
Education [1]	-0.38	0.26	-0.89	0.14	
Education [2]	0.68	0.29	0.12	1.27	*
Adaptation score [1]	-0.65	0.26	-1.16	-0.13	*
Adaptation score [2]	0.57	0.30	-0.01	1.15	

Discussion

This chapter addresses two hypotheses about the motivations for fishing decision and the applicability of assuming these decisions can be understood from purely economic cost-benefit analyses. Currently, most fishery models and management interventions assume that economic motivations to maximize profits are sufficient to understand fishers' decisions (Fulton *et. al.*, 2011; Schlüter *et. al.*, 2017). Within an SES, cumulative human decisions are a dominant factor determining the structure and function of the system (Ellis, 2015). Therefore, incorrect assumptions about how these decisions are made can cause misunderstandings about the entire system.

Beyond profit maximization in understanding fishers' attitudes towards the fishery

The first hypothesis assesses whether economic motivations sufficiently explain fishers' reported attitudes and motivations with regards to the fishery, or if a different behavioural theory can be used to better understand fishers' responses. Based on interview responses, it is clear that RAT is not consistent with most responses for most fishers. Only 8% of fishers gave responses which indicated the importance of profit more than any other factor. So, the hypothesis that economic motivations are sufficient to explain fisher attitudes and motivations is rejected and alternative behavioural theories are investigated further.

Responses to interview questions indicate heterogeneity in attitudes and motivations. The degree to which fisher responses are consistent with the expectations of the different behavioural theories changes based on the type of question. Responses to questions about the condition of the fishery indicate the importance of reliability and profit overall, which are most consistent with prospect theory or rational actor theory. On the other hand, questions about fishers' reasons for making specific fishing decisions and on the value of the fishery, are better understood using the theory of planned behaviour. The extent to which responses are consistent with the different behavioural theories also varies between fishers. Four of the five behavioural theories investigated are the most consistent with the individual responses for at least one fisher. Differences in attitudes or motivations are not fully explained by fishing community, fishing method, or gender, indicating that using these groupings to determine behavioural differences is insufficient.

Despite the fact that most fishery models and management regimes do not allow for heterogeneous attitudes and behaviours, many studies have found differences. Boonstra and Hentati-Sundberg (2016) described three fishing styles within the Swedish fishery with different motivations and definitions of a good fisherman. These styles are largely determined by location and can be explained partially through cultural history. The current study does not find geographic location as a reliable predictor of fishing motivations within the scale of the study, i.e., around Pemba Bay. As the crow flies, it is less than 24km between the most separated houses interviewed for this study, even though they are in different communities. It is possible that at larger spatial scales, similarities in responses within the Pemba fishery as a whole would become apparent. There are examples of heterogeneity within communities in the literature as well. Dorward *et. al.* (2009) found differences in livelihood priorities, abilities, comfort with risk, etc., within subsistence farming communities which affect livelihood decisions. Fishers in Tanzania have varying levels of risk seeking/avoidance preferences which affect fishing decisions (Eggert & Lokina, 2007). Pollnac and Poggie (2008) contended that many fishers have a personality type that thrives on risk and therefore choose to fish because it is a way to meet this desire for adventure, although the evidence they used was from developed countries where high paying alternative livelihoods existed. This current study does not include data on risk preferences or personality type to determine if these correlate with the differences in fishing motivations. It is possible that using personality types would allow fishery scientists and managers to understand the variation in fishing behaviours and this should be investigated further.

Additionally, fishers may have different attitudes and make different choices depending on the circumstances around the choices. For example, Fisher and Mandel (2021) found that average responses to hypothetical questions depended on how the choice was presented, or how it was interpreted. Which could lead to people making different decisions to the same hypothetical choice. And Gezelius (2002) found that while Norwegian fishers generally found that following fishing rules was very important, they accepted rule breaking from some if they had bad luck fishing lately and were in more need than most. Fishers in this study often indicated a variety of motivations during interviews and as mentioned in the general methods, handline fishers using the deep-water channel would often fish the reef at the end of their fishing trip before returning home if they were unsuccessful at catching larger, more profitable, species (personal observation and conversations with fishers). These observations indicate that variation even within fishers is probable. This is something that should be studied further to understand when certain motivations or behaviours are more likely.

Since differences in fisher motivations exist, these differences are expected to lead to differences in fishery outcomes. Using an agent-based model, Wijermans *et. al.* (2020) found different fishery stocks, profits, and satisfaction levels depending on the behavioural paradigm their model agents used. In their model, fishers motivated by profit maximization always overexploit their resources and eventually cause stocks and profits to fall. This assumption that fishers are all motivated by profit maximization therefore requires controls that limit this type of behaviour. However, as Boonstra and Hentati-Sundberg (2016) noted, these types of controls would not be expected to work for fishers with some other motivations. Pollnac and Poggie (2008) pointed to fishers' desires to fish even if it became unprofitable due to their need for adventure. This can also lead to overexploitation. In this case, projects to limit fishing need to provide that sense of adventure to fishers to get them to change habits. For management to be successful fisher motivations need to be accurately understood.

While all behavioural theories examined are consistent with some fisher responses to interview questions, the theory of planned behaviour is the most consistent overall. This behavioural theory requires managers to consider several aspects of the fishery to understand fishing decisions. Responses to interview questions suggest that perceived behavioural control is important in making fishing decisions for many people. Ninety-seven percent of interviewed fishers indicate that their decision to be a fisher, or less commonly to use a particular fishing method, is largely determined by fishing being an activity they can do without needing someone else to make it possible. When mentioning lack of opportunity for other jobs, several fishers also mention the benefit of independence and self-sufficiency.

So even though guaranteeing catches is beyond the control of fishers, the fact that they can control the decision to fish is important (Ajzen, 2002). The ability to control fishing behaviours can cause fishing to be a source of empowerment and identity for some fishers (Nayak *et. al.*, 2014).

Fishing can be a source of empowerment and agency for fishers, but can also lead to marginalization. Béné (2003) found many fishers were marginalized with limited political, social, and financial power. This is implied by several fishers around Pemba Bay, like a mosquito net fisher in Chuiba mentioning being worried about access to the beach in the future and a vessel owner in Ruela stating the need for fishers to insist on their rights. In this study, fishers in all communities and at all levels of material wellbeing and education at least imply that others have the power, not them. The local fishery ministry has loans available for fishers to improve their fishing gears and, in theory, give fishers more options. However, accessing these funds is complicated, and as the same vessel owner says, loans are "risky because fishing does not have a guaranteed income." In a situation where, especially poorer, fishers do not believe they have the ability to change their behaviours, anything that restricts access to available resources reinforces feelings of marginalization and power disparities between rich and poor fishers (Béné, 2003). Fishers may be more susceptible to inflated feelings of marginalization due to "learned helplessness" where being repeatedly in uncontrollable situations, such as fishing, can lead to decreased effort to affect change in all aspects of life (Boureau *et. al.*, 2015). This sense of helplessness can be exacerbated by fish declines as it becomes more difficult for fishers to provide for their families. As Nayak *et. al.* (2014) stated, for fishers in their study site, "fish represent power" and lack of fish led to decreased empowerment. Based on the importance of behavioural control on fishing decisions, fishery interventions must address issues of power and marginalization as Béné (2003) stated.

The theory of planned behaviour does not make any specific assumptions about the priorities of the decision maker (Ajzen, 1991). Based on this behavioural theory, fishers' intentions are determined by personal attitudes towards possible outcome, perceptions about how peers perceive outcomes, and perceived control over the action. TPB does not preclude the possibility that, to the extent possible, fishers are motivated to maximize their profits. However, questions about the value of the fishery indicate that reliability (30% of responses), sustainability (18% of responses), and social interactions (18% of responses) are all important as well. An informal conversation with a young night purse-seine fishing captain made the consideration of sustainability and social norms clear. He asked about the sustainability of night fishing because it is seen by many fishers as the cause of the problems in the fishery. He was still a night fisher, but was concerned about what others think of it and whether it was contributing to declines in catch. Most (>75%) responses to question 11 about how the fishery should be managed indicated preferences for collective action and sustainability. This is not to suggest that most fishers are conservationists per-se, so much as to acknowledge that many see declines in their fishery and want to stop these declines. Fishers' desire for collective action and concern over the sustainability of their resource should not be overlooked. Johannes (2002) argued that many indigenous groups learned to conserve their resources after overexploiting them. Turner and Berkes (2006) furthered the concept of learning from resource collapse into a form of adaptive management in which cultural history and current conditions mix to allow for adaptations. It is the process of creative destructions where new social systems and norms can emerge (Gunderson & Holling, 2002; Holling, 2001). Declines in the fishery may prime local fishers for creating a new system which considers sustainability and collective action. While fishers around Pemba Bay show little indication that they are willing to forgo opportunities to catch fish based on the current situation in the fishery, many seem to desire the social organization to allow effective protection of the fishery. The possibility of promoting collective action is addressed more in the final discussion (page 154).

Ration actor theory versus prospect theory to explain fishing behaviours based on catch characteristics

The second hypothesis is that fishing behaviours are better explained by prospect theory (PT) than rational actor theory (RAT). Based on interview responses above, neither PT nor RAT are consistent with most responses. Slightly more interview responses are consistent with PT (30% of responses) compared to RAT (27% of responses). However, RAT is the most consistent overall for more fishers (8%) than PT (4%). Despite the lack of evidence in the interview responses that either RAT or PT adequately explains fishing motivations, if a simplification of the decision-making process is to be used to understand fishing catches, this study argues that PT is a better simplification than RAT. As predicted by the hypothesis, reliability of catch is important in explaining fishing decisions in Pemba Bay for many fishers. Gillnet fishing is reliable and profitable and is increasing in relative use and is the most common method fishers say they would prefer to use. Handline fishing, which is slightly more profitable than gillnet fishing on average but is also less reliable, is decreasing in relative use and less likely to be mentioned as preferred.

Neither RAT nor PT are consistent with fishers' opinions about their fishing method, as neither value nor reliability of catch is correlated with more positive opinions. Fishers with attributes which give them more options when choosing a fishing method are more likely to give a positive reason for their method, indicating again that choice is important for attitudes towards methods. In the absence of this choice, the average value or reliability of the method does not correlate with more positive attitudes. Taken together these results supports the idea that RAT is insufficient to explain many fishing behaviours, but suggests that while PT may be an improvement over RAT, it is still insufficient to completely explain fishing behaviours and attitudes. This is not unexpected based on the results from the first hypothesis. The implications of each of these types of evidence are discussed below.

Changes in method use

Value of catch alone cannot explain changes in relative use of fishing methods from 2012 to 2018, but a combination of value and reliability can. This supports our hypothesis that PT is more consistent with the results of fishing decision in the last few years than RAT. This is because gillnet fishing, which is increasing most in relative use, is not the most profitable, but is nearly as profitable, and more reliable, than more profitable handline fishing. However, gillnet fishing appears to be more profitable in some communities than handline fishing. In the fishery data, gillnet fishing catches are more valuable than handline fishing catches landed in Metuge. And Julien *et. al.* (2017) found that gillnet fishing catches were much more valuable in Pemba overall than handline catches. Yet the much larger dataset from the fishery ministry indicates that handline fishing is more profitable on average and occasionally is much more profitable. When fishers make a large catch, they are more inclined to go to Ruela to sell the catch because the prices are better (personal conversations with fishers). This would bias sites by eliminating very valuable catches from sites other than Ruela. As handline catches are the most likely to be very valuable, this is the method which would be expected to be most influenced by this bias. However, valuable handline catches are also generally made in the channel over deep water (personal communication with fishers). The channel is farther from Metuge than the other sites used in this study. It is plausible that handline fishers who are unable to fish the channel have lower value catches on average than gillnet fishers. This could indicate that gillnet fishing is the most profitable method for Metuge fishers because of the difficulty in accessing the habitat in which handline fishing becomes more profitable. Unfortunately, the data from the fishery ministry do not include the location where fishing occurred to test this supposition. This could indicate, that for Metuge, the increase in gillnet fishing is in response to its higher value rather than its reliability, but this would not be the case for other communities.

Additionally, it could be lack of skill at handline fishing that causes fishers to switch to gillnet fishing rather than handline fishing. In interviews, 60% of fishers indicated they knew how to use a handline while 45% claimed to know how to use a gillnet. So, lack of skill with a handline is also an unlikely reason for its decline in relative use and the increase in gillnet fishing.

A final complication, is that handline fishing encompasses several different fishing methods which may or may not be employed by an individual fisher, such as trolling, jigging, etc. These different techniques are not separated in the fishery ministry data nor by most fishers when talking about their fishing method. Highly profitable handline catches are most likely from demersal or pelagic species caught in Pemba's deep-water channel, while fishing the reef is considered reliable (personal communications with fishers). Some handline fishers limit their risk of failure by fishing in deep water for profitable species, but leaving time at the end of trips to fish on shallow reefs for more reliable catches if they fail to make a valuable catch (personal communication with fishers and fishing observations). How many handline fishers utilize both the deep-water channel and shallow reefs or seagrass meadows is unknown. However, separating fishers who use the deep-water channel from those who do not would most likely increase the average value, and decrease the reliability, of catches for those handline fishers using the channel. This would make this type of handline fishing even more profitable and therefore should be even more desirable if profit is the only motivation for fishing decisions. The fact that handline fishing remains the most prevalent method in all years, even though it drops from 40.6% in 2013 to 36.5% in 2018, indicates that many fishers are willing to accept high variability for high rewards. The prevalence of handline fishing, the most profitable method, around Pemba Bay and specific behaviours that allow for the possibility of high profits while limiting the risk of catch failure, indicate that fishers are concerned with the profitability and reliability of their fishing decisions as PT expects.

There is little evidence that changes in relative use of fishing methods are being affected by changes in the characteristics of catches from these methods, as when changes have occurred, they have not changed the relative order of the methods in terms of value or reliability. The catch data from 2012 through 2018 does not show general declines in catch value. The only method for which value has declined between 2012 and 2018 is purse-seine fishing. This lack of decrease in catch value per fisher per trip may be misleading due to possible increases in fishing effort by fishers to maintain catches. This is considered further in the final discussion.

Unlike value, there are declines in catch reliability from 2012 through 2018 for some methods. Beach and purse-seine catches increased in CV of catch and purse-seine and spearfishing catches decreased in the odds that the catch was sufficient for household protein requirements between 2012 and 2018. However, trap fishing became more reliable based on both metrics and handline catch CV decreased from 2012 through 2018. It is possible that the decline in catches which fishers argue have occurred in the recent past, are actually reactions to declines in reliability of catch rather than amount or value of catch. But as mentioned above, changes in fishing behaviour can also mask declining catches. These changes in catch reliability do not change the order of fishing methods, therefore it is unlikely these changes caused the changes in relative use of different methods mentioned above.

Fisher preferences for different fishing methods

Fishers' preferences for fishing methods also indicate that reliability of catch is more important than value. Despite purse-seine fishing as a vessel owner being the most profitable fishing method by far, only 2.5% of respondents indicate this would be their preferred method. It is possible that fishers do not mention wanting this because it seems too unlikely to be considered. The initial costs to a vessel owner are hundreds of times the daily income from handline fishing. And despite government indications that loans are available for fishermen, these are difficult to obtain, especially for fishers outside the city. That fishers do not want to be purse-seine vessel owners could indicate either a lack of ability to procure loans and other resources, uneasiness about the risk involved in getting these loans, or a combination of both. Holland (2008) found that many fishers were reluctant to risk their savings or livelihoods on a new method even if they believed it would be more profitable in the long term. This reluctance to risk savings can be well explained by PT but not by RAT. While lack of access to resources for purse-seine fishing might prevent fishers from even aspiring to this type of fishing despite its high potential profitability, this does not explain the lack of enthusiasm for handline fishing as the costs of entry are much lower. The average value of handline catches is slightly, but significantly, higher than for gillnet fishing in Pemba Bay, but it has higher variability. The preference for gillnet fishing over handline fishing therefore indicates a preference for reliability of profits at least when the average profits are similar, which is very similar to what Kahneman and Tversky (1979) found in experiments where participant choose between situations with different average values and reliabilities. This agrees again with PT but not RAT.

Some of the variability in fisher motivations noted in the first hypothesis are apparent in fisher preferred methods. The slight, but significant, increase in the average value of catch of a preferred method with the fisher's level of education and ecological knowledge score indicate that fishers with greater knowledge place more emphasis on value. This could be an indication of these fishers believing they are better able to make larger catches despite the variability. Eggert and Lokina (2007) found that in hypothetical choice studies, fishers with more confidence in their abilities were more likely to choose riskier options even when these did not have the highest average pay out, because they believed that they would be able to make catches closer to the maximum possible rather than the average. These behaviours cannot be well explained with RAT, as it assumes that fishers will make the choice that gives the highest average pay out without accounting for some fishers making choices which are theoretically inferior due to their belief in their ability. It could be explained by PT if different weighting values are allowed for different people, but this is not intrinsically necessary for PT. Again, this indicates the importance of recognizing the heterogeneity of fishing communities and designing management programs that account for all fishers.

One surprise in the preference data, is that women in Chuiba state a preference for less reliable methods than men. This result contradicts Codding *et. al.* (2011) who found that if potentially high value targets and reliable targets cannot be sought together, men tended to target based on value and women based on reliability. The preference for less reliable methods by women in Chuiba is most likely cultural rather than any actual preference for less reliable methods. These women mostly indicate a preference for beach-seining or mosquito net fishing. In current catch data, these methods are both unprofitable and unreliable, so reasons to choose it have to be base off considerations other than catch. Many women in Chuiba state they use their method due to it being appropriate for women, therefore their choice not to use a different method most likely is due to those methods being inappropriate for women. Gissi *et. al.* (2018) found that gender roles within fisheries were still strong in many areas. It is interesting that women in Metuge did not feel this constraint when imagining possible fishing methods. Many women interviewed in Metuge were involved with the local fisher collective, while Chuiba did not have a fisher collective at the time. This could indicate a level of women's empowerment caused by involvement in the collective allowing for greater imagination of possibilities within the fishery. The possible psychological benefits from membership in community collectives is exciting and should be researched.

Fisher opinions on their fishing methods

While fishing method use and preferences can be fairly well explained by PT, fishers' attitudes towards their individual fishing method based on its profitability or reliability cannot. The odds that a fisher gives a positive reason for his or her fishing method does not increase with the average value of the catch nor the reliability of the catch. Personal fisher characteristics, such as education, years fishing, wealth, and the number of fishing methods known increase the odds that a fisher gives a positive reason for choosing his or her method. Wealth, education, and number of fishing methods known all increase the fisher's choices, supporting the findings from the first hypothesis that choice is important in making decisions and shaping one's attitude towards fishing. So, while PT seems to be a better framework for understanding how fishers prioritize profit and reliability when making fishing decisions in many cases, it appears to be too narrowly focused to predict fisher attitudes and motivations towards the fishery in general.

Comments on methodology

This study uses interview data to divine fishers' motivations and priorities. This leads to the potential for misrepresentation of their true attitudes both in what fishers say and in how their responses are interpreted by the researcher. On the first point, fishers may intentionally or not misrepresent their beliefs and opinions about the fishery. The researcher spent time in the communities with fishers, often establishing some form of relationship with them which could influence their responses. Some fishers may have attempted to guess what the researcher wanted to hear. Culturally, the people of Pemba seem to avoid confrontation when possible (personal observation) so it seemed more likely that they would change their answers based on what they think was wanted rather than in an attempt to be contrarian. Other unintentional misrepresentations could occur from the use of hypothetical situations. It is generally impossible to be sure how one would react to a situation until it occurs, but there are few alternative ways to study behaviour change. Simulation games have been used in other areas to research resource use behaviour, however, these are generally computer based and involve university students (e.g., Costanza *et. al.*, 2014; Hutchinson *et. al.*, 2008). Many people around Pemba Bay are not literate, and far fewer are computer literate. This makes these types of simulation-based studies more difficult, although not impossible. Additionally, a person's behaviour in a game matching their behaviour in life is not guaranteed. The only way to address behaviour change in different situation is to study individuals for long periods of time. As this is infeasible in most circumstances, including for this study, most researchers assume that interview responses are "true" at some level (Parissi, 2010), even though behaviours may not always match stated intent. Due to the difficulty and time requirements to understand behaviours in light of change, interview responses to hypothetical situations are generally used to investigate behaviours (e.g., Daw *et. al.*, 2012; Hanh & Boonstra, 2019; Holland *et. al.*, 2020).

Another source of uncertainty is in how the researcher categorized responses to questions. Interviews were conducted in the local language, which the researcher does not speak. Responses were translated by the interviewer into Portuguese then by the primary researcher into English. This allowed several occasions for misunderstanding the nuances of language when trying to determine meaning. Most interviews were recorded to allow analysis by a fluent speaker in the future, but as of now this has not occurred. The inability of the primary researcher to communicate directly with most interviewees made follow up questions to understand intentions difficult, and rarely occurred. Therefore, assumptions about how to categorize responses to questions had to be made, and these may not have been correct. Some possible ambiguities in categorization were mentioned above, but others may exist. These uncertainties were dealt with in this study by addressing the issue of choice in multiple ways including analysing observed fishing behaviours.

Along with uncertainty caused by the interview process, as this study was a preliminary analysis of the consistency of the five behavioural theories, none of them was addressed specifically. This limited the strength of the results in indicating a particular theory as being a good framework. Specifically, to address the theory of planned behaviour, researchers generally ask questions about attitudes, social norms, perceived control, etc. of a specific behaviour, usually using agreement with a statement on a Likert scale (e.g., Roos & Hahn, 2019; Wu & Chen, 2014). This allows greater differentiation on the importance of the different aspects of TPB in determining behaviours. This study attempted to allow more flexibility of answers than generally found in TPB questionnaires. Research specifically addressing the components of TPB in general fishing decisions as well as possible changes to fishing decision should be conducted to confirm the above results. This was addressed more in the final discussion (page 154).

The fisheries catch surveys also introduced uncertainty. Creel survey effort was not evenly distributed through time or fishing centres. There were many more data from 2018 than 2012, the first year for which data were available. Additionally, there were many more data from Ruela, within Pemba city, than for other landing sites. Chuiba had very few catch surveys, so few that they are combined with Maringanha, a nearby community, in the data for this study. However, there is no reason to assume that catch surveys from a given year or fishing centre are biased toward any given fishing method, as technicians appear to survey all fishers in smaller fishing centres, and fairly randomly when many boats return at once. However, small catches are less likely to be sampled, as in this case fishers spend less time at the landing site, or take their catch directly home. Despite this bias against small catches, much of the data indicate small or zero catch, so these trips are still sampled. Higher sampling in Ruela also provides data from a larger section of fishers in the bay than initially apparent. As fishers mention, they can get a higher price for their fish by taking them to the fishing centre at Ruela, meaning that it is used by fishers from the other communities. The higher sampling effort from Ruela, therefore, gives a decent estimation of highly successful fishing trips for fishers from communities around the bay. This furthers the bias against unsuccessful fishing trip in Ruela. However, there is no reason to believe that any fishing method is more or less biased in the data, and since it is the proportional use of different fishing methods which is used in this study, the bias away from unsuccessful trips is unlikely to have a major effect. That fishers from all landing sites use Ruela when making a large catch indicates that the fishery is connected. While accessing fishing ground farther from the fishers' home is more difficult and time consuming, especially for fishers using canoes, it does occur. Unfortunately, data provided by the fishery ministry do not include fishing location, only landing site, so it in not possible to determine how connected the fishery is from these data. But this connection indicates that analysing the fishery as a single system, as done in much of this study, is at least somewhat valid.

These limitations from the fishery ministry data indicate that estimations of the reliability of catch may be overestimated, but there is no indication that this bias is higher for some fishing methods than others. As this study is interested in relative use, these data are most likely sufficient, however, this cannot be verified as there are very few other data from before the study began to use for comparison. Fishing observations and catch surveys by the primary researcher during the study were limited due to time and financial constraints. These data agree that handline fishing was the most profitable, but show that gillnet fishing was relatively unprofitable, data from Our Seas Our Lives show similar patterns. Despite the fact that these data sets find gillnet fishing to be fairly unprofitable, other data from Pemba suggests it can be highly profitable (Julien *et. al.*, 2017), which lends some support to the overall patterns found in the fishery ministry data. As changes in fishing method use cannot be established without a time series, these data are necessary despite their potential issues. However, continued monitoring of catches is necessary to confirm or reject findings in this study using these data. As are explicit explanations of how fishing trips are selected for a survey, how days are selected for sampling, etc. Currently this appears to be largely opportunistic based on the schedule of fishery technician (personal observation).

Finally, the use of Bayesian statistics to analyse these data has many benefits, but a couple potential problems as well. The main argument against Bayesian statistics is that by including an inappropriate prior probability distribution in the model, the researcher affects the final outcome. Setting up reasonable prior is therefore important. The brms package uses half Student-t priors with three degrees of freedom by default which are weakly informative and generally lead to good convergence of models in the absence of prior knowledge (Bürkner, 2017). Initial use of uniform priors as an uninformative prior are found to be problematic in many models due the highly non-uniform real distribution of parameters (Gelman, 2002). This study uses the default, weakly informative, prior probability to avoid these potential problems with prior probabilities.

Bayesian statistics are better at dealing with complicated response distributions and nuisance variables than frequentist statistics. Bayesian statistics are more robust to non-normal data than most frequentist statistics (Zuur & Ieno, 2016). Catch data is roughly gamma distributed with zero inflation. In some cases, zero inflation can be caused by inability to measure small effects or detect rare species. In this section, zero catches are real data and need to be included in the model. Finally, these models are better able to deal with nuisance variables, such as weather variables in the catch model, in that as long as they are not correlated with the variable of interest, they do not need to be removed from models if uninformative to address the effect of interest (Wagenmakers *et. al.,* 2008 and Zuur & Ieno, 2016).

The benefits of Bayesian statistics come at the expense of sometimes much longer computing times, and more subjective model validation. As Bayesian models use MCMC to compute the posterior distribution, they are slower to run than frequentist models which occasionally limits how many alternate models can be run. The validity of a model depends in part on subjective determination of the fit to the data based on posterior predictive plots, and determining how much match is needed for a model to be accepted is unclear. Some models used above fit the data only moderately. Posterior predictive plots which do not fit the data as well are always included in Appendix II to allow readers to address the validity of models.

Conclusion

Within the fishery SES, human decisions are a main component determining the appropriation action situation of fish removal from the marine ecosystem. These decisions interact with the conditions in that marine ecosystem to determine catches for fishers, social outcomes, and consequences for both targeted and non-targeted species. The assumption that these decisions are completely economic and can be explained by an economic cost benefit analysis is contradicted by this study as well as several others as mentioned above. The possibility exists that the solution is to account for non-monetary costs or benefits for fishers such as sustainable catch as insurance for the future as is suggested in the literature on ecosystem valuation (e.g., Morse-Jones *et. al.*, 2011). This may be a way to account for some other considerations of local fishers. However, this study indicates that even if the monetary values of less obvious ecosystem services are accounted for, this will still not explain all fishing decisions as reliability and behavioural control also appear important. This study indicates that greater understanding of catch variability is necessary to understand fishing, as suggested by prospect theory. This requires understanding on how people in the area value gains and losses in light of uncertainty. Beyond this, the consistency of many fisher responses with the theory of planned behaviour suggests that greater attention needs to be paid to empowerment of local fishers and promoting choice. From a sustainability perspective, increased choice will not necessarily increase the sustainability of the system, and it needs to be used in combination with other management interventions. However, within Pemba Bay there is some indication that fishers are looking for ways to make the fishery more reliable and allow for its continued use into the future. This is addressed further in the final discussion.

Chapter 4 Social outcomes from fishing decisions

Abstract

This chapter addresses differences in wellbeing between fishers and their non-fishing neighbours, to better understand the state of the fishery's social system. It uses material standard of living and subjective wellbeing to compare fisher with non-fishers in the area. The data indicate that fishers' wealth is comparable to non-fishers, however they have lower subjective well-beings. Additionally, fishers in Pemba Bay are not highly committed to fishing with the majority indicating a desire for alternative employment and for their children not to be fishers. Overall, these data indicate social stress within the fishery which should be addressed in any management interventions.

Introduction

As reviewed by Béné (2003), many assume that, in developing nations, fishing and poverty are linked due to the open access nature of the fishery. Fishing then becomes a reservoir, collecting excess labour, leading to overexploitation and low profits overall. This poverty can lead to increased marginalization, lack of self-esteem, and lack of empowerment (Attah *et. al.*, 2016; Béné, 2003). From Chapter 3 above, behavioural control is important in understanding fishing decisions and attitudes towards the fishery, therefore, reported lack of empowerment and control in fisheries research could have large effects on fishers' wellbeing. Understanding the material and subjective wellbeing fishers can achieve through fishing becomes important, not only for its own sake, but also as it relates back the previous chapter in understanding decision making. When dealing with chronic scarcity, some seemingly counterintuitive decisions become common, including detrimental cost-benefit analyses relating to the use of resources (Shah *et. al.*, 2012), so the extent to which this is common for fishers around Pemba Bay must be assessed to understand the fishery.

The goal of this chapter is to assess how fishers' wellbeing compare with those of non-fishers, and to what extent fishers using methods with more valuable or reliable catches have higher wellbeing. The question is, are fishers the "poorest of the poor" being forced into fishing by poverty, or is fishing a relatively productive livelihood which is chosen and respected? The question is broken into the following hypotheses about fishers' wellbeing.

h1) Fishers have material and subjective well-beings similar to non-fishers within their community;

h2) Fishers' wellbeing is correlated with the reliability of their fishing method, or alternatively with the profitability of their fishing method;

h3) Fishers using more reliable, alternatively more profitable, methods are more committed to fishing as a way of life/identity.

These hypotheses address the social outcomes from the fishing appropriation action situations. The focus is on how catch value or reliability interacts with fishers' perceived and material wellbeing and how fishers in general compare to other members of the community. Within the conceptual framework of the Pemba fishery SES (Figure 4-1), these social outcomes are expected to affect fishers' motivations and ultimately their fishing decisions, and they are also expected to affect fishers' desires for, and interaction with, potential provisioning action situations to manage the fishery and protect their common resource.

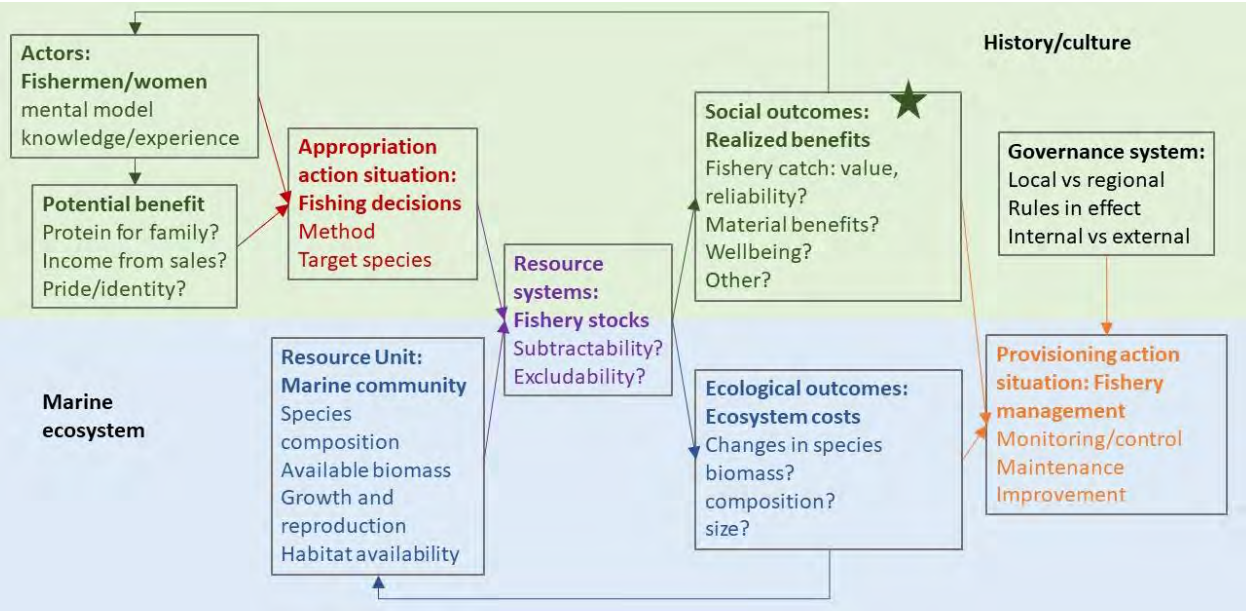

Figure 4-1: A reconstruction of the conceptual framework of the study (Figure 1-3) with a green star indicating the portion of the SES being addressed in this chapter.

Methods

This chapter used data from fisher interviews, community surveys, and fisher workshops to determine fishers' attitudes towards their own wellbeing as well as the fishery. These data were analysed using results from the catch data on the profitability and reliability of different fishing methods to determine correlations between average catch characteristics and fisher wellbeing. Fisher interview and community survey (page 24) and fisher workshop (page 26) data collection and the calculation of basic catch characteristics (page 28) were described above in the general methods sections (Chapter 2).

The similarity or difference between fishers and non-fishers within the community in regards to wealth and perceived wellbeing was assessed first. This was followed by an investigation of differences in these variables between fishers using different methods. Finally, personal attributes and catch characteristics for fishers with different wealth and wellbeing scores, reasons for fishing, and commitment to fishing were compared. All statistical analyses were run in R-studio (R Core Team, 2020).

To address the first hypothesis that fishers were as well off as their non-fishing neighbours, a series of student t-tests and chi-square analyses were used. For numeric variables such as wealth index, age, education, number of livelihood activities, household size, and years in the community, student t-tests were used to determine the differences between fishers and non-fishers within the communities. For the ordinal variables of subjective wellbeing and the categorical variable of what makes a good life, χ^2 analyses were run to determine differences in responses from fishing and non-fishing households.

Wealth index indicated a person's material wellbeing, therefore, to understand how certain personal characteristics affected wealth, a Bayesian model was run using the brm function in the brms library (Bürkner, 2017). Material standard of living (MSL), as estimated by wealth index, was the response, and education, number of livelihood activities, household size, and years in the community as well as categorical gender, community, financial resources, and if a fisher were predictor variables. All numerical variables were standardized using scale in R (R Core Team, 2020) and correlations between predictors were investigated using Mypairs (Zuur *et. al.,* 2009). Due to correlations between age and years in the community (cor=0.74), age was dropped from all Bayesian models.

Next, subjective wellbeing was addressed. To determine the effects that personal characteristics, including wealth, had on perceived wellbeing, ordinal Bayesian models were run again using brm. The response variables used the acat distribution family to allow category specific effects (Bürkner, 2019). All the predictors used in the wealth model, as well as standardized wealth, were used. It was possible that the methodological difference of conducting full interviews with many fishers, but never with non-fishers, affected reported subjective wellbeing. To account for the possibility that interview type (in-depth or quick survey) affected responses on subjective wellbeing, models were then run with "interview type" instead of "if a fisher" as a binomial variable. Models could not be run with both variables as only fishers had the possibility of doing an in-depth interview, so the variables were highly correlated. Models with fisher or interview type variables were compared using LOO to determine ELPD (Vehtari *et. al.,* 2017). As in the previous chapter, models were validated using R-hat equal to one, bulk and tail ESS above 1,000, and subjectively assessing posterior predictive plots (Bürkner, 2019) using pp_check in the brms library (Bürkner, 2017).

To determine the differences in wealth and wellbeing of fishers using different methods, more Bayesian models were run. All models were run in R using the brm function in the brms library. Fishers using more reliable, or profitable, methods were expected to have higher MSL and subjective wellbeing scores, give more positive reasons for fishing, and be more committed to fishing as a profession and want it for their children. A model with MSL as the response and only fishing method and fishing community as predictors was run using a Gaussian response distribution. For the different aspects of wellbeing, ordinal models using acat distributions were used with the same predictors as for MSL. Category specific relationships between predictors and responses were compared to general relationships using LOO and only kept if they improved the ELPD. This extra step was taken due to the lower sample size limiting the number of variables which could be simultaneously evaluated. Personal characteristics were added to the models (MSL and wellbeing) one at a time and kept if they improved ELPD based on LOO comparisons. These models were expanded by using the average profitability (based on monetary value of catch) and reliability (based on CV of catch and proportion sufficient) for the different methods as predictors instead of the categorical variable of fishing method. Next, an ordinal model on fishers' reasons for fishing, categorized as positive, neutral, or negative, and binomial models of fishers' commitment to fishing based on whether they wanted a different job and/or wanted their children to be fishers were run. For the ordinal and binomial models, only catch characteristics and responses to perceptions on the current state of the fishery and its change were used as initial predictors. Both current state and change were categorized as either positive, neutral, or negative. The fisher characteristics used in the wealth model above were added one-by-one and only kept if they improved the model based on ELPD calculated through LOO. Due to potential complications with having large numbers of categorical variables, current state and change variables were dropped if not significant before adding the categorical variables of if the fishers liked or disliked fishing and their definition of a good life to these models to account for other potential aspects of fishing affecting attitudes towards the fishery. Models with both likes and dislikes and definitions of a good life would not converge, so were never used. Full models were not used due to smaller sample size relative to the number of possible predictors (n=142). All models were validated using R-hat, bulk and tail ESS, and posterior predictive plots.

Results

Fishers versus non-fishers

Fishers and non-fishers were similar in their ages, years in the community, and wealth indices, but fishers had significantly less formal education, larger families, and more livelihood activities than non-fishers (Figure 4-2 and Table 4-1). This last correlation must be analysed with caution as individuals with many livelihoods were more likely to mention fishing, or any other specific livelihood activity, based on chance. The Bayesian model of MSL showed that education and household size had small, but significant, positive correlations with wealth.

Table 4-1: Results from the t-tests comparing characteristics of fishers to non-fishers. Higher means are highlighted when the groups are significantly different

Characteristic	t-value	df	p-value	mean fisher	mean non-fisher	
Education	-3.0021	378.18	0.00286	4.22	5.25	.
Household size	4.7264	389.05	3.2E-06	7.65	6.05	*
Livelihoods	9.3423	408.43	2.2E-16	2.28	1.56	***
Wealth index	-1.0061	403.85	0.315	0.40	0.43	
Age	0.1305	386.68	0.896	40.20	40.00	
Years in comm	0.0653	383.66	0.948	31.20	31.10	

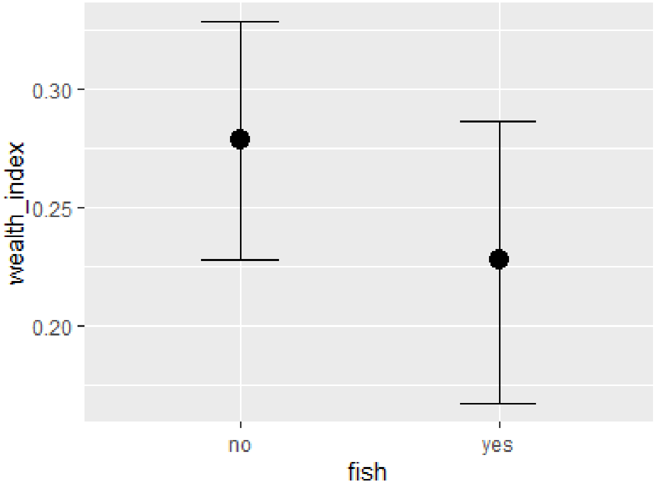

Figure 4-2: The nearly significant difference between fishers and non-fishers based on the model of MSL with all fishing methods included.

There were also gender and site differences, and being a fisher led to almost significantly lower MSL scores (Table 4-2 and Figure 4-3). The model followed the general shape of the data, but did not completely capture that shape based on the posterior predictive density plots (Appendix III, Figure III-1). A boxplot of the wealth scores of fishers using different methods compared to non-fishers shows that fishers using some fishing methods had higher median wealth scores than their non-fishing neighbours (Figure 4-4). Running the wealth model again excluding the two fishing methods with the lowest wealth scores, beach-seine workers and mosquito net fishers, eliminated the effect of fishing on MSL.

Table 4-2: Model coefficients for how individual characteristics affect MSL of respondents. "." Indicate coefficients with 95% confidence intervals which are equal to zero, * indicate coefficients with 95% CI which strictly do not overlap zero.

Variables	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept	0.28	0.03	0.23	0.33	*
Education	0.06	0.01	0.04	0.09	*
Years in community	0.03	0.01	0.00	0.05	.
Household size	0.04	0.01	0.02	0.06	*
Livelihoods	0.01	0.01	-0.01	0.04	
Male	0.07	0.02	0.02	0.11	*
Chuiba	0.06	0.03	0.01	0.12	*
Ruela	0.32	0.03	0.27	0.38	*
Fisher	-0.05	0.03	-0.10	0.00	.

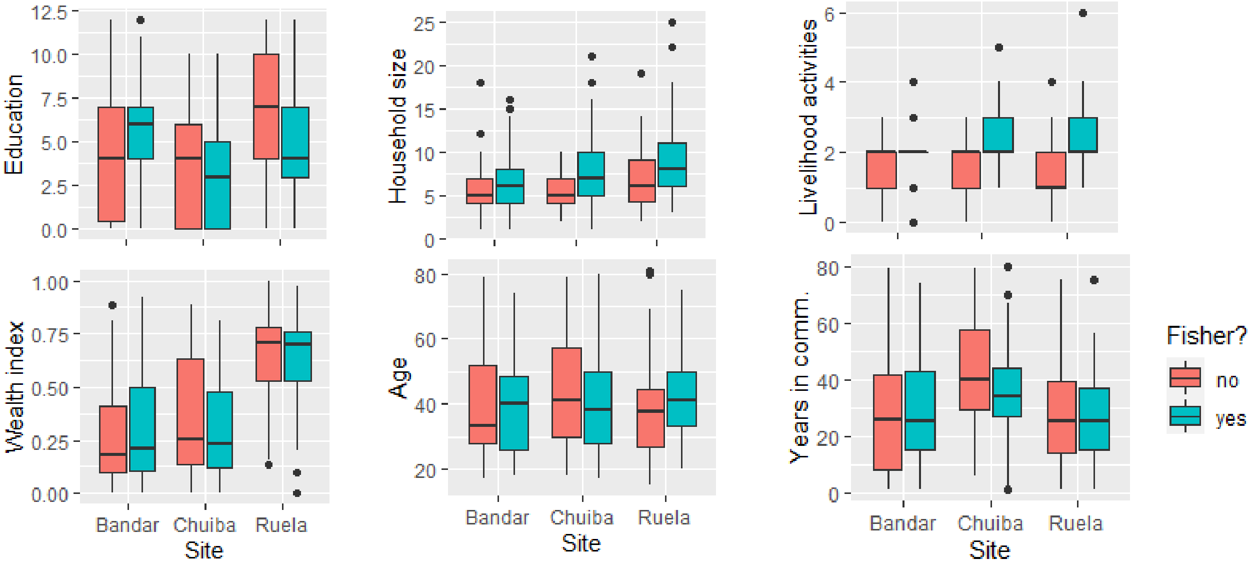

Figure 4-3: Boxplots of different characteristics of fisher and non-fisher respondents from different communities.

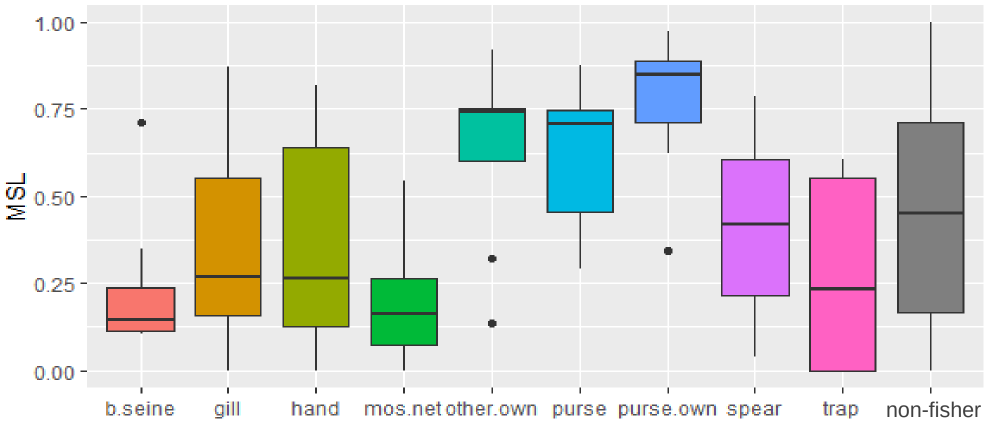

Figure 4-4: Wealth index of fishers using different methods compared to non-fishers.

Fishers most often defined a good life as having material possessions (40%), followed by working (Table 4-3 and Figure 4-5). Non-fishers showed the opposite with working being first with 39% of responses followed closely by material possessions with 36% or responses. Overall, most people in these communities reported being happy with their family life, social life, work life, safety in the community, and level of health, with more than 50% of respondents giving a positive response. Overall sense of wellbeing was just over 50% satisfied of non-fishers but only 41% satisfied for fishers. The percentages were similar for perceptions of ability to find help in the community if needed. Based on Holm-Bonferroni significance adjustments, feelings of safely in the community, likelihood of finding help in the community, and satisfaction with family, social, and work life were all more positive for non-fishers than for fishers (Table 4-3). Fishers also had slightly different access to financial resources than non-fishers. Fishers were more likely to have gotten a loan from someone other than family, more likely to own the materials they used for their livelihoods, and more likely say they bought those materials themselves than non-fishers (Table 4-3 and Figure 4-6).

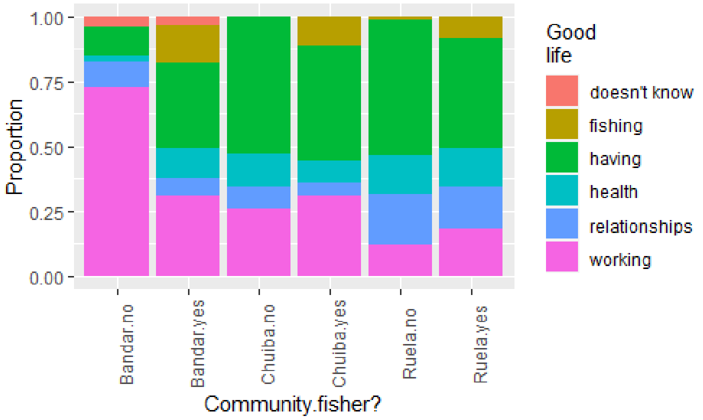

Figure 4-5: Proportion of fishers and non-fishers in each community that defines a good life based on the five basic categories above.

Table 4-3: Results from the chi-square analyses of aspects of wellbeing for fishers compared to non-fishers. Note based on Holm-Bonferroni adjusted p-values, 0.024 is not a significant result. When there are significant differences, the highlighted cell indicates the group with the higher proportional response in that category.

Aspect of wellbeing	Response	fisher	non-fisher	expectation	chi-sq	p-value
overall wellness	bad	0.316038	0.314721	0.315403	7.578	0.024
	ok	0.278302	0.172589	0.227384		
	good	0.405660	0.512690	0.457213		
safely	bad	0.203791	0.121827	0.164216	14.909	0.003
	ok	0.208531	0.111675	0.161765		
	good	0.587678	0.766497	0.674020		
help in community	no	0.388626	0.382653	0.385749	12.238	0.005
	maybe	0.194313	0.081633	0.140049		
	yes	0.417062	0.535714	0.474201		
family life	bad	0.061321	0.056410	0.058968	21.082	0.001
	ok	0.287736	0.107692	0.201474		
	good	0.650943	0.835897	0.739558		
social life	bad	0.061611	0.091837	0.076167	23.857	0.001
	ok	0.303318	0.107143	0.208845		
	good	0.635071	0.80102	0.714988		
work life	bad	0.114286	0.096447	0.105651	15.656	0.001
	ok	0.257143	0.111675	0.186732		
	good	0.628571	0.791878	0.707617		
health	bad	0.134715	0.072816	0.102757	4.455	0.116
	ok	0.207254	0.199029	0.203008		
	good	0.658031	0.728155	0.694236		
good life	doesn't know	0.010929	0.016216	0.013587	24.871	0.001
	fishing	0.114754	0.005405	0.059783		
	having	0.398907	0.356757	0.377717		
	health	0.114754	0.097297	0.105978		
	relationships	0.092896	0.129730	0.111413		
	working	0.267760	0.394595	0.318273		
Financial assets	family	0.043062	0.209424	0.12250	32.441	0.001
	loan	0.076555	0.068063	0.07250		
	not owned	0.047847	0.094241	0.07000		
	self	0.832536	0.628272	0.73500		

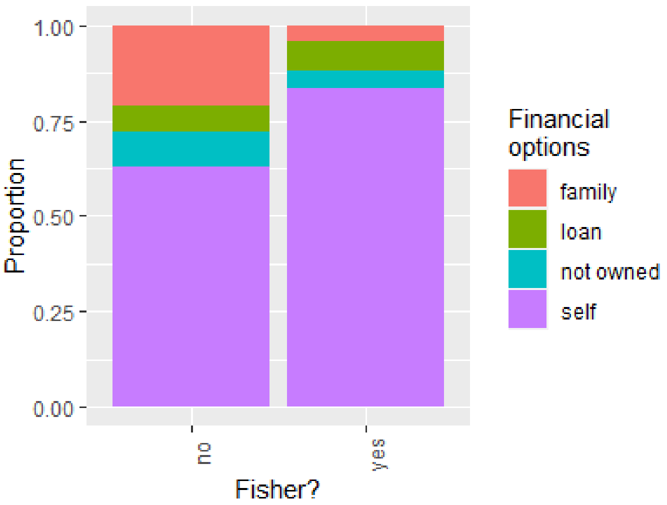

Figure 4-6: Proportion of fishers and non-fishers with access to different financial resources.

The Bayesian models of perceived wellbeing showed good fits with the data (Appendix III, Figure III-2). They indicated that even when personal characteristics were accounted for, there was still something about being a fisher that caused significantly lower subjective wellbeing scores, in agreement with the chi-square tests (Figure 4-7). Overall wellbeing was affected by fishing community, being higher in Metuge than Ruela or Chuiba, as well as the number of livelihoods practiced, which significantly decreased overall wellbeing in these data. Being a fisher negatively affected feelings of safety, perception of finding help in the community, and job, social, and family satisfaction (Appendix III, Table III-1 and Figure 4-7). Using interview type instead of fisher in the models did not have a large effect, but did cause a significantly higher ELPD for the model of overall wellbeing (ΔELPD=3.2, SE=2.7), and model of health (ΔELPD=4.6, SE=3.5), neither of which found a significant fisher effect.

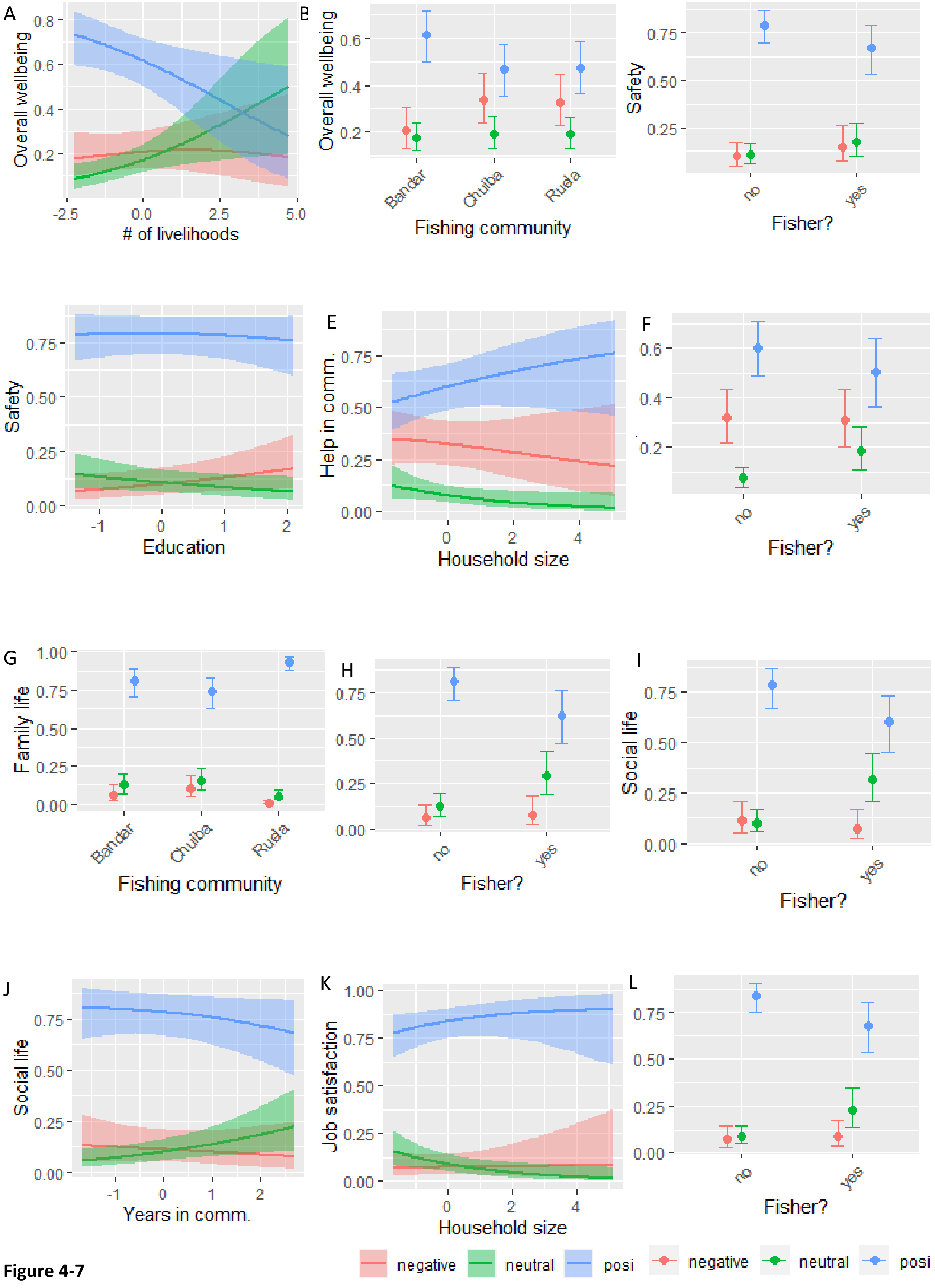
A
Overall wellbeing
0.8
0.6
0.4
0.2
-2.5
0.0
2.5
5.0
# of livelihoods
B
Overall wellbeing
0.6
0.4
0.2
Bandar
Chuiba
Ruda
Fishing community
Safety
0.75
0.50
0.25
no
yes
Fisher?
Safety
0.75
0.50
0.25
0.00
-1
0
1
2
Education
E
Help in comm.
0.75
0.50
0.25
0.00
0
2
4
Household size
F
0.6
0.4
0.2
no
yes
Fisher?
G
Family life
1.00
0.75
0.50
0.25
0.00
Bandar
Chuiba
Ruda
Fishing community
H
0.75
0.50
0.25
0.00
no
yes
Fisher?
I
Social life
0.75
0.50
0.25
0.00
no
yes
Fisher?
J
Social life
0.75
0.50
0.25
0.00
-1
0
1
2
Years in comm.
K
Job satisfaction
1.00
0.75
0.50
0.25
0.00
0
2
4
Household size
L
0.75
0.50
0.25
0.00
no
yes
Fisher?
negative
neutral
posi
negative
neutral
posi

Figure 4-7

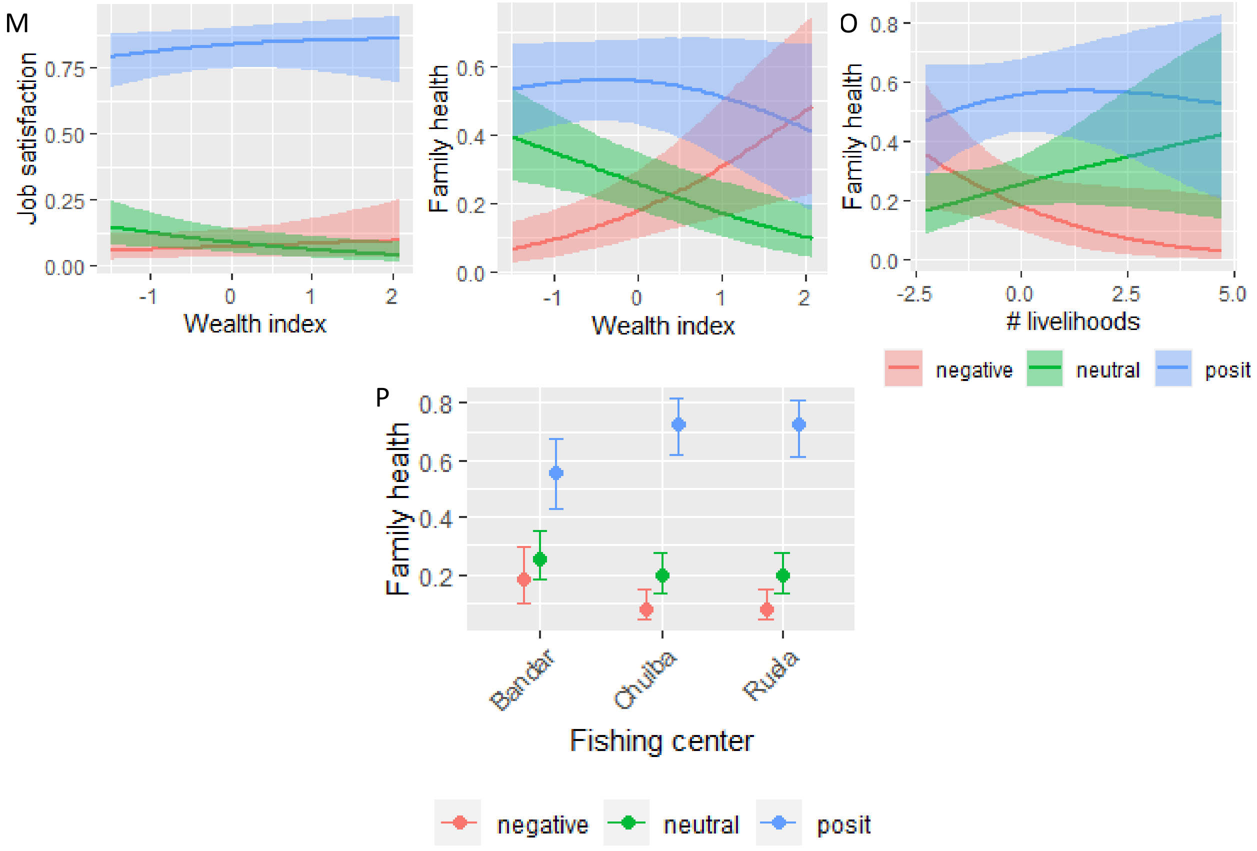

Figure 4-7 (continued): Conditional effects of the significant factors affecting overall wellbeing (A and B), safety and security (C and D), confidence in finding help (E and F), satisfaction with family (G and H) and social life (I and J), job satisfaction (K to M), and subjective health (N to P). Red indicates a negative response, green a neutral response, and blue a positive response.

Fishers' characteristics based on fishing method

There were some differences between fishers' characteristics based on the method they used. Education was significantly higher for vessel owners compared to most other methods. Vessel owners and purse-seine workers had larger households and higher MSL scores than other methods. Mosquito net fishers had the lowest MSL scores with gillnet, handline, and spear fishers in the middle. Purse-seine vessel workers had fewer livelihoods than most other methods. Age and years in the community were overlapping for all fishing methods (Figure 4-8). The results from the Bayesian models of fisher characteristics as determined by their fishing method generally confirmed the differences noted in Figure 4-8, but these do not include the effects of other variables, such as community, on these fisher characteristics.

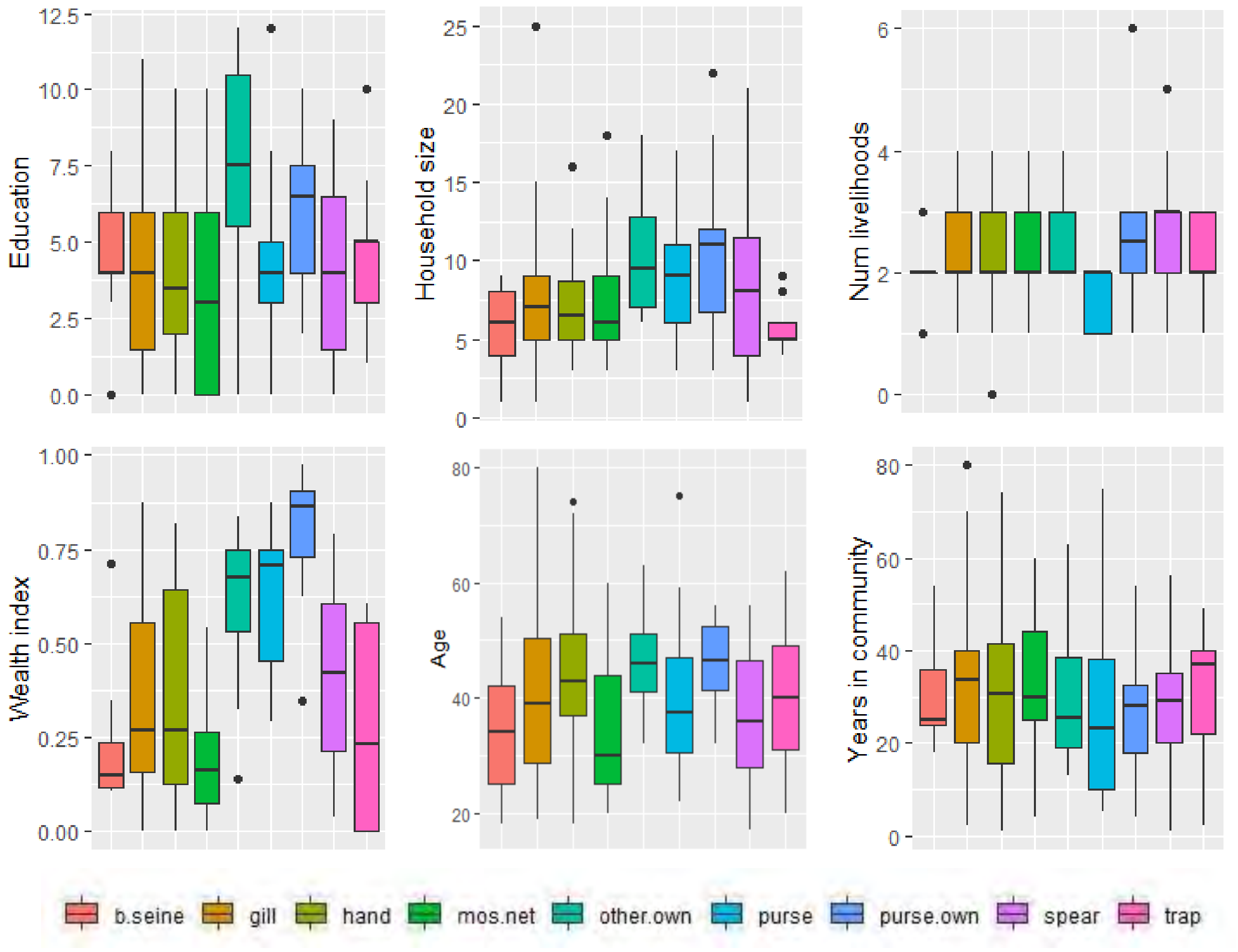

Figure 4-8: Boxplots of different household characteristics of fishers using different fishing methods. Note all communities are grouped in the data.

The models of MSL based on fisher individual characteristics and either fishing method or catch characteristics of method showed similar fits as the wealth model for combined fishers and non-fishers (Appendix III, Figure III-1 for the model with fishers and non-fishers). These models followed the general shape of the data, but did not capture it completely. In both models, standard education, household size, and being in Ruela, positively correlated with MSL. Once other variables were accounted for, the only significant differences in wealth scores between fishing methods were that purse-seine vessel owners had higher wealth scores than beach-seine, mosquito net, or trap fishers (Figure 4-9 A). Standardized average catch value for fishers' methods was almost positively correlated with the fisher's MSL (Table 4-4 and Figure 4-9 B). Neither CV of catch nor proportion of catches which were sufficient were significantly correlated with MSL nor was access to loans.

Table 4-4: Model coefficients of the MSL model using individual fisher characteristics and catch characteristics as explanatory variables. * Indicate variables which have 95% confidence intervals which do not include zero. All numerical values are standardized.

Variables	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept	0.26	0.06	0.14	0.39	*
Education	0.08	0.02	0.03	0.12	*
Years in community	0.02	0.02	-0.02	0.06	
House hold size	0.05	0.02	0.01	0.08	*
Male	0.06	0.06	-0.06	0.17	
Chuiba	0.06	0.06	-0.05	0.17	
Ruela	0.28	0.06	0.17	0.39	*
Monetary value	0.03	0.02	-0.01	0.07	
CV of catch	-0.02	0.03	-0.08	0.04	
% Sufficient	-0.02	0.04	-0.10	0.05	

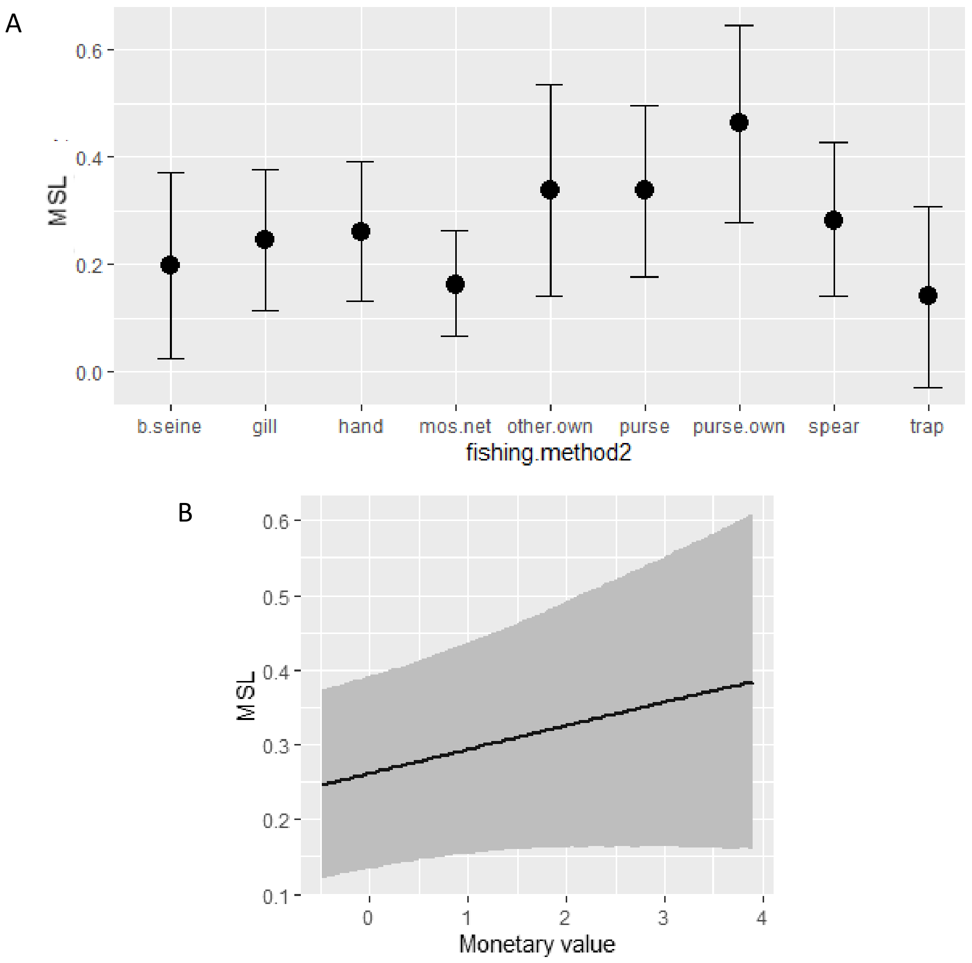

Figure 4-9: Conditional effect of fishing method (A) and average monetary value of catch (B) on MSL. B.seine indicates beach-seine fishing, other.own indicates an owner of a gillnet or beach-seine net and vessel, and purse.own indicates that the person owns a purse-seine vessel.

There were differences in the perceptions of wellbeing of fishers using different methods. For example, beach seine fishers all said working or fishing makes a good life, whereas most mosquito net fishers said having material possessions makes a good life (Figure 4-10 A). There were also differences in fishers' access to financial resources between groups with vessel owners being the most likely to have received a loan and purse-seine and beach-seine workers being the most likely not to own any of their livelihood materials (Figure 4-10 B). There were some differences between fishers using different methods on the odds that they gave positive, neutral, or negative subjective well beings. The only differences that were significant were beach-seine workers having greater family life satisfaction than purse-seine workers (coefficient=-3.7, CI (-6.5, -1.3)) or owners (coefficient=-2.8, CI (-5.7, -0.4)) and beach-seine workers having more satisfaction in their social lives than vessel owners (coefficient=-2.6, CI (-5.1, -0.5)) (Appendix III, Figure III-3). The ordinal Bayesian models of wellbeing of fishers based on method or catch characteristics showed similar matches to the data as the previous models of wellbeing. Average value of catch was positively correlated with satisfaction with family (coefficient=2.5, CI (0.4, 5.5)) and work life (coefficient=2.4, CI (0.3, 5.1)) (Figure 4-11 A and B). CV of catch was negatively correlated with family life satisfaction (coefficient= -1.7, CI (-3.5, -0.3)) (Figure 4-11 C). For these significant relationships, there was an apparent threshold above or below which (for value and CV respectively) satisfaction was fairly high. All other aspects of wellbeing were not correlated with any catch characteristics in these data.

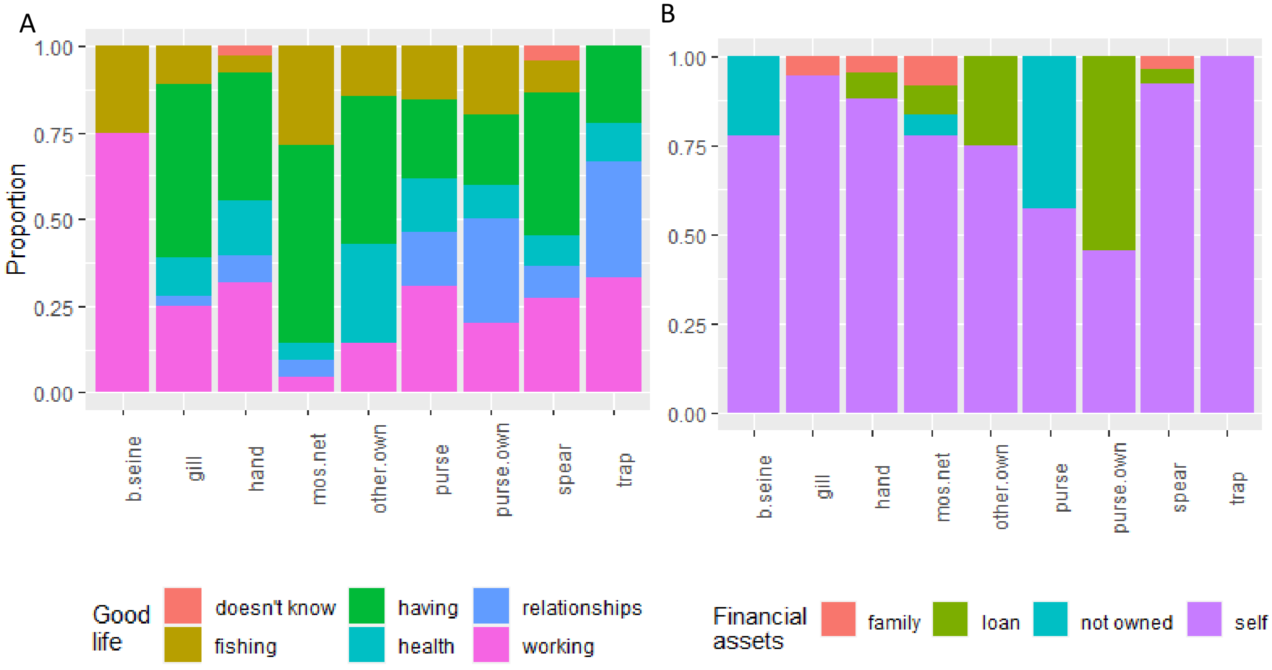

Figure 4-10: Fishers' definitions of what makes a good life (A) and their use of financial resources (B) based on the fishing methods they use.

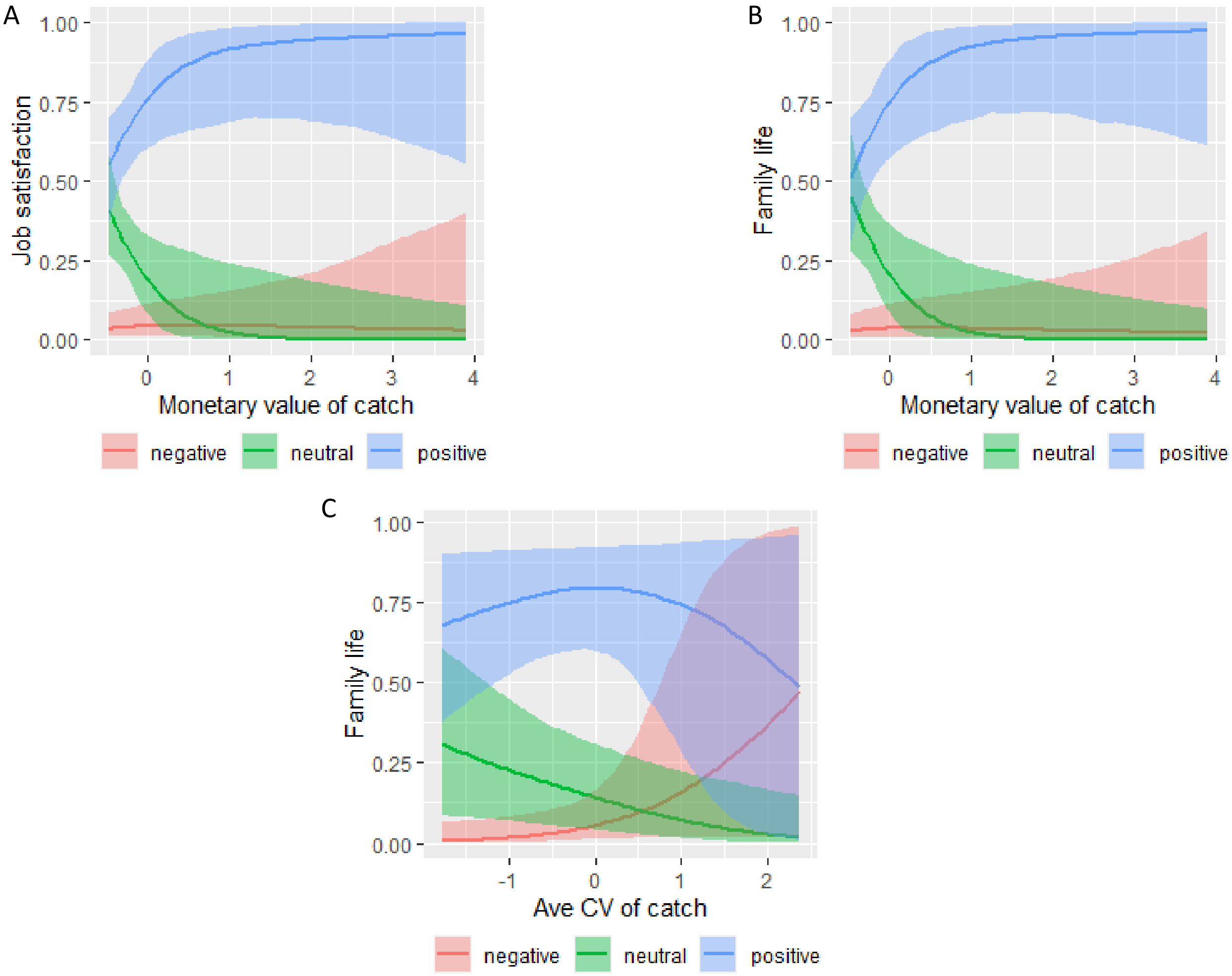

Figure 4-11: Conditional effect of average monetary value or CV of biomass on job satisfaction (A) and family life (B and C).

Commitment to fishing

Overall, 76% of fishers stated that the fishery was in bad condition, with only 11% saying it was in good condition and 86% said that the fishery had gotten worse since they started fishing (Figure 4-12 A and B). In response to declines in the fishery, most fishers said they had increased their effort (40%). Thirty-eight percent said they did not do anything in response to perceived fishery decline, 13% said they changed how they fish, and only 9% said they decreased their fishing effort to focus more on other livelihood activities. However, the fact that the data showed little movement away from fishing was biased by the fact that only current fishers were asked about their change in behaviour. Non-fishers were not asked if they used to fish and why they stopped. There were obvious differences in the common adaptations for different fishing methods (Figure 4-12 C). For example, many beach-seine workers decreased there fishing effort, whereas fishers using all other methods increased it. Spear and trap fishers often claimed no change in their behaviour due to changes in the fishery. And vessel owners were much more likely than other groups to say they changed how they fish in some way other than increased effort.

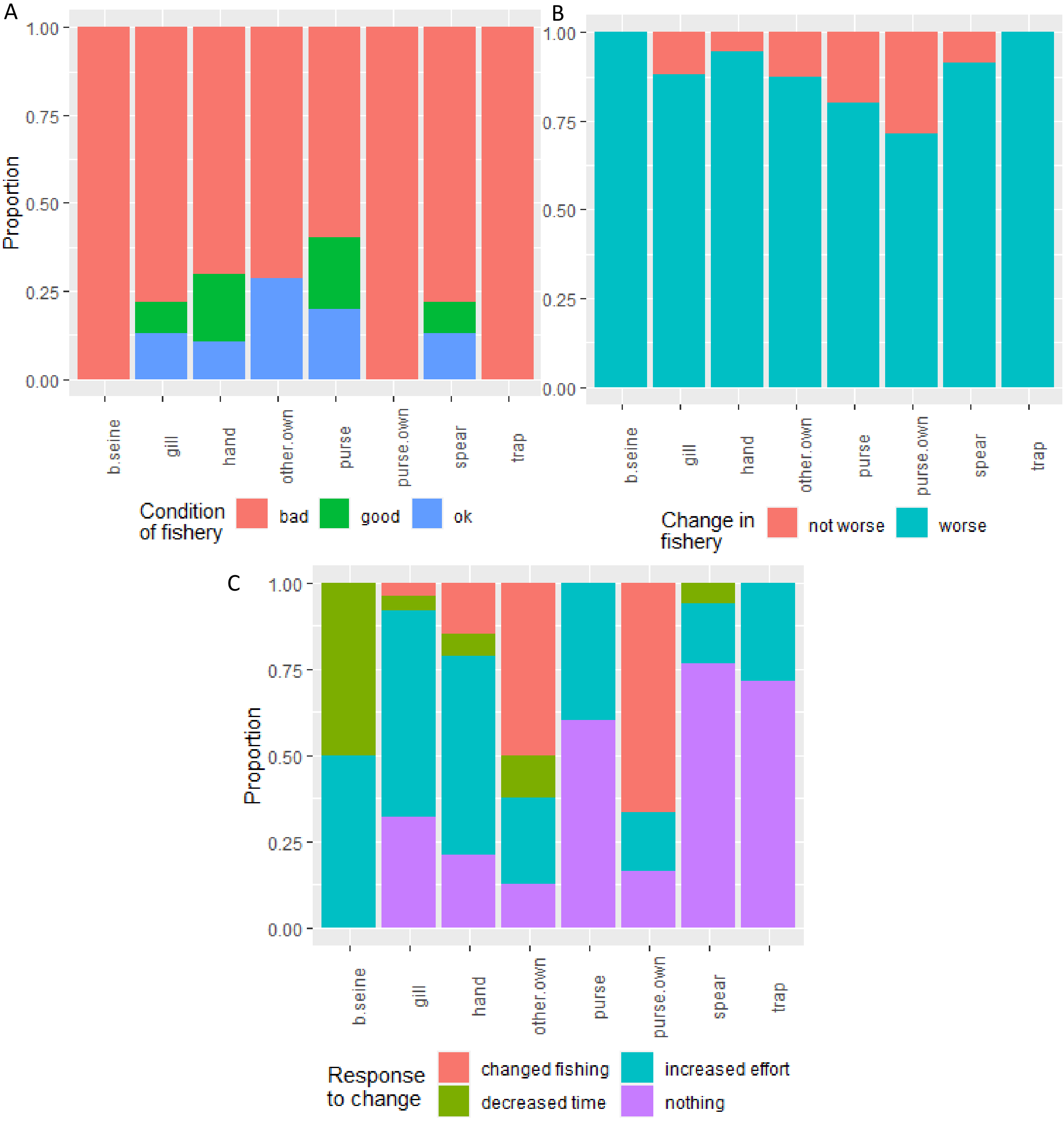

Figure 4-12: Fishers' perceptions of the state of the fishery (A), how it has changed (B), and how they have adapted to those changes (C) based on their fishing method.

In total, 20% of fishers mentioned something other than catching fish that they like about fishing. These responses included things like recreational activities on the water, enjoyment of being on the water, and excitement about the feel of a fish on the line. There were apparent differences in the proportion of fishers who mention likes or dislikes between methods (Figure 4-13). For example, many vessel owners using gill or beach-seine nets mentioned things they like about fishing, whereas purse-seine owner and workers mentioned dislikes more often.

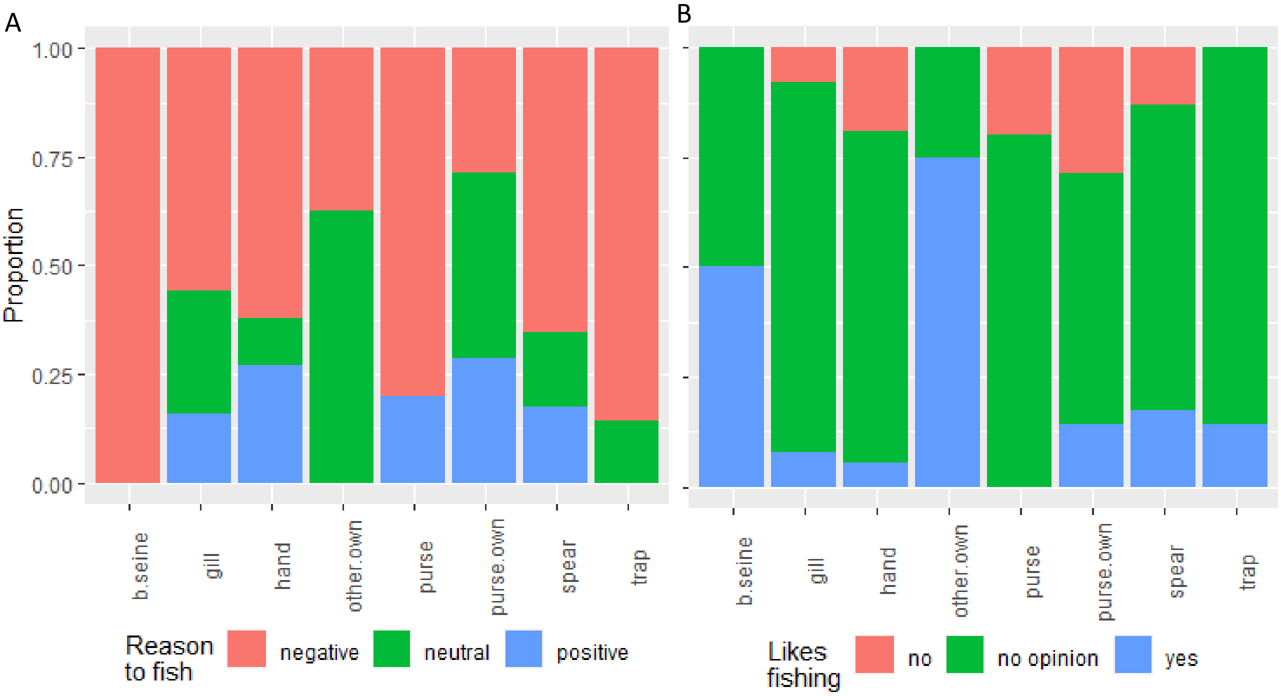

Figure 4-13: Fisher stated reasons for fishing categorized as positive, neutral, or negative (A) and proportion of fisher who mention something they like or dislike about fishing (B).

The majority of interviewees gave negative reasons for fishing (68%), generally lack of work or because it is all they knew how to do. As one woman put it, “We suffer, so we fish. But we are afraid because we are not allowed to fish in the temporary closure.” This woman alluded to a sense of marginalization that many fishers implied. Or as another man stated, “Other activities require money to be learned, fishing can be done without learning.” Several fishers mentioned lack of formal education as a reason they had to fish. Only 15% gave a positive reason for fishing. For example, one fisher said it was because he was from the coast and liked working on the water. Another mentioned that while it was true that there were few opportunities for other work, fishing was a family tradition, it made good money, and paid daily.

In contrast to the negative reasons for fishing given in interviews, in workshops around Pemba Bay, fishers displayed a pride and commitment to fishing. A fisherman in Metuge commented that, through fishing, he raised 22 children and built a house. He bristled at the implication that he fishes only out of desperation, stating that fishing was a respected profession. This sentiment was echoed by many in this workshop. One fisher commented that through fishing he was able to survive without resorting to theft and other illegal behaviours. The spokesperson giving a summary of the fishers' discussion in Ruela commented on how being a fisherman contributes to their self-esteem as well as their survival. When talking with a group of fisherwomen in Chuiba about the possibility of getting a boat as a collective and potentially fishing fewer days if they could catch more total fish for the week, they dismissed the idea of fishing less. They said they would want to fish more days even if they could catch more than they do currently in fewer days, indicating some considerations other than catch in their fishing decisions. In all workshops, fishers defended fishing as a profession.

The Bayesian ordinal model of reasons to fish showed good match with the data (Appendix III, Figure III-4). Standardized average value of catch was positively correlated with the odds that a fisher gave a neutral reason for fishing but not a positive one. CV of catch and proportion of catches which were sufficient were positively correlated with the odds of giving a positive reason for fishing (Table 4-5 and Figure 4-14). The positive correlation between CV and positive reasons for fishing was not expected. This indicated that fishers using more unreliable methods were choosing to fish rather than being forced into it. The correlation between proportion of catches which were sufficient and CV of catch was -0.60, which was close to our correlation limit of an absolute correlation of 0.7 or higher requiring dropping one of the variables. So, it was possible that the positive correlation between CV of catch and odds of giving a positive reason for choosing to fish was due to an interaction between proportion sufficient and CV of catch. Running the model with an interaction between the two variables, or removing proportion sufficient, caused correlation between CV and positive reasons for fishing to become non-significant. However, these models were slightly worse based on ELPD than the original model. It was also possible that some social component of less reliable methods made fishers using them more likely to want to be a fisher. The correlation between average number of fishers and CV of catch was moderate (0.59). Adding standardized mean number of fishers per fishing trip as a coarse measure of this social component gave a model which was statistically indistinguishable from the model without it (ΔELPD= -0.9, SE=2.2). Number of fishers was positively correlated to the odds that a fisher gave a neutral reason for fishing, but it did not change the relationship between catch CV and probability of giving a positive reason to fish.

Table 4-5: Model coefficients from the ordinal model of reseasons people choose to be fishers ranked from negative(1) through positive (3). Coefficient [1] give the influence on transitioning from negative to neutral, [2] give the influence on transitioning from neutral to positive.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept [1]	1.96	0.61	0.84	3.25	*
Intercept [2]	2.09	0.86	0.55	3.86	*
Condition of fishery good	0.36	0.39	-0.43	1.14	
Condition of fishery ok	0.77	0.47	-0.14	1.71	
Change in fishery worse	0.80	0.55	-0.20	1.97	
Monetary value [1]	0.62	0.28	0.09	1.20	*
Monetary value [2]	-0.73	0.35	-1.43	-0.04	*
CV of catch [1]	-0.83	0.49	-1.84	0.08	
CV of catch [2]	1.94	0.72	0.58	3.44	*
% Sufficient [1]	-1.04	0.66	-2.40	0.15	
% Sufficient [2]	3.69	1.28	1.56	6.49	*
Education [1]	0.14	0.37	-0.59	0.85	
Education [2]	1.35	0.53	0.35	2.42	*

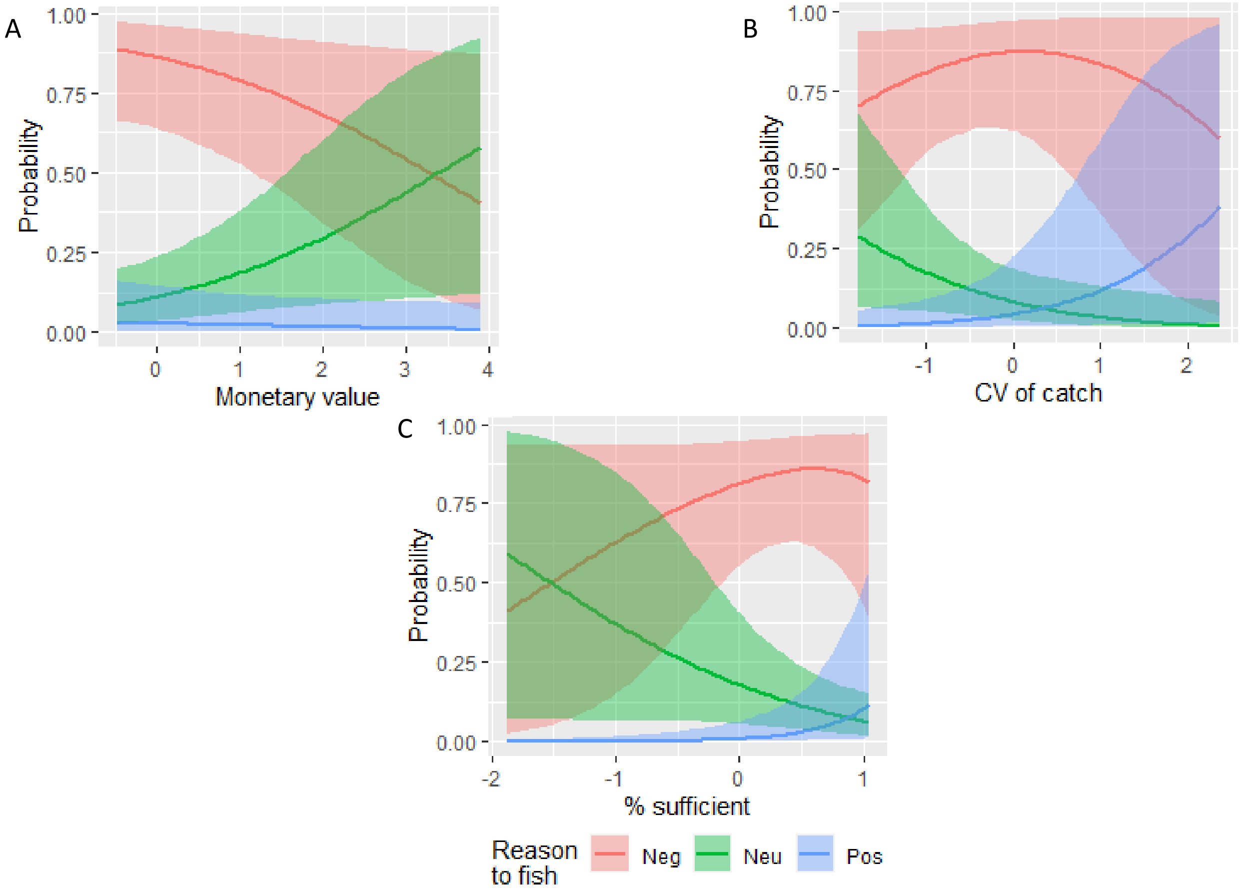

Figure 4-14: Conditional effects of monetary value (A), CV of catch weight (B), and proportion of catches which are sufficient for household protein requirements (C), on fishers' reasons to fish, red indicates a negative reason, green a neutral one, and blue a positive reason to fish.

Most fishers indicated a willingness to decrease their fishing activities. Eighty-eight percent of fishers said they wanted a different job and/or didn't want their children to be fishers, although interestingly, there was not complete overlap between responses to the two questions. No catch characteristics had significant effects on the odds of stating a desire for other employment or for their children to be fishers. Nor were fishers who felt more positively about the fishery or how it was changing less likely to want other employment or more likely to want their children to be fishers. On the contrary, fishers who said the fishery had gotten worse were more likely to want their children to fish (Figure 4-15 B). If instead of using the condition of the fishery, fishers disliking something about fishing was used to explain desire for alternative employment or wanting their children to fish, mentioning a dislike of fishing had a significant effect in both models (Table 4-6). Fishers who mentioned things they dislike about fishing were significantly more likely to want alternative employment and less likely to want their children to be fishers (Figure 4-15 A and C). In a workshop with fishers in Metuge, when declines in the fishery were discussed, one fisher mentioned that they were unable to quit fishing despite declines in catch. When asked about what their children would do if all the fish were gone, he said they need to study so they can do something else. This generally agrees with interview responses. Fishers desire to leave the fishery may be overstated in interviews however, because the question did not specify that having a different job meant the person had to stop fishing.

Table 4-6: Model coefficients for the odds that a fisher wants a different job (A) or wants their children to fish (B) from the model with the highest ELPD. All numeric variables are standardized.

A

Variable	Estim	Est. Error	l-95% CI	u-95% CI	Sig
Intercept	2.33	0.53	1.41	3.48	*
Monetary val	0.70	0.71	-0.40	2.36	
CV of catch	-0.89	0.63	-2.21	0.25	
Education	1.61	0.51	0.67	2.67	*
Household size	0.47	0.37	-0.22	1.26	
Prop sufficient	-0.20	0.85	-1.98	1.35	
Dislikes fishing	22.02	29.75	1.12	90.69	*

B

Variable	Estim	Est. Error	l-95% CI	u-95% CI	Sig
Intercept	-46.90	78.28	-214.70	-4.67	*
CV of catch	0.55	0.53	-0.46	1.61	
Fishery worse	44.35	78.26	2.22	212.60	*
Household size	0.52	0.25	0.03	1.03	*
Prop sufficient	1.87	1.13	0.02	4.37	*
Dislikes fishing	-37.10	96.27	-165.80	-2.15	*

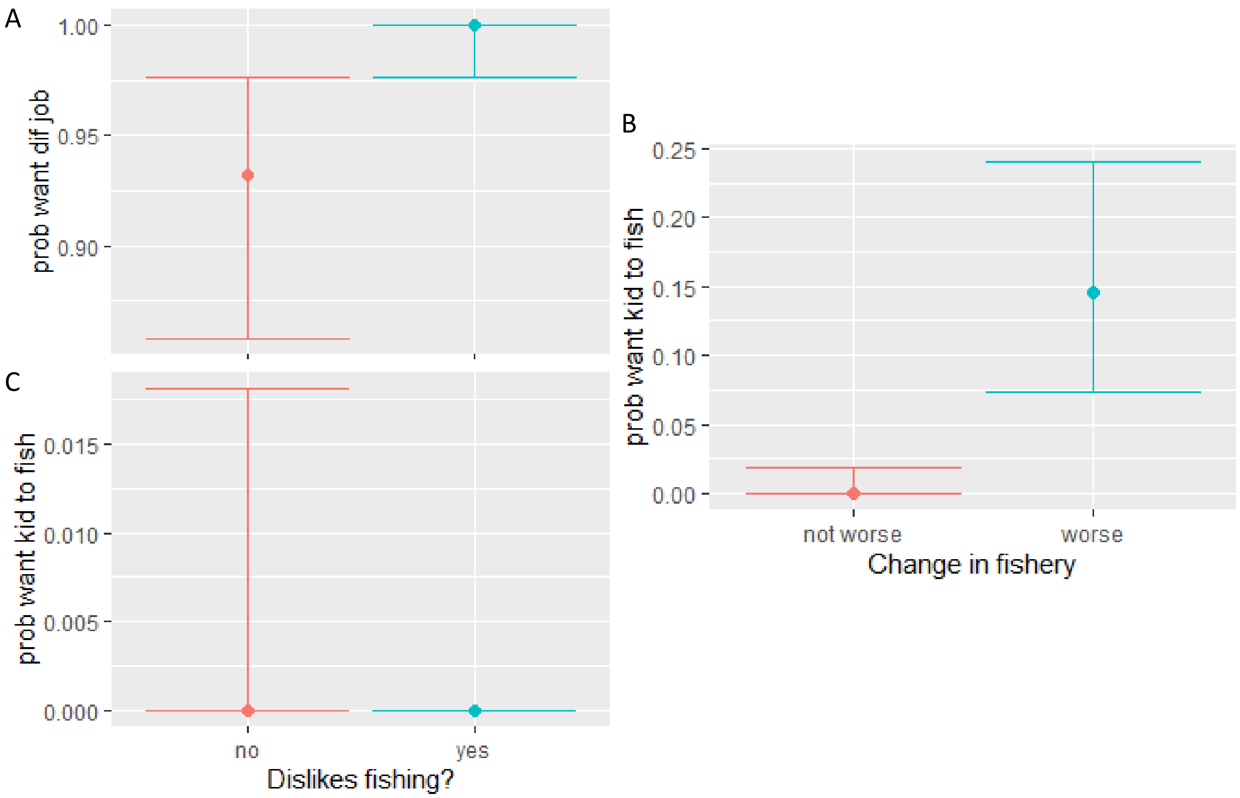

Figure 4-15: Conditional effect of fishers stating a dislike about fishing on their desire for their children to become fishers (A) and preference for different work (B) and perceived changes in the fishery on their desire for their children to fish (C).

Interestingly, of the 12% of fishers who claimed that fishing was what makes a good life, all of them, for which the data existed, indicated they would like a different job and did not want their children to fish. In fact, if fishers' definition of a good life was added to the model of wanting a different job and wanting their children to fish, defining a good life as fishing was significantly correlated with increased probability of wanting a different job and decreased probability of wanting their children to fish (Figure 4-16). However, people who felt that relationships were what make a good life were more likely to want their children to fish and less likely to want a different job, indicating a possible social aspect to fishing which was not well captured in the current study. Having, working, and health were associate with larger probabilities of wanting their children to fish than those who defined a good life as fishing.

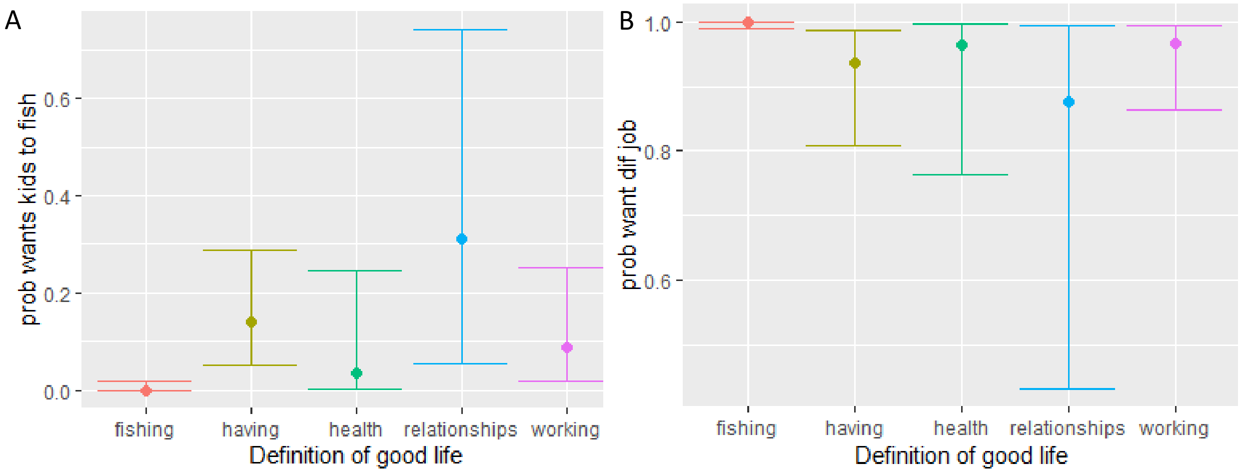

Figure 4-16: Conditional effect of an individual's definition of a good life on their desire for alternative employment (A) and wanting their children to be fishers (B) based on the Bayesian model.

Discussion

This chapter addresses the social outcomes from fishing appropriation action situations based on Hinkel *et. al.'s* (2015) formalization of Ostrom's SES framework (Ostrom, 2009). The basic question is whether fishers' well-beings are equivalent with non-fishers and the extent to which catch characteristics affect their well-beings. The hypotheses are that fishing in Pemba Bay is a reasonably profitable livelihood for the area and, therefore, fishers' wealth and wellbeing are similar to non-fishers in the area, that wealth and wellbeing are related to catch profitability or reliability, and that fishers are committed to fishing as a way of life.

The first part of the hypothesis is partially supported in that, for most fishing methods, fisher MSL scores are similar to non-fishers, as is overall subjective wellbeing and subjective family health. Material standard of living for mosquito net and beach-seine fishers appear to be lower than non-fishers and fishers using other methods, therefore, these particular methods may be a livelihood of last resort (Béné, 2003). However, other fishing methods do not fit with these assumptions of fishers being the poorest in their communities. These hypotheses on fishing and poverty assume that there are few barriers to entry for fishing, and our data indicate some places where this is not true. The costs of fishing materials, especially for vessel owners, are high, which is likely to limit entry into purse-seine and beach-seine fishing. Additionally, spearfishing, in particular, is mentioned as being technically difficult. These barriers for non-fishers to start using most fishing methods may explain why these methods can continue to make decent profits for the area. However, it should be noted, the overall wellbeing and MSL are relatively low for all respondents. Less than half of respondents say they are satisfied with their lives (51% of non-fishers and 41% of fishers). And Baex *et. al.* (2018) estimated that 50% of the population in Cabo Delgado was living in poverty. So even though fishers are not worse off than their non-fishing neighbours in general, the entire community is relatively poor.

While fishers are similar to non-fishers in their wealth and overall subjective wellbeing, they have lower specific subjective wellbeing scores in many aspects. There appears to be some aspect of the fishing experience that decreases fishers' feelings of safety, confidence in finding help in the community, and satisfaction with work, family, and social life. The stress and unpredictability of fishing may cause these decreases in subjective wellbeing. Reid (2017) found that money and jobs were the main contributors to lower subjective wellbeing. Attah *et. al.* (2016) found one of the benefits of consistent payment to poor families in sub-Saharan Africa were decreased stress due to knowledge that they would be able to afford basic necessities. Additionally, self-esteem and relationships improved as recipients became more confident that they could contribute in their relationships (Attah *et. al.* 2016). The lack of consistency in catches may have the opposite effect by increasing stress because fishers do not know that they will be able to pay for essential materials, even if ultimately, most of them can. Additionally, as the fishery is perceived to be in decline, this could increase their stress.

It is also possible that these differences are due to sampling technique. Only fishers received full interviews and most fishers indicated that catches were declining and worried that there were fewer fish, so reminding them of this before asking about how they feel may have caused more negative perceptions. Using sampling method instead of if a fisher to account for these correlations is not supported based on the ELPDs of the models. Additionally, Pudney (2010) did not find a difference in reported subjective wellbeing scores based on the location of the question within their interviews. Therefore, it seems unlikely that these differences in subjective wellbeing are an artifact of interview method, but it is still possible.

Material standard of living and overall subjective wellbeing are not lower for fishers than for non-fishers around Pemba Bay. However, fishers are less educated on average and have more people living in their houses. Lack of education is mentioned by many fishers who feel they have no choice but to fish. And education is an important predictor of a person's MSL score. This lack of education should cause fishers to have lower levels of MSL. It appears, however, that fishers compensated for lower levels of education through larger household sizes, which is positively correlate with MSL in this study. The tendency of fishers to have larger families and diversify their livelihoods may be adaptive behaviours to allow higher standards of living while still fishing. Cinner *et. al.* (2010) found that fishers in Kenya had greater livelihood diversity than their non-fishing neighbours. They posit that the high risk involved in fishing makes fishers more likely to diversify their livelihood portfolios. To address this possibility, a correlation between the number of livelihood activities that fishers use and the reliability of their fishing method was checked, but no correlation was found. However, this study does not have the data to look at the difference between the overall predictability of fishing as a livelihood compared to other livelihoods. It is possible that the range of variation within fishing is small compared to the difference between fishers and non-fishers in livelihood predictability. It is possible that the riskiness of fishing in general causes livelihood diversification to be more common among fishers. However, Tucker *et. al.* (2013) found that in Madagascar, farming was considered riskier than fishing. This could be an indication that Madagascar's fisheries are more intact, although this is unlikely (Andréfouët *et. al.*, 2013), or caused by local soil or weather patterns. No matter the cause, it indicates that assuming fishing is seen as risky may not be accurate.

The second hypothesis that fishers with either more reliable or more profitable catches have higher material and subjective wellbeing is not well supported. Average catch value is somewhat correlated with MSL scores of fishers, but this trend is not significant, and CV of catch is not correlated with MSL. Fishers with higher average catch value and lower variability indicate greater satisfaction with family life, but this plateaus for both predictors, indicating that using the least profitable methods or most unreliable ones decreases satisfaction with family life, but little difference past that. Fishers tend to have larger families and practice more livelihood activities in general, so profits from fishing only provide some of the resources for fishing families which could be the reason that there is not a correlation between MSL and catch characteristics.

It is also surprising that catch characteristics don't have more effect on subjective wellbeing based on the discussion above about the importance of economic considerations on wellbeing. From the above, it appears that predictability of income may be as important as actual income in reducing stress and allowing more focus on other aspects of life. From these data, it appears that even fishers using methods which make a decent income overall and are relatively predictable still suffer from stress related to fishing. However, the lack of correlation between catch and MSL or subjective wellbeing could also be methodological. Catch characteristics are based on averages for the community and fishing method rather than individual profits or reliability of catches. Since these data cannot distinguish between highly successful fishers using a method and those who are less successful, they cannot determine how individual catch characteristics affect the individuals MSL and wellbeing. Initial interviews included questions on fishing profits; however, these questions made fishers uncomfortable, so were dropped from later interviews.

The third hypothesis that fishers using more reliable or profitable fishing methods are more committed to fishing is not supported. Catch average value and reliability are both correlated with the odds that fishers give a positive reason for being fishers. Yet this does not translate into greater commitment to fishing. Fisher commitment to fishing is complicated by inconsistency between interview responses and workshops. At workshops, fishers defend fishing as a respectable profession, not something one does out of desperation.

It is possible that the seemingly incongruous results between interviews and workshops are caused by the question not specifying whether fishers would stop fishing if they had a different job. Often, when alternative employment projects occur, fishers engage in both fishing and the new activities (e.g., Hill *et. al.*, 2012). Hanh and Boonstra (2019) argued that researchers often misunderstand fishers' motivations for alternative employment. They found that older people working in fisheries and aquaculture were interested in alternative livelihoods to supplement their marine activities, while their children were trying to get out of the occupation altogether. Fishers in Pemba most likely follow similar patterns. Fishers' overwhelming desire for alternative employment is most likely thought of as a supplement to fishing rather than as a replacement. Fishers' ownership of fishing materials also makes them less likely to exit the fishery entirely. Daw *et. al.* (2012) found most fishers stated an unwillingness to leave the fishery even with a 50% decrease in catch, but that contrary to their expectations, wealthier fishers were less likely to leave than poorer ones who tend to have diverse livelihood strategies. Blythe (2015) found community level infrastructure decreased fishers' resilience to changes in the fishery in central Mozambique as well. At individual and community levels, having assets in fishing equipment or infrastructure makes exiting the fishery more difficult.

Despite fishers stating a desire for alternative employments, very few decreased their time on fishing to focus more on other livelihoods in response to perceived changes in the fishery. Béné *et. al.* (2016) found that fishers rarely responded to crises by decreasing fishing. This makes sense in that exploring is costly (Wilson, 2017), and when it is difficult to meet current needs, people are unlikely to take the time and mental energy to commit to other activities, even looking for better alternatives (Shah *et. al.*, 2012). Additionally, exploring to find more profitable alternatives often decreases short term gains and leads to less reliable outcomes (Osiyevskyy *et. al.*, 2020). There is some indication that vessel owners, who have the most resources tied up in fishing equipment, are also the most likely to vary how they fish rather than just increasing effort, however they have not decreased their fishing effort. It is possible that fishers with more resources overall feel more confidence to explore somewhat, or that people more comfortable with exploring different options are more likely to become vessel owners. These data cannot address either possibility.

While interview and workshop responses seem to contradict each other about fishers' willingness to decrease fishing effort, they are in agreement about fishers' desire for their children to find alternative occupations. Many see declines in the fishery and some assume their children will not be able to survive on fishing. Ha and van Dijk (2013) found the same in Vietnam where 65% of fishers interviewed did not want their children to be fishers due to concerns about declining catches. Also, as mentioned above, Hanh and Boonstra (2019) found younger people generally wanted alternative livelihoods to exit the fishery, indicating some agreement between generations that fishing may not be a viable alternative in the future. Only 12% of respondents in this study hoped their children would be fishers. Catch characteristics do not correlate with the probability of interviewees wanting their children to fish. However, there is a slight indication that people who value relationships and use them to define a good life are more inclined for their children to be fishers. Also, fishers who mention specific things they dislike about the fishery are less likely to want their children to fish than others. There appear to be qualitative values to fishing for some fishers which are not captured in this study, but may be important in understanding some fishers' commitment to fishing as a way of life.

Comments on methodology

This section of the study depends on fisher interviews and average catch characteristics, both of which can cause issues with the data. As mentioned in the last chapter, the interview data could be misinterpreted in many ways. Translation of interview questions from Portuguese to Macua occurred as a collaborative effort over a few days to assure that the intention of the questions was understood by translators, however, misunderstandings were still possible. In the translation back to Portuguese by translators, and then to English by the primary researcher, differences in intended meaning are also possible. As mentioned above, most interviews were recorded so that these translations could be checked, but this has not occurred. Workshops with fishers allow another avenue to confirm or contradict results from interviews, both of which occur in these data. When workshop and interview data agree this gives greater credibility to the data. When they disagree, it indicates potential misunderstandings which need to be addressed.

Despite these potential problems, the major findings should be robust regarding these issues. Material standard of living is determined by presence of physical items: type of house, source of water, etc. Therefore, misunderstandings about the exact answer to questions is unlikely to have an effect. Subjective wellbeing scores were simplified to a three-point scale. Many other studies use a five-point scale rather than a three-point scale (e.g., Reid, 2016). This was also attempted in this study, but increased frustration between interviewees and interviewers, so was simplified. Reid (2017) found few responses of subjective wellbeing which were very positive or negative, so it is unlikely that this simplification had much effect on the overall data. Using Likert scales makes misinterpretation of responses impossible if the person understood the question.

Questions about commitment to the fishery are also potentially problematic. Specifically, the primary researcher did not specify whether having another job meant exiting the fishery or expanding the livelihood base. This was an oversight; however, it does not change the basic pattern of most fishers suggesting a willingness to decrease their fishing effort. The direct question about whether fishers want their children to also be fishers is less ambiguous and also indicates lack of commitment by most to fishing. Overall, the use of several questions to address attitudes and commitment to the fishery allows relative confidence in these results as do some aspects of the workshop results, but not all, as discussed above.

The use of average catch characteristics based on fishing method use eliminates differences between fisher catches based on their individual abilities. Initial interviews attempted to address these differences in fishing catch profitability and reliability by asking about average catch and income from fishing. Fishers were uncomfortable with these questions, and so they were dropped in later interviews. The study also attempted to get some fishers in the area to keep fishing journals with their catch from every day for analysis. This also proved impossible within the current setting. Multiple creel surveys or fishing trip observations for each fisher interviewed could provide individual level measures of catch profitability and reliability. This would have required more time and financial resources than were available for the current study, but may be incorporated in an adaptive management plan and is addressed in the final discussion (page 154). The extent to which the lack of correlation between fisher MSL and wellbeing and fishing catch profitability or reliability is affected by the use of average values is unknown.

Conclusion

The social outcomes from fishing indicate that fishers using most methods are as well-off materially as non-fishers in the area. This indicates that fishing is not the last resort of all the livelihood options available around Pemba Bay. However, there is a lot of poverty around Pemba Bay, so while fishing allows a comparable lifestyle to other livelihood options, this is not an indication that fishers are well-off. Still, as many fishers mention in workshops, fishing allows them to support themselves and their families. Despite fishing allowing similar MSL, it appears that the stress of fishing causes decreased wellbeing. This indicates stress in the social component of the fishery SES around Pemba Bay. Based on fisher comments about the poor and worsening state of the fishery, their apparent willingness to decrease their fishing effort, if not exit the fishery entirely, and the current costs to fishers in wellbeing, the fishery is poised for some form of change. However, without intervention from collective actions or external assistance, it is unlikely that most fishers will drastically change their behaviours even as resources decline. This could lead to a poverty trap (Gunderson and Holling, 2002). Carpenter and Brock (2008) mention that in these situations, there is a lot of potential for innovation, but without some resources to promote these innovations, they are difficult to achieve. This is considered further in the final discussion (page 154).

Chapter 5 Ecological impacts of fishing

Abstract

This chapter addresses the ecological differences between Pemba Bay and other areas in Northern Mozambique with lower fishing, and other anthropogenic, pressure. It uses stereo baited remote underwater videos to assess mobile marine and habitat characteristics in the different areas. The data show that Pemba has significantly lower biomass and smaller specimens than other sites in the area. However, functional diversity is not significantly different. Additionally individual lengths and functional group biomasses are not correlated with fishery catch in Pemba Bay. So direct removals by fishing is not the only cause of differences between sites. These data, in conjunction with other studies in the area, suggest that the fishery is at or below the lower limit for sustainability and needs to be managed carefully to promote human and ecosystem wellbeing.

Introduction

There is a growing understanding that small scale fisheries can have drastic detrimental effects on local marine ecosystems (Johnson *et. al.*, 2013). Fishing often causes decreases in fish biomass (Campbell & Pardede, 2006; McClanahan & Kaunda-Arara, 1996), decreases in functional diversity of marine communities (Brewer *et. al.*, 2012; Martins *et. al.*, 2012), and decreases individual sizes as larger individuals are targeted (Kuparinen & Merilä, 2007; Laugen *et. al.*, 2014). All these fishing effects can cause further impacts. Decreases in biomass of target species can cause cascading effects on predators and prey which can affect still more species (Chassot *et. al.*, 2005; Knight *et. al.*, 2005; Shurin *et. al.*, 2002). Loss of diversity can lead to decreased productivity of the system and decreased fisheries catch (Worm *et. al.*, 2006). Also, removal of the largest individuals can have immediate effects on population dynamics, as these individuals are often the most fecund, and longer-term effects based on changes in life history that decrease stock replacement rates (Kuparinen & Merilä, 2007; Law, 2007). Taken together, ecological impacts of fishing can decrease stock replacement to the fishery which would have direct effects on fishers who depend on the fishery, as well as on the fishery ecosystem.

Despite the potential impacts these fisheries can have on ecosystems and social systems, as discussed above, these fisheries are often data poor, and, in many cases, realistic estimates of catch are lacking (e.g., Jacquet *et. al.,* 2010). In Mozambique, small-scale fishing represents 75% of catch from 1950 to

2010 yet most of this was unreported to FAO (Doherty *et. al.*, 2015; Jacquet *et. al.*, 2010). Based on reconstructions of Mozambique's catch over this time, catch trends change from being largely increasing since 2000 to falling for all sectors since around 1980 (Doherty *et. al.*, 2015; Jacquet *et. al.*, 2010). Managing fisheries without even knowing if overall catch is increasing or decreasing is all but impossible.

Further, funding for management of small-scale fisheries is often insufficient compared to industrial fisheries, even though these fisheries seem to have similar total catches and employ far more people (Jacquet & Pauly, 2008). This is partly because the dispersed nature of the fishery with many landing sites often in remote areas with little infrastructure, which makes management more difficult (Jacquet & Pauly, 2008). Mozambique has over 1500 artisanal fishing centres (JONE & MALATE, 2013) and fishers do not always use these, but can instead go straight home from fishing. While small-scale fisheries have the potential to be sustainable, in the absence of management, unsustainable fishing practices can occur (e.g., Cinner & McClanahan, 2006; Johnson *et. al.*, 2013; McClanahan, Hicks, *et. al.*, 2008).

From the catch data from Chapter 3 above, it appears that Pemba catches in value per fisher per trip are relatively stable between 2012 and 2018. Yet previous surveys of Pemba reefs indicated that they were at risk of overexploitation (McClanahan & Muthiga, 2012). In interviews and workshops, many local fishers agreed that catches had declined, and there were fewer fish in the sea. In order to address the contradiction between catch data and fisher experiences, in-water observations can be used. By comparing marine communities within Pemba Bay with nearby areas with less fishing pressure, this study attempts to determine the ecological state of the fishery, whether it is stable, as catches suggest, or in decline as fishers and a previous study state.

Within the SES, as envisioned in the conceptual model (Figure 5-1), ecological impacts occur due to fishing decisions causing changes in the resource system. Other anthropogenic and non-anthropogenic causes of ecosystem change are not addressed in this study. If the fishery is subtractable, meaning extraction exceeds replacement, then fishing pressure around Pemba Bay can cause decreases in fish abundance, and probably size and functional diversity, within the bay compared to less fished sites in Northern Mozambique. The goal of this chapter is to understand the current state of the marine ecosystem in Pemba Bay compared to other sites in Northern Mozambique. This is accomplished by analysing in-water functional diversity, biomass, and individual sizes to determine differences which could indicate degradation of the Pemba fishery and the extent to which functional groups targeted by fishing are disproportionately negatively affected in Pemba compared to other sites. The hypotheses tested are:

h1) The fishing pressure around Pemba Bay causes lower marine biomass, functional diversity, and maximum fish size around Pemba Bay compared to other areas in Northern Mozambique with less fishing pressure;

h2) Direct removals of species due to fishing is the most important cause of the differences in biomass and/or size, so functional groups which are targeted by fishing are most negatively affected in Pemba Bay compared to other sites.

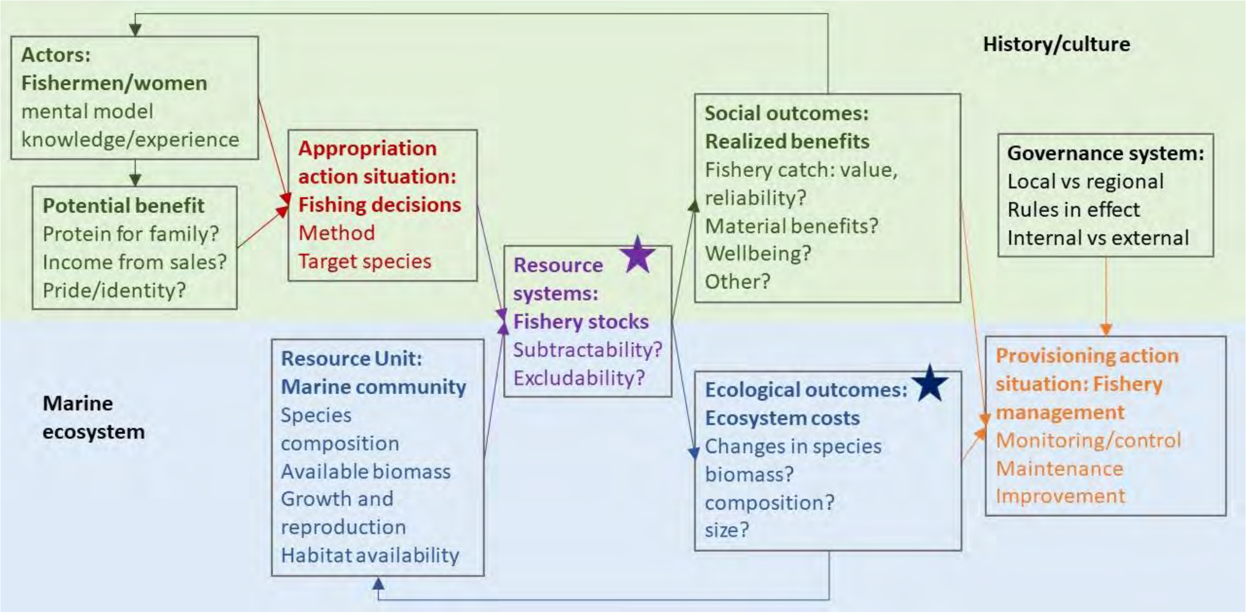

Figure 5-1: Reproduction of the conceptual model from the introduction indicating the part of the model addressed in this chapter by the first (blue star) and second (purple star) hypotheses.

Methods

Differences between Pemba Bay and other sites

To address the first hypothesis, stereo-BRUV data from four sites around Northern Mozambique including Pemba Bay were compared. Site locations and stereo-BRUV data collection and processing was discussed above in the general methods section (page 31). This chapter used functional groups to determine functional diversity, differences in abundance, and differences in individual sizes in Pemba Bay compared to other sites. The creation of functional groups was also discussed in the general methods section (page 33). Sites within Pemba Bay were compared with the three sites outside the bay using habitat characteristics, function group compositions based on proportional and total biomass estimates, and functional diversity measures. Habitat characteristics consisted of 34 morphotypes identified in the stereo-BRUV videos (page 33). Functional group compositions consisted of the 51 functional groups. Functional diversity measures had three variables: richness, evenness, and divergence. The creation of all these variables was explained in the general methods section.

Multinomial models of mobile and sessile marine communities

For habitat morphotype and functional group data, NMDS analyses were run to visualize differences between samples from different sites, followed by PERMANOVAs, pairwise PERMANOVAs, and CAPs. Together these analyses allowed determination of where differences between locations existed, the significance of those differences, and the extent to which community composition allowed for accurate predictions of a sample's site identification. MetaMDS in the vegan library in R (Oksanen *et. al.,* 2020) was used to run an NMDS on samples from the four locations around Northern Mozambique. Bray-Curtis dissimilarity measures were used (Bray & Curtis, 1957). A step-across algorithm to find the shortest path between two sites without any shared species was used when necessary (Williamson, 1978; Bradfield & Kenkel, 1987). These algorithms were used due to the prevalence of Bray-Curtis dissimilarities in analysing ecological abundance data. Step-across algorithms assist in sites with a lot of beta diversity, potentially causing samples with no shared species. This problem is resolved by optimizing the shortest distance between samples which do not share species by moving through intermediate samples.

This was followed by a PERMANOVA using the adonis function also in vegan. PERMANOVAs were run using first the full model, predictors for the full models of habitat morphotypes, proportion of functional groups, and biomass of functional groups is available in Table 5-1. All numeric variables were standardized using scale in R (R Core Team, 2020). Akaike Information Criterion corrected for small sample size (AICc) scores were used to determine the best-fit model using the AICc.PERMANOVA function (https://github.com/kdyson/R_Scripts/blob/master/AICc_PERMANOVA.R). Habitat variables, not including site, in the full model which were not significant were moved to the first position in the model to increase their odds of significance. If still not significant, the PERMANOVA with and without said variable were compared using AICc scores. If the AICc score without the variable was lower than with it, the variable was dropped and the process continued until no variable could be removed without increasing the AICc score. Site variables always occurred last in the formula to ensure that they were only considered significant if differences could not be explained by habitat variables alone. All numerical variables were standardized using scale in R (R Core Team, 2020). Pairwise comparisons of site locations were conducted using pairwise.adonis (Arbizu, 2020). These pairwise comparisons require that the categorical variable of site be added the model first, increasing the odds that they were significant. Other variables found in the best-fit models were included in the pairwise comparison after site.

Finally, the CAP was run using the CAPdiscrim function in BiodiversityR (Kindt & Coe, 2005). The CAP analysis used 999 permutations to allow significance testing. Due to differences in samples per site, CAPs were also run with equal sized samples from each site (n=11) with random samples from sites with more samples. One-hundred CAPs were run with these equal sized samples using 99 permutations due to computing time constraints.

Table 5-1: Response and predictor variables used in the full models of community composition PERMANOVAs.

Response var	# Of groups	Predictors in full models
Habitat morphotypes	34	Standardized depth, standardized relief, and site
Functional group proportions	50	Standardized biomass, water temperature, % water column, depth, visibility, relief, habitat 1*, habitat 2, habitat 3 and habitat 4, and site
Functional group biomass	50	Standardized water temperature, % water column, depth, visibility, relief, habitat 1, habitat 2, habitat 3 and habitat 4, and site

*Habitat 1, 2, 3 and 4 indicate the scores from the compressed habitat morphotype data calculated by the NMDS of habitat morphotypes above.

Functional diversity differences

For the functional diversity measures, Bayesian analyses were conducted with response variables of functional Richness, Evenness, or Divergence. For all models, predictors included sampled biomass, water temperature, % water column, depth, visibility, relief, habitat 1, habitat 2, habitat 3 and habitat 4, and site. All numeric variables were standardized using scale in R as above. This used the brm functions in the brms library (Bürkner, 2017) in R. There were five samples with outliers in the predictor variables, so these were removed and the model re-run to identify the extent to which these outliers affected the results.

Additionally, possible temporal autocorrelations were assessed using the acf function in R (R Core Team 2020). Spatial autocorrelation was assessed using bubble in the sp library (Pebesma & Bivand, 2005) to make a bubble plot of model residuals based on location. Due to possible autocorrelation evident in the bubble plots, a nearest neighbour association, based on Euclidian distance, was created using the dnearneigh function in the spdep library in R (Bivand & Wong, 2018). Sp.correlogram in the spdep library in R was used to graph the amount of autocorrelation with different levels of lag based on the nearest neighbour associations above. Spatial autocorrelation was found and accounted for using the spatial simultaneous autoregressive (sar) correlation structure within the brm models. Sar used a weight matrix to determine the correlation between samples based on Euclidian distance, which was created using the nb2mat function in spdep. Nb2mat converted nearest neighbour associations into a weight matrix. If autocorrelation remained the distance at which samples were considered neighbours was expanded until it disappeared. Models were validated using R-hat, ESS, and posterior prediction plots (Bürkner, 2019) using pp_check in brms (Bürkner, 2017).

Functional group abundance and fishery catch

This section used the stereo-BRUV data as above as well as catch data. Collection and processing of catch data was covered in the general methods section on catch surveys and estimating total catch (pages 27 and 30, respectively). Functional group catch was the sum of catch from all species within a given group. Average monthly catch for each functional group was used to determine any correlations between fishery catches and Pemba Bay abundance and size estimates compared with other sites from the stereo-BRUV samples.

To determine the extent to which marine community composition around Pemba Bay was directly affected by species removal from the different fishing methods, the relationship between biomass of functional groups and average monthly catch from the different fishing methods used around Pemba Bay was analysed. These monthly averages included all seasons, so the yearly average catch was the monthly catch multiplied by 12. This allowed assessment of direct effects only. Secondary effects such as trophic cascades could not be measured in this model. Fishing catch was averaged over the entire data set, 2012 through 2018, while stereo-BRUV data were only collected in 2017 and 2018. As ecological data should change over time with fishing pressure, understanding how the history of fishing affects ecological characteristics was considered. More detailed fishing metrics could be used in the future to determine if changes in fishing method use through time affect ecological characteristics.

If a fishing method was having a direct effect on the marine community based on species removal, then a more negative effect of catch on functional group biomass would be expected in Pemba Bay than other sites. This possibility was addressed in several Bayesian models. The first models analysed the differences in total biomass of samples from different areas using either site or distance from Pemba city centre as the variable of concern but including standardized depth, water temperature, percentage water column in video, visibility, relief, and habitat composition scores 1 to 4 as additional variables. All numeric variables were standardized using scale in R (R Core Team, 2020). Biomasses were not normally distributed, so a gamma distribution family was used in this model. Spatial and temporal autocorrelation in the residuals were assessed and addressed using sp.correlogram and acf as above. The models were validated using R-hat, ESS, and posterior predictions (Bürkner, 2019).

To determine site effects on functional group biomasses, a large Bayesian model using functional group biomass as the response variable and a combination of habitat and site variables as predictors was run. In total, this model had 9,027 biomass measurements, (51 functional groups multiplied by 177 samples), however only 3,121 of these were non-zero biomasses. To determine the effects of site on functional group biomass from stereo-BRUV samples, a Bayesian model was run with functional group biomass from stereo-BRUV samples as the response using a hurdle-gamma response distribution. As in the last model, predictors included standardized depth, water temperature, percentage water column in video, visibility, relief, habitat composition scores 1 to 4, and site. Unlike the last model, in this model, all predictors were grouped by functional group. Potential spatial and temporal correlation were assessed as above using sp.correlogram and acf. The model was validated using R-hat, ESS, and posterior prediction plots also as above.

To determine the effect that the average monthly amount of fishery catch in Pemba for different functional groups had on the biomass of those groups in Pemba stereo-BRUV samples compared to other sites, a large Bayesian model was run. The model used the six habitat characteristics grouped by functional group, five monthly catch variables with an interaction with site, two detectability variables and a grouped intercept variable of sample. Habitat variables were grouped by functional group because different functional groups had different habitat preferences and were therefore expected to have different responses to these variables. Catch variables interacted with site because it was expected that Pemba specifically would have more negative catch effects than the other sites with lower fishing pressures. As above, all numeric variables were standardized. Models were run with either maximum or minimum fishing catch estimates based on the inclusion or exclusion of months with zero catches when estimating total catch to determine the effect of the range of possible catch amounts. Relief was not included due to moderate correlation with hab1 (0.64). Mypairs (Zuur *et. al.,* 2009) was used to determine any correlations between predictor variables and all numeric variables were standardized using scale in R's base library (R Core Team, 2020). The model was run both with and without the zero biomasses using hurdle-gamma and gamma response distribution families respectively. The model was run using brm in the brms library in R as above. Also, as above issues of temporal or spatial autocorrelation were assessed using acf for temporal autocorrelation and bubble in the sp library and sp.correlogram in spdep for spatial autocorrelation. Models were validated using R-hat, bulk and tail ESS, and posterior prediction plots as above.

Lastly, the relationships between catch from different methods and the maximum lengths of those species seen in stereo-BRUV videos from different sites were analysed. The first model used scaled maximum lengths from each species in a sample based on the proportion of maximum length for the species from fishbase.org or sealifebase.org to get a relative maximum length that accounted for differences in species sizes. In total, 3,760 maximum length measures from all samples existed. Relative maximum length was used in a Bayesian model with standardized percent water column, visibility, habitat 1, habitat 2, habitat 3, habitat 4, depth, and water temperature as universal predictors and catch by method interacting with site. A model using maximum length of preferred species without correcting for normal species size was also run using the same predictors as above but including species as a grouping variable to account for differences in size (n=1,392). Preferred species, were those fishery targets mentioned by fishers as preferred in interviews (Chapter 2, page 24). Species which belonged to a target group mentioned by any fisher were considered preferred. Five samples had to be dropped due to having less than 5 lengths in the stereo-BRUV data. Length data was skewed, so a gamma response distribution was used. Again, the models were run using brm in R; temporal and spatial autocorrelation were assessed and addressed as above, and models were validated using R-hat, bulk and tail ESS, and posterior prediction plots.

Results

Ecosystem differences based on site

Sampled habitats were different in the different sites around Northern Mozambique. For habitat morphotypes, the NMDS took four axes to find a convergent solution. The non-metric R^2 was 0.993 indicating a good fit to the data. Looking at a plot (Appendix IV, Figure IV-1), the NMDS showed separation of samples with different dominant substrates with Pemba sites being fairly distributed in the space but absent from the upper right corner associated with branching and foliose plate coral. Correlation between sites and the four habitat axes were used in the analyses of mobile species as habitat characteristics 1 to 4 below. They most closely correlate:

Habitat variable 1: Positively with coral cover and negatively with seagrass, and sandy bottoms;
Habitat variable 2: Positively with sand and bioturbation;
Habitat variable 3: Positively with filamentous macroalgae and columnar or sub-massive corals;

Habitat variable 4: Positively with branching coral and negatively with macroalgae.

The PERMANOVA showed that site was a significant factor in determining habitat morphotypes after accounting for depth and relief (Table 5-2). Pairwise PERMANOVAs confirmed that all sites were different from each other (p=0.001 for most comparisons), although Pemba and Situ (p=0.021) and Vamizi and Nuarro (p=0.046) were less significantly different than the other pairs possibly due to differences in sampling method (Appendix IV, Table IV-1). Running the PERMANOVA without sand and seagrass dominated sites, as these were not sampled in all sites, still showed all sites as significantly different from each other with p values less than 0.05. However, the differences were less significant than when all data were included (e.g., p=0.008 between Pemba and Vamizi compared to 0.001 when all data were used). The CAP required 10 axes to find its optimal solution which correctly identified 61% of samples to sites with a probability level of 0.003. However, the percentage of samples correctly identified varied from 9% for Situ to 86% for Pemba. Figure 5-2 shows decent separation of sites based on the CAP with seagrass and sand samples being much more likely in Pemba than other areas. The lack of seagrass and sand sites in Vamizi and Nuarro were associated with the sampling protocols in those areas which focused on coral habitats, compared to Pemba where all habitats were sampled. If the CAP was run without sand and seagrass dominated samples to account for the lack of these types of samples in Vamizi and Nuarro, 60% of samples were correctly identified to site with a significance level of 0.001. Running the CAP with equal sample sizes based on site gave mean percent correctly identified near 50% for most sites with the minimum for Vamizi at 37.18% (Table 5-3). The significances of these CAPs ranged from 0.01 to 0.5 with 23% of runs giving a p-value above 0.05. The median value was the minimum, 0.01. The 15 morphotypes with the greatest overall correlation with the first 4 CAP axes showed that Pemba samples had more seagrass and substrate as expected, and also higher proportions of columnar coral and laminate and articulated calcareous macroalgae but proportionally low amount of branching coral (Figure 5-3).

Table 5-2: Results of the PERMANOVA of habitat variables based on site and standardized depth and relief.

Variable	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
Depth	1	1.659	1.6585	5.984	0.02680	0.001	***
Relief	1	10.599	10.5989	38.239	0.17125	0.001	***
Site	3	2.239	0.7462	2.692	0.03617	0.001	***
Residuals	171	47.397	0.2772		0.76579		
Total	176	61.893			1		

Table 5-3: Mean, median, and standard deviation of percent of samples correctly identified to site based on their habitat composition from the CAPs using equal sized samples from each site.

Variable	Mean % correct	Median % correct	Std. Deviation
Nuarro	56.91	54.55	12.90
Pemba	52.36	54.55	16.60
Situ	64.00	63.64	13.36
Vamizi	37.18	36.36	15.02
Total	52.61	52.27	7.31
Significance	0.045	0.010	0.077

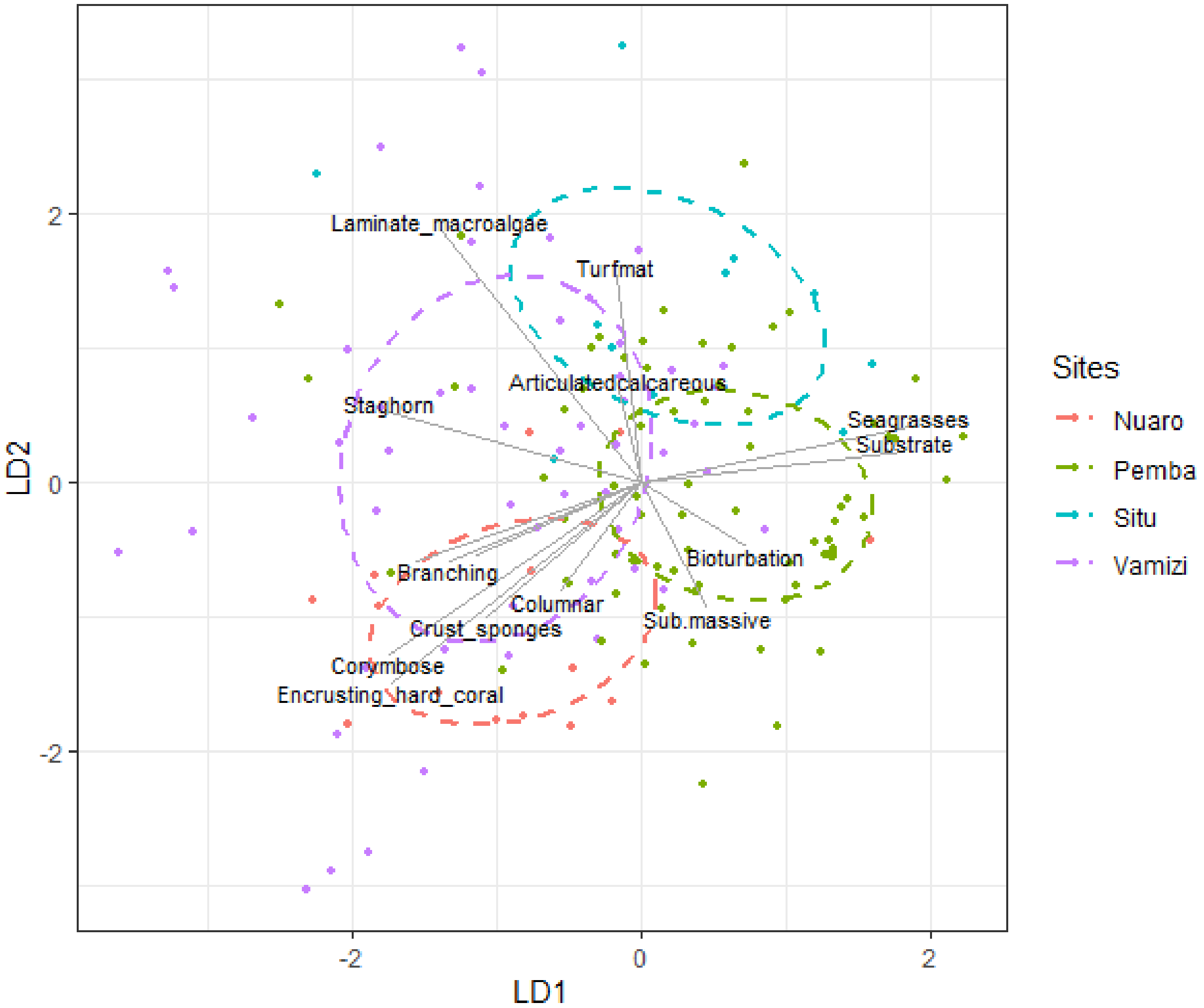

Figure 5-2: Stereo-BRUV sample positions on the first two (of 10) axes from the CAP of habitat proportional cover of morphotypes. Vectors indicate correlations with the first two dimensions of morphotypes with the largest correlation with the axes. Ellipses are based on covariance measures around the center for each site.

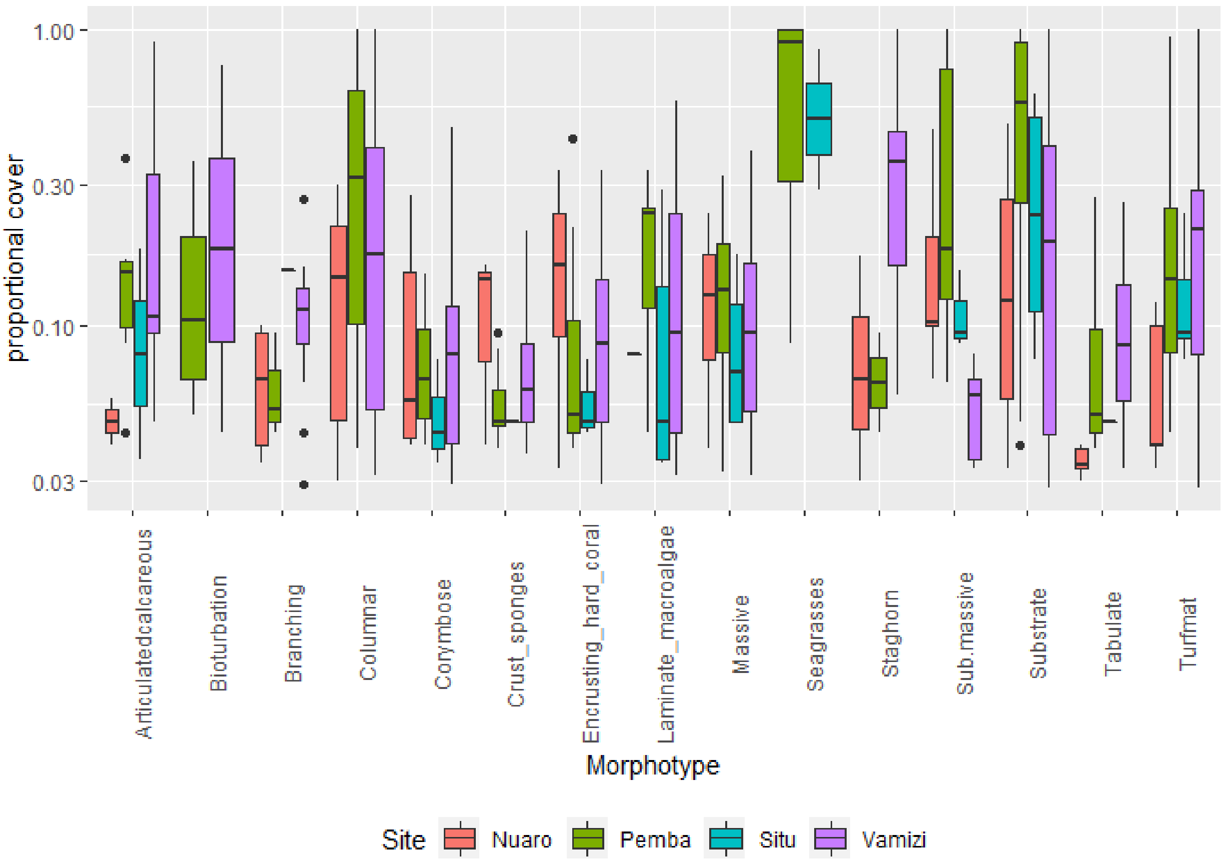

Figure 5-3: Boxplots of the proportional abundance of the most influential morphotypes based on the CAP analysis of habitat morphotypes. Zero proportion data are removed, if these data are included all median values are zero. Also note the log scale.

For mobile species functional group proportional composition, there were differences based on sites. All the variables in the full PERMANOVA were significant, including site (Table 5-4). The pairwise PERMANOVA showed that all sites were different from each other (p=0.001 in most cases, p=0.006 comparing Pemba to Situ; Appendix IV, Table IV-2). The CAP gave a total percent correctly identified to site of 70.5% which was significant at 0.001. Again, the percentage of samples correctly identified to site varied from 18.2% for Situ to 81.6% for Pemba. The CAP required 9 dimensions to find the optimal solution and showed Pemba sites associated with invertivores and some generalist carnivore groups (Figure 5-4). In the CAP with equal sized samples, the mean total of 54.3% of samples correctly identified to site and the mean significance level was 0.028 and the median 0.01, 15% of the runs of the CAP gave significance values greater than 0.05 (Table 5-5). Compared to the CAP, the NMDS showed less separation between sites, but the same basic patterns with Pemba sites being associated with proportionally high amounts of predatory species (Appendix IV, Figure IV-2). The Non-metric R^2 of the NMDS was 0.963. The NMDS needed 4 dimensions for convergence. The boxplot of the functional groups with the greatest correlation with the CAP axes confirms Pemba had the highest median proportion of all three generalist carnivores, three of the four invertivores and the only piscivore (Figure 5-5). The next section examines biomass rather than proportional biomass.

Table 5-4: Results of the PERMANOVA of functional group proportional biomass of mobile functional groups.

Variable	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	
biomass	1	1.421	1.42076	4.0875	0.02072	0.001	***
Water temp	1	0.715	0.71499	2.0570	0.01043	0.005	**
% Water column	1	1.106	1.10618	3.1824	0.01613	0.001	***
Depth	1	0.631	0.63125	1.8161	0.00921	0.014	*
Visibility	1	1.937	1.93674	5.5719	0.02825	0.001	***
Habitat 1	1	2.141	2.14090	6.1593	0.03123	0.001	***
Habitat 2	1	0.678	0.67809	1.9508	0.00989	0.007	**
Habitat 3	1	0.533	0.53321	1.5340	0.00778	0.049	*
Habitat 4	1	0.562	0.56222	1.6175	0.00820	0.040	*
site	3	2.182	0.72738	2.0926	0.03183	0.001	***
Residuals	163	56.657	0.34759		0.82634		
Total	175	68.563			1		

Table 5-5: Mean and median percent correct from 100 random runs of the CAP of functional group proportional composition with equal sized samples (n=11).

Variable	Mean % correct	Median % correct	SD % correct
Nuarro	70.09	72.73	12.28
Pemba	46.82	45.45	14.52
Situ	52.36	54.55	10.51
Vamizi	47.91	45.45	14.78
Total	54.30	54.55	6.06
Significance	0.028	0.010	0.043

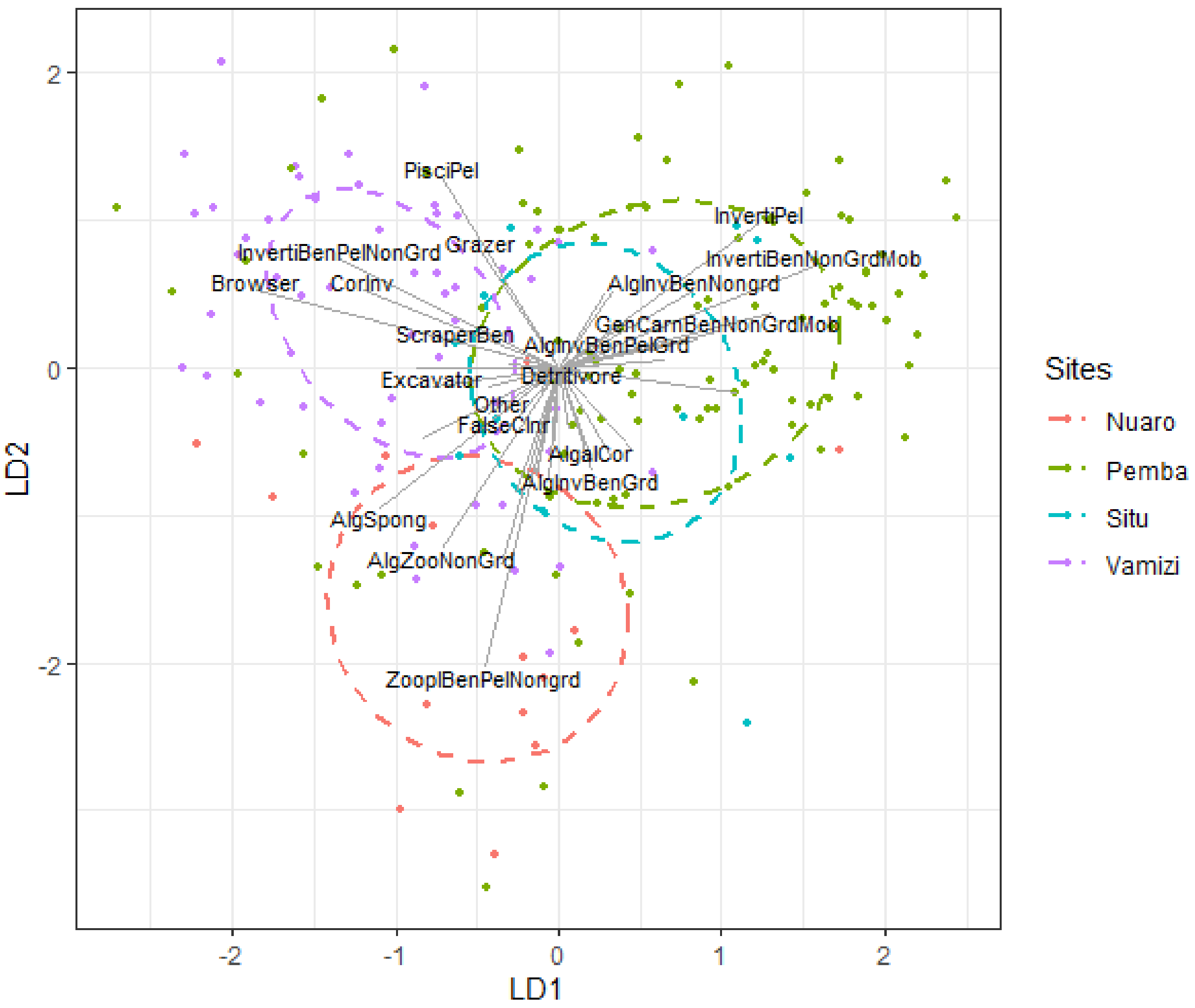

Figure 5-4: Stereo-BRUV samples positions on the first two (of 9) axes from the CAP of functional group proportional biomass. Vectors indicate functional group correlation with the axes. Functional groups are based mostly on trophic group followed by other characteristics, such as water column location and breeding guild, used to distinguish between groups. I.e., AlgSpong represents algal spongivores, Inverti represent invertivores, etc., Ben indicates benthic, Pel indicates pelagic and BenPel indicates bentho-pelagic, NonGrd represents non-guarder species and Grd guarder species. Ellipses are covariance ellipses for each site.

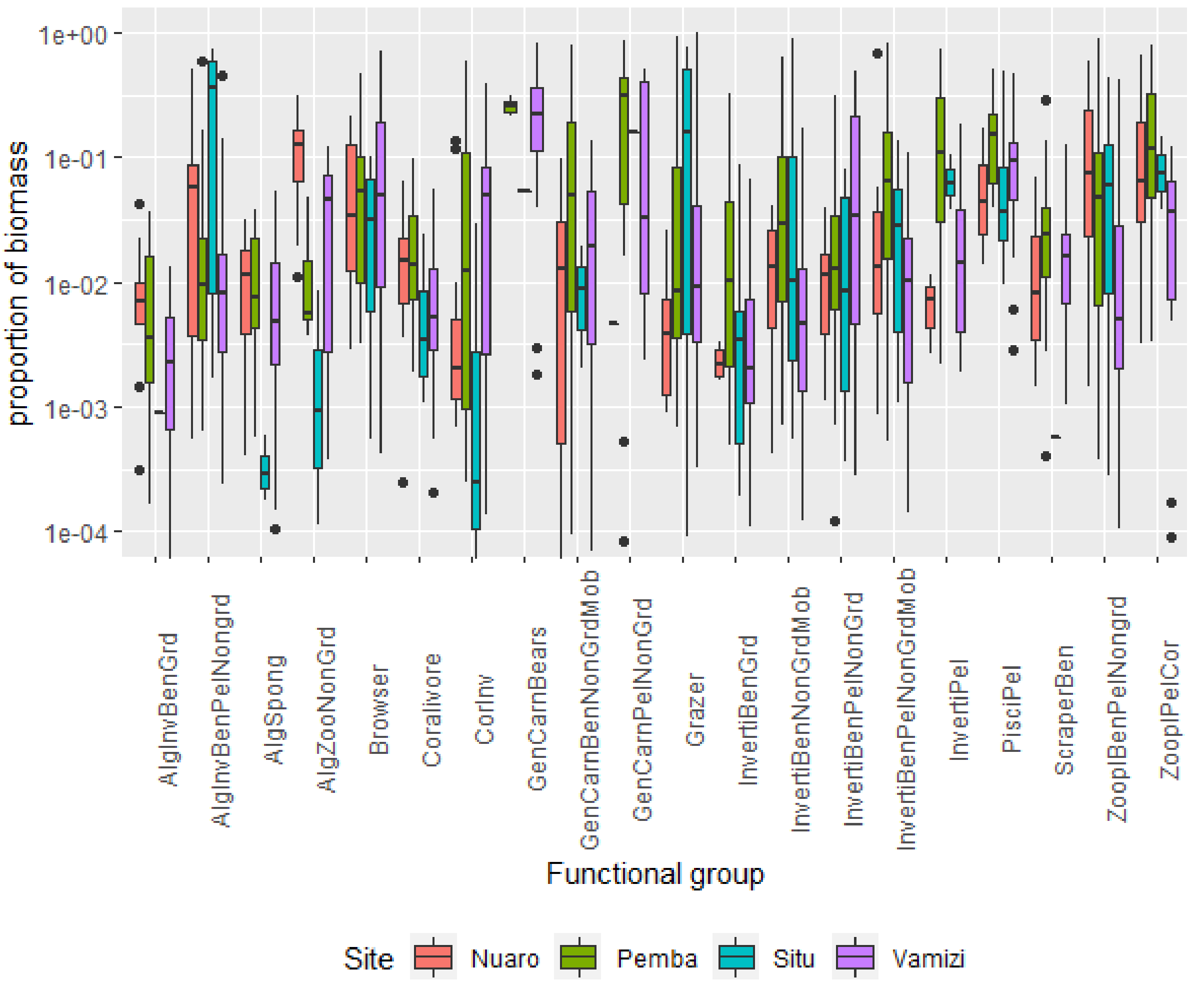

Figure 5-5: Boxplot of the proportion of biomass from the functional groups with the strongest correlations to the CAP axes above. Functional group names are based primarily on trophic group, followed by water column use, breeding guild, mobility, and coral use when needed. E.g., AlgInvBenPelNonGrd is a bentho-pelagic algal-invertivore that doesn't guard its young.

Functional group biomass compositions showed all sites were significantly different from each other. The non-metric R^2 of the NMDS was 0.977. The NMDS plot shows that Pemba samples are more spread out in the space than samples from the other sites (Figure 5-6). The PERMANOVA showed all variables in the full model as significant (Table 5-6). And the pairwise PERMANOVA showed that all site comparisons were significantly different (p=0.001, Appendix IV, Table IV-4). The CAP had 72.2% of samples correctly identified to site, with a significance level of 0.001, however, this again varied from 9.1% correctly identified to Situ to 81.1% correctly identified to Vamizi. The CAP needed 9 dimensions to distinguish between sites. The CAP with equal sample sizes from each site (n=11) had a median 65.9% of samples correctly identified to site with a median significance of 0.01 and none of the runs gave a significance level above 0.05 (Table 5-7). The first two axes from the CAP showed better separation of samples based on site than in the NMDS (Figure 5-7). And biomasses of the most influential functional groups were all in the opposite direction as most Pemba sites in the plot. Overall, biomasses of these influential groups were sometimes lower in Pemba than other sites, but there was a lot of variation (Figure 5-8). Particularly, grazers appear to be lower in biomass in Pemba stereo-BRUV samples than Situ or Vamizi samples. Bayesian models, below, were used to better understand these differences in biomass between functional groups.

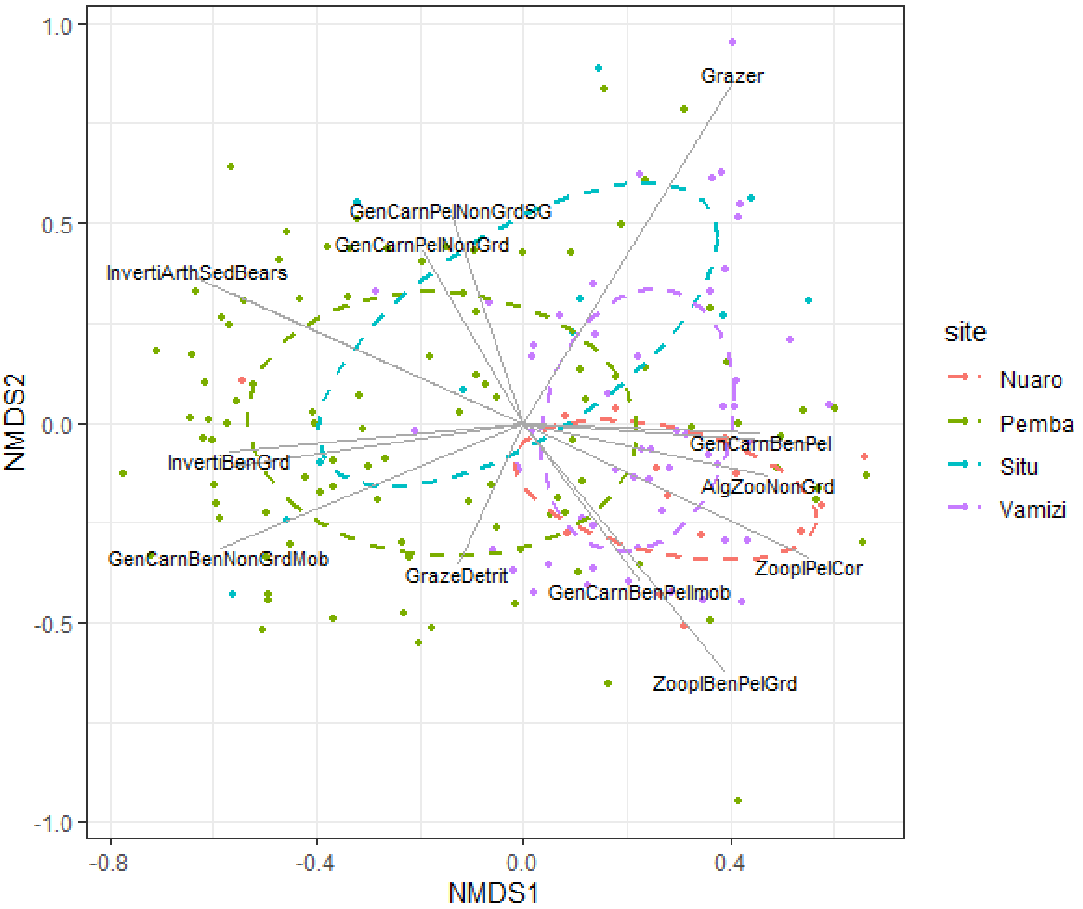

Figure 5-6: Stereo-BRUV sample positions based on the first two (of 5) NMDS axes based on biomass of functional groups. Vectors show correlations between functional groups and axes. Functional groups are based mostly on trophic group followed by other characteristics, such as water column location, mobility, breeding guild, and habitat of coral or seagrass use, used to distinguish between groups. E.g., InvertiArthSedBears is an invertivore arthropod which is sedentary and bears it young and GenCarnPelNonGrdSG is a pelagic generalist carnivore which does not guard its young and is commonly found in seagrass meadows. Ellipses represent covariance for each site.

Table 5-6: Results from the PERMANOVA of samples based on functional group biomass. All numerical variables are standardized.

Variable	Df	SumsOfSqs	MeanSqs	F.Model	R2	Pr(>F)	Sig
Water temp	1	0.693	0.69307	1.8757	0.00953	0.003	**
% Water column	1	0.966	0.96555	2.6131	0.01328	0.001	***
Depth	1	1.008	1.00827	2.7287	0.01387	0.001	***
Visibility	1	3.155	3.15516	8.5390	0.04341	0.001	***
Habitat 1	1	2.054	2.05407	5.5591	0.02826	0.001	***
Habitat 2	1	0.675	0.67536	1.8278	0.00929	0.004	**
Habitat 3	1	0.676	0.67597	1.8294	0.00930	0.008	**
Habitat 4	1	0.643	0.64344	1.7414	0.00885	0.017	*
Site	3	2.222	0.74066	2.0045	0.03057	0.001	***
Residuals	164	60.598	0.36950		0.83364		
Total	175	72.691			1		

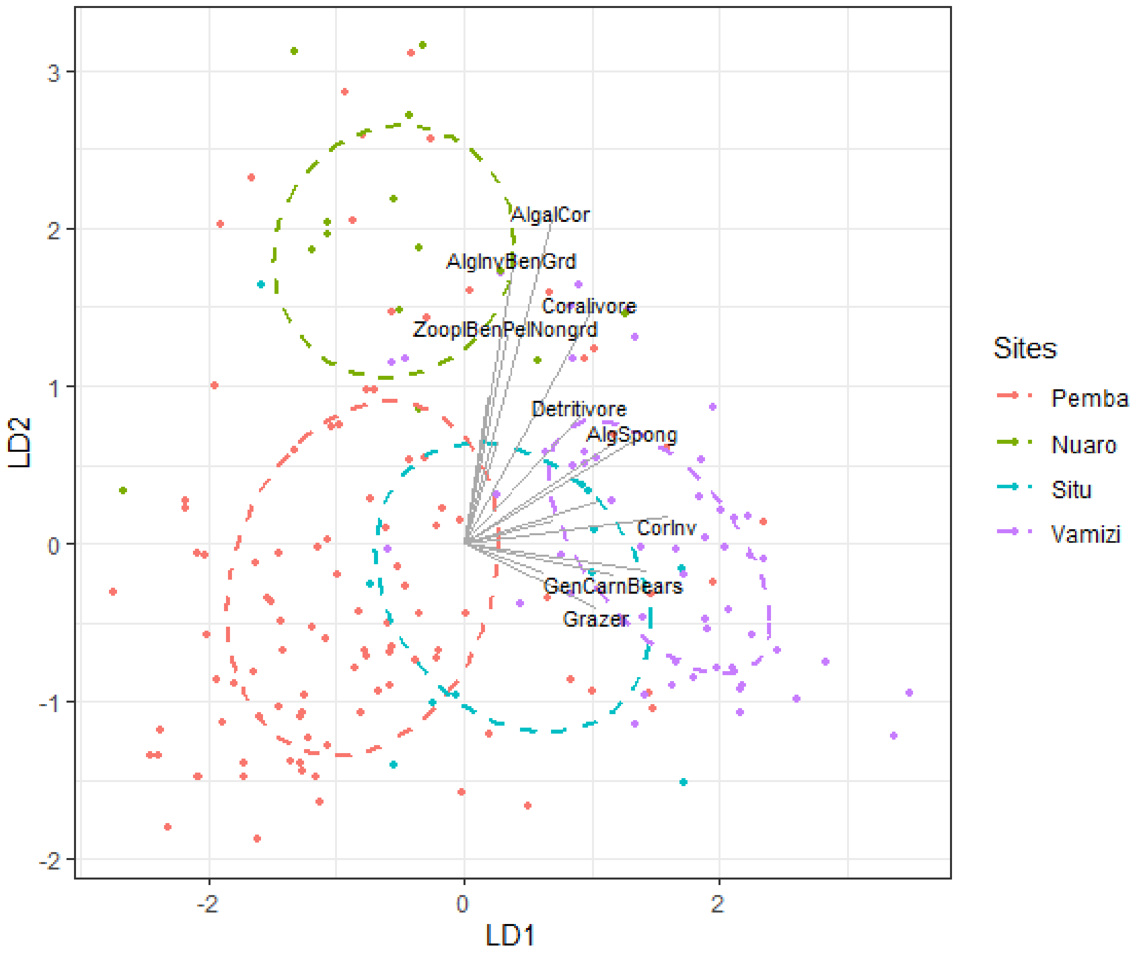

Figure 5-7: Stereo-BRUV sample positions on the first two (of 9) axes from the CAP of functional group biomass. Vectors show position of functional groups with the largest correlation with the CAP axes. Functional groups are based mostly on trophic group followed by use of the water column and breeding guild, used to distinguish between groups. I.e., AlgInvBenGrd is a benthic algal-invertivore that guards its young. Ellipses were based on covariance between samples from each site.

Table 5-7: Average percent correct from the 100 runs of the CAP with equal sample sizes for each site.

Variable	Mean % correct	Median % correct	SD % correct
Nuarro	79.18	81.82	10.03
Pemba	63.18	63.64	14.41
Situ	58.73	63.63	16.26
Vamizi	58.73	63.64	14.76
Total	64.95	65.91	6.57
Significance	0.012	0.010	0.005

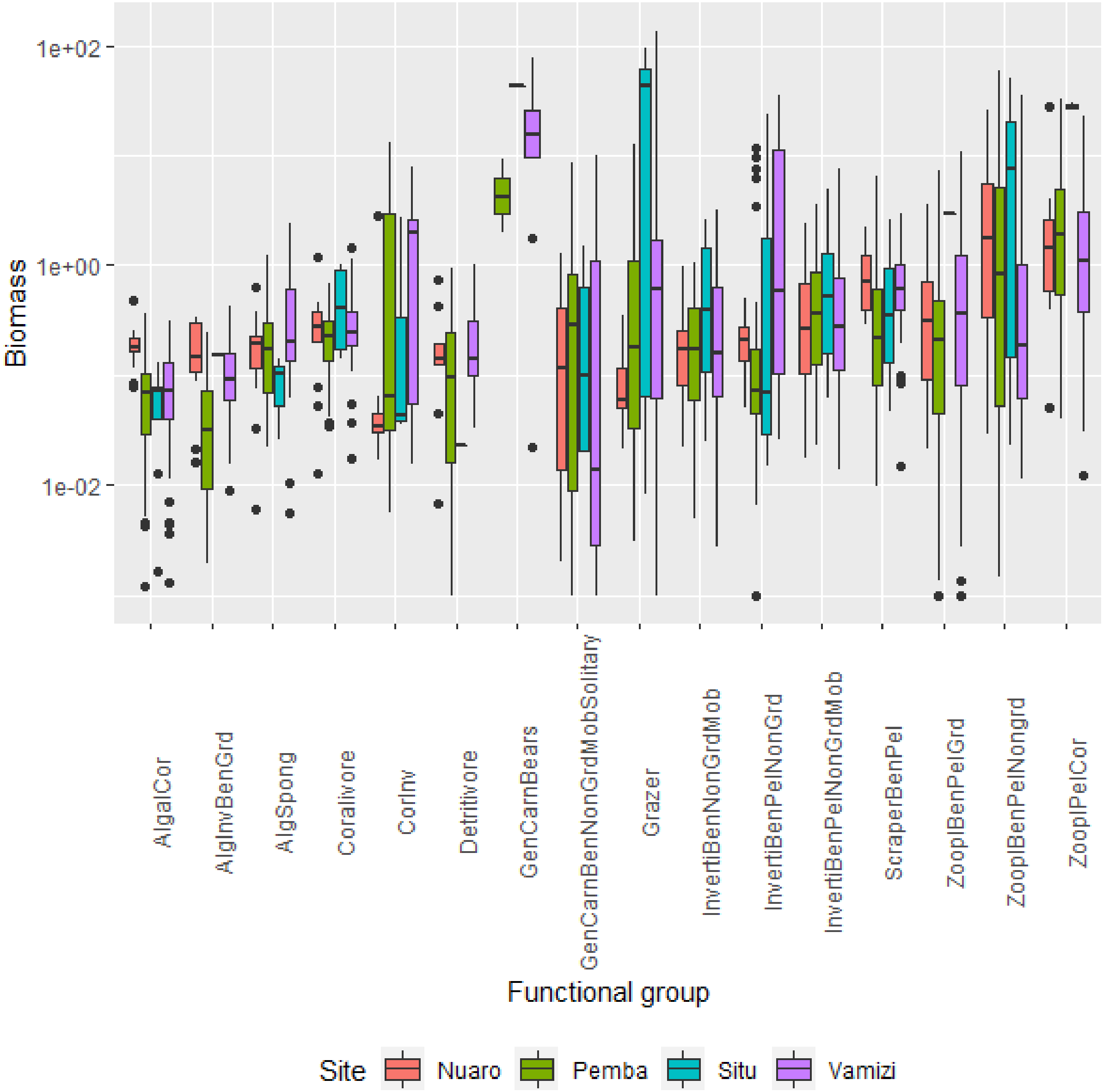

Figure 5-8: Box-and-whisker plots of the most influential species on the biomass CAP above. Functional groups are name primarily by trophic group, followed by use of the water column, mobility, breeding guild, and use of coral if necessary. E.g., GenCarnBenNonGrdMobSolitary is a benthic generalist carnivore that is solitary, moves between habitats, and doesn't guard its young. Zero biomass data are removed. Note the log scale.

Functional diversity indices

The functional diversity indices were slightly different for Pemba than other sites. Pemba had the lowest richness overall, but the highest divergence and evenness (Figure 5-9). Only using site to determine differences in functional divergence made these differences appear to be significant. However, once habitat and detectability variables were added, there were no significant differences between any of the functional diversity indices in Pemba samples compared to other sites, all 95% confidence intervals comparing Pemba samples to other sites include zero (Appendix IV, Table IV-3). This indicated that the apparent differences in functional diversity measures seen in Figure 5-9 were caused by habitat differences in samples between sites. Running the models without seagrass and sand dominated samples which do not occur in Vamizi or Nuarro there are still no significant differences in any of the functional diversity measures. The apparent lower functional richness in Pemba Bay was caused by the inclusion of sand and seagrass dominated stereo-BRUV samples. Without these samples, the median values of Pemba samples were still lowest, but closer to the medial values in other sites.

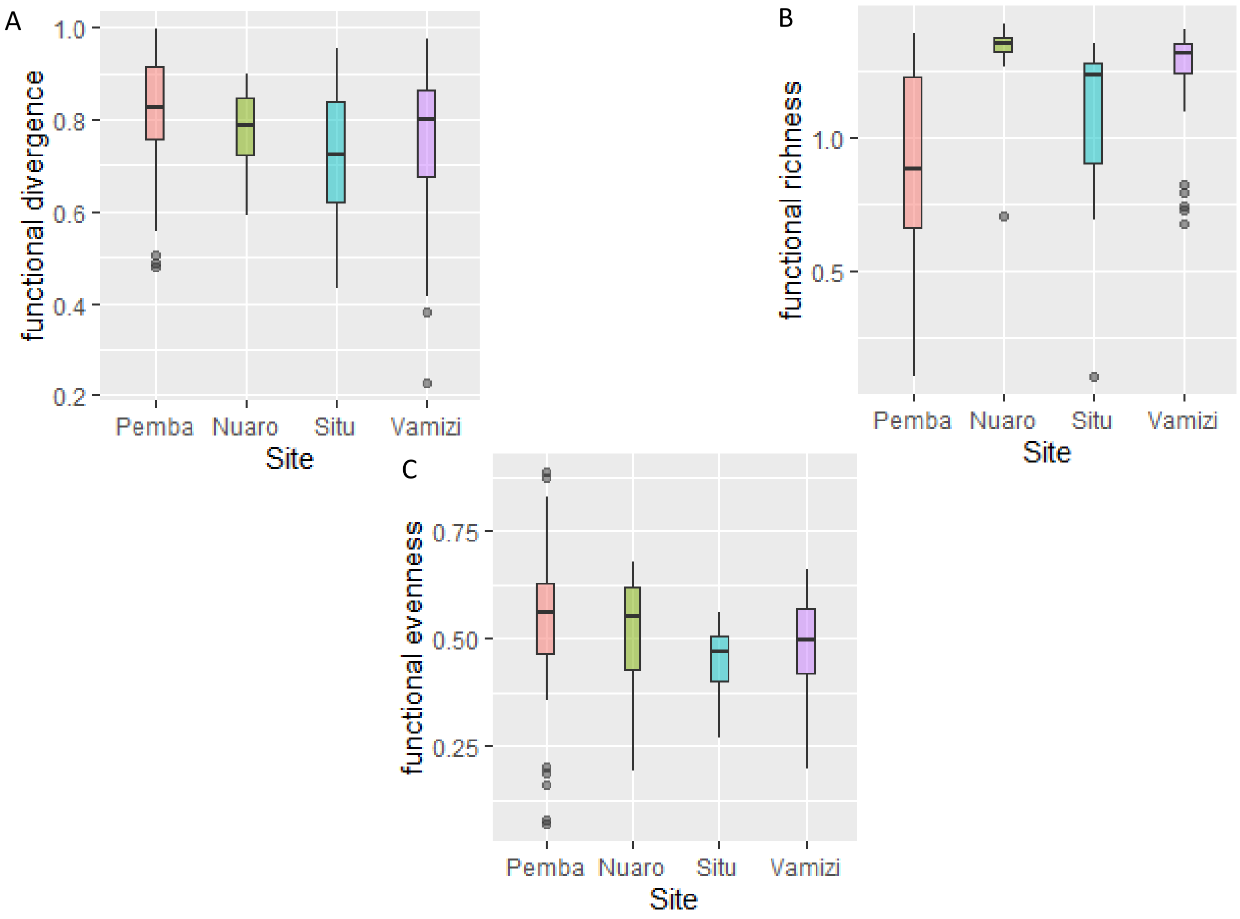

Figure 5-9: Sample functional divergence (A), functional richness (B), and functional evenness (C) based on the site in which samples were collected.

Functional group biomass and fishery catch

Fishery catch

Fishery catch estimates were only from Pemba Bay. Fishing at other sites occurred, but data on the extent of fishing was not collected. It was assumed that fishing pressure was lower at other sites than Pemba Bay based on the lower population density and existence of tourist lodges at all three sites which were promoting reef conservation, and marine reserves in Situ and Vamizi.

The maximum estimates of monthly catch for specific fishing methods around Pemba Bay varied from 0 for non-target functional groups such as cleaners, to 34,802 tons for pelagic zooplanktivores. Note that even for functional groups with zero reported catch, some unrecorded catch or discarded bi-catch was likely. The average monthly catch for all functional groups was 4,133 tons per month (Table 5-8). The minimal estimates for monthly catch, which include zero catches in some months, had a maximum catch for pelagic zooplanktivores of just 6,480 tons compared to 34,800 tons when zeros were excluded. Based on whether zero catches in some months were considered accurate, total catch in Pemba Bay varied from 32,170 tons to 210,800 tons per month. Fishing methods varied in recorded monthly catch from 2,048 tons for the upper limit of catch for spearfishing, to about 130,000 tons for purse-seine fishing. Minimum estimates were about 6.5 times smaller than maximum ones, except for beach-seine fishing, which was 15 times smaller in the minimal estimate than the maximal one, indicating more reported zero catches than for other methods.

Maximum monthly average catches from the different fishing methods were not correlated when based on individual species. This was the same for minimum monthly catches. However, when species were grouped into functional groups, there were correlations between catches from different methods. Gillnet catches were correlated with purse-seine catches (cor=0.73, Appendix IV, Figure IV-3). Minimum monthly captures showed beach and purse-seine catches were somewhat correlated (cor=0.65), other correlation scores were all below 0.4.

Table 5-8: Maximum estimated catch around Pemba Bay for each functional group by each fishing method as well as total catch. Green cells indicate low catches for that group/method and red cells relatively high catches.

Functional group	beach	gill	hand	purse	spear	Total
Algal-corallivores	3	0	0	0	0	3
Algal-invertivore benthic guarders	0	0	9	0	0	9
Algal-invertivore benthic non-guarders	405	47	26	0	1	479
Algal-invertivore bentho-pelagic guarders	0	0	0	0	0	0
Algal-invertivore bentho-pelagic nonguarders	1	49	6	0	7	63
Algal-spongivores	0	0	0	238	4	242
Algal-zooplanktivore guarders	0	10	0	220	0	230
Algal-zooplanktivore non-guarders	1008	2883	818	9458	1	14168
Browsers	274	212	327	105	107	1025
Cleaners	0	0	0	0	0	0
Corallivores	0	0	0	0	3	3
Coral-invertivores	0	6	18	0	9	33
Detritivores	0	97	104	9	69	278
Excavators	0	0	11	4349	1	4361
False cleaners	0	0	0	0	0	0
Generalist carnivore bearers	0	0	220	0	1	222
Generalist carnivore benthic non-guarders	733	276	869	119	78	2074
Generalist carnivore benthic non-guarders mobile	158	283	1049	173	8	1671
Generalist carnivore benthic non-guarders mobile seagrass associated	1420	499	1433	45	77	3474
Generalist carnivore benthic non-guarders mobile solitary	17	169	2057	0	20	2263
Generalist carnivore bentho-pelagic	1360	1011	3238	3894	31	9535
Generalist carnivore bentho-pelagic mobile	0	4	29	0	12	45
Generalist carnivore bentho-pelagic seagrass associated	366	258	787	1834	102	3348
Generalist carnivore guarders	3546	204	2591	482	28	6851
Generalist carnivore pelagic non-guarders	822	2013	7707	22895	79	33516
Generalist carnivore pelagic non-guarders seagrass associated	949	269	626	435	7	2287
Grazer/Detritivore	849	339	645	221	250	2305
Grazer	593	19	5	870	3	1490
Invertivore arthropod sedentary bearers	1250	570	367	0	131	2317

Table 5-8 (continued)

Functional group	beach	gill	hand	purse	spear	Total
Invertivore benthic guarders	768	0	112	155	354	1389
Invertivore benthic non-guarders	25	16	98	0	31	170
Invertivore benthic non-guarders mobile	1238	493	1554	1978	21	5284
Invertivore bentho-pelagic guarders	39	0	0	160	9	207
Invertivore bentho-pelagic non-guarders	243	241	92	38	4	618
Invertivore bentho-pelagic non-guarders mobile	632	374	735	1255	33	3029
Invertivore chordate sedentary bearers	3	0	0	0	0	3
Invertivore mobile Bearers	213	1	907	390	118	1629
Invertivore pelagic	948	471	645	5739	5	7808
Other	341	0	356	142	0	839
Piscivore benthic	145	121	486	38	92	882
Piscivore bentho-pelagic	431	614	313	337	9	1704
Piscivore pelagic	1266	2208	1081	2616	10	7181
Planktivores	0	0	250	13	1	264
Scraper benthic	225	110	158	183	198	874
Scraper bentho-pelagic	14	12	127	0	26	179
Zooplanktivore benthic guarders	62	0	3	13	0	79
Zooplanktivore benthic non-guarders	481	237	4	239	4	965
Zooplanktivore bentho-pelagic guarders	0	0	0	422	0	422
Zooplanktivore bentho-pelagic non-guarders	329	333	760	19540	32	20995
Zooplanktivore pelagic	2128	3439	1229	27993	12	34802
Zooplanktivore pelagic coral associated	3361	1330	774	23645	56	29165
total	26646	19216	32627	130245	2043	210778

BRUV biomass between sites

Total biomasses from stereo-BRUV samples were lower on average for Pemba than any other sites (Figure 5-10), but this was before accounting for habitat differences that could affect sampled biomass. There was one outlier in total biomass of stereo-BRUV samples with a value of 744kg, the next largest biomass was just 269kg. In this video, a school of large trevally passed by the bait canister causing the very high biomass. With or without this sample, Bayesian models of stereo-BRUV biomasses were similar. The results below were for the models without the outlier for ease of viewing in figures. Models used either site or distance to Pemba city centre as predictors of interest to explain difference in biomasses from stereo-BRUV samples. The posterior prediction plots of both site and distance models showed relatively good fit to the data (Appendix IV, Figure IV-4). Based on the site model, Pemba had significantly lower biomasses in stereo-BRUV samples than Situ (coefficient=1.08, 95% CI (0.35-1.85)) and Vamizi (coefficient=0.58, 95% CI (0.13-1.03)) once the other variables were accounted for. The other significant predictors were visibility, average relief, and habitat 3 (Table 5-9 and Figure 5-11 A to D). Habitat variable three was most associated with filamentous macroalgae, and columnar and sub-massive corals. The same detectability and habitat variables, and distance to Pemba (coefficient=0.23, 95% CI (0.02-0.43), were significant for the model of stereo-BRUV sampled biomass using distance to Pemba City instead of site as a predictor (Table 5-10 and Figure 5-11 E). The shape of the relationships in this second model of visibility, relief, and habitat 3 were very similar to the model using site.

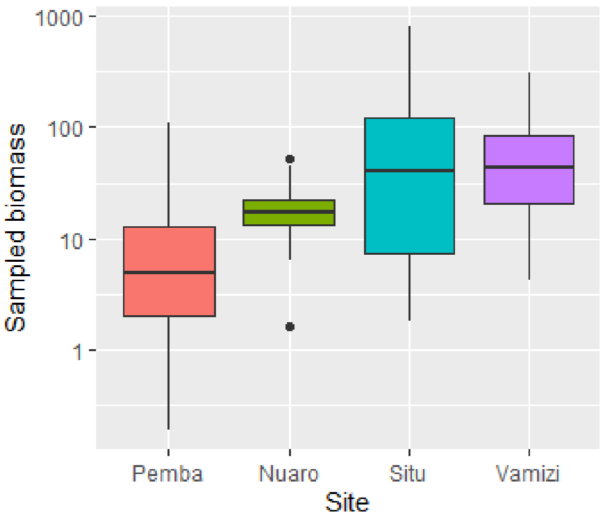

Figure 5-10: Sampled stereo-BRUV biomass based on site where the sample was taken.

Table 5-9: Model coefficients for detectability, habitat, and site variables in determining total sampled biomass. All numeric variables are standardized. Habitat indicates one of the combined habitat variables based on the NMDS of habitat morphotypes.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	2.71	0.12	2.49	2.94	*
Depth	0.02	0.10	-0.18	0.21	
Water temp	0.02	0.09	-0.16	0.20	
% Water column	0.11	0.07	-0.04	0.25	
Visibility	0.78	0.11	0.57	1.00	*
Habitat 1	-0.06	0.14	-0.34	0.22	
Habitat 2	0.14	0.12	-0.10	0.37	
Habitat 3	-0.24	0.09	-0.40	-0.07	*
Habitat 4	-0.09	0.08	-0.24	0.06	
Relief	0.46	0.16	0.15	0.79	*
Nuarro	0.26	0.33	-0.35	0.94	
Situ	1.08	0.38	0.35	1.85	*
Vamizi	0.58	0.23	0.13	1.03	*

Table 5-10: Model coefficients for detectability, habitat, and distance to Pemba variables in determining total sampled biomass. All variables are standardized. Habitat indicates one of the combined habitat variables based on the NMDS of habitat morphotypes.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	2.98	0.07	2.84	3.13	*
Depth	0.07	0.09	-0.11	0.25	
Water temp	-0.09	0.08	-0.25	0.07	
% Water column	0.12	0.07	-0.02	0.26	
Visibility	0.80	0.12	0.58	1.03	*
Habitat 1	-0.13	0.14	-0.41	0.13	
Habitat 2	0.17	0.12	-0.07	0.39	
Habitat 3	-0.31	0.09	-0.47	-0.14	*
Habitat 4	-0.09	0.08	-0.23	0.06	
Relief	0.55	0.17	0.23	0.87	*
Distance to Pemba	0.23	0.11	0.02	0.43	*

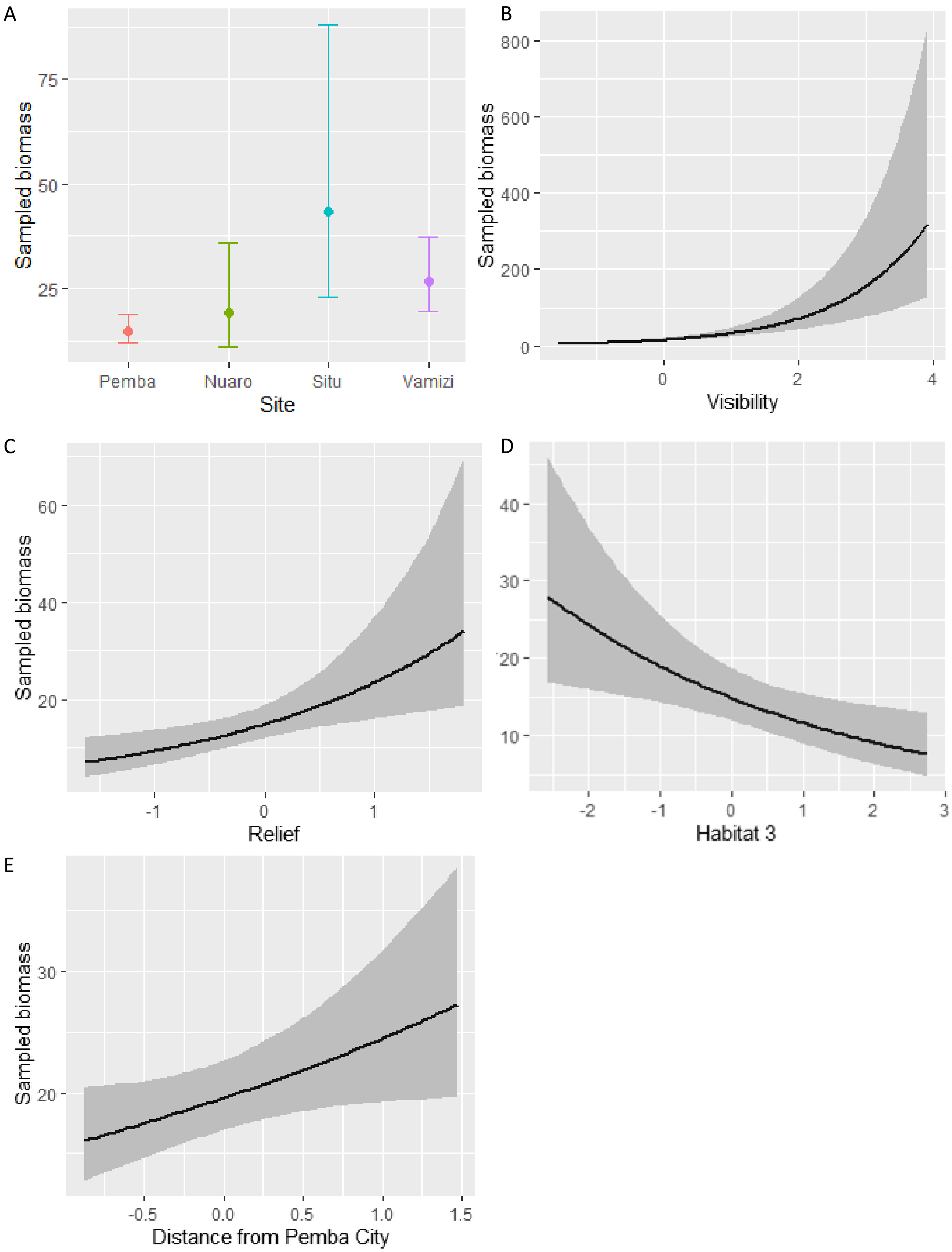

Figure 5-11: Conditional effects of all statistically significant predictors on sampled biomass based on the Bayesian models of sampled biomass based on site (A to D) or distance to Pemba (E) with 95% confidence intervals.

Functional group biomass was significantly lower in Pemba stereo-BRUV samples than Situ or Vamizi stereo-BRUV samples for seven (14%) functional groups after habitat characteristics were accounted for. Nuarro had two functional groups which were significantly different, one higher in Nuarro, and one lower. Grazers were significantly higher in Situ and Vamizi samples, and significantly lower in Nuarro samples, than Pemba samples (Table 5-11). Browsers had significantly higher biomass in Vamizi than Pemba (coefficient=0.7, CI (0.04, 1.4) (Appendix IV, Table IV-5)). The model follows the basic shape of the data, but the mean and SD of the data is much lower than some model runs (Appendix IV, Figure IV-5).

Table 5-11: Coefficients of site, compared to Pemba, for the grazers functional group from the model of functional group biomass based on site and habitat characteristics grouped by functional group

Site	Estimate	Est.Error	Q2.5	Q97.5
Nuarro	-1.23134	0.631564	-2.5192	-0.08521
Situ	2.01777	0.700997	0.7182	3.42020
Vamizi	2.04667	0.520971	1.0373	3.06883

Functional group biomass and fishery catch

Bayesian models using average fishery catch per functional group in Pemba Bay as a predictor of functional group biomass from stereo-BRUV samples were used to understand how removal by fishing in Pemba Bay affected the difference in functional group biomass from stereo-BRUV samples in Pemba Bay compared to the other three sites. Functional group biomass had a single outlier which did not affect the results. Including or excluding zero biomass data also did not affect the direction nor significance of any coefficients. The results presented were for the model with all biomass data. The model of functional group biomass in stereo-BRUV samples based on the average maximum total fishing catch per month interacting with site as the predictor of interest, fitted the data fairly well based on R-hat, ESS, and the posterior prediction empirical cumulative distribution function. Mean and standard deviation from the data was surrounded by model estimates, but many model runs had much higher mean and SD measures than the data (Appendix IV, Figure IV-6). Functional groups in Pemba stereo-BRUV samples had significantly lower biomasses than Situ and Vamizi when all other variables were accounted for, but were not different from Nuarro (Table 5-12 and Figure 5-12 A). Additionally, total catch had a significant positive correlation with biomass which was similar for all sites (Table 5-12 and Figure 5-12 B). All other variables are grouped by functional group to account for habitat and detectability and not included in the table below. Using the minimum average total monthly catch estimate rather than the maximum in the model, total catch did not have a significant correlation with functional group biomass for any site.

Table 5-12: Model coefficients for the Bayesian model of functional group biomass based on total fishing catch interacting with site. Detectability and habitat variables are grouped by functional group and not shown. Pemba is the base factor for site.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	-1.24	0.24	-1.72	-0.77	*
Total catch	0.77	0.24	0.29	1.25	*
Nuarro	0.28	0.17	-0.06	0.62	
Situ	1.16	0.22	0.72	1.60	*
Vamizi	0.55	0.13	0.30	0.79	*
Total catch: Nuarro	-0.10	0.13	-0.34	0.16	
Total catch: Situ	0.06	0.18	-0.29	0.41	
Total catch: Vamizi	-0.30	0.10	-0.49	-0.11	*

Using fishing catch separated into the different methods to explain differences in functional biomass from stereo-BRUV samples yielded similar results to the model with combined catch above. Using all biomasses as the response variable, the model fit was similar to the last model with the posterior empirical cumulative distribution function fitting the shape of the data, but the mean and SD of values from the data were much lower than some model runs (Appendix IV, Figure IV-7). Based on this model, it was purse-seine catch which was driving the positive correlation between functional group biomass in stereo-BRUV samples and total catch above (Table 5-13 and Figure 5-13). Gillnet and purse-seine catches were correlated (cor=0.73), so gillnet catches were not included in this model meaning that this correlation could be due to gillnet catches or a combination of the two rather than purely purse-seine catches.

Table 5-13: Model coefficients of the effects of method specific Pemba maximum catch on functional group biomass. Habitat and detectability variables are grouped by functional group, not shown. * Indicate 95% confidence intervals which do not overlap zero.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	-1.24	0.25	-1.72	-0.75	*
Beach catch	0.01	0.28	-0.55	0.57	
Hand catch	0.23	0.26	-0.29	0.74	
Purse catch	0.65	0.31	0.05	1.27	*
Spear catch	-0.03	0.21	-0.43	0.39	
Nuarro	0.23	0.18	-0.11	0.57	
Situ	1.19	0.23	0.75	1.63	*
Vamizi	0.57	0.12	0.32	0.81	*
Beach: Nuarro	-0.24	0.19	-0.62	0.13	
Beach: Situ	0.14	0.23	-0.30	0.61	
Beach: Vamizi	0.04	0.12	-0.19	0.27	
Hand: Nuarro	0.04	0.22	-0.38	0.46	
Hand: Situ	0.26	0.24	-0.17	0.76	
Hand: Vamizi	0.18	0.11	-0.05	0.39	
Purse: Nuarro	0.09	0.18	-0.25	0.44	
Purse: Situ	-0.11	0.22	-0.54	0.31	
Purse: Vamizi	-0.44	0.12	-0.69	-0.20	*
Spear: Nuarro	-0.23	0.10	-0.42	-0.03	*
Spear: Situ	-0.11	0.13	-0.35	0.14	
Spear: Vamizi	-0.07	0.07	-0.20	0.07	

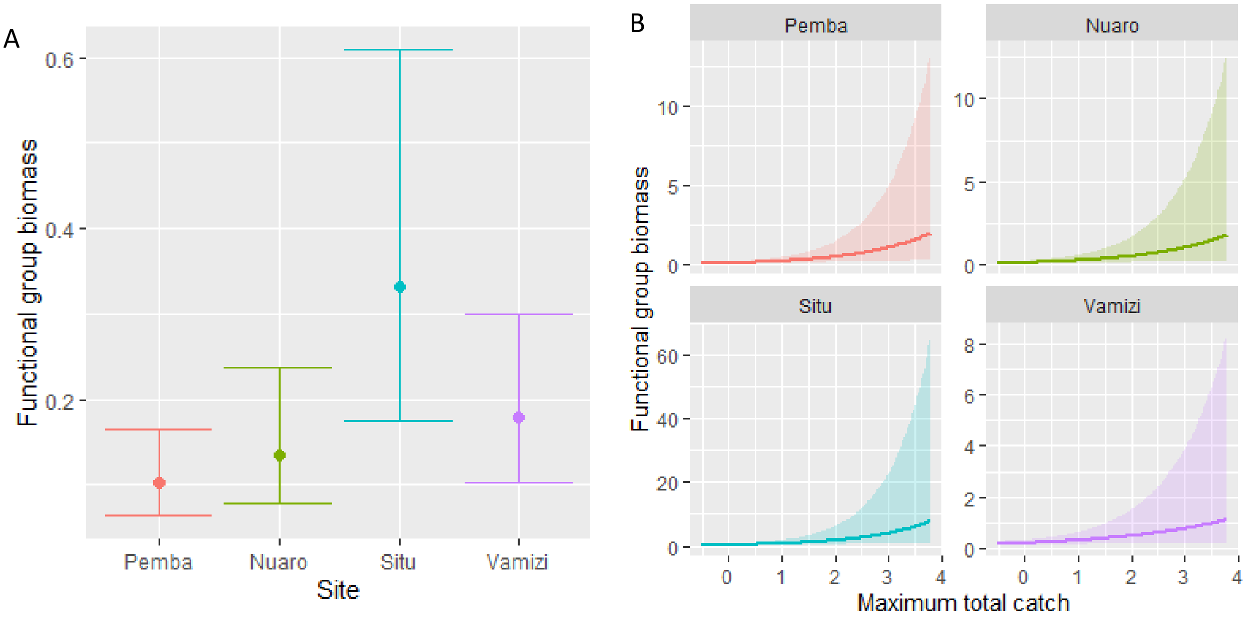

Figure 5-12: Conditional effects of site (A) and total fishing catch interacting with site (B) on functional group biomass with 95% confidence intervals.

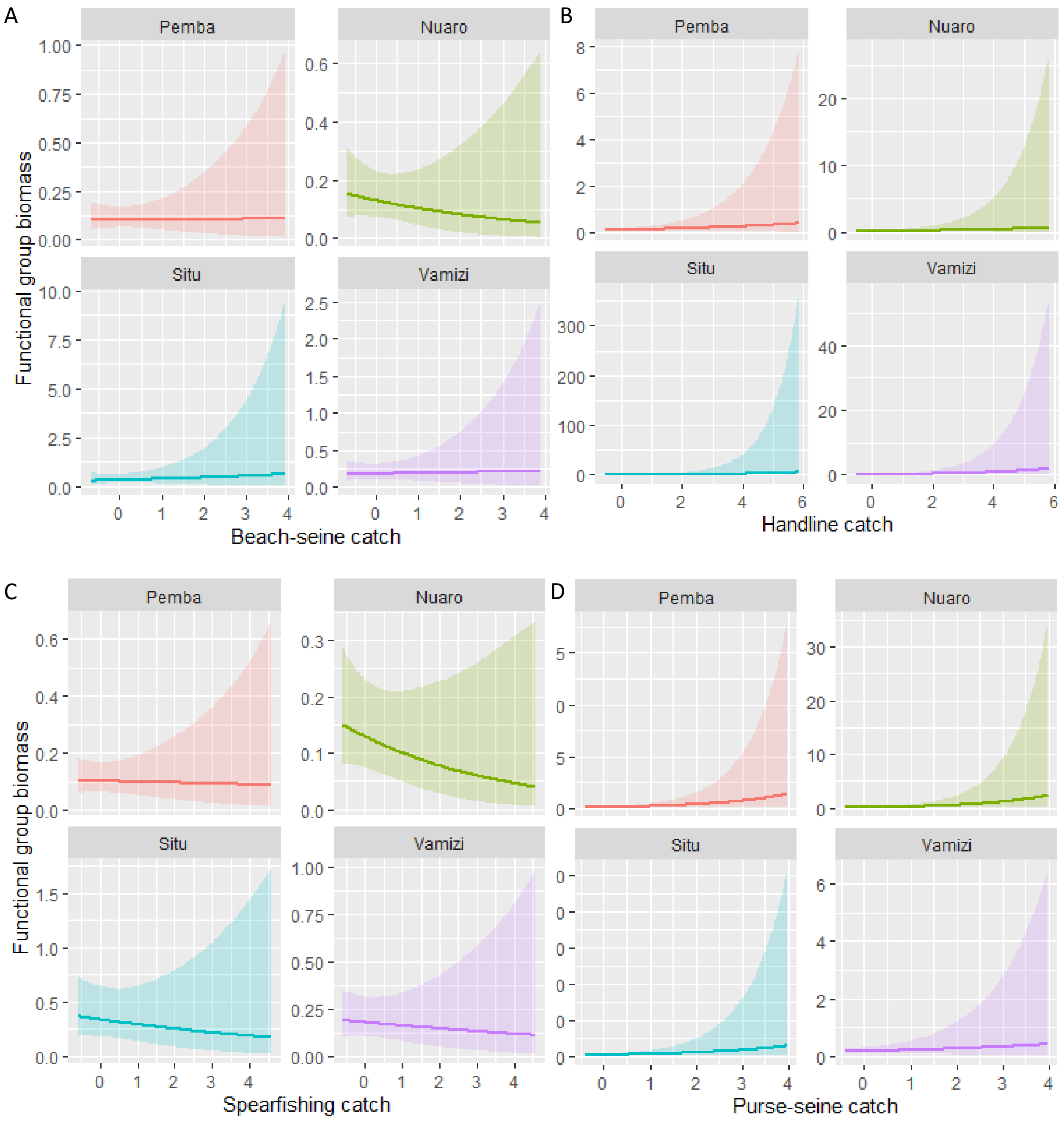

Figure 5-13: Conditional effects of maximum estimated monthly beach-seine (A), handline (B), spearfishing (C) and purse-seine (D) catches interacting with site on functional group biomass with 95% confidence intervals.

Length and species catch

Pemba sites had maximum individual lengths per stereo-BRUV sample which were smaller than other sites (Figure 5-14). However, largest proportional lengths per species, compared to their reported maximum lengths from fishbase.org and sealifebase.org, were less obviously different. The model using habitat variables, detectability variables, and maximum average monthly catch from the various methods interacting with site to explain proportional length, fitted the data well (Appendix IV, Figure IV-8). Overall, the proportional lengths of individuals in stereo-BRUV samples were significantly shorter in Pemba than in Situ (coefficient=0.06, CI (0.026-0.093)) or Nuarro (coefficient=0.056, CI (0.028-0.084)) once habitat variables were accounted for (Table 5-14 and Figure 5-15 A). Gillnet catches had a significant negative correlation with proportional length of individuals and handline catch coefficient was nearly significantly negative. Purse-seine catches had a significant positive correlation with proportional length (Table 5-14 and Figure 5-15 C to E). However, these correlations between length and catch were not significantly more negative in Pemba than in other sites. Using minimum average monthly catch rather than maximum average monthly catch, the same basic patterns emerge except that now handline catch had a significant correlation with proportional length and spearfishing and gillnet catch had nearly significant negative correlations.

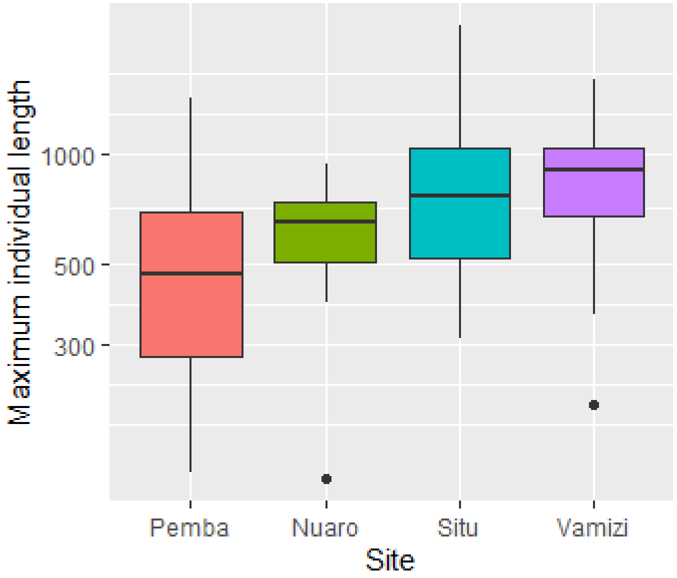

Figure 5-14: Boxplot of the maximum length of all species in a stereo-BRUV sample from the different sites.

The model assessing all lengths of species which fishers mention as preferred in stereo-BRUV samples also fitted the data well (Appendix IV, Figure IV-9). This model did not use proportional lengths, so a species random intercept was used to account for intrinsic differences in length. This model found that individuals in Pemba samples were smaller than in all other sites (Table 5-15 and Figure 5-16). However, maximum average monthly catch in Pemba did not negatively correlate with the size of individuals in Pemba compared to the other three sites. Spearfishing catches had a negative correlation with individual lengths in Situ and Vamizi. And gillnet catches were significantly correlated with Nuarro and Vamizi lengths.

Table 5-14: Model coefficients for the effects of habitat variables, detectability variables, and maximum monthly fishery catch from Pemba Bay for each method interacting with site on the proportional length of the largest individual per species in each sample. All numeric variables are standardized.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	0.517	0.006	0.505	0.530	*
Beach catch	-0.002	0.008	-0.018	0.014	
Gill catch	-0.023	0.007	-0.037	-0.008	*
Hand catch	-0.010	0.006	-0.022	0.002	.
Purse catch	0.028	0.008	0.013	0.044	*
Spear catch	-0.003	0.004	-0.011	0.004	
Nuarro	0.056	0.014	0.028	0.084	*
Situ	0.060	0.017	0.026	0.093	*
Vamizi	0.011	0.010	-0.009	0.031	
% Water column	0.005	0.003	-0.002	0.012	
Visibility	0.016	0.004	0.008	0.025	*
Habitat 1	0.008	0.003	0.002	0.015	
Habitat 2	-0.003	0.004	-0.010	0.004	
Habitat 3	-0.008	0.003	-0.014	-0.001	*
Habitat 4	-0.001	0.003	-0.008	0.005	
Depth	-0.007	0.004	-0.014	0.001	.
Water temp	0.004	0.004	-0.004	0.012	
Beach: Nuarro	-0.014	0.025	-0.063	0.035	
Beach: Situ	0.022	0.017	-0.011	0.055	
Beach: Vamizi	0.015	0.012	-0.009	0.038	
Gill: Nuarro	0.031	0.022	-0.013	0.075	
Gill: Situ	0.004	0.019	-0.034	0.043	
Gill: Vamizi	-0.003	0.014	-0.030	0.025	
Hand: Nuarro	0.003	0.019	-0.034	0.039	
Hand: Situ	0.000	0.015	-0.030	0.030	
Hand: Vamizi	-0.002	0.008	-0.017	0.012	
Purse: Nuarro	-0.052	0.019	-0.090	-0.014	*
Purse: Situ	-0.011	0.020	-0.050	0.028	
Purse: Vamizi	-0.021	0.012	-0.045	0.003	.
Spear: Nuarro	-0.021	0.026	-0.073	0.029	
Spear: Situ	-0.008	0.011	-0.029	0.013	
Spear: Vamizi	-0.010	0.009	-0.028	0.007	

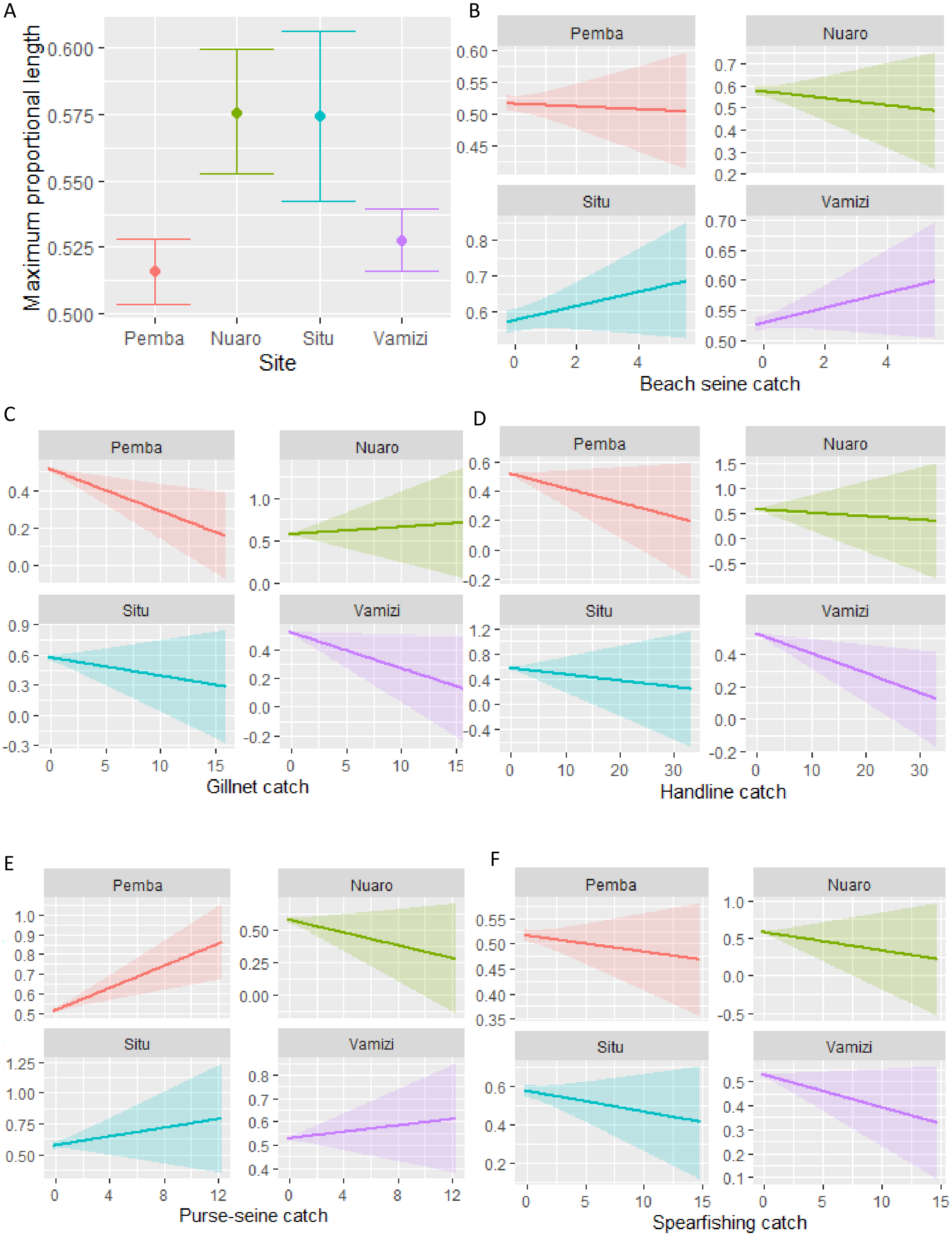

Figure 5-15: Conditional effects of site (A) and fishing method catch by site (B though F) of the model of maximum proportional length of each species per sample with 95% confidence intervals.

Table 5-15: Model coefficients for preferred species lengths based on habitat variables, detectability variables, and maximum yearly fishery catch for different methods interacting with site. Lengths are not standardized by species, so species is included as a grouping intercept variable to account for inherent differences in size. All numeric variables are standardized.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	5.45	0.05	5.36	5.55	*
Beach catch	-0.01	0.05	-0.10	0.09	
Gill catch	-0.03	0.04	-0.10	0.05	
Hand catch	-0.03	0.02	-0.07	0.01	
Purse catch	-0.01	0.04	-0.08	0.06	
Spear catch	-0.04	0.03	-0.10	0.02	
Nuarro	0.10	0.03	0.04	0.17	*
Situ	0.22	0.03	0.16	0.28	*
Vamizi	0.07	0.02	0.03	0.10	*
% Water column	0.00	0.01	-0.01	0.01	
Visibility	0.05	0.01	0.03	0.06	*
Habitat 1	0.01	0.01	0.00	0.02	.
Habitat 2	0.00	0.01	-0.01	0.02	
Habitat 3	0.00	0.01	-0.02	0.01	
Habitat 4	0.01	0.01	-0.01	0.02	
Depth	0.02	0.01	0.00	0.03	.
Water temp	0.02	0.01	0.00	0.03	.
Beach: Nuarro	0.00	0.03	-0.06	0.07	
Beach: Situ	0.00	0.02	-0.04	0.04	
Beach: Vamizi	0.01	0.01	-0.01	0.03	
Gill: Nuarro	0.07	0.03	0.01	0.12	*
Gill: Situ	0.02	0.03	-0.04	0.09	
Gill: Vamizi	-0.04	0.02	-0.08	-0.01	*
Hand: Nuarro	0.02	0.03	-0.03	0.08	
Hand: Situ	-0.01	0.02	-0.04	0.03	
Hand: Vamizi	0.03	0.01	0.00	0.05	.
Purse: Nuarro	-0.10	0.02	-0.14	-0.07	
Purse: Situ	0.01	0.03	-0.04	0.06	
Purse: Vamizi	-0.02	0.02	-0.05	0.01	
Spear: Nuarro	-0.03	0.04	-0.12	0.05	
Spear: Situ	-0.03	0.01	-0.05	-0.01	*
Spear: Vamizi	-0.04	0.02	-0.07	-0.01	*

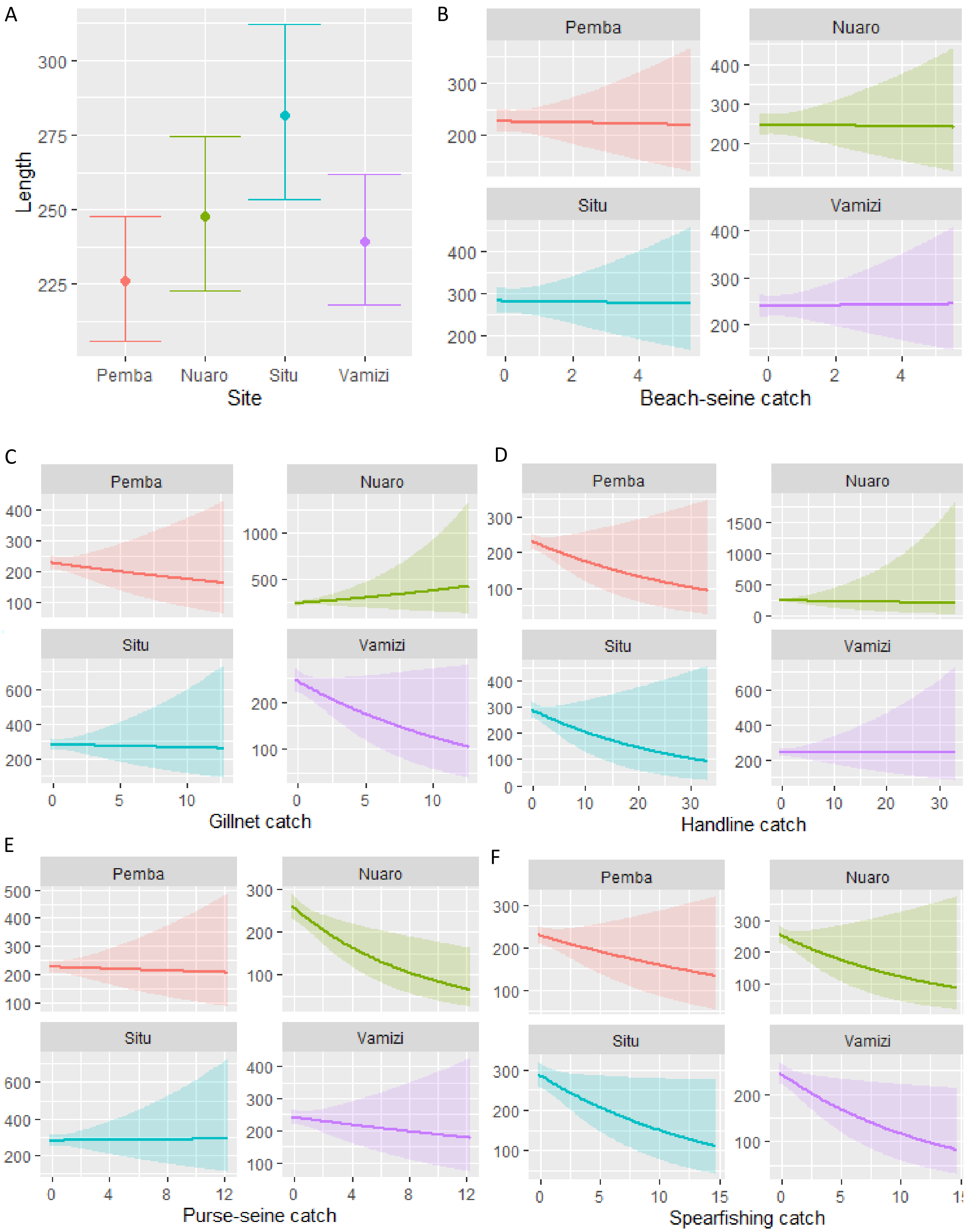

Figure 5-16: Conditional effects of site (A) and fishing method catch per site (B through F) of the model of preferred species lengths based on habitat variables, detection variables, and maximum monthly catch per method in Pemba Bay interacting with site all with 95% confidences intervals.

Discussion

Overall, there is evidence in support of part of our first hypothesis for question 3, in that biomasses are lower, and individuals smaller in Pemba Bay than at other sites in Northern Mozambique. However, functional diversity is not significantly affected. Based on the data in this study, there is no evidence for the second hypothesis that direct removals from fishing are the dominant disturbance around Pemba Bay.

Differences between Pemba Bay and nearby sites

The aquatic ecosystem in Pemba Bay is a combination of coral reefs, seagrass beds, mangrove forests, sand flats, and deep channels. Stereo-BRUV samples taken solely for this project attempted to sample coral, seagrass, and sand habitats. These included samples taken in Pemba Bay and Situ. Data collected in Nuarro and Vamizi were initially collected in an attempt to determine elasmobranch presence on reefs, therefore, only reefs were sampled. This means, the diversity of habitat around Pemba Bay is not necessarily different from other sites in the area. Within coral habitats, Pemba samples appear to have less branching coral than other sites, which could be caused in part by direct contact between fishing gears and corals (personal observation).

While important marine habitats for fishing exist in Pemba Bay, there is evidence that fishing practices harm these habitats. In observations of purse-seine fishing, many, but not all, of these nets are used in shallow waters, not more than 15m. These nets depend on reaching from the surface to the substrate, and are pulled in while being dragged along the bottom with fishers in the water to help the net get over coral obstacles. Considerable contact with coral is common. Beach-seine nets try to avoid coral as it can damage the nets, but they often pull up considerable amounts of seagrass (personal observation). Hand-spear fishing often involves walking on coral during low tide, and evidence of discarded gears including all types of nets and traps exists around Pemba Bay. Mangi and Roberts (2006) found that many fishing methods have direct effects on the marine ecosystem, such as direct coral damage, especially beach-seine and hand spear fishing.

Despite some destruction of coral and seagrass habitats, Pemba Bay retains a diverse marine ecosystem. Many workshop participants mention the importance of protecting the mangroves as well as other marine habitats, and Bandeira *et. al.* (2009) found that Pemba Bay mangrove forests are relatively intact. Coral sites around Pemba Bay are variable, with some showing significant algal overgrowth and others appearing largely intact (personal observation). The multinomial models of habitat morphotypes show that Pemba samples exist in all parts of the 2-D space, indicating that some samples are similar to reefs found in the other sites. McClanahan and Muthiga (2017) found that coral reefs near Pemba were relatively healthy with high coral diversity. The continued diversity of marine habitats around Pemba Bay is probably helpful to the Pemba Fishery. For example, Berkström *et. al.* (2012) found 50% of species around Zanzibar were found on reefs and seagrass or mangroves, including many species important to the fishery such as emperors and snappers. Gell and Whittington (2002) found juveniles of many species important to the fishery in seagrass beds in the Quirimbas just north of Pemba Bay.

Even though there are relatively intact sections of coral reef, seagrass beds, and mangrove forests in and around Pemba Bay, mobile marine functional groups are adversely affected in the bay compared to other sites. Functional group compositions are different in Pemba Bay than other sites around northern Mozambique, even after accounting for habitat differences. The differences in proportional biomass of functional groups in Pemba Bay compared to other sites indicates that not all functional groups are being affected in the same way by fishing activities in Pemba Bay. Surprisingly, these differential effects on different functional groups do not equate to differences in functional diversity indices. This lack of difference is unexpected, as many find that fishing causes declines in biodiversity (Jackson *et. al.*, 2001; Pandolfi *et. al.*, 2003; Worm *et. al.*, 2006), or depletion of higher trophic level, predatory fish species (Pauly *et. al.*, 1998). In a simulation model, Martins *et. al.* (2012) found that fishery removals cause large declines in measures of functional diversity, however, they mention that these declines were tempered by species richness. Pemba Bay still has fairly high species richness with over 600 species encountered in this study and high coral diversity (McClanahan & Muthiga, 2017). This continued richness could dampen the effects of fishing on functional diversity. It is also possible that the lack of effects on functional diversity in Pemba Bay is due to the fishery being relatively unselective. Garcia *et. al.* (2011) hypothesized that less selective fishing causes fewer ecological impacts than selective fishing. The Pemba Bay fishery is somewhat selective; however, most species are caught at least on occasion or during certain stages. Mangi and Roberts (2006) found that beach-seine fishing, in particular, catches many juveniles which use seagrass beds as nurseries. From personal observations of beach-seine catches, this appears to occur in Pemba Bay as well. So, while fishers seem to target specific functional groups or species, there may be enough incidental catch of other species to limit the extent to which the entire community changes. Based on the ecological impacts that Worm *et. al.* (2006) expected due to declines in biodiversity, Pemba Bay having similar functional diversity as semi-protected reefs in Quirimbas and Vamizi is encouraging for the fishery as a whole.

While Pemba Bay is not different from these other sites in functional diversity, it does have significantly lower biomass and smaller individuals than other sites in northern Mozambique. Some herbivorous fish, such as browsers and grazers, have lower biomasses in Pemba Bay than Situ and/or Vamizi. Additionally, parrot fish tend to be smaller in Pemba Bay with one diver familiar with doing censuses around Vamizi commenting on how she is often confused by parrot fish in Pemba because they transition to males so much smaller (personal communication with Dr da Silva). The apparent lack of some herbivores on Pemba reefs is concerning, given evidence that these groups are important for reef resilience and recovery following disturbance (Adam *et. al.*, 2011; Hughes, 1994). Data in this study do not give density, however, McClanahan and Muthiga (2012) found biomass densities at a few reefs in Pemba Bay between 150 and 380kg/ha which is near or below the lower limit of 300kg/ha for sustainable yield in multi-species fisheries (McClanahan *et. al.*, 2011). As fishers' perceptions are that there are fewer fish now than a decade ago, it is probable that current densities are below the limit for sustainable yield on many reefs around Pemba Bay.

Like biomass indices, lengths are shorter in Pemba Bay than other sites. Proportional lengths of the largest individuals of each species in a sample show that Pemba Bay has individuals which are significantly smaller than in Nuarro and Situ, but Vamizi is not significantly different. Looking at the lengths of preferred species, mentioned in interviews as a preferred target, shows Pemba Bay individuals are significantly smaller than individuals in all other sites. Da Silva (2015) found that catch lengths increased with distance from Pemba when looking at catches for fishing centres throughout Cabo Delgado. These decreases in length around Pemba Bay could lead to fisheries-induced-evolution in which fish life histories, such as size at maturity, change to allow reproduction to occur, at least occasionally, before capture by the fishery (Kuparinen & Merilä, 2007; Laugen *et. al.*, 2014). Changes in size and life-history characteristics can affect fishery production further, as large individuals are often the most fecund (Garcia *et. al.*, 2011; Law, 2007). The Pemba fishery may be somewhat protected from fishery-induced-evolution due to its capture of a variety of species and size classes, but fishers target large individuals, when possible, which could cause greater deterioration of the fishery in the future.

Direct effects of fishery removals on functional group biomass and individual lengths

The hypothesis that due to direct removal by fishing, some functional groups would have lower relative biomasses and lengths in Pemba Bay than others is not supported. Even though Pemba sites have both lower biomass and smaller individuals than other sites, these differences are not correlated with fishery catches in these data. The same is true using catches from individual fishing methods. In fact, total purse-seine catch is positively correlated with functional group biomass based on stereo-BRUV samples in all sites. This suggests that purse-seine fishers are targeting more abundant species. However, if the correlation between fishing catches and functional group biomass were significantly less positive in Pemba Bay than other sites, this would still have supported the hypothesis that direct removal of target species in Pemba Bay was having a dominant effect on the marine community, as these functional groups would still be lower than they would be with less fishing pressure. Since this does not occur in these data, it suggests that secondary effects of fishing in Pemba Bay are more important than the direct removal of target species. This agrees with the findings of McClanahan and Kaunda-Arara (1996) in which all species monitored had lower biomasses in fished than unfished areas. The fact that no one fishing method has a large direct effect on the Pemba Bay fishery is important for fishers in the area because most blame changes in the fishery on one or a couple of fishing method, generally night fishing with purse-seine nets and/or mosquito net fishing. While it is still possible that these methods have larger secondary effects than other methods, the lack of large primary effects may be useful in convincing fishers using all methods that they could have an impact on the fishery and should be part of mitigating further impacts.

It is possible that declines in biomass and size are caused by other anthropogenic stressors, such as pollution and coastal development, rather than fishing. This study does not address these possible effects, and as there is no correlation between estimates of fishery catch and differences in biomass and size in Pemba Bay compared to other sites, non-fishing disturbances cannot be ruled out. Due to the amount of fishing which occurs in Pemba Bay, it is unlikely that this is not contributing to differences between Pemba Bay and other sites. The lack of correlation between functional group biomasses in stereo-BRUV samples and fishing catch in Pemba Bay could also be a methodological issue.

Comments on methodology

The stereo-BRUV data, which make up most data used in this section, are taken from four sites around Northern Mozambique, which were collected for two different projects. Data around Pemba Bay and Situ Island attempted to sample all available habitats, although this was not always possible. Data from Nuarro and Vamizi Island attempted to survey elasmobranch abundance, so stereo-BRUVs were placed almost exclusively near coral and when possible near drop-offs in an attempt to attract sharks and rays. These differences mean that site differences in percentage of habitat characteristics are at least partially caused by differences in sampling technique. These differences in habitat likely cause differences in mobile species surveys as well. This is accounted for in models which include habitat variables in explaining mobile species size and biomass. And running the models without Pemba's sand and seagrass dominated stereo-BRUV samples does not change the general findings, so these methodological differences are unlikely to have had a large effect on these results.

In addition to the difference in sample locations from the different sites, there are problems with stereo-BRUVs in establishing the actual area sampled (Taylor *et. al.*, 2013). Some species are attracted to the bait and approach from an unknown distance, while others are not attracted but are seen due to being in the area. Therefore, the area sampled depends on species characteristics. This can be somewhat addressed by distinguishing between species which interact with the bait and those which do not. However, this study does not use this variable in explaining biomass and size estimates. Somewhat surprisingly, herbivorous fish and prey species can be attracted to bait as well as predatory species (Watson *et. al.*, 2010). There is no evidence that bait would be more or less attractive in Pemba Bay than other sites, therefore, the comparison between sites is likely to be valid. However, further research on the effects of bait in more intact or degraded ecosystems is necessary to confirm this assumption.

To address potential problems with stereo-BRUV samples, this study attempted to use diver operated videos as well. Forty dive samples were collected in Pemba Bay and Situ, however, analysis of the videos did not allow reliable species identification, so these data were not used. Future use of diver operated video should include an additional diver to make a list of observed species. This would allow better species identification but still provide a video record to check against the list and to allow more accurate counts of schools of fish, sizes, and distances. To address uncertainty about marine species densities in stereo-BRUV data, visual census data can be used to compliment stereo-BRUV data, and should be considered. Diver surveys have their own biases with some species being repelled by divers and others attracted, so this is not a perfect solution (Watson & Quinn, 1997). Additionally, diver data requires more time per sample than stereo-BRUV data, so cost benefit analyses need to be considered for each project.

The grouping of species composition data into functional groups also creates potential bias and uncertainty. This study weighted trophic group most heavily in establishing functional groups so that no functional group contained more than one trophic group. This is due to the importance of trophic groups in establishing trophic connections and assumed importance in affecting fishing decisions. However, there are many non-consumptive interactions between marine species which are minimized by the focus on trophic interactions which could prove to be more important. The selection of functional groups could affect the results of the data. Additionally, by using functional groups, species not found in the catch data can be part of a functional group with a non-zero catch. These assumptions may be valid, as similar species are likely to be targeted by fishers in similar ways. However, differences in size, for example, between species within the same functional group in these data could cause differences in targeting by fishers.

Determining cut-offs for functional group creation is also subjective. This study uses a rule of thumb estimate of 0.8 tree branch height as the cut-off based on recommendations from a SAIAB employee. Increasing the number of functional groups would allow greater differentiation between functional characteristics, but potentially separate species which are functionally similar within the ecosystem based on feeding ecology, habitat use, etc. As data are collected at the species level, future uses of these data can use different traits to create functional groups for studies addressing different relationships within the marine ecosystem. Even with the ambiguity inherent in deciding on which traits to use to make functional groups and the cut-offs to use that determine the number of groups, these simplifications are necessary and allow some understanding of the functions which occur within different sites. As trophic group is often important in determining ecosystem function (Adam *et. al.*, 2011; Catano *et. al.*, 2016; Puk *et. al.*, 2016), the current groups are reasonable for this study. However, the effect that functional group identification makes on results needs to be investigated further.

Finally, there are issues with the fishery catch data, as mentioned in Chapter 3. Creel survey effort was not evenly distributed through time or fishing centres. There are much more data from 2018 than 2012, the first year for which data were available. Additionally, there are many more data from Ruela, within Pemba city, than for other landing sites. That not all fishing centres were surveyed in all months made calculating the total catch from Pemba Bay more difficult. This study assumes that catches between fishing sites are not negatively correlated and, therefore, adding the average monthly catch from different sites together is acceptable. As there being zero catch from a landing site in months without any data is highly unlikely, adding catches from all landing sites before taking the average would also be problematic by assuming that in those months no catch was made in some fishing centres.

Additionally, even when surveys were conducted at a landing site, they did not always occur regularly enough to sample all fishing methods, resulting in zero catch estimates for some methods in some months. Based on conversations with fishers, it was unlikely that any method was not used in a month. However, in some months, use or catch from some methods may have been lower than in other months, and in these cases, fishery technicians would have been less likely to survey these methods due to there being less fishers using them and/or fishers spending less time at the landing site if catches were smaller. These issues are somewhat accounted for by estimating a maximum monthly catch in which all months with zero catch are removed before taking the mean, and a minimum monthly catch, in which months with zero catch are considered valid data and included in the mean. But based on the limitation in the catch data above, neither minimum nor maximum catch estimates are accurate. However, there is no reason to believe that they are more inaccurate for some functional groups than others. As this study used the catch data to compare functional group biomass in Pemba stereo-BRUV samples with other sites, as long as the proportional catch for each functional group is accurate, the models should be accurate as well.

The potentially most problematic issue with the catch data from the fishery ministry, is that some surveys had high, sometimes 100%, of species classified as unknown. As this study has no way to assign these catches to a functional group, they are ignored in the data. Unknown species are most likely smaller species or individuals and not from a preferred target species. How much these unclassified catches would have increased the catch of some of the functional groups which appear to be uncaught or at least caught in smaller amounts, is unknown. This could have a drastic effect on the models of stereo-BRUV biomass and size based on catch, as it would indicate that some functional groups which have low total catches in the data, actually have much higher total catch. This could explain species with apparently low total catch having relatively low biomass and size in Pemba compared to other sites. More accurate and reliably collected catch data is needed to resolve these potential issues in determining the direct effects of Pemba catch on marine target population’s characteristics.

Finally, catch data was only acquired for Pemba Bay, even though at least some fishing occurred at all sites in which stereo-BRUV samples were collected. It is reasonable that fishing pressure was lower at these other sites, especially Vamizi and Situ as they had marine reserves as part of the fishery. However, local differences in fishing method use and pressure by specific methods most likely confounded the results of models of biomass and size, as fishing was probably decreasing both in other sites as well as Pemba Bay. In her thesis work, da Silva (2015) found that fishing pressure was highest at Pemba city compared to other sites in Cabo Delgado. This work did not try to estimate total catch from these sites, but used average size and trophic level of catch as a surrogate for fishing pressure. The odds that many fishing centres outside Pemba would have accurate estimates of total monthly catch is low based on the problems with these estimates in Pemba, the provincial capital.

There is an intention to investigate catch for functional groups in different ways in the future. For example, comparing results using these data with other estimates of catch from Northern Mozambique using Sea Around Us (SAU) data or FishBase estimates of catch by different fishing methods for different species to approximate fishing removals can be done. In addition, including average size of species in the model to allow larger species to be more affected by fishing could indicate a correlation between fishing and functional group biomass or size. These results can be compared to the results from this study to either support the conclusion that direct individual removal is not the dominant disturbance in Pemba Bay, or to refute it.

As in the third chapter, using Bayesian analyses to examine these data allowed the non-normal distribution to be easily accounted for and allowed complex model structures to account for habitat differences, site differences, and catch from different methods. The complexity of this model precludes the use of frequentist statistics. As above, the default weakly informative prior distributions are used, so researcher expectations did not affect the outcome from the models. These models allow the different sampling methods to be addressed by including many habitat characteristics in the model, so that the lack of certain habitats in Vamizi and Nuarro data are unlikely to affect the results of differences between sites.

Conclusion

Within the fishery SES, this chapter addresses the ecological effects based at least partially on fisher decisions. The results indicate that the fishery is being negatively affected around Pemba Bay, with both lower biomass as well as smaller individuals. It is likely that at least some of these declines are caused by fishing, however, the direct effects of fishing on targeted species are no larger than on less targeted species. And functional diversity is similar between samples in Pemba Bay stereo-BRUVs and other sites. These data in conjunction with other studies in the area suggest that the fishery is declining, but has not collapsed. A multi-gear fishery, as in Pemba Bay, may be helpful to the fishery (Garcia *et. al.* 2011) by allowing a variety of functional groups to be utilized maintaining many of the interactions within the community even though total biomass is significantly lower. However, Garcia *et. al.* (2011) mention that fisheries which target large proportion of the available community can maintain catches for longer than fisheries targeting a few species but that these systems tend to collapse suddenly in simulations. Collapse of a fishery which is already targeting most available species leaves little or no alternatives to continue fishing. The possibility of sudden collapse makes management to improve catches and the marine ecosystem urgent for both the ecological and social systems around Pemba Bay. This is addressed further in the final discussion below.

Chapter 6 General discussion

Abstract

This chapter synthesizes the results from the previous three data chapters to give a more complete assessment of the Pemba fishery and the interactions between the social and ecological systems. The data from the different sources do not always agree. Based on catch data, the fishery appears to be stable and therefore current management practices could be considered adequate. However, fisher opinions, wellbeing, and marine resource characteristics indicate that the fishery may be overexploited or, for other reasons, unable to support the amount of fishing which local communities require. Based on the perceived decline in the fishery, management has been attempted at national to local levels including the initiation of temporary closures by local fishing collectives. This study recommends increased support of local initiatives to increase empowerment of local fishers as well as find locally relevant management interventions.

Introduction

Many, if not most, ecological and social systems around the world can no longer be considered separately but, instead, need to be investigated as interacting social-ecological systems (Ellis, 2015; O'Neill & Kahn, 2000). In these systems, humans have a unique position, as our extreme behavioural plasticity and rapid cultural evolution allow us to adapt much faster than most of the species with which we share the system (Ellis, 2015; Wilson, 2017). Along with shaping ecosystems, humans are also dependent upon them for survival, even in cities where the connections between humans and nature seem weak (Collins *et. al.*, 2000). In small-scale fisheries, on the other hand, the interactions between humans and ecosystems are obvious and direct.

This study considers the motivations for fishing decisions and the social and ecological outcomes from these decisions (Figure 6-1). Ostrom's framework, as formalized by Hinkel *et. al.* (2014), is particularly useful for addressing how different aspects of the system, in this case, social characteristics, ecological state, and fisher motivations, interact to determine an appropriation action situation in which fish are extracted from the marine ecosystem. It can be expanded to address how fishers' experiences of the social and ecological systems can be used to promote provisioning action situations, i.e., fishery management or collective actions to protect the fishery and allow for continued resource provisioning.

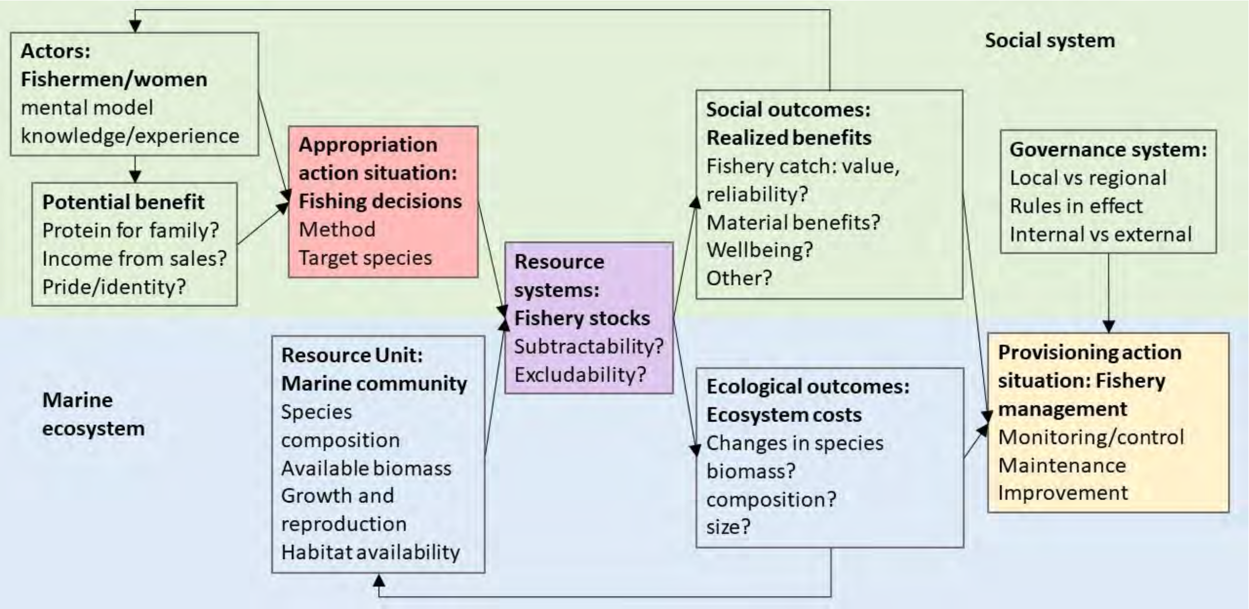

Figure 6-1: A repeat of Figure 1-3 from the introduction, with boxes indicating the part of the schematic each question and hypothesis addresses.

This final chapter focuses on how the results from the previous chapters interact to determine the state of the fishery, to understand some of the factors affecting fishing decisions, and create the need for more fishery management (in orange in Figure 6-1). It discusses some actions that are being taken at different levels to attempt to manage the fishery and makes suggestions on how management should move forward based on these results.

The state of the Pemba Fishery

Catches from Pemba Bay over the last several years indicate that the fishery is relatively stable, suggesting that it may be in a reasonably good condition. However, ecological data shows that fish sizes and biomasses are lower in Pemba Bay than other nearby sites and fishers report less fish in the fishery and having to increase their effort to maintain their catches, indicating overfishing is probably occurring. Also, local fishers state a lack of wellbeing, suggesting that the social system is also unstable and in need of transformation.

Looking at changes in catch value per fisher from these data, the Pemba fishery appears to be stable, however, there are a few reasons this should not be taken as an indication that the fishery is sustainable. In interviews and workshops, local fishers indicate that catches are declining. When the cod fishery in Newfoundland collapsed in the 1990s local fishers were aware of the problem before managers or scientists (McCay & Finlayson; 1995), so these observations should not be ignored. Many studies seem to agree with fishers that catches in the area are declining, although none of these studies was conducted in Pemba Bay. Catch reconstructions for Mozambique find that national catch has been in decline since the early 1980s (Doherty *et. al.,* 2015; Jacquet *et. al.,* 2010). Zeller *et. al.* (2021) found that small-scale fishing effort had increased around the Mozambique Channel between 1950 and 2016 and CPUE had decreased. In Tanzania, artisanal fishing CPUE declined significantly between 1983 and 2000 (Berachi, 2003). Cardinale *et. al.* (2014) found that CPUE of two species important to artisanal fishing catches in Mozambique declined between 1995 and 2010, however, this depended on fishing centres, none of which were in Pemba Bay. And Blythe *et. al.* (2013) found decreases in CPUE in central Mozambique since 1998 due to a combination of environmental and social factors. Most fishers indicate that declines became really apparent in the early 2000s. Since data used in this study only start in 2012, it is possible that some equilibrium in catch has been reached in the recent past. However, the declines in CPUE found by Cardinale *et. al.* (2014) were sometimes only apparent after accounting for fishing net length. This would indicate that, in some fishing centres, fishers mitigated declining catch by modifying their fishing gears. Blythe *et. al.* (2013) also found behavioural changes by fishers to mitigate declines in CPUE. Most catch data used in this study come from the fishery ministry in Pemba. These data measure unit effort as a fishing trip without accounting for hours fishing or amount of gear deployed. Many fishers (52%) indicate that they fish longer, farther, set more gear, or in some other way increase their fishing effort due to perceived declines in marine species abundance in the water. As most of the data used in this study do not account for these differences in effort, actual declines in CPUE could be masked by behavioural changes.

Declines in catch being mitigated by increased fishing efforts mentioned by fishers agrees with in-water data. Stereo-BRUV samples from Pemba Bay show lower biomass and smaller individuals than other sites in Northern Mozambique. A survey of a few reefs in Pemba Bay in 2012 (McClanahan & Muthiga, 2012) found that marine species density was at or below the lower limit beyond which ecosystem shifts are expected (McClanahan *et. al.,* 2011). The current study does not measure density to determine if it has declined further since that survey, however, fisher perceptions are that in-water abundances have declined and assertions that they have increased their fishing efforts make declines likely. Additionally, the smaller size of fish around Pemba could decrease recruitment into the fishery due to the loss of large fecund individuals (Kuparinen & Merilä, 2007; Law, 2007). These worrying characteristics of the fishery ecosystem are somewhat lessened by the result that functional diversity is not significantly different in Pemba Bay compared to less fished areas. Garcia *et. al.* (2011) found that more diverse systems in which many species were targeted could remain stable despite high fishing pressure, but warned that sudden regime shift to a less desirable state occurred in models of these high diversity systems. Regime shifts have been found in real fisheries as well. For example, Folke *et. al.* (2004) found that intensive fishing in the Black Sea caused regime shifts. Hughes *et. al.* (2013) warned about such regime shifts, but suggested that, even after a shift begins, there could be time to counteract detrimental changes to promote more beneficial ecosystem states. This could indicate that the maintenance of functional diversity and ability of fishers to maintain catches are masking problems that can cause a resource crisis, but that avoiding a resource crisis is still possible.

There are also social indications that the Pemba fishery is in an undesirable state. Fishers using most methods are as well off materially as non-fishers in the area, yet they indicate lower satisfaction with most aspects of their lives compared to non-fishers. Additionally, most indicate the desire to decrease their dependence on fishing and for their children to exit the fishery, showing dissatisfaction with the state of the fishery. From the changes in relative use of fishing methods and fishers' stated preferences for fishing methods, it appears that catch reliability and value are both important to fishers when making decisions, yet neither catch value nor reliability increases fisher satisfaction with most aspects of their subjective wellbeing. This indicates that lack of satisfaction is being affected by something more than catch characteristics. Based on preferences for more reliable methods, it is possible that this lower satisfaction relates to the unpredictability of fishing in general. From the descriptive statistics of catch from all methods, standard deviations of catch value are similar to mean values, indicating a lot of variation in catch. Attah *et. al.* (2016) mentioned the positive psychological benefits for people receiving predictable cash assistance in part because they knew they could pay their debts. The unpredictability of fishing could have the opposite effect of causing psychological harm. However, Tucker *et. al.* (2013) found that, in Madagascar, locals generally attributed farming as being riskier than fishing. If people in Pemba feel that fishing is a less risky occupation than other options, then unpredictable catches cannot explain their lower subjective wellbeing. Dissatisfaction may be related with marginalization and feelings of lack of control rather than catch unpredictability.

Lack of subjective wellbeing and knowledge of declines in the fishery are likely to exacerbate lack of self-esteem and make fishing decisions less likely to be innovative or adaptive. From Chapter 3, the theory of planned behaviour is the most consistent with fisher interview responses. Fishers' stated lack of ability to decrease, or even change, fishing methods, and this suggests that, even though they may want to make different fishing decisions which would increase the reliability or sustainability of the fishery, they currently do not feel empowered to do so (e.g., Béné, 2003). In India, Nayak *et. al.* (2014) found that as the fishery resource deteriorated, fishers felt less power and became more marginalized. The lack of ability to control fishing catches may increase fishers' feelings of helplessness and marginalization through learned helplessness (Boureau *et. al.*, 2015).

Due to these sometimes stated, and often implied, feelings of marginalization, even though fishers may want to change their behaviours, many feel unable to do so. Based on ecological and social characteristics, the Pemba fishery appears to be in decline and a collapse is possible. Gunderson and Holling (2002) suggest that resource crises can allow reorganization of systems as resources are freed, which can allow transformational change. Unfortunately, rather than reorganizing into a system in which the different components interact in a beneficial and adaptable way, systems can be caught in maladaptive cycles in which diversity and potential is eliminated: these are poverty traps. The lack of empowerment expressed by many fishers, increased fishing effort to avoid declining catches, and decreases in size and abundance of most marine species are some indications that without interventions, the Pemba fishery may be heading toward a poverty trap.

Managing the Pemba Fishery

Due to social dissatisfaction and relatively low marine biomass and size around Pemba Bay, there is some indication that provisioning action situations, management actions to support marine resources, are being attempted within the Pemba fishery. Fishery managers from the national to provincial level, as well as local fishers, are attempting to manage the fishery. The focus of most of these stakeholders is to increase catches and decrease poverty, however, there are indications from some that this must include protection of marine species as well.

Like many small-scale fisheries around the world, the Pemba Bay fishery cannot be managed well using the methods used for selective, industrial fisheries (Boonstra & Hentati-Sundberg, 2016). The need for different management techniques has led to the expansion of co-management arrangements all over the world, including in Mozambique (Russo de Sa, 2011). Co-management arrangements have shown some positive results (Cinner *et. al.*, 2012a; Cinner *et. al.*, 2012b; Olsson *et. al.*, 2004). Unfortunately, these efforts have been largely ineffective so far in Pemba with only a small percentage of fishers belonging to fishing collectives when they exist, and with little support from the Mozambican government (McClanahan & Muthiga, 2012). Béné *et. al.* (2016) stress that, without support from national governments, local initiatives cannot be successful. As Abdullah *et. al.* (1998) pointed out, co-management arrangements can push the cost of management to smaller communities with even less ability to afford them than national governments, which seems to be occurring in Pemba Bay. Cinner *et.*

al. (2012a) found that co-management in much of the western Indian Ocean depends on donor organizations for financial support, which was lacking in Pemba during data collection. Effective co-management depends on enforced national regulations to promote cooperation between communities (Freed *et. al.*, 2016; Léopold *et. al.*, 2013), which was also largely lacking in Pemba Bay. Finally, co-management can actually increase wealth disparities in communities, if the most powerful are able to take advantage of government programs while the poorest are not (Cinner *et al*., 2012b). That only fishers in Ruela have managed to get loans to purchase purse-seine vessels indicates this too is probably a problem in Pemba. Empowerment of fishers in different places and using different fishing methods should be investigated in the future so that steps can be taken to decrease rather than exacerbate wealth and power disparities.

Along with co-management arrangements, many researchers are calling for adaptive management regimes which allow for experimentation and modification of management interventions. Ludwig *et. al.* (1993) stated that we cannot manage fisheries at maximum sustainable yield not matter how much we learn about these fisheries due to uncertainty, natural fluctuations, and human tendencies to overcapitalize in good years. They suggested adaptive management to deal with these problems, although they did not call it that. The need to use management as local experiments and monitor the results for fisheries management is increasingly accepted (e.g., Foley *et. al.*; 2010). And Jensen *et. al.* (2012) noted that all fisheries management intervention can be thought of as large-scale experiments and should be studied as such. The necessary monitoring for adaptive management to be successful can be prohibitive, especially in small-scale fisheries with few resources for monitoring. However, the need to be able to respond quickly to local conditions makes these adaptive management regimes even more important in small-scale systems with high dependency on fishing.

Despite the difficulties involved in management of the fishery, some projects are underway to attempt to improve fishing catches. At the national level, the fishery ministry acknowledged that Mozambique's fisheries are fully or overexploited in most cases (Ministério da Pesca, 2014). This is a change from the assertion by the African Development Fund report in 2001 that the Nampula and Cabo Delgado fisheries were severely underexploited and increased harvest as well as catch preservation was recommended (Hara *et. al.*, 2001). National plans include increased land-based infrastructure such as fish markets and processing centres, increased aquaculture, increased access to larger vessels to fish coastal waters, and increased quality control and testing to assure consumers in the safety of marine products (Ministério da Pesca, 2014). The effects that these interventions will have, if enacted, is unclear. Cinner *et. al.* (2016)

found that increased access to fishing technologies and increased fish preservation, rather than relieving pressure on nearshore marine resources, exacerbated it. Even if the national priorities are enacted in Pemba Bay, they may not improve the long-term situation for most fishers.

Along with national policies to improve fisheries, local fishing collectives are also attempting management. Most Pemba fishers suggest temporary closures of parts of the fishery to improve catches over time. Toward the end of data collection, fishing collectives in Ruela and Metuge attempted to impose closures on parts of their fishing grounds, with varying success. The collective at Ruela closed a large section of the northern part of the bay to net fishing. It was recognized by the fishery ministry and seemed to be largely respected, based on conversations with fishers in the area. The other collective in Metuge closed part of their beach to fishing. Based on Mozambican fishery rules, the local collective has control of the beach in front of their village out to 2 nautical miles (*Regulamento de concessão de direitos de pesca e de licenciamento da pesca*, 2017). Yet the fishery ministry in Pemba did not recognize the closure, and local fishers complained about poaching in the closure by net boats from the city. One of the goals from co-management is increasing local fisher empowerment (Cinner *et. al.*, 2012b; Wamukota *et. al.*, 2012). The lack of support for local initiatives leading to failure may increase feelings of marginalization, hopelessness, and despair (Castro & Nielsen, 2001; Drury & Reicher, 2005). On the other hand, Tausch and Becker (2013) argued that anger could be motivating for future action. These different potential responses to failure may determine how the attempted temporary closure by Metuge fishers affects future actions.

Despite the popularity of temporary closures by Pemba fishers, the effectiveness of periodic closures for managing small-scale fisheries is contentious. For these to have any long-term sustainability effects, they need to be in a permanent cycle of open and closed periods. In a workshop in Ruela, fishers mentioned that they had a temporary closure in the past and liked it because it made the fish tamer. However, permanent closed and open periods were not established, so it is unlikely that this temporary closure benefited the overall sustainability of the Pemba fishery. Upon returning to Pemba in 2023 it was discovered that Pemba fishers have established periodic closures, rather than a single temporary closure. Yet there are still arguments about the effectiveness of temporary closures for fishery management. In areas where periodic closures are established, high intensity of harvest during open periods can exceed the benefits gained during the closure, cancelling any ecological benefits, although there can be short term increases in CPUE (Beitl, 2015; Cohen & Foale, 2013). Cohen and Foale (2013) argued that the only real benefit in these periodic closures were decreases in fishing effort. Cinner *et. al.*

(2006) found long term benefits to periodic closures in remote villages in the south Pacific, but, like Cohen and Foale, they attributed much of the success of these closures to lower overall fishing pressure in areas with closures. In a meta-analysis of periodic closures, Goetze *et. al.* (2018) found that most did allow recovery and increased catchability of some species. They argued that if open periods were timed correctly, open periods had increased CPUE without causing long term decreases in standing stock, and possibly helping them to rebound. However, Goetze *et. al.* (2018) acknowledge the potential pitfalls of intensive harvesting, eliminating any recovery from closed periods. Januchowski-Hartley *et. al.* (2014) found that the increase in catchability of fish in periodic closures was important in making them acceptable to local fishers, as is the case for Pemba fishers. In a modelling study on the use of periodic closures for fishery management, Carvalho *et. al.* (2019) stated that periodic closures, where the area was closed most of the time and only open a relatively short time, could increase CPUE, total yield, and standing stock. However, this depended on fisheries which were at least moderately well managed. In fisheries which were highly overexploited, permanent closures offered the best option, and CPUE, yield, and standing stock all equalize at very low levels relative to well managed fisheries (Carvalho *et. al.*, 2019). For Pemba fishers, if their fishery is overexploited, as seems likely, a temporary closure is unlikely to increase their catches without other measures to decrease overall fishing pressure.

One way that the Mozambican government and locals in Metuge are attempting to decrease fishing pressure is through increased aquaculture. A fisher in Metuge started an aquaculture tank several years ago which has been successful. During the last year of data collection, the government subsidized the construction of aquaculture tanks in the large tidal flood plain between Metuge and the beach. Small-scale aquaculture has been used in Malawi to increase access to protein and aquaculture is often more profitable than other agricultural products (Chimatiro, 1998). These projects use agricultural wastes, including manure, to feed the tanks, but mention that care needs to be taken in amount, as excessive inputs can cause increased parasite loads (Chimatiro, 1998). The need to determine appropriate amounts of inputs to allow fish growth while preventing parasite infection suggests a large amount of experimentation may be necessary which could delay profits. Fishers' willingness and ability to persist through these experimental phases is unclear.

Upon returning to Pemba Bay in 2023, the use of temporary closures and local management of the fishery had expanded, but the aquaculture tanks had been largely abandoned. All three of the fishing collectives which existed during data collection, one of which the researcher did not interact with, had established or re-established temporary closures which were recognized by the fishery ministry (communications with local fishers). The third community which during data collection did not have a local collective, had established one by 2023 and was discussing creating rotating open and closed sections of their local fishery to increase production and allow fish populations to recover. The apparent success of temporary closures and failure of aquaculture expansion around Pemba Bay should be treated as social-ecological experiments in an adaptive management regime and the reasons for success or failure based on social or ecological outcomes investigated further. Additionally, conflict between fishers within and outside of the local collectives is apparent in interactions in 2023 and some fishers discussed the lack of communication between local collective groups. These potential conflicts between and within fishing communities need to be better understood and institutions established to allow conflict resolution and joint goal formation if the entire area is going to be successfully managed (i.e. Folke *et. al.* 2002 and Olsson *et. al.* 2006).

Along with greater understanding of what causes some fishers to choose to be involved in collective actions and establishing links between different fishing groups, the characteristics of the fishery suggest other interventions that should be instigated as soon as possible to avoid further degradation and a potential poverty trap. The importance of behavioural control when making fishing decisions indicates the value of skill development to allow for alternative employment, i.e., people need to feel like they have more choices and agency (Cinner *et. al.*, 2018). Educational reforms in Mozambique have not eliminated poverty as naively hoped, but they have increased people's ability to start small businesses and improved social interactions and self-esteem (Buque, 2013; Fox *et. al.,* 2012). Increasing education and skill development allows for other livelihood opportunities, but perhaps, as importantly, increased self-esteem and social capital may allow a safety net which makes it easier to take risks and innovate. Self-esteem is found to increase individuals' likelihoods of making financial investments and also the amount of risk the person accepts in these investments (Sekścińska *et. al.*, 2021). Landry *et. al.* (2002) found that for business firms, increased social capital increased the odds that a company tried to innovate and increased the radicalness of that innovation. Social support likely plays a role in allowing individual people to adapt as well (Berkes & Ross, 2013). If the Pemba fishery reaches a reorganization stage, as suggested by Gunderson and Holling (2002), then exploration and experimentation will be necessary. However, focusing solely on education and depending on poor communities to provide the necessary insurance against failure that allows exploration is unrealistic. Therefore, interventions that promote social programs to allow innovation are also needed.

Institutions that promote experimentation and innovation and allow risk taking are important to promote economic growth (Bird, 2001) and system resilience (Folke, 2006). In response to resource collapse, most fishers increase fishing effort rather than changing their behaviour in any substantive way (Béné, 2016). Most fishers in Pemba Bay have done the same in response to perceived declines in marine species availability. Continuing to fish in the same way if the resource collapses is highly likely to lead to a poverty trap rather than allowing transformation of the fishery to a more sustainable state (Folke *et. al.*, 2010). The diversity of fishing methods used in Pemba Bay provides a lot of potential for adaptation as conditions change, however, without resources to allow experimentation and innovation, this diversity is unlikely to translate into changed behaviours (Carpenter & Brock, 2008). Social programs which provide insurance against failure can free mental energy for thinking about alternatives and the future (Shah *et. al.,* 2012) and increase risk-taking and innovation (Bird, 2001). Osiyevskyy *et. al.* (2020) found that for firms, exploration and innovation is generally beneficial for long-term survival, but the results are variable and it is costly in the short-term. Assuming this is true for fishers as well, which seems likely (Conrad *et. al.*, 2011), it is unrealistic for fishers experiencing current resource crises to accept the immediate costs and unpredictability of exploration and innovation without external assistance of some kind. However, these interventions need to include a large amount of local involvement in all aspects of management.

In interviews, many fishers indicated a desire for collective action at the local level to manage the fishery. Collective action can be an empowering experience for those involved at individual (Drury & Reicher, 1999) and community (Berkes & Ross, 2013) levels, so pursuit of sustainability within the Pemba Bay fishery could simultaneously change fishers' attitudes towards fishing, perceived behavioural control, and confidence in social systems and subjective norms. Cinner *et. al.* (2016) found that local involvement and tenure rights were associated with reefs in better ecological condition than expected. And Gibson *et. al.* (2000) found that the level of collective action positively correlated with forest condition under some circumstances. The multifaceted effects that collective action can have on the people involved may make them more likely to implement a change and less likely to circumvent established rules than would be expected if the changes and rules are seen as being legislated by outsiders (Gibson *et. al.,* 2000). Under the right circumstances, as collective actions cause attitudes to change, the potential exists for rapid social change which can have profound effects on the fishery (Smith *et. al.*, 2019). Promoting local collective action is already part of Mozambique's fisheries management policy through the use of co-management arrangements with local fishing collectives, and as seen above, these collectives are involved in collective actions to protect their fisheries, therefore, these arrangements need to be strengthened and supported to allow increased empowerment, collective action, and local management.

Unfortunately, increased local empowerment and opportunities do not necessarily lead to more sustainable interactions between human and non-human components of the system. As Berkes (2007) mentioned, community-based conservation is no more a panacea than government-based conservation. McClanahan *et. al.* (1997) found reefs in Kenya which still had some traditional managements were highly degraded and mentioned that these traditions were not intended to conserve the resource, although in some cases they may have had that effect. And Gibson *et. al.* (2000) found examples of forest management where local institutions did not protect their resources. For any resource use to be sustainable based on current populations, its management must include some conservation (Butler & Oluoch-Kosura, 2006). The theory of planned behaviour has been used to change behaviours by focusing on the precursors to the desired behaviour, behavioural control, attitude, and/or social influence, which most affect the intention to perform a behaviour (Ajzen & Schmidt, 2020; Steinmetz *et. al.*, 2016). By incorporating research into fisher opinions of specific types of fishing behaviours using TPB, researchers and managers could better tailor interventions to either change attitudes or facilitate behaviours if attitudes are already favourable (Ajzen & Schmidt, 2020). Fishers in Mozambique indicate desire for management to protect the fishery, echoing results from other parts of Mozambique (Rosendo, 2016). Therefore, it is not unreasonable to assume they would be open to potential behaviour changes if presented carefully.

Local involvement in the establishment of indicators to be used to determine the success or failure of management interventions can be helpful as well. Fraser *et. al.* (2006) found that determining sustainability indicators with community involvement increased local empowerment as well as giving locally relevant indications of change and increasing compliance with management. The development of indicators with the community could also decrease uncertainty about the consequences of fishing behaviours. Maas *et. al.* (2017) found that university students in a simulated resource extraction experiment were more likely to overexploit the resource when the consequences to the resources were uncertain. They found that clarifying thresholds where resources degradation occurred changed some overexploitation behaviours, although not all.

Along with specific interventions to change attitudes, if necessary, involvement of non-community actors is beneficial to allow different perspectives which might be helpful in quickly changing situations

(Berkes & Ross, 2013). For example, the Mayan people of Mexico learned to hunt crocodiles using a combination of local experience, access to outsider knowledge, and experimentation (Zamudio *et. al.*, 2013). Gelcich *et. al.* (2010) found that small scale experiments and interactions between stakeholders allowed the Chilean fishery to transform after collapse of fisheries stocks. Management that promotes adaptation of local capacities and exposure to alternative options from other places could allow local fishers to develop individual ways to adapt to challenges (Allison & Ellis, 2001).

Finally, though Pemba fishers may be willing to change behaviours, any intervention will need to be honest about costs to protecting the fishery, as well and find ways to mitigate these costs for the most vulnerable (Daw *et. al.*, 2015). Fishers in Pemba are sympathetic to trade-offs between benefits for some groups at costs to others. Many imply that despite declines in the fishery, it is immoral to exclude the poor from the fishery. This is seen in Norwegian fishers as well, where most comply with fishing rules, but accept that some are in more desperate circumstances and, therefore, more cheating from these people is tolerated (Gezelius, 2002). Any specific interventions will need to account for this moral imperative to find ways for the most vulnerable people to be involved in solutions.

The Pemba fishery and climate change

Along with local stressors which could harm the fishery, external stressors from climate change are also likely. McClanahan and Muthiga (2017) found that coral reefs around Pemba Bay were resilient to beaching, but thermal stress is likely to continue, as are other anthropogenic stresses. Northern Mozambique is expected to get hotter and drier with climate change (Jury, 2013; Marsac, 2013). This can cause adverse effect on agricultural production leading to increased reliance on fishing and fishing pressure. It can also cause decreases in the fishery itself both due to possible destruction of coral habitats, and decreased abundances of some fish populations. For example, Hoguane *et. al.* (2012) found that two years after years with a lot of rain, artisanal catches increased. The proposed interventions to increase local involvement in management, skills development, and social programs to promote experimentation and innovation are also needed to deal with climate change in Pemba Bay.

Climate change is likely to cause unexpected and novel environments and disturbances (Kaaronen *et. al.*, 2021). It is impossible to plan for all possible conditions, therefore, promoting general resilience through promotion of diversity, monitoring, and trust is necessary (Carpenter *et. al.*, 2012). Thompson *et. al.* (2012) described using scenarios to examine a range of possible futures with stakeholders to address priorities and alternative decisions while accepting large amounts of uncertainty about future conditions. It is only through this type of democratic involvement with local stakeholders that solutions to problems caused by climate change can be addressed (Rommetveit *et. al.*, 2010). Bhaskar *et. al.* (2010) suggested that this involvement could best be achieved through transdisciplinary interactions between stakeholders and researchers. Cinner *et. al.* (2018) suggested that fisher agency was the most important characteristic to allow people and communities to adapt to climate change. The suggestions above about increasing empowerment and opportunities to cope with the current problems in the fishery are likely to assist in adaptation to future challenges due to climate change as well (Berkes & Ross, 2013).

Research and management interventions to address methodology issues

Each of the above data chapters addressed some potential issues in the methodology which could have affected the results. Conducting social and ecological research as part of an adaptive management project would allow better understanding of these systems through time and with change. This study provides a baseline of the social and ecological systems' state around Pemba Bay. To understand how this system is changing requires continued monitoring. This should be incorporated into an adaptive management plan. The interventions proposed above require continued community involvement. This allows the potential for interviews at different stages of the process to address changes in attitudes, monitoring of fishing practices to address changes in fishing behaviours, and monitoring of marine ecosystems to address changes in ecosystem state and function.

The required level of community involvement in an empowerment focused adaptive management project facilitates collection of social data. As buy-in from the community is a necessary precursor to any project of this kind, once this is achieved, participants are more likely to be invested and willing to talk with researchers. This will bias answers towards those who are involved in management of the fishery, which is unlikely to be a random sample of all fishers. However, if the benefits of interventions are felt by fishers, involvement is likely to spread. During data collection for this study, fishers involved in the local CCPs were more likely to want to talk and give interviews than random fishers, even though there were no direct benefits to them. As adaptive management projects are long term by definition, this allows multiple opportunities to address fisher perceptions as well as material changes for fishers or their communities.

Fisher involvement in determining monitoring protocols and adjusting rules based on results could increase individual willingness to record personal catch data. By increasing fishers' sense of ownership of the fishery and determining monitoring targets jointly, fishers should be more invested in understanding how the fishery is changing for themselves and others. Reporting results from catch surveys back to fishers should also allow greater understanding of how the fishery is changing and, hopefully, willingness to understand those changes on a personal level. The combination of individual interviews and catch journals or surveys from participants would address the problem mentioned above of using average catch values to understand attitudes as well as issues of fishers stating a response to hypothetical changes which are not realized in actual behaviour changes.

Finally, even though the proposed interventions focus on empowerment and fisher involvement, an adaptive management plan requires understanding the ecosystem being exploited. This can be partially addressed by analysing fishing catches, however, analysing in-water characteristics is also necessary. This study finds catches have not declined in the last decade, yet in-water data suggest that the fishery is overexploited. Without this ecological data, the state of the Pemba fishery would be more likely to be misinterpreted. The collection and sharing of these ecological data with local fishers may promote behaviour change automatically if fishers feel empowered to do so, and can be used to establish interventions. Regular in-water monitoring would allow indications of the effects of different interventions so these can be adapted, as necessary for adaptive management.

Conclusion

Like many fisheries in the world, the Pemba fishery appears to be overexploited, leading to detrimental social and ecological consequences. Fisher attitudes and motivations indicate that lack of perceived control to allow different choices is partially responsible for some of the detrimental fishing behaviours which have contributed to the negative social and ecological consequences. If this fishery is going to be managed well, it requires adaptive management regimes with extensive stakeholder involvement that empowers local fishers to make different decisions. Due to local and global stressors, the Pemba fishery is changing, and as Hughes *et. al.* (2017) mention, coral reefs of the future will be different from those of the past. Dealing with unpredictable futures necessitates embracing diverse reactions to problems promoted by local exploration and innovation rather than trying to prescribe a few solutions for all situations (Kaaronen *et. al.*, 2021). The type of adaptive co-management projects which involve large groups of stakeholders suggested above are long, difficult, and expensive (Bown *et. al.*, 2013; Paterson *et. al.*, 2010; Popa *et. al.*, 2015). However, due to the heterogenous nature of fishers, the uncertainty of future conditions caused by our changing global environment, and need for diverse, site specific, solutions, they are necessary.

Appendix I

Appendix I gives supplemental information on the general methods, Chapter 2, of the thesis.

Figure I-1: Purse-seine fishers helping the net get over some coral (A) and sewing the net together to make a purse (B). All photos were taken with the permission of the fisher.

Table I-1: Fisher interview questions in Portuguese as originally workshopped with local managers and teachers, and translated to Macua.

1- Como é que a pesca é realizada agora? Manan'nani n'nohokolenho mpahari n'nava?
2- Acha que o mar é muito importante para si e sua família, porque? E acha que tem mais outras importâncias, quais são? Ipahari itu yomana pra nhuvano namuyinhou (namusinho)? Konta? Ihana ifaita ikwawe?
3- Existem muitas atividades de rendimento que podia realizar, como carpinteiro, pedreiro e mais. O que é que lhe faz realizar atividade de pesca? Jihavo miteko zikuawe pra zopela uvahani nafasse jolatana manaka, upatareiro, ukalapinteiro ninho zikuawe. Vano inwirihani uvara nteko yo wiva ihopa?
4- O que é que gosta e não gosta dentro da pesca alem de capturar peixe? Ixani inozivelani niyo ihino zivelani n'yina uhokolani mpahari?
5- Quais são as artes que usa para pescar? Qual é a mais frequente que usa? Ikarumani jintumirenho para uhokola mpahari? Pivi ntumirenho jinene? Misifi (linha de mão); nikongue, ikotopui (rede emalhar), kavoko (rede de arrasto para praia); malema, isore (gaiola); nikanharera (rede nas mangais); nlutho (arpão); kaputi (arma submarina)
6- Os instrumentos de pesca que usa para realização de sua atividade pertencem a si próprio, emprestados, alugados, ou do patrão? Ikaruma zinkuxenho ou zintumirenho para uhokola zinkala zowazimia ou zawenho?
7- Na Baia de Pemba existem muitas artes de pesca, como redes arrasto, redes emalhar, linha de mão, arma submarina. Cada um destes têm vantagens e desvantagens. Por quais motivos que lhe leva a utilizar (resposta de numero 5)? Upempa zihavo ikaruma jinji zinruaniya uluani, mana kavoko, nikonko, ikotopui, misifi, malema, nantho, nikanherera. Jihavo ikaruma jirinha ifaita nijikuawe ajinafaita. Imwuiri hani ixani ntumiriki ikaruma nokusakenho?
8- Para alem desta arte de pesca, sabe usar outras artes de pesca, e quais são? (Se já respondeu a esta pergunta não tem que lançar) Ohiya manan'na ohokolenho ala, n'najuela to makinako ohokola?
9- Neste momento, existe material de pesca de algumas ONGs, amigos, família ou outros pescadores que talvez poderia usar. Você tem aceso para usar outros materiais de pescar? Se sim, quais são? Unakalanaka nafase yotumiri ikaruma joluela mpahari ziyiri zawenho zinari zamuji, upatanini e ninho athunaka athu othajiri. Uhana nafase otumiri jathu aromoliealava?
10- Quais são as artes de pesca que gostaria de usar, e porque? Ikarumani jojivenleni n'nathuminri wala ntumiriki n'hina mohokolani? Nlatuhaya?
11- Quais são as espécies que capturam em abundancia para cada estação? Ihopani zinenjiva uhokolia wakula wakati womuaka?
12- Quando começou a pescar aqui? Iakani wanjenranhu ulwa?

13- Qual é a situação da pesca atual comparativamente quando começou? Nonerajani inana iyohokola inava invirikanihelaka uwakati wanjenrenho uhokola?
14- Quando é que começou a notar a mudança? Muanjere wona yakani wira jinarukunua?
15- O que causou estas mudanças? Ikumelenleni ou irinaliyaleni mpaka wanje itafautila?
16- Com as mudanças, como é que esta se adaptar para conseguir capturar pescado suficiente para seu sustento? Niyela itafautila n'nokitiri jani ohokola omana ukitiri uthuma iyolia, nithu jikuawe jowapuwani?
17- Quais mudanças poderão ocorrer no futuro e como poderemos enfrentar as mesmas e beneficiar por boas mudanças? (mudança em geral) Uholo ninroeho ixani in'hala ukumelela, nin'hala wirani ophela ukala wira jen'nha jihinivahe machaka?
18- Para uma boa gestão de pesca é aquela que usa instrumentos apropriadas e captura espécies com tamanho aceitáveis sem prejudicar o recurso. O que é uma boa pesca para si? Ukala wohokola worera pule intumirinho ikaruma jotuniheria para wivela ihopa tchomana (julupale) wohihonona jitojompahari. Para nho ohokola umana ixiani?
19- O que podemos fazer para que essa pesca boa seja uma realidade? Nitupankani wowira ohokola umana ukumelelaka ni ukalaka wokuweli?
20- Conhece algumas normas em uso no sector das pescas? N'najuela matumizo oholela ou ilei n'hina mohokola mpahari mwa governo?
21- Quais são os motivos da aplicação destas normas? Inkaliha ichani wira inaholelihia ilei?
22- Será que são obedecidas estas normas? Qual é o instrumento que ajuda para as pessoas obedecer as normas? Jinatarihelelia no hichimia jenha ilei? Mananane jinopwanhaya nafase ophela uhichimu ilei?
23- Acredita que se todos obedecessem estas normas podia se ter mais recursos pesqueiros no futuro? N'nawamini wira atthu othene wira yanathara ilei, yanapatikana ihopa tchomana mahuko oholo ninruen'wu?
24- Você costuma falar com outros pescadores ou qualquer pessoa sobre a pesca? Quem? (menciona todos) Munaulumaka nakwenho ou ninthu otene manan'na yolua ou tchineta npaharini? Tipani?
25- Confia na gestão da pesca para melhorar as capturas? N'nawamini wira ulwa ovirikana manan'na ophela uhokola yomana mahuku oholo?

26- Acha que pode utilizar outros tipos de gestão das pescarias que possam melhorar as capturas? Explica. Unona wira pode utumiri manan'na makhwawe n'hina mohokola wophela utthantta sana? Nihimereni.
27- Fala das espécies que costuma, e gostaria, capturar. (primeiro só escutar o que eles dizem, se não fala das sequentes três perguntas lançam.) Nihimereni ihopa tchinlwenyu tchinotchiveleni n'nevale.
28- Em que habitat se encontra estas espécies? Tchinpuanhania vai? Tchin'hokolia jimpatikania mapuroni, aula jinenjiva ukala vahini?
29- Como, quando e onde reproduzem? Jin'nharana vai, tchani, wakathini? Manana ni jintotholanaya tchen'nha inaman'nha?
30- Demoram quanto tempo para crescer? tchinkala wakathi kavi npaka unua? Para utimo unua jinkhala mahuku makavi?
31- A quem os vende? Nnathumehera apani?
32- O que determina o valor que recebe? Ixani inlanliha nsuruku?
33- Você gostaria de fazer outro tipo de serviço? Qual? Inaujivelani n'navarale nteko nkhuawe? Ntekoni?
34- Gostaria que seus filhos ou filhas fossem pescadores? Wana ujivelani axanenyu avaraka nteko unvarenyu womaka?
35- Quantos dias por semana vai pescar no tempo chuvoso e quantos dias por semana no tempo seco? Usamana mahuku makavi inruenyu ulwani wakathi opula, wakati wolimwe mahuku makavi n'norwenhu ulwani?
36- Normalmente quantas horas gasta na pesca? Ihora tchikavi tchinkalenyu n'pahari n'lwaka?
37- Você vai aonde para pescar? N'norwaka vai para uphela ulwa?
38- Porque pesca ali? Inwirihani ixani para uphela urwa ulwa neno nipuromno?

Table I-2: Demographic information collected for fishers in interviews and household surveys.

39- Anos Eaka	
40- Género Muapani	Homem Nlopwana Mulher Ntiyana

41- Estado civil Hotelia ou n’hotela	
42- Religião idini	
43- Etnia Napani	
44- Nível de educação nrina classini	
45- Anos nesta comunidade n’hana miaka mikavi nkalaka bairronimo	
46- Quantas pessoas vivem na casa? N’nokala athu akavi vapuwani va?	
47- Quantos rapazes tem a idade de ir a escola e quantos vão a escola? Nrina axilopwana akavi arina iaka yorwa oscola ni anrwa akavi?	Tem _____ e _______ vão
48- Quantas raparigas tem a idade de ir a escola e quantas vão a escola? Nrina axitiyana akavi arina iaka yorwa oscola ni anrwa akavi?	Tem _____ e _______ vão
49- Se não vão a escola, e porque? Khanrwa oscola lathu ixani?	

Table I-3: Livelihood surveys conducted during fisher interviews and household surveys.

50- Quais atividades de rendimento praticam na sua casa no tempo chuvoso? Quais atividades praticam no tempo seco? Ntekoni n’novarenyo wopuwani wenyu wakathi opula ophela upuanha nsurukhu? Ntekoni novarenyu wopuwani wenyu wakathi wolimwe ophela upuanya nsuruku?
Ele ou ela: Familiares de casa:
51- Quanto tempo por semana gasta para cada atividade (tempo chuvoso/seco)? Muntchicha iwora jikavi wosumana para cata nteko (wakati olimwe,wakati opula)?
52- Que tipo de matérias ou equipamento usa para estas atividades e como adquire? (o próprio/alugado/emprestado/outra maneira) Ikarumani n’notumirinyu ophela uvara nteko, nophwanya jani (jawinyu, jowajimia)?

53- Que formas consegue o dinheiro para a compra dessas matérias ou equipamentos (guardando pouco a pouco, banco, família, associações, confissões religiosas)? Nokhitiri jani nsurukhu ophela uthumela ikaruma (inasunka, amuji, associação, insikiti)?

Wellbeing surveys

54- Para você, o que seria uma boa vida? Para nhu, ukala omana pixani?

55- Normalmente, está satisfeito com sua vida? Unaujivelani makalelo enyu?

Não satisfeito	mais ou menos	satisfeito
Mena khinkijivela	vakani vakani	Sana sana

56- Sente-se seguro nessa comunidade? N'nakala seguro inbairro enyu?

Não seguro	mais ou menos	seguro
Mena akinkala sana	vakani vakani	sana sana

57- Acha que se precisar de ajuda é possível encontrar na comunidade?

Jokumelelani ahavo athu ophela uwajudarini inbairro inokhalenyu?

Não encontrarei	é possiavel	tenho certeza que encontrarei
Mena akinomphwanha	nlateke kinamphwanya	kinakulu vela omphwanya

58- Normalmente, está satisfeito com a sua vida familiar? Unaujivelani makhalelo enyu namuj'enyu?

Não satisfeito	mais ou menos	satisfeito
Mena nkiri sana	vakani vakani	Sana sana

59- Normalmente, está satisfeito com seus amigos? Unaujivelani makhalelo enyu naximpanyenyu?

Não satisfeito	mais ou menos	satisfeito
Mena nkiri sana	vakani vakani	Sana sana

60- Normalmente, está satisfeito com seu trabalho? Unaujivelani nteko unvarenhu?

Não satisfeito	mais ou menos	satisfeito
Mena nkiri sana	vakani vakani	Sana sana

61- Como é o estado da saúde da sua família?   Inanani ampasari amuxienyu inan’na wokumi?

Table I-4: Indications of material standard of living.

62- Tipo de casa (local, convencional) Inawana yo nupa (yobuloko ou yomiri)	
63- Tipo de cobertura (palha, zinco, luzalite, betão) ituleleini (malaxe, chapa eo zinko, luzalite, betão)	
64- Tipo de chão (terra, betão, mosaico, madeira) ihelie ifiali	
65- Tipo de casa de banho (latrina ao céu aberto, latrina tradicional, latrina coberta com sanitas) Inrina issintinani?	
66- Fonte de agua (poço, cisterna, canalizada) Inouria majini oturneira, muro, opula?	
67- Fonte de energia (elétrica, solar, candeeiro, gerador) Ininoparihela ixani wela vale?	
68- Equipamentos eletrónicos (TV, geleira, congelador, radio, fugão elétrico, celular, DVD, GoTV, ferro de engomar) Inrinani impani...	

Algo mais que você quer dizer?

N’hana ithu para ohimia ou uluma?

Obrigada Kihoxukuru

Fisher interview questions translated to English

Q1) What is the state of the fishery now?
Q2) Is the ocean very important for you and your family, how?
Q3) There are many possible forms of employment, such as carpenter, stone mason, and more. Why do you choose to fish?
Q4) What do you like and dislike about fishing other than catching fish?
Q5) What fishing methods do you use? Which do you use most often?
Q6) Are your fishing materials owned by you, borrowed, rented, or owned by an employer?
Q7) In Pemba Bay many fishing methods are used, such as beach-seine nets, gill nets, handlines, spearguns… Each of these has advantages and disadvantages. Why do you use (response from question 5)?
Q8) Aside from this fishing method, do you know how to use other methods? Which ones?

Q9) At the moment, there are fishing materials at NGOs, friends, family, or other fishers that you might be able to use. Do you have access to any of these sources of fishing materials? If so, which ones?
Q10) What fishing method would you like to use and why?
Q11) What species do you catch a lot of in each season (rainy and dry)?
Q12) When did you start fishing here?
Q13) How is the fishery compared to when you started fishing here?
Q14) When did you start to notice changes?
Q15) What caused these changes”
Q16) With these changes, how did you adapt to continue to catch enough fish?
Q17) What changes could occur in the future and how can we confront them and benefit form positive changes?
Q18) For me, a good fishery uses appropriate methods and catches sustainable species and sizes. What is a good fishery to you? (The fishery manager suggested adding a personal definition of a good fishery to help interviewees understand the question. Few responses were similar to the prompt so I don’t think it unduly prejudiced the answers.)
Q19) What can we do to make this good fishery reality?
Q20) Do you know some of the fishery rules or norms in operation? Which?
Q21) What are the reasons for these rules?
Q22) Do most people obey the rules? What helps people to obey the rules?
Q23) Do you believe that if everyone obeyed the rules there would be more marine resources in the future?
Q24) Do you often talk with other fishers or people about the fishery? Who? (Mention all)
Q25) Do you trust fishery management to improve fishing catches?
Q26) Do you think there are other ways to manage the fishery that could improve catches? Explain.
Q27) Talk about the species you catch, and want to catch. (First just listen to what they say, if they don’t talk about the next three questions, ask them.)
Q28) In what habitat to you find this species?
Q29) How, when, and where does it reproduce?
Q30) How long does it take to mature?
Q31) To whom do you sell your catch?
Q32) What determines how much you get for your catch?
Q33) Would you like to do a different job? Which?
Q34) Would you like your children to be fishers?
Q35) How many days a week do you fish in the rainy season? Dry season?
Q36) On average, how many hours do you spend on a fishing trip?
Q37) Where do you go to fish? (I was hoping for specific locations, but mostly got habitats)
Q38) Why do you fish there?
Q39) Age
Q40) Marital status
Q41) Gender
Q42) Religion
Q43) Ethnicity
Q44) Education
Q45) How many years have you lived in this community?
Q46) How many people live with you?
Q47) How many boys are school-aged in your house and how many go to school?

Q48) How many girls are school-aged in your house and how many go to school?
Q49) If they don't go to school, why not?
Q50) What livelihood activities are practiced by someone in this house in the rainy seasons? In the dry season?
Q51) How much time do you spend on each activity?
Q52) What materials do you use for your livelihood activities and how did you get it?
Q53) How did you get the money to buy any equipment (saved, bank loan, family loan, local club, religious group)?
Q54) For you, what is a good life?
Q55) Normally, are you satisfied with your life (3-point scale)?
Q56) Do you feel safe in this community (3-point scale)?
Q57) Do you think you could find help in this community if you needed it (3-point scale)?
Q58) Normally, are you satisfied with your family life (3-point scale)?
Q59) Normally, are you satisfied with your social life (3-point scale)?
Q60) Normally, are you satisfied with your work life (3-point scale)?
Q61) How is your family's health? (Converted into a 3-point scale)
Q62) Type of house (mud, concrete)
Q63) Type of roof (grass, metal, tile, concrete)
Q64) Flooring (earth, cement, tile, wood)
Q65) Type of bathroom (none, drop toilet, indoor plumbing)
Q66) Water source (well, cistern, faucet)
Q67) Energy source (electricity, solar, candles, generator)
Q68) Electronic equipment (TV, refrigerator, freezer, radio, electric stove, cellphone, DVD player, cable, iron)

Anything else you would like to say?

Table I-5: Species found in the data with their characteristics as used in the determination of their functional group assignment. Greg is short for gregariousness and is coded as solitary (S), pairs or small groups (PsG), small groups (sG), medium groups (mG), large groups (lG), or solitary, pairs or groups (SPG). Mobility is the movement of the species between habitats and through habitats to different coral clusters, and is either "within" or "between" habitats. MaxWt is the maximum normal weight of the species in grams, Coral assoc and Seagrass assoc are whether the species is associated with coral or seagrass habitats respectively. Value is the average monetary value of the species in meticais per kilogram and caloric value is the average value of the species in kilocalories per kg of wet weight. Finally, citations indicate the citation number in Table I-6 where the information used in this table was acquired. For blank cells no information was found.

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Acanthurus blochii	Chordata	grazer	bentho-pelagic	mG	within	nonguarders	4536	Yes	No	140	409	15; 21
Acanthurus dussumieri	Chordata	browser	bentho-pelagic	sG	within	nonguarders	3635	Yes	Yes	140	480	15; 14
Acanthurus leucocheilus	Chordata	grazer	bentho-pelagic	SPG	within	nonguarders	4542	Yes	No	140	480	15; 14
Acanthurus leucosternon	Chordata	browser	bentho-pelagic	SPG	within	nonguarders	2361	Yes	No	140	480	15; 14
Acanthurus mata	Chordata	planktivore	bentho-pelagic	sG	between	nonguarders	2483	Yes	Yes	140	480	15; 14
Acanthurus nigricauda	Chordata	grazer/detritivore	bentho-pelagic	SPG	within	nonguarders	1112	Yes	Yes	140	480	15; 14
Acanthurus nigrofuscus	Chordata	browser	bentho-pelagic	sG	within	nonguarders	171	Yes	Yes	140	480	15; 14
Acanthurus tennentii	Chordata	grazer	bentho-pelagic	SPG	within	nonguarders	478	Yes	No	140	480	15; 14
Acanthurus thompsoni	Chordata	zooplanktivore	bentho-pelagic	sG	within	nonguarders	248	Yes	No	140	480	15; 14
Acanthurus triostegus	Chordata	grazer/detritivore	bentho-pelagic	lG	within	nonguarders	352	Yes	No	140	480	15; 14
Acanthurus xanthopterus	Chordata	grazer/detritivore	bentho-pelagic	SPG	within	nonguarders	4847	Yes	No	140	480	15; 14
Ctenochaetus binotatus	Chordata	detritivore	benthic	SPG	within	nonguarders	286	Yes	No	140	473	15; 14
Ctenochaetus sp	Chordata	detritivore	benthic	SPG	within	nonguarders	249	Yes	No	140	473	15; 14
Ctenochaetus striatus	Chordata	detritivore	benthic	SPG	within	nonguarders	325	Yes	Yes	140	473	15; 14
Ctenochaetus truncatus	Chordata	detritivore	benthic	SPG	within	nonguarders	135	Yes	No	140	473	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Naso annulatus	Chordata	zooplanktivore	bentho-pelagic	mG	between	nonguarders	20420	Yes	No	95	473	15; 14
Naso brachycentron	Chordata	browser	bentho-pelagic	mG	between	nonguarders	19890	Yes	No	95	473	15; 14
Naso brevirostris	Chordata	zooplanktivore	bentho-pelagic	mG	between	nonguarders	4466	Yes	No	95	473	15; 14
Naso elegans	Chordata	browser	bentho-pelagic	SPG	between	nonguarders	3285	Yes	No	95	473	15; 14
Naso hexacanthus	Chordata	zooplanktivore	bentho-pelagic	lG	between	nonguarders	12078	Yes	No	95	473	15; 14
Naso lituratus	Chordata	browser	bentho-pelagic	mG	between	nonguarders	3935	Yes	No	95	473	15; 14
Naso minor	Chordata	algal/zooplanktivore	bentho-pelagic	mG	between	nonguarders	1093	Yes	No	95	473	15; 14
Naso thynnoides	Chordata	zooplanktivore	bentho-pelagic	lG	between	nonguarders	2494	Yes	No	95	473	15; 14
Naso tuberosus	Chordata	browser	bentho-pelagic	sG	between	nonguarders	7825	Yes	No	95	473	15; 14
Naso unicornis	Chordata	browser	bentho-pelagic	SPG	between	nonguarders	8845	Yes	Yes	95	473	15; 14
Naso vlamingii	Chordata	algal/zooplanktivore	bentho-pelagic	SPG	between	nonguarders	5918	Yes	No	95	473	15; 14
Paracanthurus hepatus	Chordata	planktivore	bentho-pelagic	sG	between	nonguarders	609	Yes	No	120	473	15; 14
Zebrasoma desjardinii	Chordata	grazer	benthic	PsG	within	nonguarders	1128	Yes	Yes	120	473	15; 14
Zebrasoma scopas	Chordata	grazer	benthic	mG	within	nonguarders	2299	Yes	No	120	473	15; 14
Synagrops japonicus	Chordata	generalist carnivore	bentho-pelagic	sG		nonguarders	900	No	No	150	501	15; 50
Alpheidae sp	Arthropoda	detritivore	benthic	S	within	bearers	5	No	No	0	160	32; 14
Cheilodipterus quinquelineatus	Chordata	invertivore	benthic	SPG	within	bearers	32	Yes	Yes	20	989	15; 14
Fowleria variegata	Chordata	invertivore	benthic	SPG	within	bearers	10	Yes	Yes	20	989	15; 14
Lachneratus phasmaticus	Chordata	invertivore	benthic		within	bearers	10	Yes	No	20	989	15; 14
Ostorhinchus apogonoides	Chordata	invertivore	bentho-pelagic	PsG	within	bearers	10	Yes	No	20	989	15; 28
Ostorhinchus cookii	Chordata	invertivore	benthic	PsG	within	bearers	18	Yes	No	20	989	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Ostorhinchus nigrofasciatus	Chordata	invertivore	benthic	S	within	bearers	19	Yes	Yes	20	989	15; 14
Ostorhinchus sp	Chordata	invertivore	benthic	PsG	within	bearers	16	Yes	No	20	989	15; 14
Siphamia mossambica	Chordata	zooplanktivore	benthic	sG	within	bearers	1	Yes	Yes	20	989	15; 14
Taeniamia mozambiquensis	Chordata	zooplanktivore	benthic	sG	within	bearers	16	Yes	No	20	989	15; 14
Verulux cypselurus	Chordata	zooplanktivore	bentho-pelagic	lG	within	bearers	4	Yes	No	20	989	15; 14
Aristeus antennatus	Arthropoda	invertivore	benthic		between	bearers	73	No	No	300	538	32; 42
Aulostomus chinensis	Chordata	generalist carnivore	bentho-pelagic	S	within	nonguarders	2460	Yes	Yes	100	565	15; 11
Abalistes stellaris	Chordata	invertivore	bentho-pelagic	S	within	guarders	5012	Yes	No	100	447	15; 46
Balistapus undulatus	Chordata	generalist carnivore	bentho-pelagic	S	within	guarders	666	Yes	Yes	100	554	15; 14
Balistoides conspicillum	Chordata	invertivore	bentho-pelagic	S	between	guarders	2540	Yes	No	100	554	15; 14
Balistoides viridescens	Chordata	coral/invertivore	bentho-pelagic	S	between	guarders	11993	Yes	Yes	100	554	15; 14
Melichthys niger	Chordata	algal/zooplanktivore	bentho-pelagic	SPG	between	guarders	2461	Yes	Yes	100	563	15; 17
Odonus niger	Chordata	zooplanktivore	bentho-pelagic	lG	between	guarders	2483	Yes	No	100	554	15; 14
Pseudobalistes flavimarginatus	Chordata	coral/invertivore	bentho-pelagic	SPG	between	guarders	4342	Yes	No	100	554	15; 14
Pseudobalistes fuscus	Chordata	coral/invertivore	bentho-pelagic	S	between	guarders	4831	Yes	No	100	554	15; 14
Sufflamen bursa	Chordata	algal/invertivore	benthic	S	within	guarders	316	Yes	No	100	554	15; 14
Sufflamen chrysopterum	Chordata	invertivore	benthic	SPG	within	guarders	530	Yes	Yes	100	554	15; 14
Sufflamen fraenatum	Chordata	algal/spongivore	benthic	SPG	between	guarders	1108	Yes	Yes	100	651	15; 17
Xanthichthys lineopunctatus	Chordata	zooplanktivore	bentho-pelagic	sG	between	guarders	83	Yes	No	100	554	15; 14
Ablennes hians	Chordata	piscivore	pelagic	mG	between	nonguarders	3913	No	No	225	545	15; 45
Tylosurus crocodilus	Chordata	piscivore	pelagic	SPG	between	nonguarders	6034	Yes	Yes	225	567	15; 44

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Aspidontus dussumieri	Chordata	grazer	benthic	S	within	guarders	1	Yes	No	20	536	15; 14; 19
Aspidontus tractus	Chordata	false cleaner	benthic	S	within	guarders	6	Yes	No	20	536	15; 14; 19
Meiacanthus mossambicus	Chordata	algal/zooplanktivore	benthic	S	within	guarders	12	No	Yes	20	536	15; 14; 19
Petroscirtes xestus	Chordata	algal/zooplanktivore	benthic	S	within	guarders	3	Yes	Yes	20	536	15; 14; 19
Plagiotremus rhinorhynchos	Chordata	false cleaner	benthic	SPG	within	guarders	30	Yes	No	20	536	15; 14; 19
Plagiotremus tapeinosoma	Chordata	false cleaner	benthic	SPG	within	guarders	12	Yes	No	20	536	15; 14; 19
Valenciennea helsdingenii	Chordata	invertivore	benthic	SPG	within	guarders	180	Yes	No	20	536	15; 14; 19
Bornella anguilla	Mollusca	corallivore	benthic	S	within	nonguarders	4	Yes	No	0	414	32; 59
Arnoglossus capensis	Chordata	invertivore	benthic	S	between	nonguarders	84	No	No	120	360	15; 14
Bothidae sp	Chordata	invertivore	benthic	S	between	nonguarders	391	Yes	Yes	120	360	15; 45
Bothus pantherinus	Chordata	invertivore	benthic	S	between	nonguarders	699	Yes	Yes	120	360	15; 14
Caesio caerulaurea	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	716	Yes	Yes	135	448	15; 46
Caesio lunaris	Chordata	zooplanktivore	pelagic	lG	within	nonguarders	1358	Yes	Yes	135	568	15; 25
Caesio teres	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	1283	Yes	Yes	135	485	15; 14
Caesio xanthalytos	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	398	No	No	135	485	15; 14
Caesio xanthonota	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	1097	Yes	Yes	135	438	15; 56
Caesionidae sp	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	676	Yes	Yes	135	438	15; 14
Gymnocaesio gymnoptera	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	98	Yes	No	135	438	15; 14
Pterocaesio marri	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	649	Yes	Yes	135	438	15; 14
Pterocaesio pisang	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	186	Yes	Yes	135	438	15; 14
Pterocaesio tile	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	430	Yes	No	135	242	15; 21
Pterocaesio trilineata	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	126	Yes	No	135	242	15; 14
Calappa hepatica	Arthropoda	invertivore	benthic			bearers	127	Yes	Yes	120	171	32; 14
Alectis indica	Chordata	piscivore	pelagic	S	between	nonguarders	25000	Yes	Yes	165	591	15; 14
Alepes djedaba	Chordata	invertivore	pelagic	sG	between	nonguarders	718	Yes	No	165	610	15; 46

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Atule mate	Chordata	invertivore	pelagic	SPG	between	nonguarders	325	No	No	165	489	15; 46
Carangidae sp	Chordata	generalist carnivore	pelagic		between	nonguarders	13068	Yes	Yes	190	591	15; 14
Carangoides armatus	Chordata	generalist carnivore	pelagic	SPG	between	nonguarders	3500	Yes	No	225	612	15; 14
Carangoides chrysophrys	Chordata	generalist carnivore	pelagic	sG	between	nonguarders	6881	Yes	Yes	225	445	15; 26
Carangoides coeruleopinnatus	Chordata	invertivore	pelagic	sG	between	nonguarders	1298	Yes	No	225	612	15; 14
Carangoides dinema	Chordata	generalist carnivore	pelagic	SPG	between	nonguarders	8164	No	No	225	612	15; 14
Carangoides ferdau	Chordata	generalist carnivore	pelagic	sG	between	nonguarders	8000	Yes	Yes	225	612	15; 14
Carangoides fulvoguttatus	Chordata	generalist carnivore	pelagic	sG	between	nonguarders	18000	Yes	Yes	225	612	15; 14
Carangoides gymnostethus	Chordata	invertivore	pelagic	S	between	nonguarders	14500	Yes	No	225	612	15; 14
Carangoides hedlandensis	Chordata	generalist carnivore	pelagic	PsG	between	nonguarders	741	No	No	225	612	15; 14
Carangoides malabaricus	Chordata	generalist carnivore	pelagic	mG	between	nonguarders	3406	Yes	No	225	615	15; 46
Carangoides oblongus	Chordata	invertivore	pelagic	sG	between	nonguarders	1334	No	No	225	612	15; 14
Carangoides orthogrammus	Chordata	generalist carnivore	pelagic	SPG	between	nonguarders	6600	Yes	Yes	225	612	15; 14
Carangoides plagiotaenia	Chordata	generalist carnivore	pelagic	SPG	between	nonguarders	2065	Yes	No	225	612	15; 14
Carangoides praeustus	Chordata	invertivore	pelagic	sG	between	nonguarders	330	Yes	No	225	776	15; 21
Carangoides sp	Chordata	generalist carnivore	pelagic		between	nonguarders	5755	Yes	Yes	225	612	15; 14
Caranx heberi	Chordata	generalist carnivore	pelagic	sG	between	nonguarders	12500	Yes	No	225	562	15; 14
Caranx ignobilis	Chordata	generalist carnivore	pelagic	S	within	nonguarders	80000	Yes	Yes	225	582	15; 14
Caranx melampygus	Chordata	piscivore	pelagic	SPG	between	nonguarders	43500	Yes	No	225	562	15; 14
Caranx papuensis	Chordata	piscivore	pelagic	SPG	between	nonguarders	6400	Yes	No	225	562	15; 14
Caranx sexfasciatus	Chordata	generalist carnivore	pelagic	S	between	nonguarders	18000	Yes	No	225	629	15; 56
Caranx sp	Chordata	generalist carnivore	pelagic		between	nonguarders	32080	Yes	Yes	225	554	15; 14
Decapterus kurroides	Chordata	zooplanktivore	pelagic	sG	between	nonguarders	1193	No	No	165	590	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Decapterus macarellus	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	1494	No	No	165	574	15; 14
Decapterus macrosoma	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	389	No	No	165	558	15; 25
Decapterus russelli	Chordata	generalist carnivore	bentho-pelagic	mG	between	nonguarders	110	No	No	165	574	15; 14
Decapterus sp	Chordata	zooplanktivore		mG	between	nonguarders	749	No	No	165	574	15; 14
Decapterus tabl	Chordata	zooplanktivore	bentho-pelagic	lG	between	nonguarders	560	Yes	No	165	574	15; 14
Gnathanodon speciosus	Chordata	generalist carnivore	pelagic	mG	between	nonguarders	15000	Yes	No	225	591	15; 14
Megalaspis cordyla	Chordata	piscivore	pelagic	lG	between	nonguarders	4000	Yes	No	105	672	15; 46
Scomberoides commersonnianus	Chordata	generalist carnivore	pelagic	sG	between	nonguarders	16000	Yes	Yes	105	573	15; 14
Scomberoides lysan	Chordata	generalist carnivore	pelagic	S	between	nonguarders	11000	No	No	105	573	15; 46
Scomberoides sp	Chordata	generalist carnivore	pelagic	sG	between	nonguarders	9170	Yes	Yes	105	573	15; 14
Scomberoides tol	Chordata	piscivore	pelagic	sG	between	nonguarders	510	No	No	105	573	15; 14
Scomberomorus commerson	Chordata	generalist carnivore	pelagic	S	between	nonguarders	70000	Yes	No	225	631	15; 5
Selar crumenophthalmus	Chordata	generalist carnivore	pelagic	lG	between	nonguarders	4250	Yes	No	165	592	15; 46
Seriolina nigrofasciata	Chordata	generalist carnivore	pelagic	S	between	nonguarders	5200	No	No	165	591	15; 14
Trachinotus africanus	Chordata	invertivore	pelagic	PsG	between	nonguarders	14100	Yes	No	165	591	15; 14
Trachinotus blochii	Chordata	invertivore	pelagic	S	between	nonguarders	3400	Yes	No	165	591	15; 14
Trachurus delagoa	Chordata	generalist carnivore	pelagic	mG	between	nonguarders	432	No	No	165	709	15; 14
Carcharhinus amblyrhynchos	Chordata	generalist carnivore	bentho-pelagic	S	between	bearers	174819	Yes	No	150	722	15; 46
Carcharhinus melanopterus	Chordata	generalist carnivore	bentho-pelagic	S	between	bearers	46278	Yes	No	150	740	15; 14
Carcharhinus sp	Chordata	generalist carnivore	bentho-pelagic	S	between	bearers	110549	Yes	No	150	758	15; 14
Aeoliscus punctulatus	Chordata	zooplanktivore	benthic	sG		nonguarders	18	No	Yes	0	565	15; 11
Chaetodon auriga	Chordata	corallivore	benthic	SPG	within	nonguarders	296	Yes	Yes	70	464	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Chaetodon bennetti	Chordata	algal/corallivore	bentho-pelagic	PsG	within	nonguarders	174	Yes	No	70	464	15; 14
Chaetodon falcula	Chordata	algal/invertivore	bentho-pelagic	PsG	within	nonguarders	193	Yes	No	70	464	15; 14
Chaetodon guttatissimus	Chordata	coral/invertivore	bentho-pelagic	PsG	within	nonguarders	42	Yes	No	70	464	15; 14
Chaetodon interruptus	Chordata	algal/corallivore	bentho-pelagic	PsG	within	nonguarders	193	Yes	No	70	464	15; 14
Chaetodon kleinii	Chordata	algal/corallivore	bentho-pelagic	SPG	within	nonguarders	114	Yes	Yes	70	464	15; 14
Chaetodon lineolatus	Chordata	corallivore	bentho-pelagic	SPG	within	nonguarders	522	Yes	No	70	464	15; 14
Chaetodon lunula	Chordata	algal/invertivore	bentho-pelagic	PsG	within	nonguarders	193	Yes	No	70	464	15; 14
Chaetodon madagaskariensis	Chordata	algal/invertivore	bentho-pelagic	SPG	within	nonguarders	53	Yes	No	70	464	15; 14
Chaetodon melannotus	Chordata	corallivore	bentho-pelagic	SPG	within	nonguarders	134	Yes	Yes	70	464	15; 14
Chaetodon meyeri	Chordata	corallivore	bentho-pelagic	PsG	within	nonguarders	193	Yes	No	70	464	15; 14
Chaetodon sp	Chordata	algal/corallivore	bentho-pelagic		within	nonguarders	174	Yes	Yes	70	464	15; 14
Chaetodon trifascialis	Chordata	corallivore	bentho-pelagic	PsG	within	nonguarders	111	Yes	No	70	464	15; 14
Chaetodon trifasciatus	Chordata	corallivore	bentho-pelagic	PsG	within	nonguarders	93	Yes	No	70	464	15; 14
Chaetodon vagabundus	Chordata	algal/corallivore	bentho-pelagic	PsG	within	nonguarders	235	Yes	No	70	464	15; 14
Chaetodon xanthocephalus	Chordata	algal/invertivore	bentho-pelagic	S	within	nonguarders	189	Yes	Yes	70	464	15; 14
Chaetodon zanzibarensis	Chordata	corallivore	bentho-pelagic	SPG	within	nonguarders	41	Yes	No	70	464	15; 14
Forcipiger flavissimus	Chordata	invertivore	bentho-pelagic	SPG	within	nonguarders	171	Yes	No	70	464	15; 14
Forcipiger longirostris	Chordata	invertivore	bentho-pelagic	PsG	within	nonguarders	142	Yes	No	70	464	15; 14
Forcipiger sp	Chordata	invertivore	bentho-pelagic	SPG	within	nonguarders	157	Yes	No	70	464	15; 14
Hemitaurichthys zoster	Chordata	algal/zooplanktivore	bentho-pelagic	mG	within	nonguarders	135	Yes	Yes	70	464	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Heniochus acuminatus	Chordata	zooplanktivore	benthic	PsG	between	nonguarders	392	Yes	Yes	70	464	15; 14
Heniochus diphreutes	Chordata	zooplanktivore	bentho-pelagic	lG	between	nonguarders	209	Yes	No	70	464	15; 14
Heniochus monoceros	Chordata	invertivore	benthic	PsG	between	nonguarders	319	Yes	No	70	464	15; 14
Chelonia mydas	Chordata	grazer	bentho-pelagic	S	between	nonguarders	1400000	No	Yes	0	254	15; 25
Chirocentrus dorab	Chordata	piscivore	pelagic	sG	between	nonguarders	7687	Yes	Yes	100	640	15; 14
Cirrhitichthys oxycephalus	Chordata	generalist carnivore	benthic	SPG	within	nonguarders	15	Yes	No	70	565	15; 11
Paracirrhites arcatus	Chordata	invertivore	benthic	S	within	nonguarders	111	Yes	No	70	565	15; 14
Paracirrhites forsteri	Chordata	piscivore	benthic	S	within	nonguarders	148	Yes	No	70	565	15; 14
Amblygaster sirm	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	358	Yes	No	103	862	15; 14
Hilsa kelee	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	482	No	No	103	1189	15; 14
Sardinella albella	Chordata	algal/zooplanktivore	bentho-pelagic	lG	between	nonguarders	47	Yes	No	103	824	15; 14
Sardinella gibbosa	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	256	No	Yes	80	719	15; 59
Sardinops sagax	Chordata	algal/zooplanktivore	bentho-pelagic	lG	between	nonguarders	490	No	No	103	805	15; 14
Heteroconger hassi	Chordata	zooplanktivore	benthic	lG	within	nonguarders	81	No	No	0	1273	15; 56
Cynoglossus lachneri	Chordata	invertivore	benthic	S		nonguarders	1084	No	No	120	330	15; 14
Dasyatis chrysonota	Chordata	generalist carnivore	benthic	S	between	bearers	93615	No	No	125	434	15; 46
Dasyatis thetidis	Chordata	invertivore	benthic	S	between	bearers	762828	Yes	No	125	283	15; 25
Maculabatis gerrardi	Chordata	invertivore	benthic	S	between	bearers	129760	No	No	125	347	15; 14
Neotrygon kuhlii	Chordata	invertivore	benthic	S	between	bearers	5867	Yes	No	125	324	15; 25; 33
Pastinachus sephen	Chordata	generalist carnivore	benthic	S	between	bearers	249560	Yes	No	125	347	15; 14
Taeniura lymma	Chordata	invertivore	benthic	S	between	bearers	4088	Yes	Yes	125	347	15; 14
Taeniurops meyeni	Chordata	invertivore	benthic	S	between	bearers	150000	Yes	No	125	347	15; 14
Urogymnus asperrimus	Chordata	generalist carnivore	benthic	S	between	bearers	177447	No	No	125	347	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Dasyatidae sp	Chordata	generalist carnivore	benthic	S	between	bearers	196646	Yes	No	125	347	15; 14
Diadema savignyi	Echinodermata	grazer	benthic	lG		guarders	14	No	No	0	229	32; 14
Echinothrix diadema	Echinodermata	algal/corallivore	benthic			guarders	8	Yes	No	0	229	32; 14
Diodon holocanthus	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	3281	Yes	No	0	371	15; 14; 52
Diodon liturosus	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	5361	Yes	Yes	0	371	15; 14; 52
Dardanus megistos	Arthropoda	algal/invertivore	benthic			bearers	17	Yes	Yes	0	160	32; 14
Echeneis naucrates	Chordata	zooplanktivore	pelagic	S	between	nonguarders	2300	Yes	Yes	100	565	15; 11
Elops machnata	Chordata	generalist carnivore	bentho-pelagic		between	nonguarders	15550	No	No	70	614	15; 25
Encrasicholina punctifer	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	20	No	No	70	1021	15; 14
Stolephorus commersonnii	Chordata	zooplanktivore	bentho-pelagic	lG	between	nonguarders	14	Yes	No	70	783	15; 46
Stolephorus indicus	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	52	No	No	70	783	15; 14
Platax orbicularis	Chordata	algal/invertivore	bentho-pelagic	SPG	between	nonguarders	5637	Yes	Yes	160	518	15; 27
Exocoetidae sp	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	296	No	No	160	493	15; 45
Latirus polygonus	Mollusca	invertivore	benthic		within	nonguarders	8	Yes	No	0	414	32; 59
Fistularia commersonii	Chordata	piscivore	bentho-pelagic	S	within	nonguarders	4766	Yes	Yes	100	565	15; 11
Gerres filamentosus	Chordata	invertivore	benthic		within	nonguarders	1324	Yes	Yes	185	480	15; 48
Gerres longirostris	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	1990	Yes	Yes	185	480	15; 14
Gerres methueni	Chordata	invertivore	bentho-pelagic	mG	within	nonguarders	550	Yes	No	185	480	15; 14
Gerres oblongus	Chordata	invertivore	bentho-pelagic	mG	within	nonguarders	579	Yes	No	185	480	15; 14
Gerres oyena	Chordata	invertivore	bentho-pelagic	SPG	within	nonguarders	678	Yes	Yes	185	480	15; 14
Amblyeleotris wheeleri	Chordata	invertivore	benthic	S	within	guarders	14	Yes	No	30	421	15; 14; 19
Amblygobius semicinctus	Chordata	algal/invertivore	benthic	PsG	within	guarders	14	No	Yes	30	307	15; 25; 19

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Bryaninops ridens	Chordata	zooplanktivore	benthic	PsG	within	guarders	1	Yes	No	30	539	15; 25; 19
Gnatholepis cauerensis	Chordata	algal/invertivore	benthic	SPG	within	guarders	4	Yes	No	30	536	15; 14; 19
Istigobius decoratus	Chordata	detritivore	benthic	S	within	guarders	17	Yes	No	30	536	15; 14; 19
Oxyurichthys papuensis	Chordata	invertivore	benthic	S	within	guarders	114	Yes	No	30	952	15; 25; 19
Diagramma labiosum	Chordata	invertivore	bentho-pelagic	lG	between	nonguarders	11600	No	No	150	371	15; 14
Diagramma pictum	Chordata	generalist carnivore	bentho-pelagic	SPG	between	nonguarders	14006	Yes	Yes	150	371	15; 46
Haemulidae sp	Chordata	generalist carnivore	bentho-pelagic		between	nonguarders	6394	Yes	Yes	170	480	15; 14
Plectorhinchus chubbi	Chordata	generalist carnivore	bentho-pelagic	SPG	between	nonguarders	6762	Yes	No	165	470	15; 14
Plectorhinchus flavomaculatus	Chordata	generalist carnivore	bentho-pelagic	SPG	between	nonguarders	3981	Yes	Yes	165	470	15; 14
Plectorhinchus gaterinus	Chordata	generalist carnivore	bentho-pelagic	mG	between	nonguarders	1713	Yes	Yes	165	470	15; 14
Plectorhinchus gibbosus	Chordata	generalist carnivore	bentho-pelagic	S	between	nonguarders	6221	Yes	Yes	165	470	15; 14
Plectorhinchus playfairi	Chordata	generalist carnivore	bentho-pelagic	S	between	nonguarders	10287	Yes	No	165	470	15; 14
Plectorhinchus schotaf	Chordata	zooplanktivore	bentho-pelagic	SPG	between	nonguarders	7216	Yes	Yes	165	470	15; 14
Plectorhinchus sordidus	Chordata	generalist carnivore	bentho-pelagic	SPG	between	nonguarders	2812	Yes	Yes	165	470	15; 14
Pomadasys commersonnii	Chordata	invertivore	bentho-pelagic		between	nonguarders	7676	Yes	No	150	539	15; 46
Pomadasys kaakan	Chordata	generalist carnivore	bentho-pelagic		between	nonguarders	6778	No	No	225	539	15; 14
Pomadasys maculatus	Chordata	generalist carnivore	bentho-pelagic		between	nonguarders	3200	Yes	No	150	539	15; 14
Pomadasys multimaculatus	Chordata	generalist carnivore	bentho-pelagic		between	nonguarders	7157	Yes	No	225	539	15; 14
Hemipristis elongata	Chordata	piscivore	bentho-pelagic	S	between	bearers	72024	Yes	No	150	740	15; 14
Hemiramphus far	Chordata	algal/zooplanktivore	benthic	mG	between	nonguarders	320	Yes	No	145	439	15; 26
Hemiramphus lutkei	Chordata	algal/zooplanktivore	bentho-pelagic		between	nonguarders	398	Yes	No	145	439	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Hyporhamphus affinis	Chordata	zooplanktivore	bentho-pelagic	mG	between	nonguarders	214	Yes	No	145	467	15; 56
Myripristis adusta	Chordata	zooplanktivore	benthic	SPG	within	nonguarders	974	Yes	No	98	857	15; 14
Myripristis berndti	Chordata	generalist carnivore	bentho-pelagic	sG	within	nonguarders	495	Yes	Yes	98	857	15; 14
Myripristis botche	Chordata	generalist carnivore	bentho-pelagic	PsG	within	nonguarders	1133	Yes	No	98	857	15; 14
Myripristis kuntee	Chordata	invertivore	bentho-pelagic	lG	within	nonguarders	566	Yes	No	98	857	15; 14
Myripristis murdjan	Chordata	zooplanktivore	bentho-pelagic	mG	within	nonguarders	4456	Yes	No	98	857	15; 14
Myripristis violacea	Chordata	generalist carnivore	bentho-pelagic		within	nonguarders	1132	Yes	No	98	857	15; 14
Neoniphon argenteus	Chordata	invertivore	bentho-pelagic		within	nonguarders	223	Yes	No	150	752	15; 14
Sargocentron caudimaculatum	Chordata	generalist carnivore	bentho-pelagic	sG	within	nonguarders	1115	Yes	No	150	815	15; 14
Sargocentron diadema	Chordata	generalist carnivore	bentho-pelagic	sG	within	nonguarders	243	Yes	Yes	150	815	15; 14
Sargocentron rubrum	Chordata	generalist carnivore	bentho-pelagic	SPG	within	nonguarders	786	Yes	Yes	150	815	15; 14
Sargocentron sp	Chordata	generalist carnivore	bentho-pelagic		within	nonguarders	511			150	815	15; 14
Sargocentron spiniferum	Chordata	generalist carnivore	bentho-pelagic	S	within	nonguarders	2600	Yes	No	150	815	15; 14
Pearsonothuria graeffei	Echinodermata	corallivore	benthic	S	within	guarders	1300	Yes	No	70	705	32; 14; 37
Istiompax indica	Chordata	generalist carnivore	pelagic	S	between	nonguarders	750000	Yes	No	250	917	15; 31
Istiophorus platypterus	Chordata	generalist carnivore	pelagic	mG	between	nonguarders	100200	Yes	No	250	837	15; 25
Makaira mazara	Chordata	generalist carnivore	pelagic	sG	between	nonguarders	170000	Yes	No	250	647	15; 56
Kyphosus bigibbus	Chordata	invertivore	bentho-pelagic	mG	between	nonguarders	1900	Yes	No	200	768	15; 45
Kyphosus cinerascens	Chordata	algal/invertivore	bentho-pelagic	mG	between	nonguarders	3746	Yes	No	200	667	15; 56
Kyphosus vaigiensis	Chordata	algal/invertivore	bentho-pelagic	mG	between	nonguarders	6077	Yes	Yes	200	966	15; 56
Anampses caeruleopunctatus	Chordata	invertivore	benthic	SPG	within	nonguarders	922	Yes	Yes	150	863	15; 17

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Anampses lineatus	Chordata	invertivore	benthic	sG	within	nonguarders	26	Yes	No	150	863	15; 14
Anampses meleagrides	Chordata	invertivore	benthic	SPG	within	nonguarders	129	Yes	No	150	863	15; 14
Anampses twistii	Chordata	invertivore	benthic	S	within	nonguarders	75	Yes	No	150	863	15; 14
Bodianus anthioides	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	357	Yes	No	150	519	15; 14
Bodianus axillaris	Chordata	invertivore	bentho-pelagic	S	between	nonguarders	205	Yes	No	150	519	15; 14
Bodianus bilunulatus	Chordata	piscivore	bentho-pelagic	S	between	nonguarders	1932	Yes	No	150	519	15; 56
Bodianus diana	Chordata	invertivore	benthic	S	within	nonguarders	123	Yes	No	150	519	15; 14
Cheilinus chlorourus	Chordata	invertivore	benthic	S	within	nonguarders	1391	Yes	Yes	150	736	15; 14
Cheilinus fasciatus	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	1352	Yes	No	150	736	15; 14
Cheilinus oxycephalus	Chordata	invertivore	benthic	PsG	within	nonguarders	70	Yes	Yes	150	736	15; 14
Cheilinus sp	Chordata	invertivore	benthic	S	within	nonguarders	1137	Yes	Yes	150	736	15; 14
Cheilinus trilobatus	Chordata	invertivore	benthic	S	within	nonguarders	1736	Yes	Yes	150	736	15; 14
Cheilinus undulatus	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	191000	Yes	Yes	150	736	15; 14
Cheilio inermis	Chordata	invertivore	bentho-pelagic	sG	within	nonguarders	1028	Yes	Yes	100	736	15; 14
Cirrhilabrus africanus	Chordata	zooplanktivore	bentho-pelagic	sG	within	nonguarders	8	Yes	No	150	736	15; 14
Cirrhilabrus exquisitus	Chordata	zooplanktivore	bentho-pelagic	sG	within	nonguarders	45	Yes	No	150	736	15; 14
Coris aygula	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	26636	Yes	No	150	736	15; 14
Coris batuensis	Chordata	invertivore	bentho-pelagic	SPG	within	nonguarders	59	Yes	No	150	736	15; 14
Coris caudimacula	Chordata	invertivore	benthic	PsG	within	nonguarders	97	Yes	Yes	150	736	15; 14
Coris cuvieri	Chordata	invertivore	benthic	S	within	nonguarders	689	Yes	No	150	736	15; 14
Coris formosa	Chordata	invertivore	benthic	S	within	nonguarders	2761	Yes	No	150	736	15; 14
Coris sp	Chordata	invertivore	benthic	SPG	within	nonguarders	902	Yes	Yes	150	736	15; 14
Cymolutes praetextatus	Chordata	invertivore	benthic	S	within	nonguarders	83	Yes	Yes	150	736	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Epibulus insidiator	Chordata	piscivore	bentho-pelagic	S	within	nonguarders	4804	Yes	No	150	736	15; 14
Gomphosus caeruleus	Chordata	invertivore	benthic	S	within	nonguarders	362	Yes	No	150	695	15; 17
Halichoeres cosmetus	Chordata	invertivore	benthic	SPG	within	nonguarders	27	Yes	No	150	736	15; 14
Halichoeres hortulanus	Chordata	invertivore	benthic	SPG	within	nonguarders	254	Yes	Yes	150	736	15; 14
Halichoeres iridis	Chordata	invertivore	benthic	PsG	within	nonguarders	18	Yes	No	150	736	15; 14
Halichoeres marginatus	Chordata	invertivore	bentho-pelagic	SPG	within	nonguarders	87	Yes	Yes	150	736	15; 14
Halichoeres nebulosus	Chordata	invertivore	benthic	SPG	within	nonguarders	21	Yes	No	150	736	15; 14
Halichoeres scapularis	Chordata	invertivore	bentho-pelagic	SPG	within	nonguarders	119	Yes	Yes	150	736	15; 14
Halichoeres zeylonicus	Chordata	invertivore	benthic	sG	within	nonguarders	100	No	Yes	150	736	15; 14
Hemigymnus fasciatus	Chordata	invertivore	benthic	SPG	within	nonguarders	347	Yes	No	150	736	15; 14
Hemigymnus melapterus	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	1349	Yes	No	150	736	15; 14
Hologymnosus annulatus	Chordata	piscivore	benthic	S	within	nonguarders	795	Yes	No	150	736	15; 14
Hologymnosus doliatus	Chordata	generalist carnivore	benthic	SPG	within	nonguarders	942	Yes	No	150	736	15; 14
Iniistius melanopus	Chordata	invertivore	benthic	sG	within	guarders	225	No	No	150	736	15; 14
Iniistius pavo	Chordata	invertivore	bentho-pelagic	S	within	guarders	965	Yes	Yes	150	736	15; 14
Labrichthys unilineatus	Chordata	corallivore	benthic	S	within	nonguarders	68	Yes	No	150	736	15; 14
Labroides bicolor	Chordata	cleaner	benthic	SPG	within	nonguarders	22	Yes	No	150	736	15; 14
Labroides dimidiatus	Chordata	cleaner	benthic	SPG	within	nonguarders	25	Yes	Yes	150	736	15; 14
Labropsis xanthonota	Chordata	cleaner	benthic	sG	within	nonguarders	23	Yes	No	150	736	15; 14
Novaculichthys taeniourus	Chordata	invertivore	bentho-pelagic	SPG	within	guarders	486	Yes	Yes	150	736	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Novaculoides macrolepidotus	Chordata	invertivore	benthic	SPG	within	guarders	35	No	Yes	150	736	15; 14
Oxycheilinus bimaculatus	Chordata	invertivore	bentho-pelagic	S	within	guarders	34	Yes	Yes	150	716	15; 14
Oxycheilinus digramma	Chordata	invertivore	bentho-pelagic	S	within	guarders	1823	Yes	Yes	150	716	15; 14
Oxycheilinus mentalis	Chordata	invertivore	bentho-pelagic	S	within	guarders	115	Yes	No	150	716	15; 14
Oxycheilinus orientalis	Chordata	generalist carnivore	bentho-pelagic	sG	within	guarders	115	Yes	No	150	716	15; 14
Paracheilinus mccoskeri	Chordata	zooplanktivore	benthic	sG	within	nonguarders	6	Yes	No	150	736	15; 14
Pseudocheilinus evanidus	Chordata	invertivore	bentho-pelagic	S	within	guarders	12	Yes	No	150	736	15; 14
Pseudocheilinus hexataenia	Chordata	zooplanktivore	benthic	sG	within	guarders	13	Yes	No	150	736	15; 14
Pseudocoris yamashiroi	Chordata	zooplanktivore	bentho-pelagic	mG	within	nonguarders	27	Yes	No	150	736	15; 14
Pseudodax moluccanus	Chordata	algal/invertivore	benthic	SPG	within	guarders	347	Yes	No	150	736	15; 14
Pseudojuloides polackorum	Chordata	invertivore	benthic	sG	within		22	Yes	No	150	736	15; 14
Pseudojuloides severnsi	Chordata	detritivore	benthic	sG	within		16	Yes	No	150	736	15; 14
Pteragogus cryptus	Chordata	invertivore	benthic	S	within	nonguarders	12	Yes	No	150	736	15; 14
Pteragogus taeniops	Chordata	zooplanktivore	benthic		within	nonguarders	48	No	No	150	736	15; 14
Stethojulis albovittata	Chordata	invertivore	benthic	SPG	within	guarders	34	Yes	Yes	150	736	15; 14
Stethojulis interrupta	Chordata	invertivore	benthic	sG	within	guarders	26	Yes	Yes	150	736	15; 14
Stethojulis strigiventer	Chordata	invertivore	benthic	sG	within	guarders	28	Yes	Yes	150	736	15; 14
Thalassoma amblycephalum	Chordata	zooplanktivore	benthic	lG	within	guarders	75	Yes	No	150	865	15; 17
Thalassoma hardwicke	Chordata	zooplanktivore	benthic	mG	within	guarders	92	Yes	No	150	865	15; 14
Thalassoma hebraicum	Chordata	zooplanktivore	benthic	mG	within	guarders	183	Yes	No	150	865	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Thalassoma lunare	Chordata	invertivore	benthic	mG	within	guarders	970	Yes	No	150	865	15; 14
Thalassoma purpureum	Chordata	generalist carnivore	bentho-pelagic	mG	within	nonguarders	2524	Yes	Yes	150	865	15; 14
Equulites elongatus	Chordata	zooplanktivore	bentho-pelagic	mG		nonguarders	13			120	308	15; 14
Equulites leuciscus	Chordata	zooplanktivore	benthic	mG		nonguarders	298	No	No	120	308	15; 14
Eubleekeria splendens	Chordata	algal/zooplanktivore	bentho-pelagic	mG		nonguarders	88	Yes	No	120	330	15; 14
Leiognathus equulus	Chordata	algal/zooplanktivore	benthic	mG		nonguarders	427	Yes	Yes	120	396	15; 25
Equulites lineolatus	Chordata	generalist carnivore	benthic	mG		nonguarders	26	No	No	120	308	15; 14
Gnathodentex aureolineatus	Chordata	generalist carnivore	bentho-pelagic	SPG		nonguarders	438	Yes	Yes	200	539	15; 14
Gymnocranius elongatus	Chordata	invertivore	bentho-pelagic	SPG	between	nonguarders	670	Yes	No	200	539	15; 14
Gymnocranius grandoculis	Chordata	generalist carnivore	bentho-pelagic	SPG	between	nonguarders	5500	Yes	Yes	200	539	15; 14
Lethrinidae sp	Chordata	generalist carnivore			between	nonguarders	3910	Yes	Yes	200	539	15; 14
Lethrinus conchyliatus	Chordata	generalist carnivore	bentho-pelagic	S	between	nonguarders	6074	Yes	No	200	546	15; 14
Lethrinus erythracanthus	Chordata	invertivore	bentho-pelagic	S	between	nonguarders	3951	Yes	No	200	546	15; 14
Lethrinus erythropterus	Chordata	invertivore	bentho-pelagic	SPG	between	nonguarders	3183	No	No	200	546	15; 14
Lethrinus genivittatus	Chordata	invertivore	bentho-pelagic	SPG	between	nonguarders	193	Yes	Yes	200	546	15; 14
Lethrinus harak	Chordata	invertivore	bentho-pelagic	SPG	between	nonguarders	1737	Yes	Yes	200	546	15; 14
Lethrinus lentjan	Chordata	generalist carnivore	benthic	sG	between	nonguarders	1922	Yes	No	200	546	15; 14
Lethrinus mahsena	Chordata	generalist carnivore	benthic	S	between	nonguarders	4027	Yes	No	200	546	15; 14
Lethrinus microdon	Chordata	generalist carnivore	benthic	sG	between	nonguarders	4900	Yes	Yes	200	546	15; 14
Lethrinus nebulosus	Chordata	generalist carnivore	benthic	SPG	between	nonguarders	8400	Yes	Yes	200	541	15; 56
Lethrinus obsoletus	Chordata	invertivore	benthic	SPG	between	nonguarders	2338	Yes	No	200	546	15; 14
Lethrinus olivaceus	Chordata	generalist carnivore	benthic	sG	between	nonguarders	14000	Yes	Yes	200	546	15; 14
Lethrinus rubrioperculatus	Chordata	generalist carnivore	benthic	mG	between	nonguarders	1633	Yes	Yes	200	546	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Lethrinus sp	Chordata	generalist carnivore	benthic		between	nonguarders	4134	Yes	Yes	200	550	15; 59
Lethrinus variegatus	Chordata	invertivore	benthic	SPG	between	nonguarders	114	Yes	Yes	200	546	15; 14
Lethrinus xanthochilus	Chordata	generalist carnivore	benthic	sG	between	nonguarders	5400	Yes	Yes	200	546	15; 14
Monotaxis grandoculis	Chordata	invertivore	bentho-pelagic	SPG	between	nonguarders	5900	Yes	Yes	200	442	15; 25
Loliginidae sp	Mollusca	generalist carnivore	benthic		between	guarders	1650	Yes	Yes	160	760	32; 25
Sepioteuthis lessoniana	Mollusca	generalist carnivore	benthic	mG	between	guarders	1800	No	No	160	653	32; 14; 47
Uroteuthis duvaucelii	Mollusca	generalist carnivore	benthic		between	guarders	1500	No	No	160	547	32; 21
Aphareus furca	Chordata	piscivore	bentho-pelagic	SPG	between	nonguarders	910	Yes	No	165	571	15; 14
Aphareus rutilans	Chordata	generalist carnivore	pelagic	PsG	between	nonguarders	11300	Yes	No	165	571	15; 14
Aprion virescens	Chordata	generalist carnivore	bentho-pelagic	S	between	nonguarders	15400	Yes	No	165	571	15; 14
Etelis carbunculus	Chordata	generalist carnivore	bentho-pelagic		between	nonguarders	33882	No	No	165	571	15; 14
Lutjanus argentimaculatus	Chordata	generalist carnivore	bentho-pelagic	mG	between	nonguarders	8700	Yes	No	165	513	15; 14
Lutjanus bengalensis	Chordata	invertivore	benthic	sG	between	nonguarders	364	Yes	No	165	580	15; 14
Lutjanus bohar	Chordata	generalist carnivore	bentho-pelagic	S	between	nonguarders	12500	Yes	Yes	165	580	15; 14
Lutjanus fulviflamma	Chordata	generalist carnivore	bentho-pelagic	mG	between	nonguarders	633	Yes	Yes	165	580	15; 14
Lutjanus gibbus	Chordata	invertivore	bentho-pelagic	mG	between	nonguarders	1750	Yes	Yes	165	580	15; 14
Lutjanus kasmira	Chordata	generalist carnivore	bentho-pelagic	lG	between	nonguarders	879	Yes	Yes	165	580	15; 14
Lutjanus lutjanus	Chordata	generalist carnivore	bentho-pelagic	lG	between	nonguarders	569	Yes	Yes	165	682	15; 21
Lutjanus monostigma	Chordata	piscivore	benthic	SPG	between	nonguarders	2531	Yes	No	165	580	15; 14
Lutjanus notatus	Chordata	generalist carnivore	bentho-pelagic	SPG	between	nonguarders	212	Yes	No	165	580	15; 14
Lutjanus rivulatus	Chordata	generalist carnivore	benthic	SPG	between	nonguarders	11000	No	No	165	548	15; 46
Lutjanus russellii	Chordata	generalist carnivore	benthic		between	nonguarders	1584	Yes	No	165	545	15; 46

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Lutjanus sebae	Chordata	generalist carnivore	benthic	SPG	between	nonguarders	32700	Yes	No	165	580	15; 14
Lutjanus sp	Chordata	generalist carnivore	benthic		between	nonguarders	5370	Yes	Yes	165	568	15; 31
Lutjanus vitta	Chordata	generalist carnivore	benthic	SPG	between	nonguarders	859	Yes	No	165	580	15; 14
Macolor niger	Chordata	generalist carnivore	bentho-pelagic	lG	between	nonguarders	6134	Yes	No	165	571	15; 14
Paracaesio xanthura	Chordata	zooplanktivore	pelagic	lG	between	nonguarders	3033	Yes	No	165	571	15; 14
Pristipomoides filamentosus	Chordata	generalist carnivore	pelagic	mG	between	nonguarders	8200	Yes	No	165	509	15; 46
Pristipomoides sieboldii	Chordata	generalist carnivore	bentho-pelagic		between	nonguarders	8400	No	No	165	509	15; 14
Hoplolatilus cuniculus	Chordata	zooplanktivore	benthic	sG	within	nonguarders	25	Yes	No	70	658	15; 14
Malacanthus brevirostris	Chordata	zooplanktivore	bentho-pelagic	PsG	within	nonguarders	20	Yes	Yes	70	658	15; 14
Malacanthus latovittatus	Chordata	invertivore	benthic	S	within	nonguarders	159	Yes	No	70	658	15; 14
Mene maculata	Chordata	zooplanktivore	benthic	mG		guarders	646	Yes	No	120	639	15; 4
Gunnellichthys curiosus	Chordata	zooplanktivore	bentho-pelagic	PsG	within	guarders	17	Yes	No	0	536	15; 14
Gunnellichthys monostigma	Chordata	zooplanktivore	bentho-pelagic	S	within	guarders	34	No	No	0	536	15; 14
Nemateleotris magnifica	Chordata	zooplanktivore	benthic	SPG	within	guarders	4	Yes	No	0	536	15; 14
Ptereleotris evides	Chordata	zooplanktivore	benthic	PsG	within	guarders	15	Yes	No	0	536	15; 14
Acreichthys tomentosus	Chordata	algal/invertivore	benthic	S	within	nonguarders	122	No	Yes	100	312	15; 14
Aluterus monoceros	Chordata	invertivore	bentho-pelagic	SPG	within	guarders	5144	Yes	No	100	265	15; 23
Aluterus scriptus	Chordata	algal/invertivore	bentho-pelagic	S	within	guarders	2500	Yes	Yes	100	265	15; 14
Amanses scopas	Chordata	corallivore	benthic	S	within	guarders	138	Yes	Yes	100	296	15; 14
Cantherhines dumerilii	Chordata	corallivore	bentho-pelagic	S	within	guarders	1016	Yes	No	100	312	15; 14
Cantherhines fronticinctus	Chordata	invertivore	benthic	S	within	guarders	264	Yes	No	100	312	15; 14
Cantherhines pardalis	Chordata	invertivore	bentho-pelagic	S	within	guarders	175	Yes	No	100	312	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Oxymonacanthus longirostris	Chordata	corallivore	benthic	PsG	within	nonguarders	175	Yes	No	100	296	15; 14
Paraluteres prionurus	Chordata	algal/invertivore	benthic	PsG	within	guarders	23	Yes	Yes	100	296	15; 14
Paramonacanthus frenatus	Chordata	algal/invertivore	benthic		within	guarders	21	No	Yes	100	296	15; 14
Pervagor janthinosoma	Chordata	algal/invertivore	benthic	PsG	within	guarders	67	Yes	No	100	296	15; 14
Pervagor melanocephalus	Chordata	algal/invertivore	benthic	PsG	within	guarders	72	Yes	No	100	296	15; 14
Pervagor randalli	Chordata	algal/invertivore	benthic		within	guarders	10	Yes	No	100	296	15; 14
Pseudalutarius nasicornis	Chordata	invertivore	benthic	SPG	within	guarders	83	Yes	Yes	100	296	15; 14
Liza luciae	Chordata	algal/zooplanktivore			between	nonguarders	84	Yes	No	200	441	15; 14
Moolgarda seheli	Chordata	algal/zooplanktivore	benthic	mG	between	nonguarders	8000	Yes	No	200	641	15; 46
Mugil cephalus	Chordata	algal/invertivore	bentho-pelagic	mG	between	nonguarders	17166	Yes	No	200	634	15; 28
Mullidae sp	Chordata	invertivore	benthic		between	nonguarders	803	Yes	Yes	200	522	15; 14
Mulloidichthys flavolineatus	Chordata	generalist carnivore	bentho-pelagic	mG	between	nonguarders	1152	Yes	Yes	200	522	15; 14
Mulloidichthys vanicolensis	Chordata	invertivore	bentho-pelagic	mG	between	nonguarders	612	Yes	Yes	200	522	15; 14
Parupeneus barberinus	Chordata	invertivore	benthic	PsG	between	nonguarders	3228	Yes	Yes	200	522	15; 14
Parupeneus cyclostomus	Chordata	generalist carnivore	bentho-pelagic	S	between	nonguarders	2300	Yes	Yes	200	522	15; 14
Parupeneus heptacanthus	Chordata	generalist carnivore	benthic	SPG	between	nonguarders	747	Yes	Yes	200	522	15; 14
Parupeneus indicus	Chordata	invertivore	benthic	SPG	between	nonguarders	1452	Yes	Yes	200	522	15; 26
Parupeneus macronemus	Chordata	invertivore	benthic	S	between	nonguarders	1001	Yes	Yes	200	522	15; 14
Parupeneus pleurostigma	Chordata	invertivore	bentho-pelagic	S	between	nonguarders	423	Yes	No	200	522	15; 14
Parupeneus rubescens	Chordata	invertivore	benthic	sG	between	nonguarders	1011	Yes	Yes	200	522	15; 14
Parupeneus trifasciatus	Chordata	piscivore	benthic	mG	between	nonguarders	646	Yes	No	200	522	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Upeneus moluccensis	Chordata	invertivore	benthic	lG	between	nonguarders	130	Yes	Yes	200	576	15; 12
Upeneus oligospilus	Chordata	invertivore	benthic		between	nonguarders	109	Yes	No	200	521	15; 14
Upeneus sp	Chordata	invertivore	benthic		between	nonguarders	178	Yes	Yes	200	521	15; 14
Upeneus sulphureus	Chordata	invertivore	benthic	mG	between	nonguarders	18	Yes	No	200	521	15; 14
Upeneus sundaicus	Chordata	invertivore	benthic	mG	between	nonguarders	131	No	No	200	521	15; 14
Upeneus taeniopterus	Chordata	invertivore	benthic	sG	between	nonguarders	390	No	Yes	200	521	15; 14
Upeneus tragula	Chordata	invertivore	benthic	SPG	between	nonguarders	174	Yes	Yes	200	521	15; 14
Upeneus vittatus	Chordata	invertivore	bentho-pelagic	mG	between	nonguarders	289	No	Yes	200	466	15; 21
Echidna nebulosa	Chordata	invertivore	benthic	S	between	nonguarders	1160	Yes	Yes	125	960	15; 14
Gymnothorax favagineus	Chordata	generalist carnivore	benthic	S	between	nonguarders	45080	Yes	No	125	960	15; 3; 14
Gymnothorax flavimarginatus	Chordata	generalist carnivore	benthic	S	between	nonguarders	21507	Yes	No	125	960	15; 3; 14
Gymnothorax griseus	Chordata	piscivore	benthic	S	between	nonguarders	412	Yes	No	125	960	15; 3; 14
Gymnothorax hepaticus	Chordata	generalist carnivore	benthic	S	between	nonguarders	1438	Yes	No	125	960	15; 3; 14
Gymnothorax javanicus	Chordata	generalist carnivore	benthic	S	between	nonguarders	30000	Yes	No	125	960	15; 3; 14
Gymnothorax meleagris	Chordata	piscivore	benthic	S	between	nonguarders	3612	Yes	No	125	960	15; 3; 14
Gymnothorax monochrous	Chordata	generalist carnivore	benthic	S	between	nonguarders	722	Yes	No	125	960	15; 3; 14
Gymnothorax richardsonii	Chordata	generalist carnivore	benthic	S	between	nonguarders	51	Yes	Yes	125	960	15; 3; 14
Gymnothorax sp	Chordata	generalist carnivore	benthic	S	between	nonguarders	10915	Yes	No	125	960	15; 3; 14
Gymnothorax thyrsoideus	Chordata	generalist carnivore	benthic	PsG	between	nonguarders	479	Yes	No	125	960	15; 3; 14
Gymnothorax undulatus	Chordata	generalist carnivore	benthic	S	between	nonguarders	6183	Yes	No	125	960	15; 17
Gymnothorax zonipectis	Chordata	generalist carnivore	benthic	S	between	nonguarders	148	Yes	No	125	960	15; 3; 14
Muraenidae sp	Chordata	generalist carnivore	benthic	S	between	nonguarders	8830	Yes	No	125	960	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Pseudechidna brummeri	Chordata	invertivore	benthic	S	between	nonguarders	1616	Yes	No	125	960	15; 14
Scuticaria tigrina	Chordata	generalist carnivore	benthic	S	between	nonguarders	3765	Yes	No	125	960	15; 14
Strophidon sathete	Chordata	generalist carnivore	benthic	S	between	nonguarders	48133	Yes	No	125	960	15; 14
Uropterygius concolor	Chordata	generalist carnivore	benthic	S	between	nonguarders	161	Yes	No	125	960	15; 14
Uropterygius kamar	Chordata	generalist carnivore	benthic	S	between	nonguarders	64	Yes	No	125	960	15; 14
Murex tribulus	Mollusca	invertivore	benthic		within	nonguarders	36	No	No	0	414	32; 59
Aetobatus narinari	Chordata	invertivore	bentho-pelagic	lG	between	bearers	230000	Yes	No	125	347	15; 14
Aetomylaeus bovinus	Chordata	invertivore	bentho-pelagic	S	between	bearers	116000	No	No	125	347	15; 14
Mobula birostris	Chordata	zooplanktivore	pelagic	SPG	between	bearers	3000000	Yes	No	125	347	15; 14
Myliobatis aquila	Chordata	generalist carnivore	bentho-pelagic	mG	between	bearers	14500	No	No	125	347	15; 14; 7
Bullia annulata	Mollusca	detritivore	benthic		within	nonguarders	14	Yes	No	20	414	32; 59
Nassarius papillosus	Mollusca	detritivore	benthic		within	nonguarders	9	Yes	No	20	414	32
Nemipterus bipunctatus	Chordata	generalist carnivore	benthic	mG	between	nonguarders	5700	No	No	160	430	15; 14
Nemipterus japonicus	Chordata	generalist carnivore	benthic	mG	between	nonguarders	600	Yes	Yes	160	495	15; 46
Nemipterus randalli	Chordata	generalist carnivore	benthic	mG	between	nonguarders	143	Yes	No	160	430	15; 14
Nemipterus sp	Chordata	generalist carnivore	benthic	mG	between	nonguarders	2148	Yes	Yes	160	430	15; 25
Scolopsis bimaculata	Chordata	generalist carnivore	benthic	mG	between	nonguarders	478	Yes	Yes	160	446	15; 14
Scolopsis ghanam	Chordata	generalist carnivore	benthic	mG	between	nonguarders	419	Yes	Yes	160	446	15; 14
Scolopsis vosmeri	Chordata	invertivore	benthic	mG	between	nonguarders	194	Yes	No	160	446	15; 14
Amphioctopus aegina	Mollusca	invertivore	benthic	S	within	guarders	458	No	No	100	696	32; 14; 38
Callistoctopus macropus	Mollusca	invertivore	benthic	S	within	guarders	2000	Yes	No	100	562	32; 25
Cistopus indicus	Mollusca	invertivore	benthic	S	within	guarders	994	No	No	100	638	32; 14
Octopodidae sp	Mollusca	invertivore	benthic		within	guarders	977	Yes	No	100	638	32; 14
Octopus cyanea	Mollusca	invertivore	benthic	PsG	within	guarders	6000	Yes	No	100	668	32; 17; 18

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Octopus vulgaris	Mollusca	invertivore	benthic	PsG	within	guarders	10000	Yes	Yes	100	627	32; 21
Odontodactylus scyllarus	Arthropoda	invertivore	benthic	S	within	bearers	35	Yes	No	120	340	32; 14; 2
Ommastrephes bartramii	Mollusca	generalist carnivore	bentho-pelagic	mG	between	guarders	1800	No	No	160	659	32; 14
Myrichthys maculosus	Chordata	generalist carnivore	benthic	S	between	nonguarders	953	Yes	No	70	514	15; 45
Ophichthus erabo	Chordata	generalist carnivore	benthic	S	#N/A	nonguarders	367	Yes	No	70	436	15; 45
Linckia laevigata	Echinodermata	detritivore	benthic	S	within	nonguarders	57	Yes	Yes	0	467	32; 14; 6
Fromia indica	Echinodermata	detritivore	benthic	S	within	nonguarders	1	Yes	No	0	467	32; 14; 6
Choriaster granulatus	Echinodermata	coral/invertivore	benthic	S	within	nonguarders	102	Yes	No	0	467	32; 14; 6
Protoreaster nodosus	Echinodermata	grazer/detritivore	benthic	S	within	nonguarders	70	Yes	Yes	0	467	32; 14; 6
Lactoria cornuta	Chordata	invertivore	benthic	S	within	nonguarders	824	Yes	Yes	70	394	15; 14
Lactoria fornasini	Chordata	invertivore	bentho-pelagic	S	within	nonguarders	238	Yes	No	70	394	15; 14
Ostracion meleagris	Chordata	algal/spongivore	benthic	S	between	nonguarders	301	Yes	No	70	394	15; 14
Panulirus ornatus	Arthropoda	invertivore	benthic	SPG	within	bearers	2669	Yes	No	775	310	32; 20; 54
Panulirus penicillatus	Arthropoda	invertivore	benthic	S	within	bearers	551	Yes	No	775	483	32; 17; 35
Panulirus versicolor	Arthropoda	invertivore	benthic	S	within	bearers	2627	Yes	No	775	396	32; 20; 16; 55
Palinuridae sp	Arthropoda	invertivore	benthic	S	within	bearers	1949	Yes	No	775	396	32; 14
Pempheris mangula	Chordata	zooplanktivore	benthic	mG	within	nonguarders	65	Yes	No	70	565	15; 11
Fenneropenaeus indicus	Arthropoda	algal/invertivore	benthic	S	#N/A	nonguarders	35	No	No	160	552	32; 14
Penaeidae sp	Arthropoda	algal/invertivore	benthic	S		nonguarders	106			160	526	32; 14
Penaeus monodon	Arthropoda	invertivore	benthic	S	#N/A	bearers	250	No	No	160	566	32; 14
Penaeus semisulcatus	Arthropoda	algal/invertivore	benthic	sG	#N/A	bearers	130	No	Yes	160	563	32; 14
Parapercis hexophtalma	Chordata	generalist carnivore	benthic	S	within	nonguarders	297	Yes	No	115	431	15; 56; 8
Parapercis maculata	Chordata	invertivore	benthic	S	within	nonguarders	68	No	No	115	507	15; 56; 8

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Parapercis punctulata	Chordata	invertivore	benthic	PsG	within	nonguarders	18	Yes	No	115	469	15; 56; 8
Atrina pectinata	Mollusca	planktivore	benthic		within	nonguarders	988	No	No	20	130	32; 14
Cociella heemstrai	Chordata	generalist carnivore	benthic		within	nonguarders	652	No	No	165	617	15; 14
Papilloculiceps longiceps	Chordata	generalist carnivore	benthic		within	nonguarders	2190	Yes	Yes	165	617	15; 14
Platycephalidae sp	Chordata	generalist carnivore	benthic		within	nonguarders	2610	No	No	165	778	15; 28
Platycephalus indicus	Chordata	generalist carnivore	benthic		within	nonguarders	6305	Yes	No	165	456	15; 5
Plesiobatis daviesi	Chordata	generalist carnivore	benthic		between	bearers	246233	No	No	125	347	15; 14
Samariscus triocellatus	Chordata	invertivore	benthic	S	within	nonguarders	37	Yes	No	120	435	15; 53
Plotosus lineatus	Chordata	algal/invertivore	benthic	SPG	between	guarders	372	Yes	Yes	95	761	15; 28
Polynoidae sp	Annelida	invertivore	benthic	S			16			0	130	32; 14
Apolemichthys trimaculatus	Chordata	algal/spongivore	benthic	sG	within	nonguarders	319	Yes	No	180	565	15; 11
Centropyge acanthops	Chordata	algal/corallivore	benthic	sG	within	nonguarders	10	Yes	No	180	565	15; 14
Centropyge fisheri	Chordata	algal/corallivore	bentho-pelagic	sG	within	nonguarders	11	Yes	No	180	565	15; 14
Centropyge multispinis	Chordata	algal/corallivore	benthic	sG	within	nonguarders	66	Yes	Yes	180	565	15; 14
Genicanthus caudovittatus	Chordata	zooplanktivore	bentho-pelagic	PsG	within	nonguarders	61	Yes	No	180	565	15; 14
Pomacanthus chrysurus	Chordata	algal/spongivore	benthic	S	within	nonguarders	1629	Yes	Yes	180	565	15; 14
Pomacanthus imperator	Chordata	algal/spongivore	benthic	PsG	within	nonguarders	2101	Yes	No	180	565	15; 14
Pomacanthus semicirculatus	Chordata	algal/spongivore	benthic	S	within	nonguarders	1672	Yes	No	180	565	15; 14
Pygoplites diacanthus	Chordata	spongivore	benthic	SPG	within	nonguarders	402	Yes	No	180	565	15; 14
Abudefduf sexfasciatus	Chordata	algal/zooplanktivore	bentho-pelagic	mG	within	guarders	186	Yes	Yes	70	347	15; 14
Abudefduf sparoides	Chordata	zooplanktivore	bentho-pelagic	SPG	within	guarders	101	Yes	Yes	70	347	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Abudefduf vaigiensis	Chordata	algal/zooplanktivore	bentho-pelagic	sG	within	guarders	202	Yes	Yes	70	347	15; 14
Amblyglyphidodon leucogaster	Chordata	zooplanktivore	bentho-pelagic	SPG	within	guarders	41	Yes	No	70	347	15; 14
Amphiprion akallopisos	Chordata	algal/zooplanktivore	benthic	sG	within	guarders	30	Yes	No	70	347	15; 14
Amphiprion allardi	Chordata	algal/zooplanktivore	benthic	SPG	within	guarders	61	Yes	Yes	70	347	15; 14
Chromis agilis	Chordata	algal/zooplanktivore	bentho-pelagic	sG	within	guarders	17	Yes	No	70	347	15; 56
Chromis dimidiata	Chordata	algal/zooplanktivore	bentho-pelagic	lG	within	guarders	12	Yes	No	70	347	15; 14
Chromis lepidolepis	Chordata	zooplanktivore	benthic	SPG	within	guarders	13	Yes	No	70	347	15; 14
Chromis nigroanalis	Chordata	zooplanktivore	bentho-pelagic		within	guarders	31	Yes	No	70	347	15; 14
Chromis nigrura	Chordata	zooplanktivore	benthic	SPG	within	guarders	2	Yes	No	70	347	15; 14
Chromis opercularis	Chordata	algal/zooplanktivore	benthic	SPG	within	guarders	67	No	Yes	70	347	15; 14
Chromis ternatensis	Chordata	zooplanktivore	bentho-pelagic	lG	within	guarders	28	Yes	No	70	347	15; 14
Chromis weberi	Chordata	zooplanktivore	benthic	sG	within	guarders	44	Yes	No	70	347	15; 14
Chromis xutha	Chordata	zooplanktivore	benthic		within	guarders	6	Yes	No	70	347	15; 14
Chrysiptera unimaculata	Chordata	grazer	benthic	SPG	within	guarders	14	Yes	No	70	347	15; 14
Dascyllus carneus	Chordata	algal/zooplanktivore	benthic	sG	within	guarders	5	Yes	Yes	70	347	15; 14
Dascyllus trimaculatus	Chordata	algal/zooplanktivore	benthic	PsG	within	guarders	84	Yes	Yes	70	347	15; 14
Neoglyphidodon melas	Chordata	corallivore	benthic	S	within	guarders	118	Yes	Yes	70	347	15; 14
Neopomacentrus fuliginosus	Chordata	zooplanktivore	benthic		within	guarders	19	No	Yes	70	347	15; 14
Plectroglyphidodon dickii	Chordata	algal/invertivore	benthic	S	within	guarders	32	Yes	No	70	347	15; 14
Plectroglyphidodon imparipennis	Chordata	algal/invertivore	bentho-pelagic	S	within	guarders	3	Yes	No	70	347	15; 14
Plectroglyphidodon johnstonianus	Chordata	algal/corallivore	bentho-pelagic	S	within	guarders	48	Yes	No	70	347	15; 14
Plectroglyphidodon lacrymatus	Chordata	algal/invertivore	benthic	S	within	guarders	20	Yes	Yes	70	347	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Pomacentrus baenschi	Chordata	algal/zooplanktivore	benthic	PsG	within	guarders	22	Yes	No	70	347	15; 14
Pomacentrus caeruleus	Chordata	algal/zooplanktivore	benthic	sG	within	guarders	13	Yes	No	70	347	15; 14
Pomacentrus sulfureus	Chordata	algal/zooplanktivore	benthic	PsG	within	guarders	17	Yes	No	70	347	15; 14
Pomacentrus trichrourus	Chordata	algal/zooplanktivore	benthic	PsG	within	guarders	27	Yes	Yes	70	347	15; 14
Pomacentrus trilineatus	Chordata	algal/zooplanktivore	benthic	PsG	within	guarders	22	Yes	Yes	70	347	15; 14
Stegastes fasciolatus	Chordata	grazer	bentho-pelagic	S	within	guarders	110	Yes	No	70	347	15; 14
Charybdis feriatus	Arthropoda	invertivore	benthic		within	bearers	1115	No	No	120	160	32; 14
Podophthalmus vigil	Arthropoda	invertivore	benthic		within	bearers	243	No	No	120	136	32; 40
Portunidae sp	Arthropoda	invertivore	benthic		within	bearers	922	No	No	120	160	32; 14
Portunus pelagicus	Arthropoda	invertivore	benthic		within	bearers	511	Yes	Yes	120	186	32; 14; 34; 49; 1; 36
Portunus sanguinolentus	Arthropoda	invertivore	benthic		within	bearers	558	No	No	120	160	32; 14; 49; 57
Scylla serrata	Arthropoda	invertivore	benthic		within	bearers	3000	No	No	185	156	32; 14; 29
Priacanthus hamrur	Chordata	generalist carnivore	bentho-pelagic	sG	between	nonguarders	1026	Yes	Yes	125	467	15; 56
Pristigenys niphonia	Chordata	generalist carnivore	bentho-pelagic	sG	between	nonguarders	678	No	No	125	394	15; 56
Pellona ditchela	Chordata	zooplanktivore	pelagic		between	nonguarders	69	No	No	103	641	15; 56
Ranina ranina	Arthropoda	invertivore	benthic		within	bearers	900	No	No	120	340	32; 14
Bolbometopon muricatum	Chordata	excavator	bentho-pelagic	sG	between	nonguarders	46000	Yes	No	175	384	15; 14; 41
Calotomus carolinus	Chordata	browser	bentho-pelagic	SPG	within	nonguarders	3253	Yes	Yes	175	461	15; 45
Calotomus viridescens	Chordata	browser	benthic	SPG	within	nonguarders	347	Yes	Yes	175	461	15; 14
Cetoscarus ocellatus	Chordata	excavator	benthic	sG	within	nonguarders	15070	Yes	No	175	384	15; 14; 41
Chlorurus atrilunula	Chordata	scraper	bentho-pelagic	S	between	nonguarders	437	Yes	No	175	586	15; 17

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Chlorurus capistratoides	Chordata	scraper	benthic	sG		nonguarders	1048	Yes	No	175	586	15; 14
Chlorurus sordidus	Chordata	scraper	bentho-pelagic	S	within	nonguarders	1237	Yes	Yes	175	586	15; 14; 41
Chlorurus strongylocephalus	Chordata	scraper	bentho-pelagic	S	between	nonguarders	5744	Yes	No	175	586	15; 14
Hipposcarus harid	Chordata	scraper	bentho-pelagic	SPG	between	nonguarders	2300	Yes	Yes	175	384	15; 14; 41
Leptoscarus vaigiensis	Chordata	browser	benthic	sG		nonguarders	401	Yes	Yes	140	384	15; 14
Scarus caudofasciatus	Chordata	scraper	benthic	S	within	nonguarders	1600	Yes	No	175	315	15; 14; 41
Scarus ferrugineus	Chordata	scraper	benthic	sG	within	nonguarders	1618	Yes	No	175	315	15; 14; 41
Scarus festivus	Chordata	scraper	benthic			nonguarders	1910	Yes	No	175	315	15; 14; 41
Scarus frenatus	Chordata	scraper	benthic	SPG	within	nonguarders	3139	Yes	No	175	315	15; 14; 41
Scarus ghobban	Chordata	scraper	benthic	SPG	between	nonguarders	7245	Yes	Yes	175	315	15; 14; 9
Scarus globiceps	Chordata	scraper	benthic	sG		nonguarders	1344	Yes	No	175	315	15; 14; 41
Scarus niger	Chordata	scraper	benthic	SPG	between	nonguarders	1488	Yes	No	175	315	15; 14; 41
Scarus psittacus	Chordata	scraper	bentho-pelagic	SPG	within	nonguarders	900	Yes	Yes	175	315	15; 14; 41
Scarus rubroviolaceus	Chordata	scraper	bentho-pelagic	PsG	within	nonguarders	6626	Yes	No	175	315	15; 14; 41
Scarus russelii	Chordata	scraper	benthic	S	between	nonguarders	1100	Yes	No	175	315	15; 14; 41
Scarus scaber	Chordata	scraper	benthic	S	within	nonguarders	900	Yes	No	175	315	15; 14; 41
Scarus sp	Chordata	scraper	benthic			nonguarders	2454	Yes	No	175	215	15; 25
Scarus tricolor	Chordata	scraper	benthic	SPG	between	nonguarders	2500	Yes	No	175	315	15; 14; 41
Scarus viridifucatus	Chordata	scraper	benthic	S	between	nonguarders	1533	Yes	No	175	315	15; 14; 41
Auxis thazard	Chordata	generalist carnivore	pelagic	mG	between	nonguarders	1700	No	No	200	828	15; 14
Gymnosarda unicolor	Chordata	piscivore	pelagic	mG	between	nonguarders	131000	Yes	No	200	926	15; 14
Katsuwonus pelamis	Chordata	generalist carnivore	pelagic	lG	between	nonguarders	34500	No	No	200	853	15; 14
Rastrelliger kanagurta	Chordata	zooplanktivore	pelagic	mG	between	nonguarders	830	Yes	Yes	200	661	15; 14
Sarda orientalis	Chordata	generalist carnivore	pelagic	mG	between	nonguarders	10700	No	No	200	1368	15; 56

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Scomber japonicus	Chordata	zooplanktivore	pelagic	mG	between	nonguarders	2900	No	No	200	1119	15; 56
Thunnus alalunga	Chordata	generalist carnivore	pelagic	mG	between	nonguarders	60300	No	No	200	828	15; 14
Thunnus albacares	Chordata	generalist carnivore	pelagic	sG	between	nonguarders	200000	No	No	200	828	15; 14
Pterois miles	Chordata	generalist carnivore	benthic	SPG	within	nonguarders	1159	Yes	Yes	100	463	15; 14
Scorpaenopsis diabolus	Chordata	piscivore	benthic	S	within	nonguarders	292	Yes	No	100	342	15; 56
Scorpaenopsis oxycephala	Chordata	generalist carnivore	benthic	S	within	nonguarders	617	Yes	No	100	342	15; 56
Thenus orientalis	Arthropoda	invertivore	benthic		between	bearers	293	No	No	120	396	22; 24; 43
Sepia australis	Mollusca	generalist carnivore	bentho-pelagic	S	between	guarders	50	No	No	185	555	32; 14; 60
Sepia latimanus	Mollusca	invertivore	bentho-pelagic	S	between	guarders	10000	Yes	No	185	555	32; 14; 60
Sepia pharaonis	Mollusca	generalist carnivore	benthic	S	between	guarders	5000	No	Yes	185	555	32; 14; 60
Sepia prashadi	Mollusca	generalist carnivore	bentho-pelagic	S	between	guarders	219	No	No	185	555	32; 14; 60; 13
Sepia sp	Mollusca	generalist carnivore	bentho-pelagic	S	between	guarders	1305			185	555	32; 14
Aethaloperca rogaa	Chordata	generalist carnivore	benthic	S	within	nonguarders	4512	Yes	Yes	250	597	15; 14
Anyperodon leucogrammicus	Chordata	generalist carnivore	benthic	S	within	nonguarders	3557	Yes	No	250	597	15; 14
Belonoperca chabanaudi	Chordata	generalist carnivore	benthic	S	within	nonguarders	25	Yes	No	250	597	15; 14
Cephalopholis argus	Chordata	generalist carnivore	benthic	sG	within	nonguarders	2990	Yes	Yes	250	563	15; 45
Cephalopholis boenak	Chordata	generalist carnivore	benthic	S	within	nonguarders	398	Yes	No	250	556	15; 26
Cephalopholis leopardus	Chordata	generalist carnivore	benthic	S	within	nonguarders	184	Yes	No	250	581	15; 14
Cephalopholis miniata	Chordata	generalist carnivore	benthic	sG	within	nonguarders	1695	No	Yes	250	498	15; 56
Cephalopholis nigripinnis	Chordata	generalist carnivore	benthic	S	within	nonguarders	309	Yes	No	250	581	15; 14
Cephalopholis sexmaculata	Chordata	generalist carnivore	benthic	SPG	within	nonguarders	1103	Yes	No	250	581	15; 14
Cephalopholis sonnerati	Chordata	generalist carnivore	benthic	S	within	nonguarders	2920	Yes	No	250	708	15; 31

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Cephalopholis sp	Chordata	generalist carnivore	benthic	S	within	nonguarders	1162	Yes	No	250	581	15; 14
Cephalopholis spiloparaea	Chordata	invertivore	benthic	S	within	nonguarders	549	Yes	No	250	581	15; 14
Cephalopholis urodeta	Chordata	generalist carnivore	benthic	S	within	nonguarders	309	Yes	No	250	581	15; 14
Epinephelus albomarginatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	13000	Yes	No	250	643	15; 14; 9
Epinephelus andersoni	Chordata	generalist carnivore	benthic	S	within	nonguarders	8700	Yes	No	250	627	15; 14; 9
Epinephelus areolatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	1400	Yes	Yes	250	627	15; 14; 9
Epinephelus chlorostigma	Chordata	generalist carnivore	benthic	S	within	nonguarders	7000	Yes	Yes	250	627	15; 14; 9
Epinephelus coeruleopunctatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	4925	Yes	No	250	627	15; 14; 9
Epinephelus fasciatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	2000	Yes	Yes	250	627	15; 14; 9
Epinephelus fuscoguttatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	11000	Yes	Yes	250	627	15; 14; 9
Epinephelus hexagonatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	236	Yes	No	250	627	15; 14; 9
Epinephelus lanceolatus	Chordata	generalist carnivore	bentho-pelagic	S	within	nonguarders	400000	Yes	No	250	627	15; 14; 9
Epinephelus longispinis	Chordata	invertivore	benthic	S	within	nonguarders	2700	Yes	Yes	250	627	15; 14; 9
Epinephelus macrospilos	Chordata	invertivore	benthic	S	within	nonguarders	2000	Yes	No	250	627	15; 14; 9
Epinephelus malabaricus	Chordata	generalist carnivore	benthic	S	within	nonguarders	150000	Yes	No	250	627	15; 56; 9
Epinephelus marginatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	60000	No	No	250	627	15; 56; 9
Epinephelus melanostigma	Chordata	generalist carnivore	benthic	S	within	nonguarders	594	Yes	No	250	627	15; 56; 9
Epinephelus merra	Chordata	piscivore	benthic	S	within	nonguarders	442	Yes	Yes	250	627	15; 56; 9
Epinephelus posteli	Chordata	generalist carnivore	benthic		within	nonguarders	10000	Yes	No	250	627	15; 56; 9
Epinephelus rivulatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	1400	Yes	Yes	250	627	15; 46; 9
Epinephelus sp	Chordata	generalist carnivore	benthic	S	within	nonguarders	41365	Yes	Yes	250	627	15; 46; 9

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Epinephelus spilotoceps	Chordata	generalist carnivore	benthic	S	within	nonguarders	537	Yes	No	250	627	15; 14; 9
Epinephelus tukula	Chordata	generalist carnivore	bentho-pelagic	S	within	nonguarders	110000	Yes	No	250	627	15; 14; 9
Gracila albomarginata	Chordata	piscivore	bentho-pelagic	S	between	nonguarders	832	Yes	No	150	607	15; 14
Nemanthias carberryi	Chordata	zooplanktivore	benthic		within	nonguarders	19	Yes	No	150	607	15; 14
Plectropomus laevis	Chordata	piscivore	bentho-pelagic	S	between	nonguarders	24200	Yes	No	150	607	15; 14
Plectropomus leopardus	Chordata	piscivore	bentho-pelagic	S	between	nonguarders	23600	Yes	No	150	607	15; 14
Plectropomus punctatus	Chordata	piscivore	bentho-pelagic	SPG	between	nonguarders	17300	Yes	No	150	607	15; 14
Pseudanthias cooperi	Chordata	zooplanktivore	benthic	lG	within	nonguarders	37	Yes	No	70	607	15; 14
Pseudanthias evansi	Chordata	zooplanktivore	benthic	lG	within	nonguarders	42	Yes	No	70	607	15; 14
Pseudanthias sp	Chordata	zooplanktivore	benthic	lG	within	nonguarders	43	Yes	No	70	607	15; 14
Pseudanthias squamipinnis	Chordata	zooplanktivore	benthic	lG	within	nonguarders	50	Yes	No	70	607	15; 14
Variola albimarginata	Chordata	piscivore	bentho-pelagic	SPG	between	nonguarders	4962	Yes	No	150	607	15; 14
Variola louti	Chordata	generalist carnivore	benthic	SPG	between	nonguarders	12000	Yes	No	150	607	15; 14
Siganus argenteus	Chordata	invertivore	bentho-pelagic	lG	between	nonguarders	900	Yes	Yes	185	494	15; 14; 58
Siganus luridus	Chordata	grazer/detritivore	benthic	mG	between	nonguarders	318	Yes	Yes	185	493	15; 14; 58
Siganus sp	Chordata	grazer/detritivore	benthic		between	nonguarders	1138	Yes	Yes	185	476	15; 46
Siganus stellatus	Chordata	grazer/detritivore	benthic	PsG	between	nonguarders	964	Yes	Yes	185	493	15; 14; 58
Siganus sutor	Chordata	grazer/detritivore	benthic	mG	between	nonguarders	2368	Yes	Yes	185	493	15; 56; 58
Sillago aeolus	Chordata	invertivore	benthic	mG	within	nonguarders	358	No	No	135	470	15; 46
Sillago sihama	Chordata	invertivore	benthic	lG	between	nonguarders	14985	Yes	No	135	504	15; 46
Crenidens crenidens	Chordata	algal/invertivore	benthic			nonguarders	498	No	Yes	200	566	15; 14
Polysteganus coeruleopunctatus	Chordata	invertivore	bentho-pelagic	S	between	nonguarders	3219	No	No	200	604	15; 14
Sphyraena acutipinnis	Chordata	piscivore	bentho-pelagic	mG	between	nonguarders	2557	Yes	No	200	523	15; 31

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Sphyraena barracuda	Chordata	piscivore	bentho-pelagic	S	between	nonguarders	50000	Yes	Yes	200	612	15; 56
Sphyraena forsteri	Chordata	piscivore	bentho-pelagic	lG	between	nonguarders	2413	Yes	No	200	368	15; 56
Sphyraena jello	Chordata	piscivore	bentho-pelagic	S	between	nonguarders	11500	No	Yes	200	503	15; 14
Sphyraena putnamae	Chordata	piscivore	benthic	S	between	nonguarders	3947	No	Yes	200	503	15; 14
Sphyraena sp	Chordata	piscivore	bentho-pelagic		between	nonguarders	11871	Yes	Yes	200	503	15; 14
Thelenota anax	Echinodermata	detritivore	benthic	S	within	nonguarders	6000	Yes	No	70	705	32; 30
Saurida gracilis	Chordata	generalist carnivore	benthic	S	within	nonguarders	669	Yes	Yes	115	471	15; 59
Saurida wanieso	Chordata	generalist carnivore	benthic	S	within	nonguarders	2668	No	No	115	467	15; 56
Synodus binotatus	Chordata	generalist carnivore	benthic	S	within	nonguarders	37	Yes	Yes	115	486	15; 56; 51
Synodus dermatogenys	Chordata	generalist carnivore	benthic	SPG	within	nonguarders	173	Yes	No	115	486	15; 14; 51
Synodus indicus	Chordata	piscivore	benthic	S	within	nonguarders	291	No	No	115	486	15; 14; 51
Synodus jaculum	Chordata	generalist carnivore	benthic	SPG	within	nonguarders	60	Yes	No	115	486	15; 14; 51
Synodus sp	Chordata	generalist carnivore	benthic	S	within	nonguarders	244	Yes	Yes	115	486	15; 14
Synodus variegatus	Chordata	piscivore	benthic	PsG	within	nonguarders	662	Yes	Yes	115	486	15; 14; 51
Terapon jarbua	Chordata	generalist carnivore	benthic	mG	between	guarders	792	No	Yes	150	1168	15; 28
Terapon puta	Chordata	generalist carnivore	bentho-pelagic	mG	between	guarders	25	Yes	Yes	150	1168	15; 14
Terapon theraps	Chordata	generalist carnivore	bentho-pelagic	mG	between	guarders	720	No	Yes	150	1168	15; 14
Arothron caeruleopunctatus	Chordata	algal/invertivore	bentho-pelagic	S	within	guarders	8334	Yes	No	95	422	15; 45
Arothron immaculatus	Chordata	algal/invertivore	bentho-pelagic	S	within	guarders	568	Yes	No	95	422	15; 14
Arothron meleagris	Chordata	corallivore	bentho-pelagic	S	within	guarders	2547	Yes	Yes	95	422	15; 14
Arothron nigropunctatus	Chordata	algal/invertivore	bentho-pelagic	PsG	within	guarders	488	Yes	Yes	95	422	15; 14
Arothron stellatus	Chordata	algal/invertivore	bentho-pelagic	S	between	guarders	37643	Yes	Yes	95	422	15; 14

Table I-5 (continued)

Species	Phylum	Trophic group	Water column	Greg	Mobility	Reproduction	MaxWt (g)	Coral assoc	Sea-grass assoc	Value (mts/kg)	Caloric value (Cal/kg)	citation
Canthigaster bennetti	Chordata	grazer	benthic	SPG	within	guarders	25	Yes	Yes	95	394	15; 14
Canthigaster cyanospilota	Chordata	algal/invertivore	bentho-pelagic	S	within	guarders	61	Yes	No	95	394	15; 14
Canthigaster janthinoptera	Chordata	algal/spongivore	benthic	S	within	guarders	18	Yes	Yes	95	394	15; 14
Canthigaster smithae	Chordata	algal/invertivore	benthic	S	within	guarders	52	Yes	No	95	394	15; 14
Canthigaster solandri	Chordata	algal/corallivore	bentho-pelagic	PsG	within	guarders	160	Yes	Yes	95	394	15; 14
Canthigaster sp	Chordata	algal/corallivore	benthic		within	guarders	57	Yes	Yes	95	394	15; 14
Canthigaster valentini	Chordata	algal/corallivore	benthic	sG	within	nonguarders	31	Yes	No	95	394	15; 14
Lagocephalus lunaris	Chordata	invertivore	benthic		between	guarders	3106	Yes	No	95	321	15; 56
Lagocephalus sceleratus	Chordata	generalist carnivore	benthic		between	guarders	11096	Yes	Yes	95	321	15; 14
Torquigener flavimaculosus	Chordata	invertivore	benthic			guarders	99	Yes	No	95	394	15; 14
Torquigener hypselogeneion	Chordata	generalist carnivore	benthic	sG		guarders	14	No	No	95	394	15; 14
Torpedo sinuspersici	Chordata	generalist carnivore	benthic	S	between	bearers	33845	Yes	No	125	347	15; 14
Tripneustes gratilla	Echinodermata	scraper	benthic		within	guarders	344	Yes	Yes	20	229	32; 10
Trichiurus lepturus	Chordata	zooplanktivore	bentho-pelagic	SPG	between	nonguarders	5000	Yes	No	90	811	15; 56
Aurelia aurita	Cnideria	zooplanktivore	pelagic		between	nonguarders	3128	No	No	0	17	32; 39
Zanclus cornutus	Chordata	algal/spongivore	benthic	PsG	between	nonguarders	249	Yes	Yes	100	565	15; 11

Table I-6: References used in Table I-5 above.

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Appendix II

This section has supplementary tables and figures from Chapter 3 addressing the behavioural theories which could be used to explain fishing behaviours around Pemba Bay.

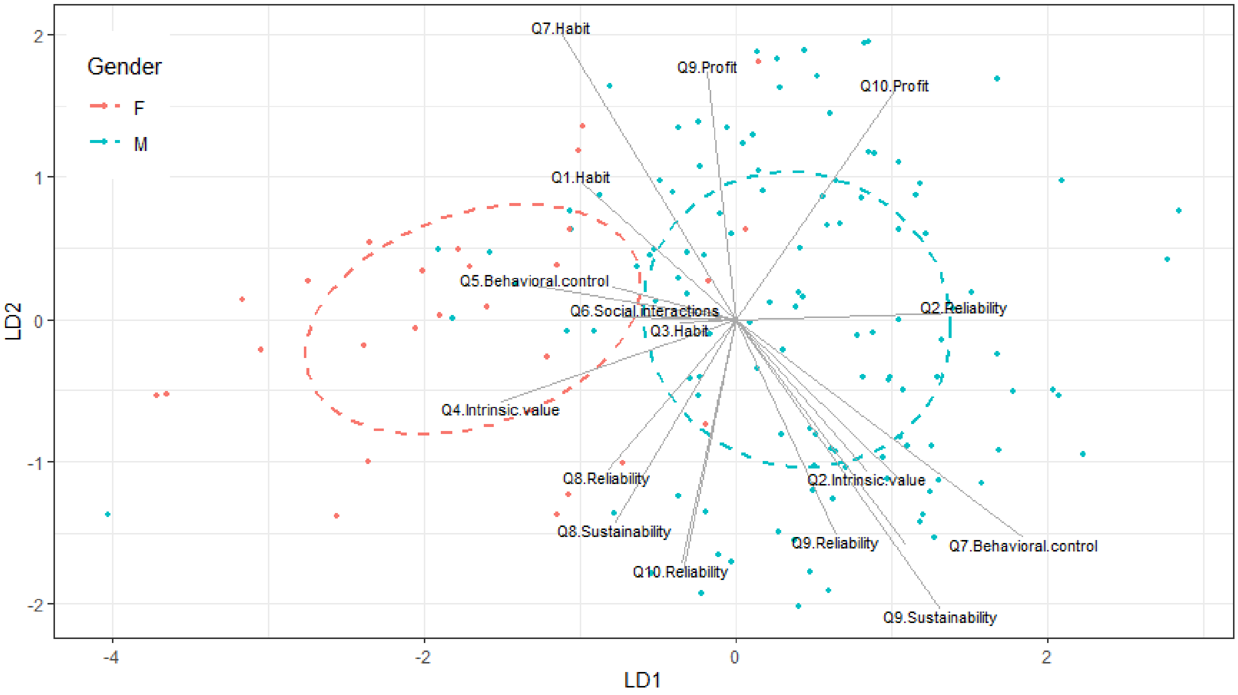

Figure II-1: Interviewee location on the first two axes of the CAP using gender to determine differences in responses to interview questions. Vectors indicate categorical agreement to specific questions most correlated to these axes. Paths represent covariance ellipses.

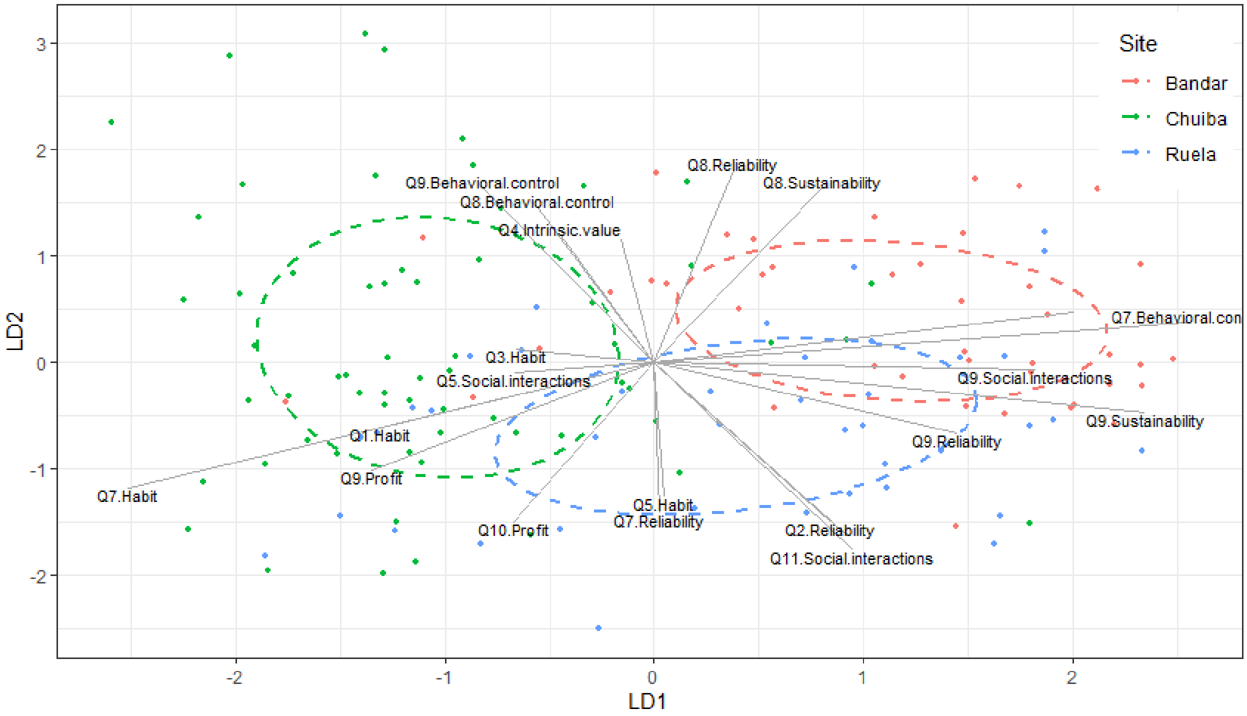

Figure II-2: Interviewee location on the first two axes of the CAP using fishing community to determine differences in responses to interview questions. Vectors indicate categorical agreement to specific questions most correlated to these axes. Paths represent covariance ellipses.

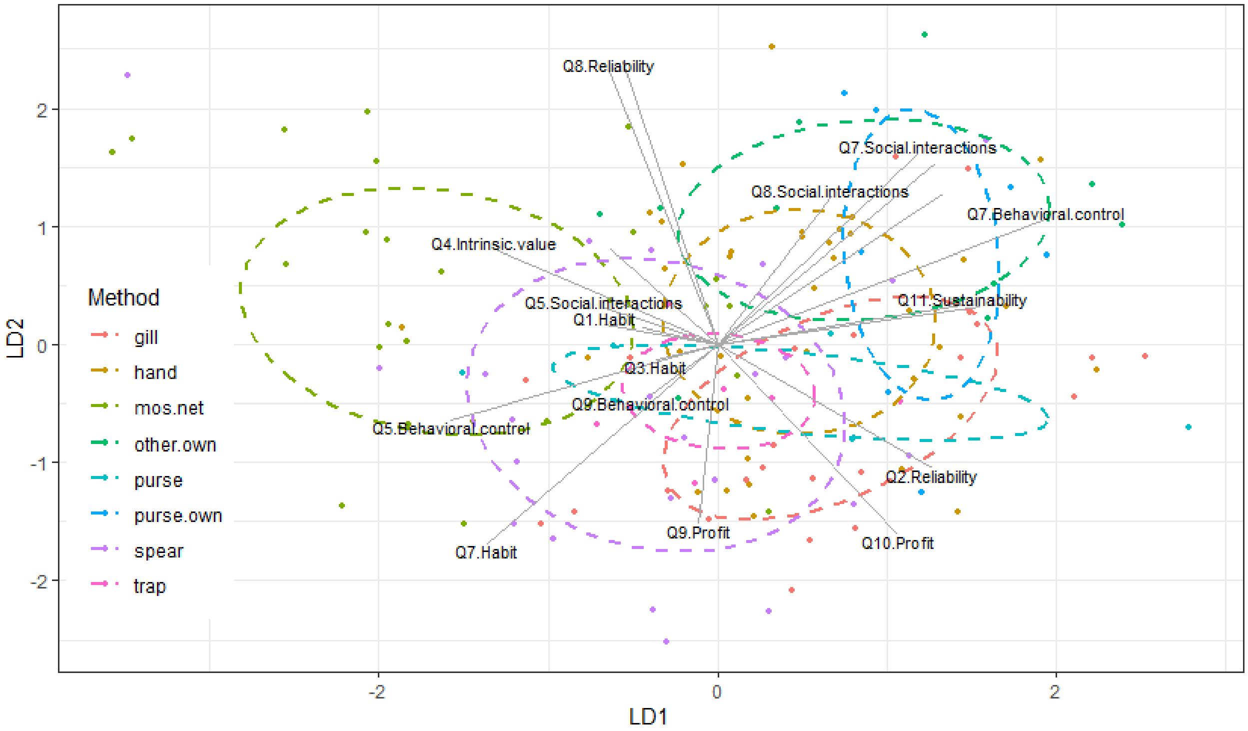

Figure II-3: Interviewee location on the first two axes of the CAP using fishing method to determine differences in responses to interview questions. Vectors indicate categorical agreement to specific questions most correlated to these axes. Paths represent covariance ellipses.

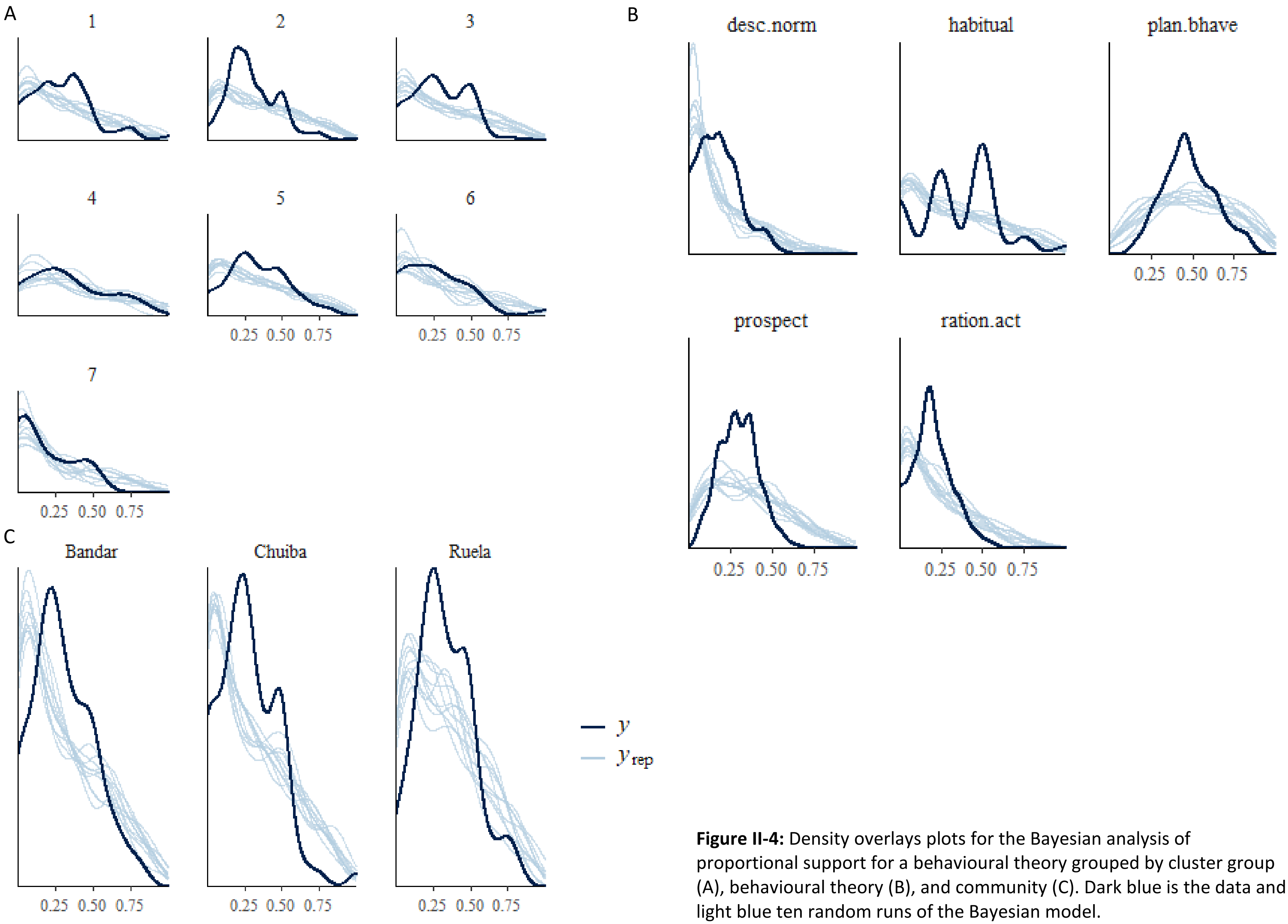

Figure II-4: Density overlays plots for the Bayesian analysis of proportional support for a behavioural theory grouped by cluster group (A), behavioural theory (B), and community (C). Dark blue is the data and light blue ten random runs of the Bayesian model.

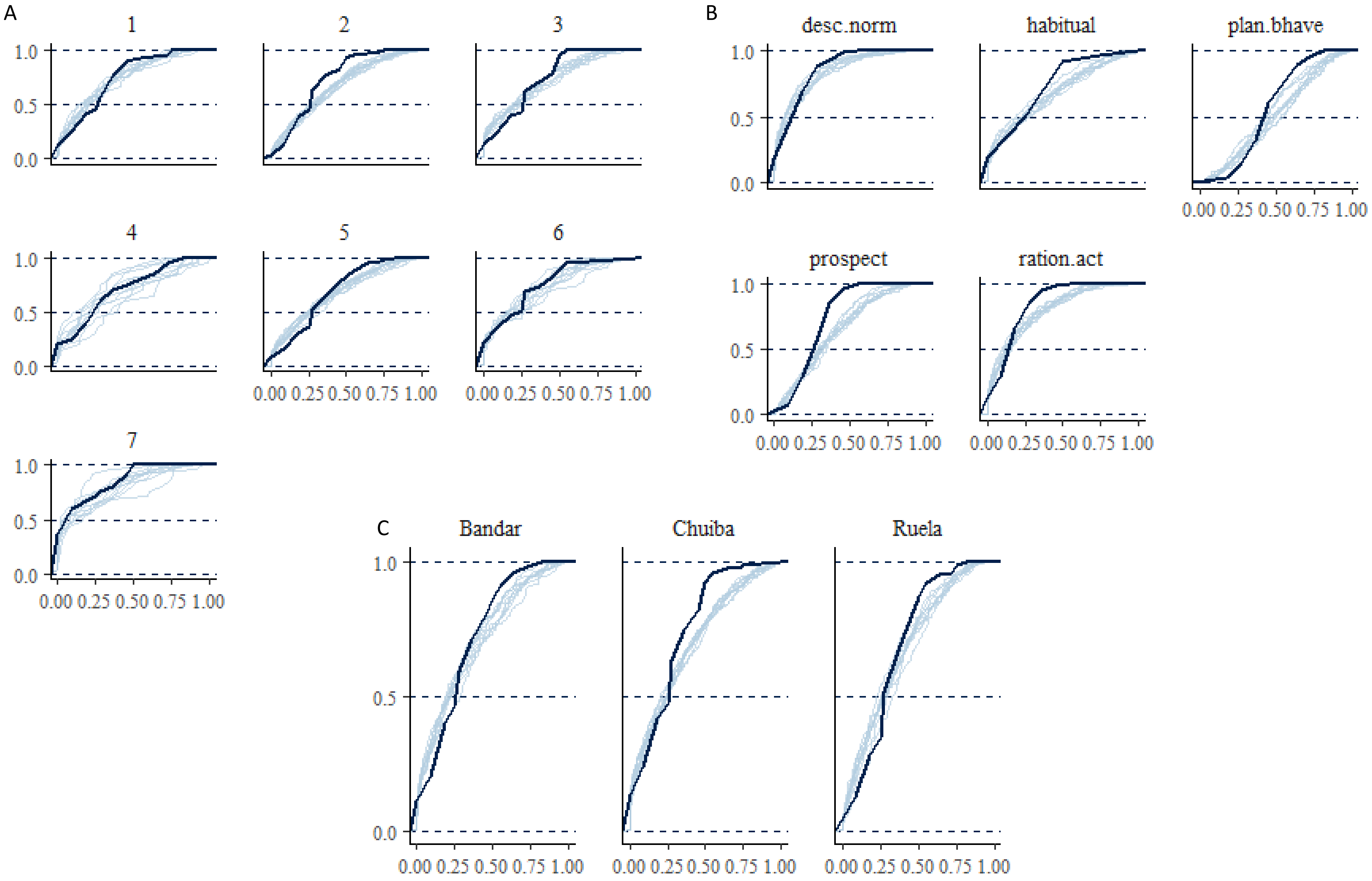

Figure II-5: Empirical cumulative density function overlays for the Bayesian analysis of proportional support for a behavioural theory grouped by cluster group (A), behavioural theory (B), and community (C). Dark blue is the data and light blue ten random runs of the Bayesian model.

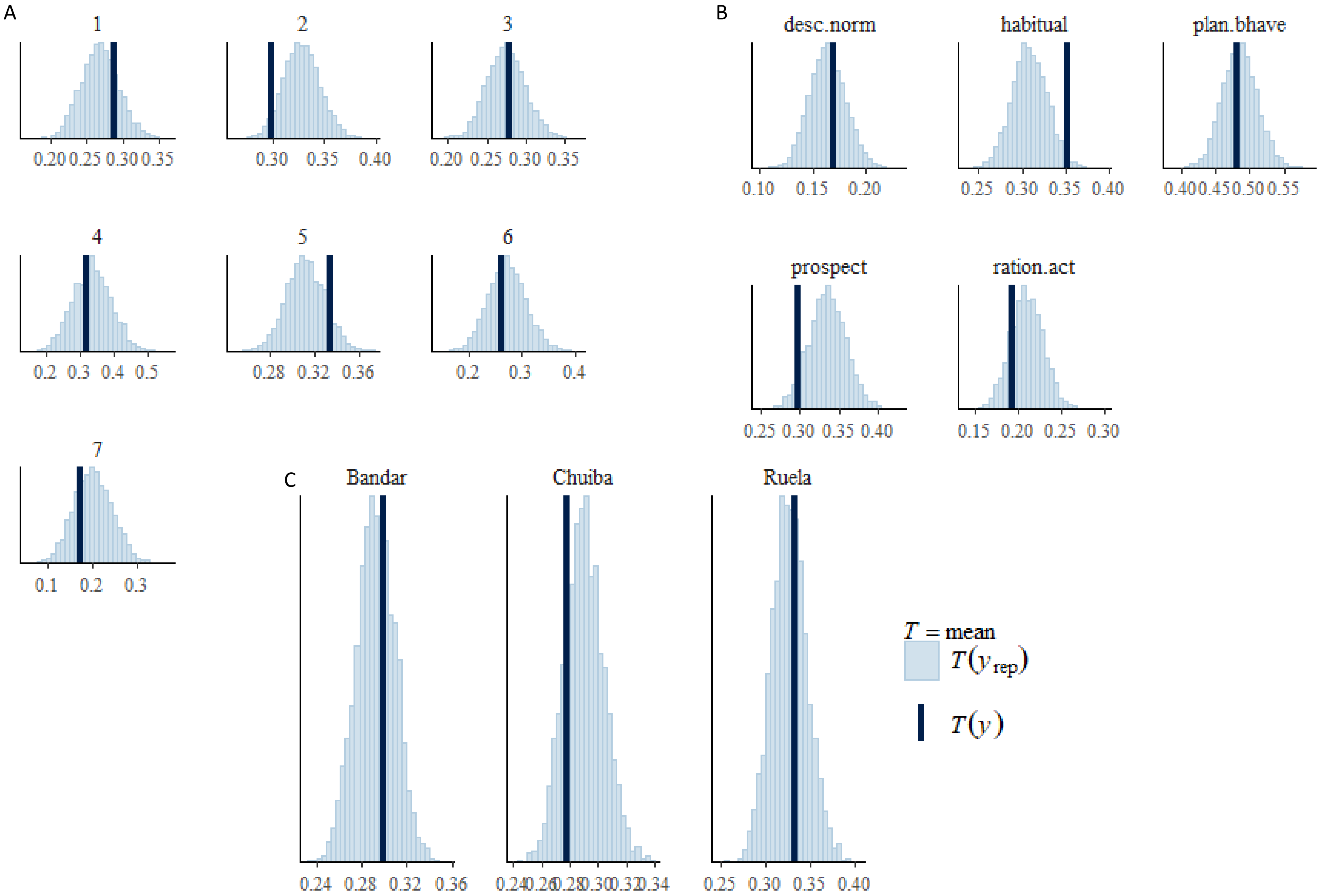

Figure II-6: The mean value from the model compared to the actual value for each group based on cluster group (A), behavioural theory (B), and community (C). Dark blue bars are the data, light blue are histograms of the mean value from all model runs.

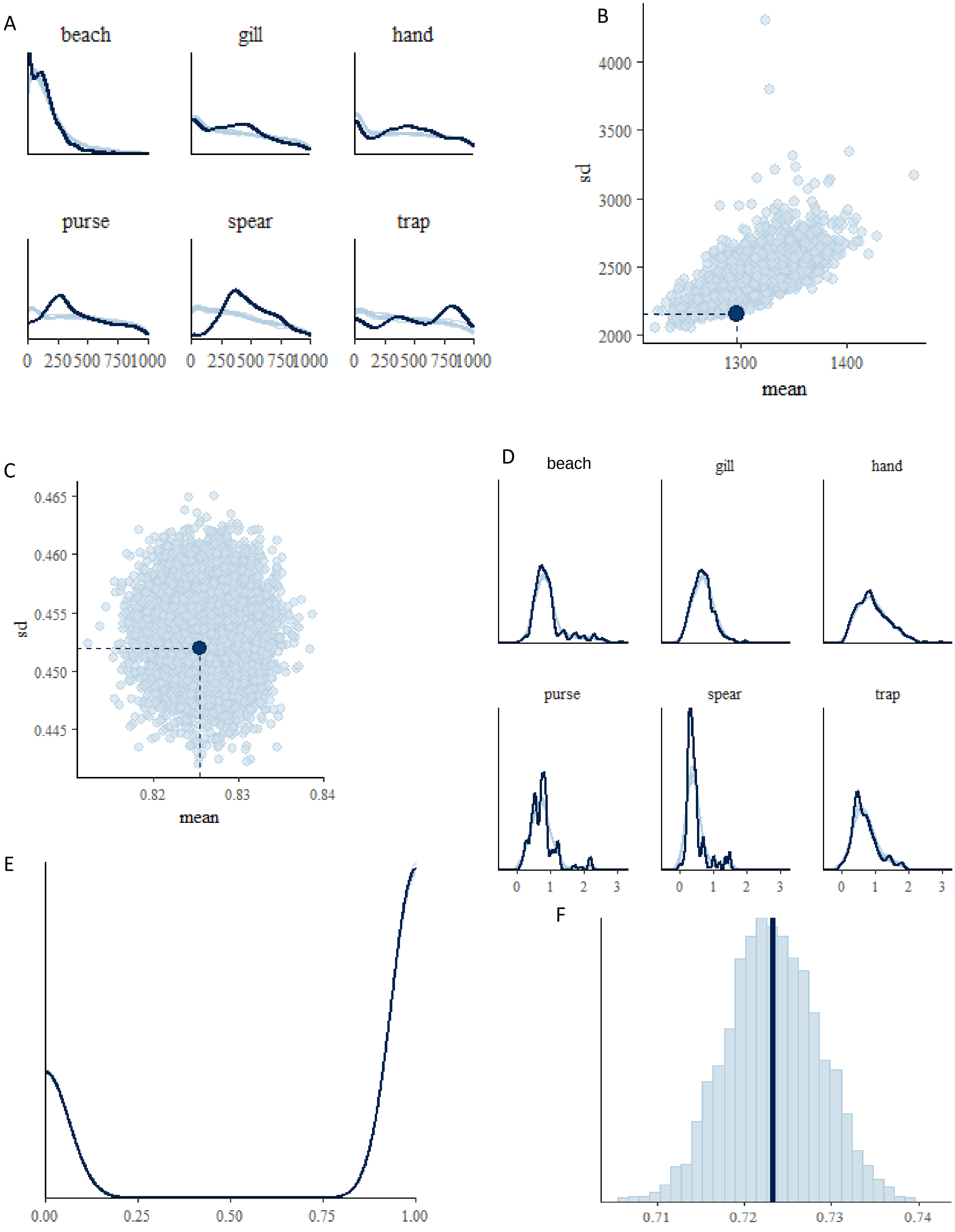

Figure II-7: The density overlay (A, D, and E), mean and standard deviation (B and C), and mean value (F) of the data (dark blue) to random posterior predictions (light blue) from the Bayesian model of monetary value of catch per fisher (A and B), CV of catch weight (C and D), and probability catch is sufficient for home use (E and F).

Table II-1: Model coefficients from the model of monetary value of catch per fisher per fishing trip from the catch data. * Indicate 95% confidence intervals which do not overlap zero.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	5.533	0.463	4.630	6.456	*
Cloud cover	0.027	0.011	0.005	0.048	*
Ave. wind speed	-0.010	0.011	-0.032	0.011	
Ave temperature	0.060	0.012	0.037	0.083	*
Rained	0.034	0.026	-0.018	0.087	
Wet season	-0.007	0.028	-0.063	0.049	
Year	0.098	0.025	0.048	0.148	*
Gill	1.417	0.037	1.343	1.488	*
Hand	1.704	0.034	1.637	1.771	*
Purse	0.217	0.042	0.136	0.299	*
Spear	1.280	0.044	1.193	1.366	*
Trap	1.049	0.056	0.940	1.159	*
Year: gill	0.075	0.034	0.008	0.142	*
Year: hand	-0.122	0.029	-0.178	-0.065	*
Year: purse	-0.132	0.031	-0.192	-0.070	*
Year: spear	0.055	0.038	-0.020	0.131	
Year: trap	0.088	0.050	-0.011	0.184	

Table II-2: Model coefficients from the model of CV of catch weight per fishing method, fishing center, and month from the catch data. * Indicate 95% confidence intervals which do not overlap zero.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	0.95	0.11	0.71	1.18	*
Cloud cover	0.00	0.01	-0.02	0.01	
Ave. wind speed	0.00	0.01	-0.02	0.02	
Ave temperature	0.03	0.01	0.01	0.06	*
Rained	-0.01	0.02	-0.05	0.02	
Wet season	-0.01	0.03	-0.07	0.06	
Year	0.06	0.02	0.01	0.10	*
Gill	-0.36	0.01	-0.38	-0.33	*
Hand	-0.03	0.01	-0.05	-0.01	*
Purse	-0.37	0.02	-0.4	-0.34	*
Spear	-0.33	0.02	-0.37	-0.30	*
Trap	-0.25	0.02	-0.29	-0.21	*
Year: gill	0.02	0.01	-0.01	0.04	
Year: hand	-0.14	0.01	-0.16	-0.11	*
Year: purse	0.03	0.02	0.00	0.06	.
Year: spear	0.00	0.02	-0.03	0.03	
Year: trap	-0.24	0.02	-0.28	-0.20	*

Table II-3: Model coefficients from the binomial model on whether a catch was sufficient (at least 1.75kg per fisher) from the catch data. Coefficients are considered significant if their 95% confidence intervals (CI) do not overlap zero.

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	sig
Intercept	-1.40	0.57	-2.56	-0.33	*
Cloud cover	-0.01	0.03	-0.07	0.05	
Ave. wind speed	-0.02	0.03	-0.08	0.05	
Ave temperature	0.10	0.04	0.03	0.17	*
Rained	0.06	0.08	-0.10	0.22	
Wet season	0.10	0.08	-0.05	0.26	
Year	0.07	0.08	-0.08	0.22	
Gill	2.70	0.10	2.51	2.90	*
Hand	2.61	0.09	2.43	2.79	*
Purse	3.29	0.12	3.06	3.52	*
Spear	2.64	0.16	2.35	2.95	*
Trap	3.09	0.17	2.77	3.42	*
Year: gill	-0.10	0.10	-0.30	0.09	
Year: hand	-0.11	0.09	-0.28	0.06	
Year: purse	-0.65	0.11	-0.86	-0.43	*
Year: spear	-0.42	0.15	-0.71	-0.14	*
Year: trap	0.51	0.17	0.18	0.86	*

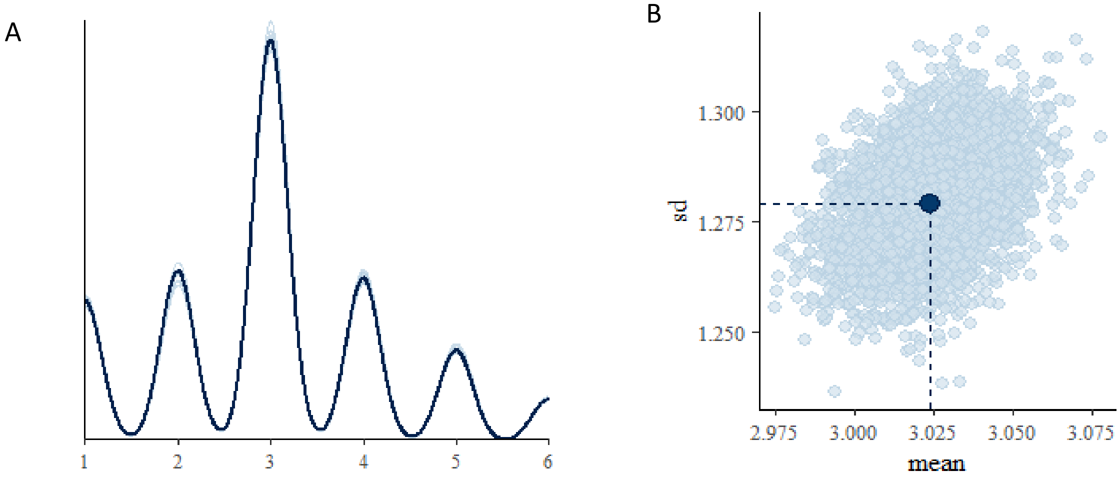

Figure II-8: Posterior predictive density overlay (A) and mean and standard deviation (B) of the categorical model of the odds that a fishing trip used a particular method with data is in dark bule and model predictions in light blue.

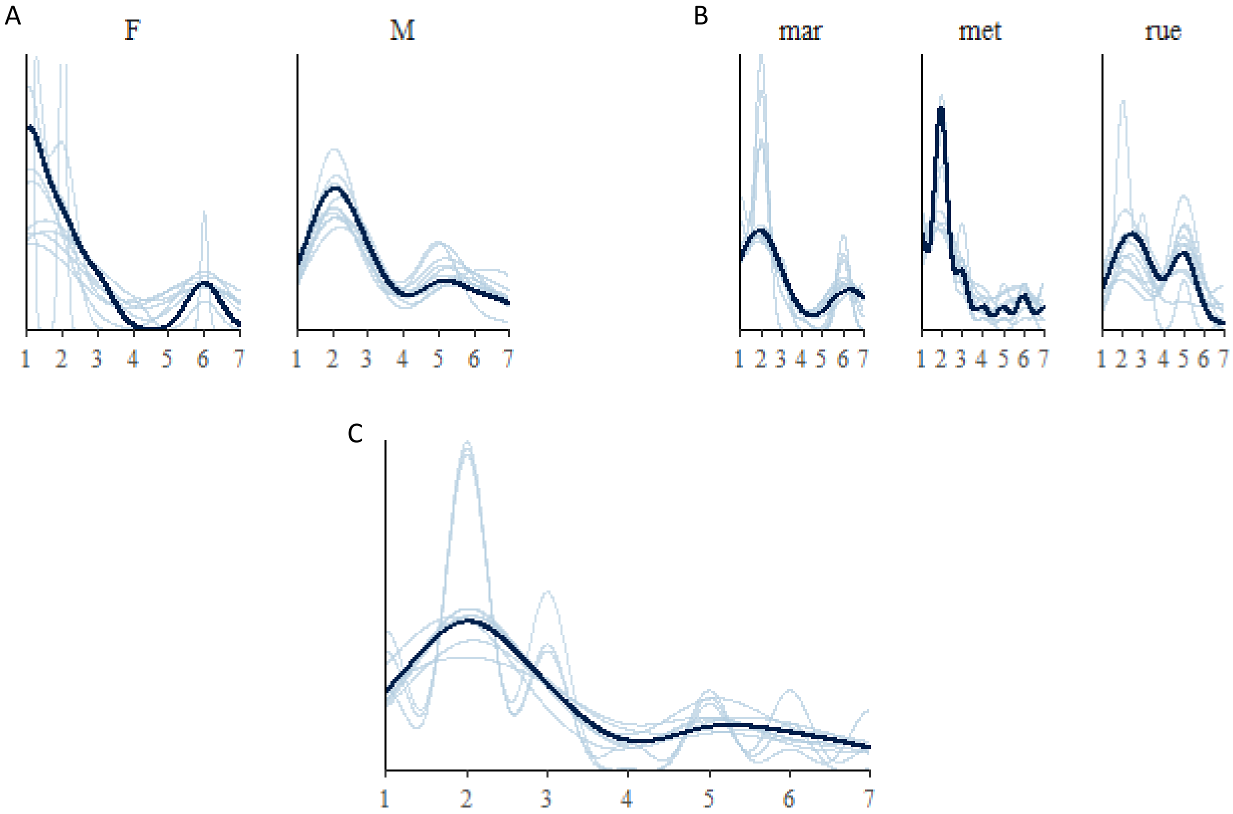

Figure II-9: Posterior prediction density overlays of the categorical model of fisher preferred method based on fisher characteristics. Posterior predictions grouped by gender (A), fishing centre (B), and ungrouped (C) with data in dark blue and model predictions in light blue.

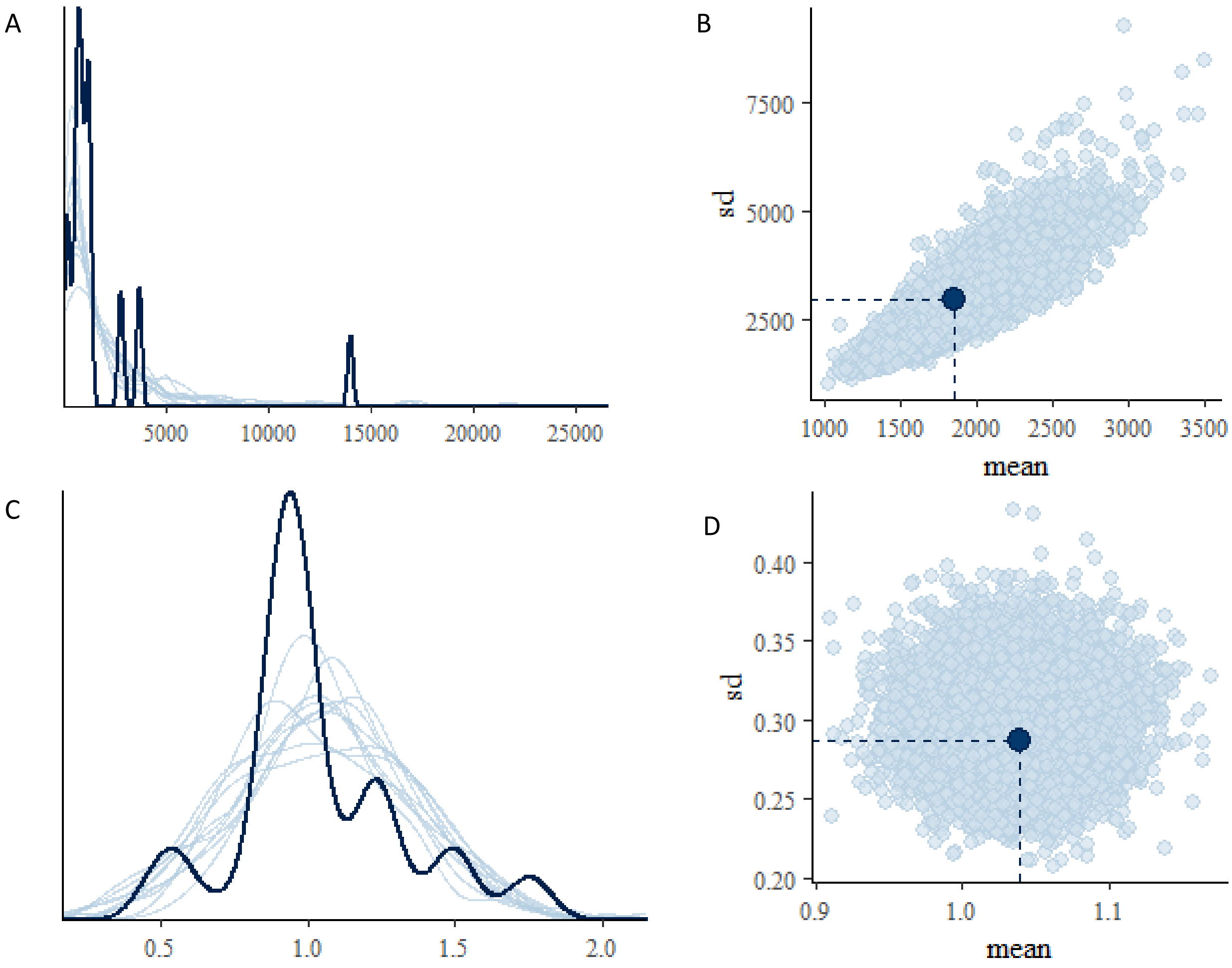

Figure II-10: Posterior prediction density overlay (A and C) and model mean value and standard deviation (B and D) of the multivariate model of preferred method characteristics of monetary value (A and B) and CV of catch weight (C and D) using fisher characteristics as predictors. Data is dark blue; model runs are light blue.

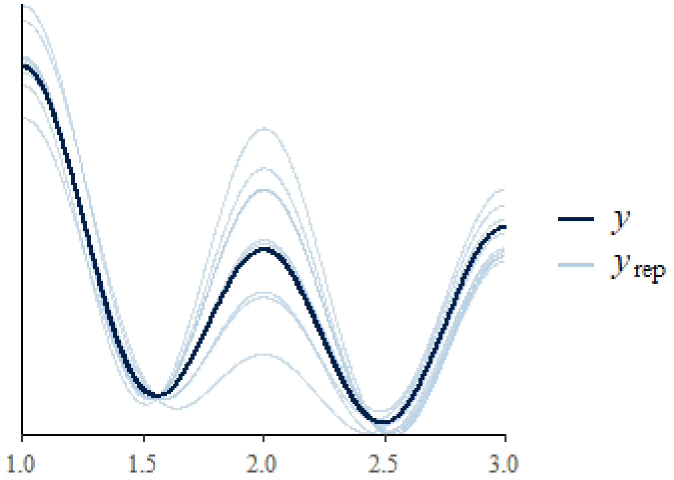

Figure II-11: Posterior prediction density overlay plot of the ordinal model of fishers' opinions of their fishing method based on catch and fisher characteristics. Data is dark blue and 10 random runs of the model are light blue.

Appendix III

This Appendix gives the extra tables and figures which complement the analyses in Chapter 4.

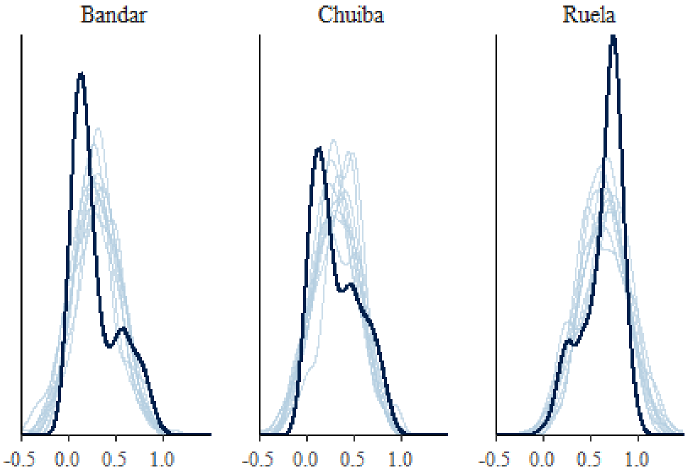

Figure III-1: Posterior prediction density overlay of the MSL model of fishers and non-fishers (light blue) compared to the data (dark blue).

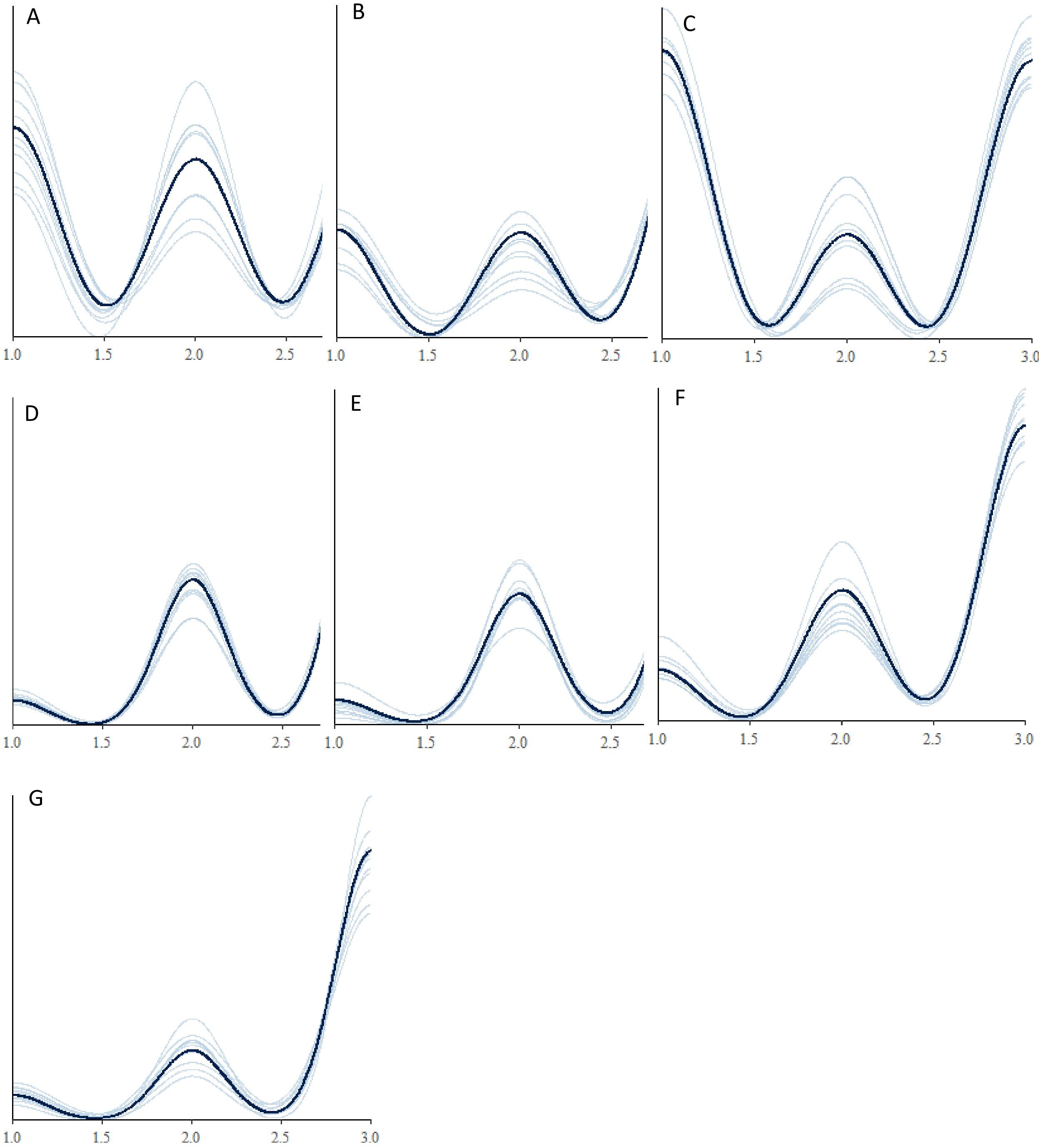

Figure III-2: Posterior prediction density overlays for ten runs of the model (light blue) compared to the data (dark blue) for overall wellbeing (A), safety in the community (B), access to help in the community (C), family, social, and work life (D-F), and family health (G) for all respondents, fishers and non-fishers. The only values are one, two, and three which is why there are humps at these spots and valleys between.

Table III-1: Coefficients from the Bayesian models of: overall perceived wellbeing (A), feelings of safety in the community (B), expectation of finding help in the community (C), satisfaction with family life (D), satisfaction with social life (E), job satisfaction (F), and subjective family health (G).

A

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept[1]	0.18	0.28	-0.37	0.71	
Intercept[2]	-1.27	0.25	-1.76	-0.78	*
Chuiba	-0.38	0.16	-0.70	-0.07	*
Ruela	-0.36	0.17	-0.71	-0.02	*
MSL[1]	-0.01	0.16	-0.33	0.31	
MSL[2]	0.24	0.15	-0.05	0.55	
Education[1]	-0.19	0.16	-0.52	0.12	
Education[2]	0.17	0.15	-0.13	0.47	
Years in community[1]	0.18	0.15	-0.12	0.48	
Years in community[2]	-0.04	0.14	-0.31	0.23	
Household size[1]	0.01	0.15	-0.28	0.29	
Household size[2]	0.03	0.15	-0.26	0.32	
# of livelihoods[1]	0.24	0.15	-0.05	0.55	
# of livelihoods[2]	-0.39	0.15	-0.70	-0.10	*
Male[1]	-0.35	0.31	-0.97	0.26	
Male[2]	-0.25	0.29	-0.81	0.32	
Fisher[1]	0.40	0.35	-0.27	1.07	
Fisher[2]	-0.25	0.32	-0.87	0.39	

B

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept[1]	-0.07	0.36	-0.75	0.64	
Intercept[2]	-2.02	0.29	-2.62	-1.47	*
Chuiba	-0.29	0.19	-0.65	0.06	
Ruela	0.08	0.21	-0.32	0.47	
MSL[1]	0.12	0.20	-0.26	0.52	
MSL[2]	0.09	0.17	-0.24	0.41	
Education[1]	-0.51	0.21	-0.93	-0.11	*
Education[2]	0.22	0.17	-0.1	0.55	
Years in community[1]	-0.10	0.19	-0.47	0.27	
Years in community[2]	0.00	0.15	-0.29	0.29	
Household size[1]	-0.26	0.20	-0.67	0.13	
Household size[2]	0.22	0.17	-0.10	0.57	
# of livelihoods[1]	0.15	0.19	-0.22	0.52	
# of livelihoods[2]	-0.27	0.16	-0.58	0.03	
Male[1]	-0.18	0.38	-0.94	0.55	
Male[2]	-0.06	0.31	-0.66	0.56	
Fisher[1]	0.10	0.43	-0.76	0.95	
Fisher[2]	-0.67	0.34	-1.32	-0.02	*

Table III-1 (continued)

C

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept[1]	1.46	0.33	0.82	2.10	*
Intercept[2]	-2.08	0.32	-2.73	-1.48	*
Chuiba	-0.09	0.15	-0.40	0.20	
Ruela	-0.14	0.16	-0.45	0.17	
MSL[1]	-0.16	0.19	-0.53	0.19	
MSL[2]	0.27	0.19	-0.08	0.64	
Education[1]	-0.29	0.20	-0.69	0.09	
Education[2]	0.24	0.19	-0.13	0.63	
Years in community[1]	0.22	0.17	-0.12	0.56	
Years in community[2]	-0.27	0.17	-0.61	0.05	
Household size[1]	-0.25	0.19	-0.63	0.12	
Household size[2]	0.37	0.19	0.02	0.75	*
# of livelihoods[1]	0.21	0.18	-0.14	0.57	
# of livelihoods[2]	-0.27	0.18	-0.61	0.08	
Male[1]	-0.47	0.35	-1.17	0.20	
Male[2]	0.08	0.35	-0.60	0.78	
Fisher[1]	0.93	0.41	0.15	1.74	*
Fisher[2]	-1.07	0.40	-1.88	-0.32	*

D

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept[1]	-0.72	0.47	-1.65	0.16	
Intercept[2]	-1.88	0.31	-2.51	-1.30	*
Chuiba	-0.30	0.23	-0.76	0.13	
Ruela	0.99	0.30	0.41	1.60	*
MSL[1]	-0.57	0.27	-1.10	-0.06	
MSL[2]	0.00	0.16	-0.30	0.30	
Education[1]	0.06	0.29	-0.54	0.62	
Education[2]	-0.04	0.16	-0.35	0.29	
Years in community[1]	0.16	0.27	-0.36	0.69	
Years in community[2]	-0.20	0.15	-0.49	0.08	
Household size[1]	0.01	0.29	-0.53	0.60	
Household size[2]	0.20	0.15	-0.09	0.50	
# of livelihoods[1]	0.28	0.28	-0.27	0.84	
# of livelihoods[2]	-0.27	0.15	-0.57	0.02	
Male[1]	0.24	0.55	-0.83	1.32	
Male[2]	0.10	0.30	-0.50	0.67	
Fisher[1]	0.64	0.58	-0.52	1.79	
Fisher[2]	-1.13	0.33	-1.80	-0.49	*

Table III-1 (continued)

E

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept[1]	0.09	0.40	-0.69	0.88	
Intercept[2]	-2.05	0.31	-2.66	-1.46	*
Chuiba	-0.17	0.21	-0.58	0.25	
Ruela	0.41	0.26	-0.09	0.91	
MSL[1]	-0.20	0.26	-0.68	0.31	
MSL[2]	0.21	0.16	-0.09	0.52	
Education[1]	0.05	0.25	-0.44	0.54	
Education[2]	-0.10	0.16	-0.41	0.22	
Years in community[1]	0.43	0.24	-0.05	0.91	
Years in community[2]	-0.35	0.14	-0.64	-0.07	*
Household size[1]	-0.34	0.24	-0.8	0.13	
Household size[2]	0.21	0.15	-0.08	0.52	
# of livelihoods[1]	0.08	0.24	-0.40	0.57	
# of livelihoods[2]	-0.09	0.15	-0.39	0.21	
Male[1]	0.40	0.48	-0.55	1.37	
Male[2]	0.18	0.29	-0.41	0.75	
Fisher[1]	1.55	0.56	0.48	2.64	*
Fisher[2]	-1.41	0.34	-2.10	-0.75	*

F

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept[1]	-0.19	0.39	-0.95	0.58	
Intercept[2]	-2.27	0.30	-2.88	-1.69	*
Chuiba	-0.42	0.21	-0.83	-0.02	*
Ruela	0.00	0.23	-0.45	0.45	
MSL[1]	-0.51	0.23	-0.97	-0.07	*
MSL[2]	0.38	0.16	0.07	0.71	*
Education[1]	-0.21	0.24	-0.68	0.25	
Education[2]	-0.08	0.17	-0.40	0.24	
Years in community[1]	0.18	0.23	-0.27	0.61	
Years in community[2]	-0.18	0.15	-0.47	0.12	
Household size[1]	-0.39	0.22	-0.83	0.04	
Household size[2]	0.38	0.17	0.06	0.73	*
# of livelihoods[1]	-0.05	0.22	-0.49	0.38	
# of livelihoods[2]	-0.07	0.16	-0.38	0.23	
Male[1]	0.05	0.43	-0.79	0.91	
Male[2]	0.10	0.30	-0.50	0.70	
Fisher[1]	0.82	0.49	-0.17	1.77	
Fisher[2]	-1.18	0.35	-1.87	-0.49	*

Table III-1 (continued)

G

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept[1]	-0.37	0.34	-1.05	0.29	
Intercept[2]	-0.77	0.26	-1.28	-0.27	*
Chuiba	0.55	0.22	0.11	0.98	*
Ruela	0.55	0.22	0.10	0.99	*
MSL[1]	-0.94	0.24	-1.41	-0.49	*
MSL[2]	0.31	0.16	0.01	0.62	*
Education[1]	-0.02	0.22	-0.44	0.41	
Education[2]	-0.07	0.15	-0.38	0.23	
Years in community[1]	0.23	0.22	-0.22	0.64	
Years in community[2]	-0.11	0.14	-0.39	0.16	
Household size[1]	-0.14	0.22	-0.57	0.29	
Household size[2]	0.07	0.15	-0.22	0.37	
# of livelihoods[1]	0.49	0.24	0.02	0.96	*
# of livelihoods[2]	-0.12	0.15	-0.40	0.17	
Male[1]	0.52	0.48	-0.45	1.47	
Male[2]	0.36	0.29	-0.21	0.92	
Fisher[1]	0.00	0.50	-0.96	0.99	
Fisher[2]	0.04	0.30	-0.56	0.65	

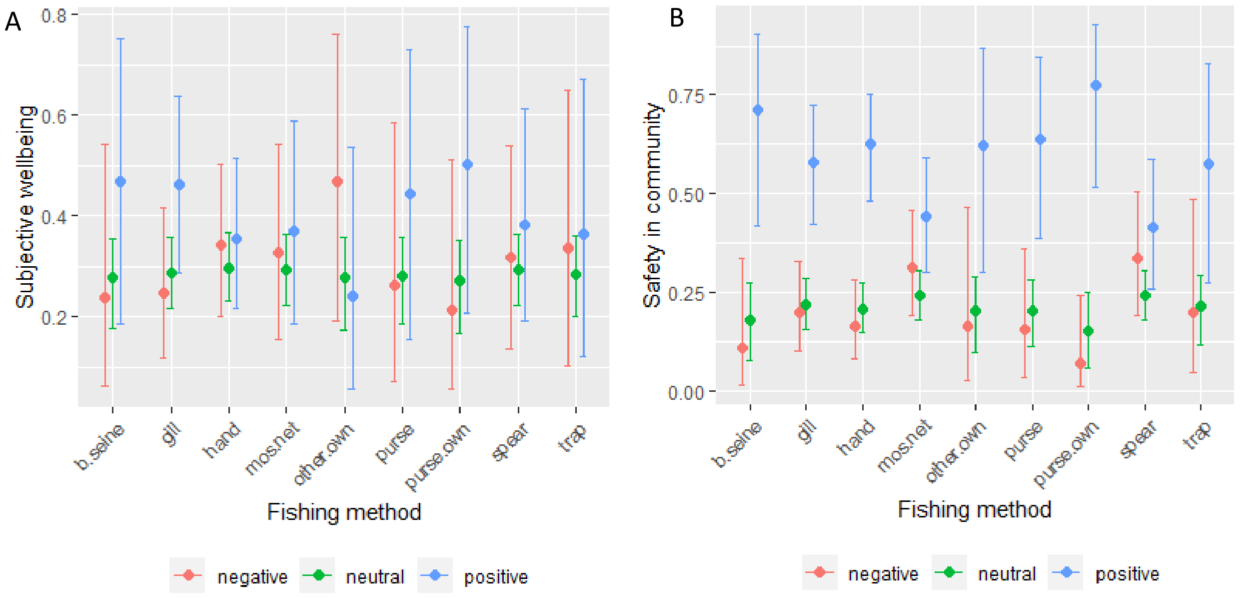

Figure III-3

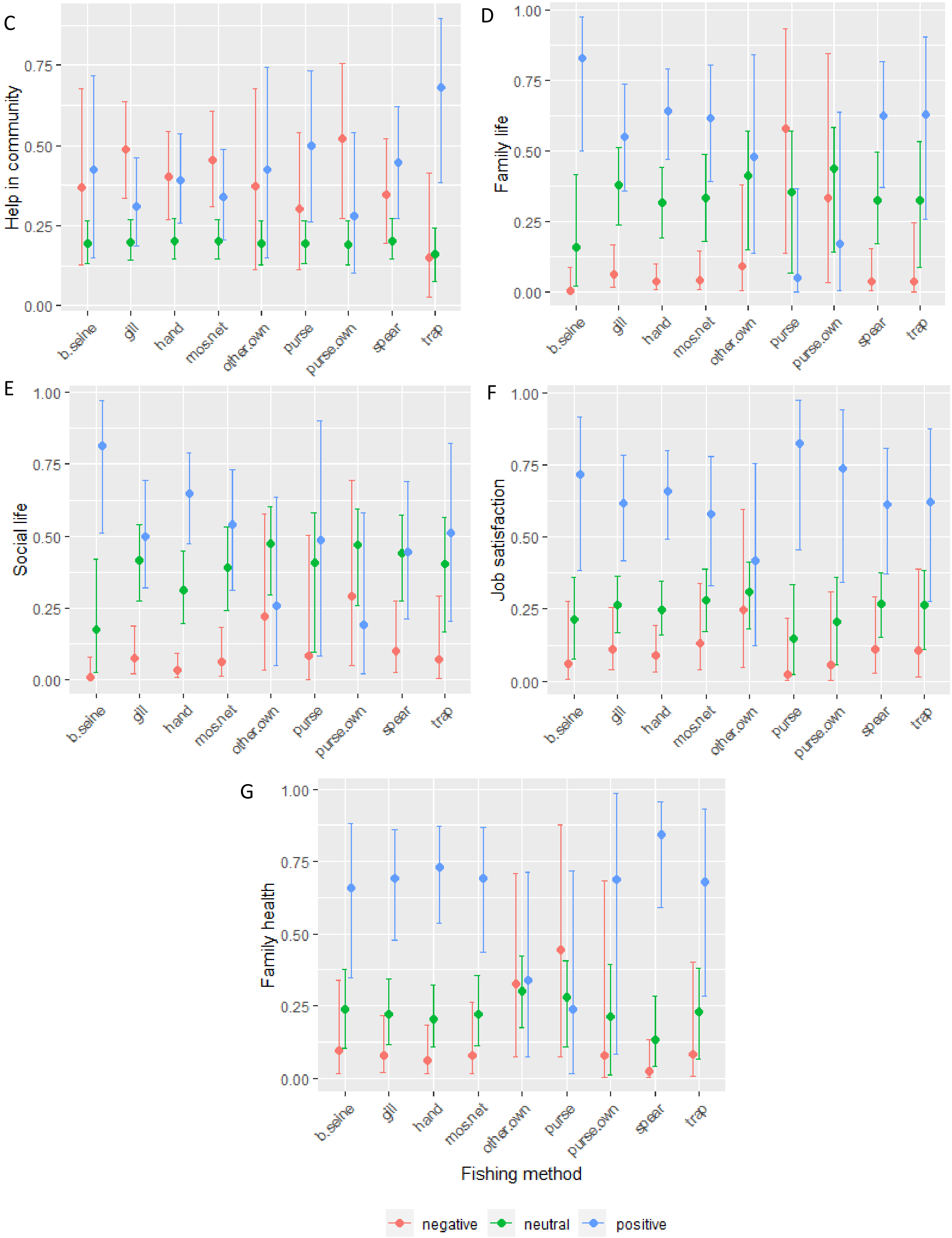

Figure III-3 (continued): Conditional effects of fishing method on subjective overall wellbeing (A), feelings of safety and security (B), confidence in finding help (C), satisfaction with family life (D), satisfaction with social life (E), job satisfaction (F), and family health (G).

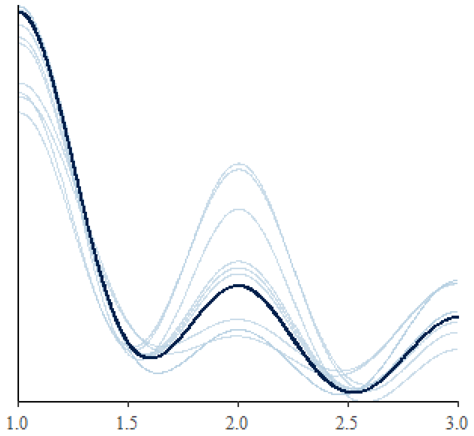

Figure III-4: Posterior prediction density overlay of the ordinal model of reasons to fish (light blue) with the actual data (dark blue).

Appendix IV

This appendix includes supplementary tables and figures from Chapter 5 about the ecological impacts of fishing in Pemba Bay.

Table IV-1: Pairwise PERMANOVAs of site habitat characteristics. N is the total number of samples in the two sites

Site pairs	N	F.Model	R2	Pr(>F)	
Situ_Pemba	110	2.3937	0.01717	0.021	*
Situ_Vamizi	64	2.7879	0.03709	0.006	**
Situ_Nuarro	25	4.2029	0.14006	0.001	***
Pemba_Vamizi	152	9.3081	0.04864	0.001	***
Pemba_Nuarro	113	6.1157	0.04251	0.001	***
Vamizi_Nuarro	67	1.8743	0.02446	0.046	*

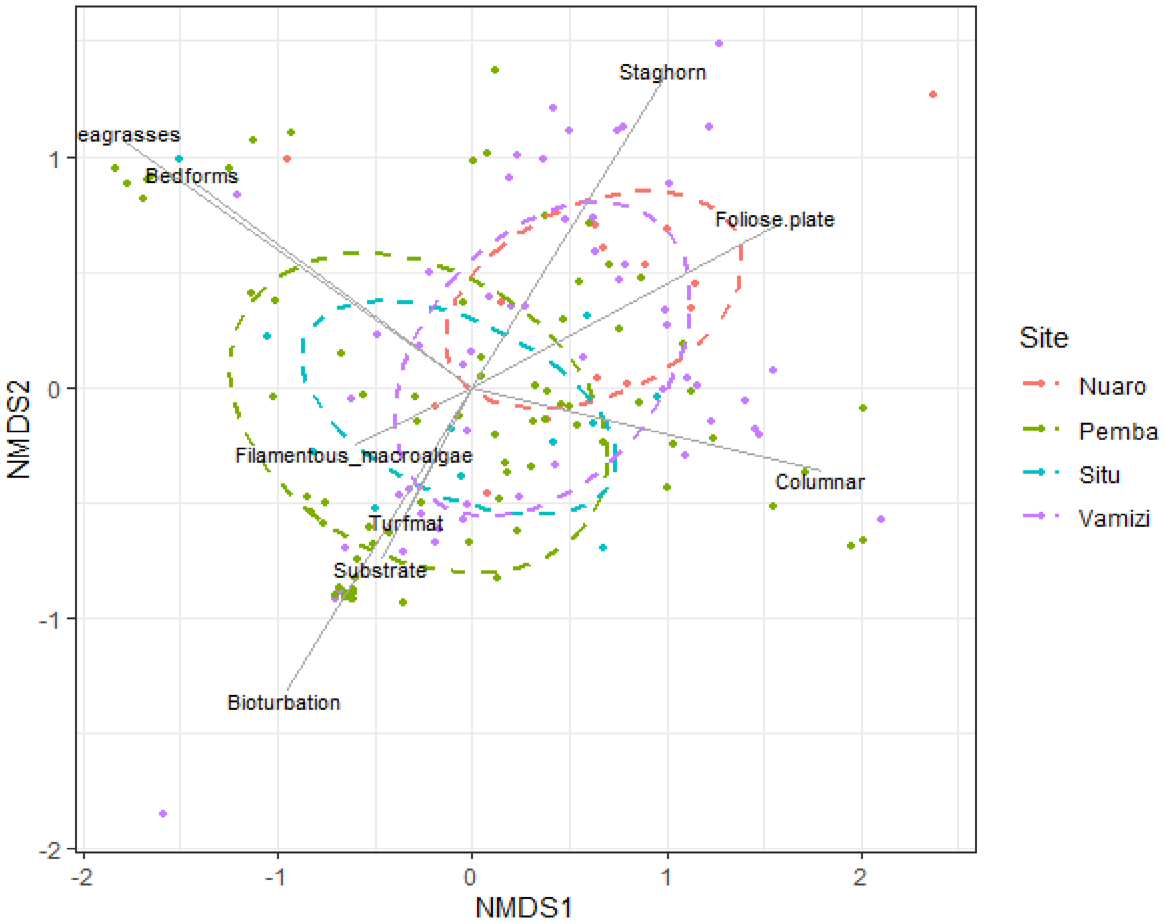

Figure IV-1: Stereo-BRUV sample positions on the first two axes (of 4) of the NMDS of habitat characteristics grouped by site. Vectors give correlations with the first two axes of the morphotype groups. Paths represent covariance ellipses.

Table IV-2: Pairwise PERMANOVA of sites based proportional functional group composition. N is the total number of samples in both sites in the comparison.

Pairs	N	F.Model	R2	Pr(>F)	
Situ_Pemba	110	1.9052	0.01589	0.006	**
Situ_Vamizi	64	3.0879	0.04398	0.002	**
Situ_Nuarro	25	2.8960	0.11041	0.001	***
Pemba_Vamizi	152	7.1950	0.04253	0.001	***
Pemba_Nuarro	113	4.0555	0.03215	0.001	***
Vamizi_Nuarro	67	3.6546	0.04914	0.001	***

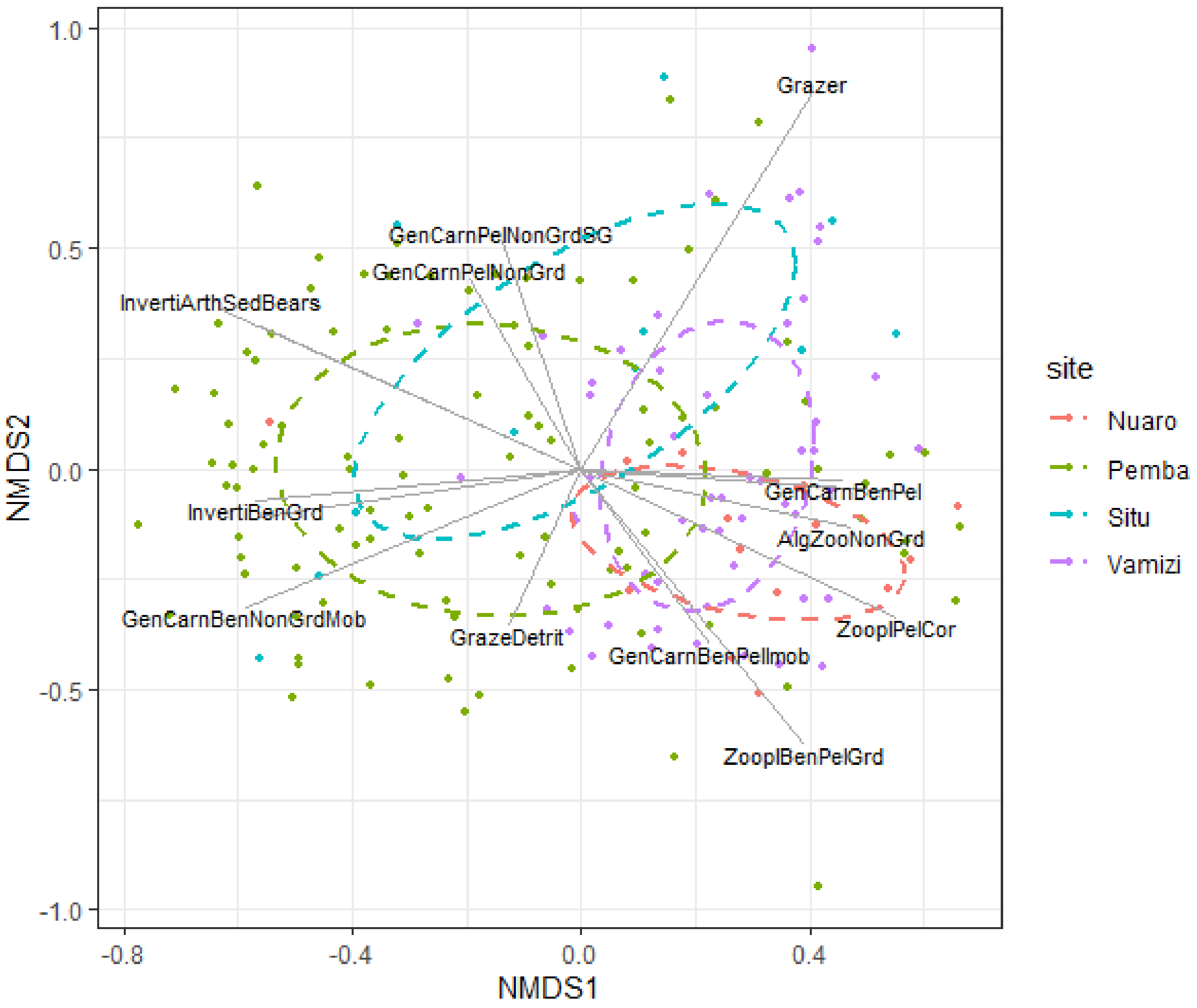

Figure IV-2: Stereo-BRUV sample positions on the first two (of 4) axes from the NMDS of mobile functional group composition data based on proportional biomass. Vectors show the correlations of functional groups to these first two axes. Paths represent covariance ellipses.

Table IV-4: Pairwise PERMANOVA of sites based on functional group biomass composition. N indicates the total number of samples in the comparison

Site pairs	N	F.Model	R2	Pr(>F)	
Situ_Pemba	110	2.4204	0.02024	0.001	***
Situ_Vamizi	64	2.6583	0.03912	0.001	***
Situ_Nuarro	25	3.0471	0.11492	0.001	***
Pemba_Vamizi	152	9.2186	0.05484	0.001	***
Pemba_Nuarro	113	3.6900	0.03001	0.001	***
Vamizi_Nuarro	67	3.8103	0.05283	0.001	***

Table IV-3: Model coefficients of the functional diversity models of divergence (A), richness (B), and evenness (C) as predicted by habitat characteristics, detectability variables, and site.

A

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept	0.79	0.10	0.61	0.98	*
Biomass	-0.01	0.01	-0.04	0.01	
Water temp.	0.00	0.01	-0.02	0.02	
% water col	-0.02	0.01	-0.04	0.00	.
Depth	0.03	0.01	0.00	0.06	.
Visibility	0.00	0.01	-0.03	0.03	
Habitat1	0.00	0.01	-0.02	0.03	
Habitat2	0.00	0.01	-0.02	0.03	
Habitat3	0.01	0.01	-0.01	0.03	
Habitat4	0.01	0.01	-0.01	0.03	
Nuarro	-0.07	0.05	-0.16	0.02	
Situ	-0.11	0.05	-0.21	0.00	.
Vamizi	-0.07	0.04	-0.14	0.00	.

B

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept	0.90	0.10	0.72	1.10	*
Biomass	0.04	0.02	0.00	0.08	.
Water temp.	0.04	0.02	0.00	0.08	.
% water col	-0.05	0.02	-0.08	-0.01	*
Depth	-0.01	0.02	-0.05	0.04	
Visibility	0.10	0.02	0.06	0.15	*
Habitat1	0.17	0.02	0.14	0.21	*
Habitat2	-0.03	0.02	-0.07	0.01	
Habitat3	-0.02	0.02	-0.05	0.02	
Habitat4	-0.01	0.02	-0.04	0.03	
Nuarro	0.01	0.08	-0.14	0.17	
Situ	0.03	0.09	-0.14	0.20	
Vamizi	-0.04	0.06	-0.16	0.08	

Table IV-4 continued

C

Variable	Estimate	Est.Error	l-95% CI	u-95% CI	Sig
Intercept	0.52	0.07	0.38	0.67	*
Biomass	-0.02	0.01	-0.04	0.00	.
Water temp.	0.02	0.01	0.00	0.05	.
% water col	-0.01	0.01	-0.03	0.01	
Depth	0.01	0.01	-0.02	0.03	
Visibility	0.00	0.01	-0.03	0.03	
Habitat1	0.00	0.01	-0.02	0.02	
Habitat2	-0.01	0.01	-0.04	0.01	
Habitat3	-0.01	0.01	-0.03	0.01	
Habitat4	0.00	0.01	-0.02	0.02	
Nuarro	-0.04	0.05	-0.13	0.05	
Situ	-0.04	0.05	-0.15	0.07	
Vamizi	-0.07	0.04	-0.14	0.00	.

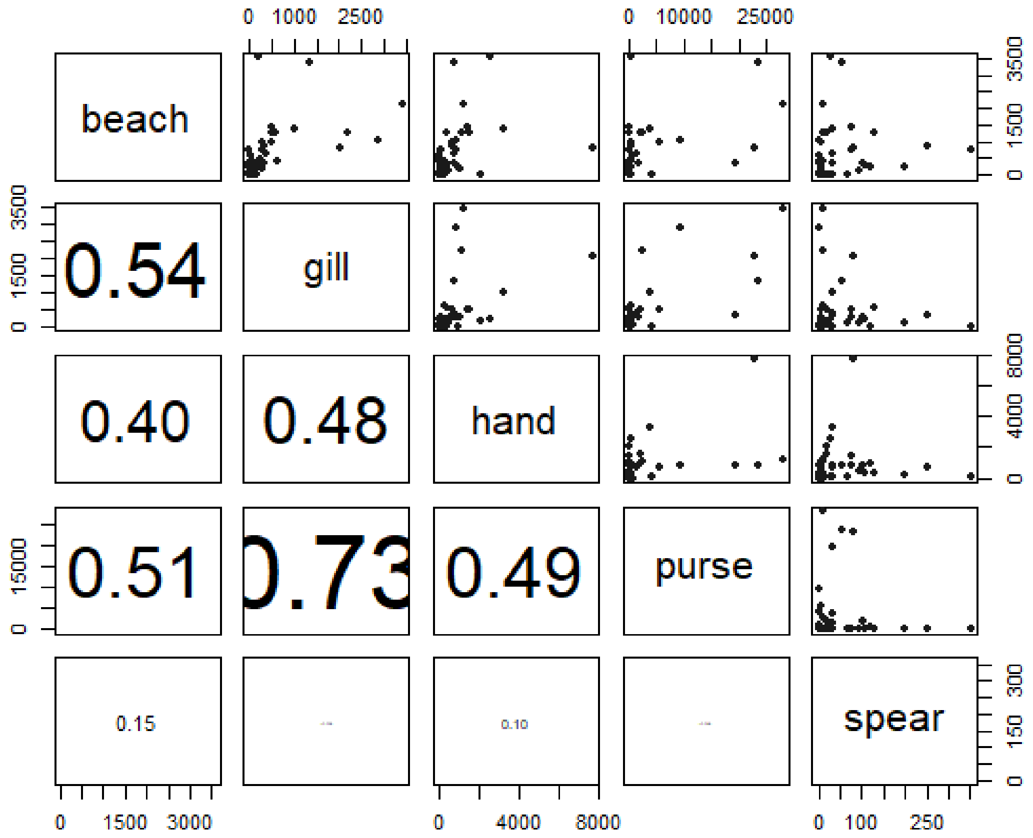

Figure IV-3: Correlation between maximum monthly catch of functional groups per method in Pemba Bay. The correlation factor is below the diagonal and plots are above the diagonal, with the diagonal giving the names of the methods being compared.

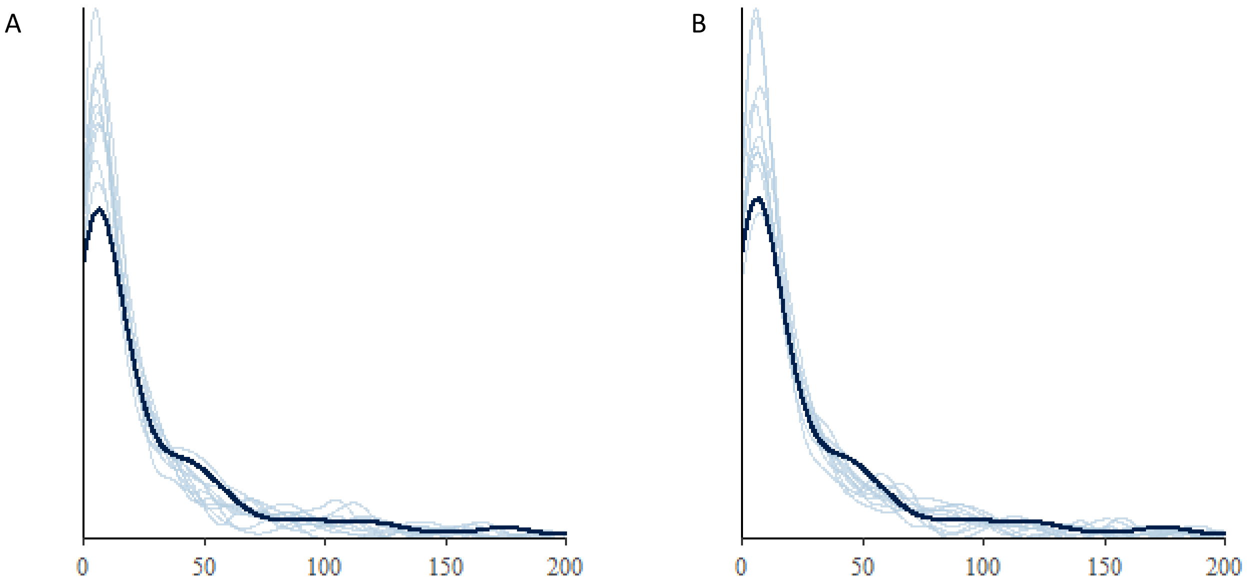

Figure IV-4: Posterior prediction density overlay of the brm model of total sampled biomass in stereo-BRUV samples based on habitat characteristics and site (A) or distance to Pemba City (B). Dark blue is the data and light blue are random runs of the brm model.

Table IV-5: Grouped coefficient of site: Situ (A) or Vamizi (B) compared to Pemba on functional group biomass from stereo-BRUV samples.

A

Functional group	Estimate	Est.Error	Q2.5	Q97.5	Sig
Algal-Coralivore	-0.286	0.551	-1.327	0.832	
Algal-Invertivore Benthic Guarder	0.029	1.005	-1.842	2.112	
Algal-Invertivore Benthic Non-guarder	-0.244	1.449	-3.131	2.653	
Algal-Invertivore Bentho-Pelagic Guarder	-0.581	1.281	-3.095	1.965	
Algal-Invertivore Bentho-Pelagic Non-guarder	3.524	0.809	2.016	5.158	*
Algal-Spongivore	-0.550	0.865	-2.236	1.168	
Algal-Zooplanktivore Guarder	0.494	0.653	-0.726	1.821	
Algal-Zooplanktivore Non-gaurder	-0.583	1.000	-2.503	1.479	
Browser	0.164	0.743	-1.219	1.675	
Cleaner	-0.596	0.726	-1.978	0.901	
Coralivore	0.197	0.700	-1.120	1.648	
Coral-Invertivore	-0.333	0.797	-1.832	1.267	
Detritivore	0.132	1.019	-1.764	2.155	
Excavator	0.584	1.403	-2.261	3.420	
FalseCleaner	-1.028	1.449	-4.038	1.797	
Generalist carnivore Bearer	0.845	1.150	-1.360	3.144	
Generalist carnivore Benthic NonGuarder	2.369	0.656	1.110	3.714	*
Generalist carnivore Benthic Non-guarder Mobile	0.012	0.777	-1.454	1.607	
Generalist carnivore Benthic Non-guarder Mobile seagrass associated	2.233	0.693	0.880	3.611	*
Generalist carnivore Benthic Non-guarder Mobile Solitary	0.371	0.842	-1.177	2.117	
Generalist carnivore Bentho-Pelagic	-0.235	0.818	-1.782	1.398	
Generalist carnivore Bentho-Pelagic Sedentary	1.546	0.829	-0.018	3.259	
Generalist carnivore Bentho-Pelagic seagrass associated	2.199	0.710	0.906	3.637	*
Generalist carnivore Guarder	-0.021	1.443	-2.866	2.887	
Generalist carnivore Pelagic Non-guarder	0.731	1.036	-1.248	2.812	
Generalist carnivore Pelagic Non-guarder seagrass associated	1.289	0.829	-0.238	2.949	
Grazer-Detritivore	-0.134	0.982	-1.963	1.911	
Grazer	2.018	0.701	0.718	3.420	*
Invertivore Arthropod Sedentary Bearer	1.145	0.956	-0.674	3.157	
Invertivore Benthic Guarder	-0.129	0.495	-1.077	0.867	
Invertivore Benthic Non-guarder	-0.470	0.499	-1.415	0.548	
Invertivore Benthic Non-guarder Mobile	0.679	0.472	-0.274	1.612	
Invertivore Bentho-Pelagic Guarder	1.108	0.621	-0.127	2.362	
Invertivore Bentho-Pelagic Non-guarder	0.816	0.663	-0.424	2.166	
Invertivore Bentho-Pelagic Non-guarder Mobile	0.755	0.578	-0.324	1.904	
Invertivore Chordate Sedentary Bearer	-0.378	1.506	-3.484	2.673	
Invertivore Mobile Bearer	-0.153	1.548	-3.237	2.801	

Table IV-5 (continued)

Functional group	Estimate	Est.Error	Q2.5	Q97.5	Sig
Invertivore Pelagic	0.492	0.847	-1.140	2.214	
Other	1.155	1.035	-0.834	3.188	
Piscivore Benthic	1.323	0.832	-0.248	3.059	
Piscivore Bentho-Pelagic	-0.080	0.768	-1.514	1.511	
Piscivore Pelagic	1.918	0.793	0.429	3.545	*
Planktivore	2.682	1.012	0.828	4.752	*
Scraper Benthic	-0.750	1.080	-2.857	1.371	
Scraper Bentho-Pelagic	-0.011	0.898	-1.723	1.781	
Zooplanktivore Benthic Guarder	-0.960	0.666	-2.216	0.393	
Zooplanktivore Benthic Non-guarder	-1.541	0.814	-3.094	0.096	
Zooplanktivore Bentho-Pelagic Guarder	0.777	0.931	-0.933	2.732	
Zooplanktivore Bentho-Pelagic Non-guarder	0.459	0.700	-0.904	1.878	
Zooplanktivore Pelagic	1.465	1.207	-0.815	3.924	
Zooplanktivore Pelagic Coral associated	-0.161	0.824	-1.704	1.492	

B

Functional group	Estimate	Est.Error	Q2.5	Q97.5	Sig
Algal-Coralivore	-0.367	0.315	-0.988	0.224	
Algal-Invertivore Benthic Guarder	-0.096	0.403	-0.884	0.687	
Algal-Invertivore Benthic Non-guarder	0.110	0.662	-1.173	1.420	
Algal-Invertivore Bentho-Pelagic Guarder	0.127	0.554	-0.932	1.209	
Algal-Invertivore Bentho-Pelagic Non-guarder	0.533	0.465	-0.363	1.470	
Algal-Spongivore	0.308	0.323	-0.322	0.923	
Algal-Zooplanktivore Guarder	-0.364	0.344	-1.039	0.312	
Algal-Zooplanktivore Non-gaurder	0.131	0.521	-0.864	1.194	
Browser	0.725	0.356	0.046	1.431	*
Cleaner	-0.127	0.410	-0.925	0.685	
Coralivore	-0.026	0.321	-0.650	0.614	
Coral-Invertivore	0.814	0.361	0.116	1.543	*
Detritivore	-0.224	0.381	-0.960	0.504	
Excavator	0.787	0.719	-0.569	2.272	
FalseCleaner	-0.456	0.538	-1.495	0.617	
Generalist carnivore Bearer	0.355	0.601	-0.851	1.550	
Generalist carnivore Benthic NonGuarder	0.369	0.340	-0.296	1.030	
Generalist carnivore Benthic Non-guarder Mobile	0.967	0.434	0.142	1.850	*
Generalist carnivore Benthic Non-guarder Mobile seagrass associated	0.512	0.430	-0.306	1.346	
Generalist carnivore Benthic Non-guarder Mobile Solitary	0.313	0.434	-0.515	1.191	
Generalist carnivore Bentho-Pelagic	0.099	0.481	-0.853	1.023	
Generalist carnivore Bentho-Pelagic Sedentary	-0.164	0.411	-1.006	0.643	

Table IV-5 (continued)

Functional group	Estimate	Est.Error	Q2.5	Q97.5	Sig
Generalist carnivore Bentho-Pelagic seagrass associated	1.257	0.389	0.513	2.019	*
Generalist carnivore Guarder	0.013	0.734	-1.431	1.466	
Generalist carnivore Pelagic Non-guarder	0.126	0.565	-0.967	1.262	
Generalist carnivore Pelagic Non-guarder seagrass associated	-0.079	0.455	-0.966	0.794	
Grazer-Detritivore	0.466	0.491	-0.475	1.444	
Grazer	2.047	0.521	1.037	3.069	*
Invertivore Arthropod Sedentary Bearer	1.183	0.749	-0.207	2.715	
Invertivore Benthic Guarder	0.016	0.338	-0.680	0.676	
Invertivore Benthic Non-guarder	-0.050	0.291	-0.612	0.539	
Invertivore Benthic Non-guarder Mobile	0.223	0.282	-0.337	0.774	
Invertivore Bentho-Pelagic Guarder	0.071	0.327	-0.571	0.717	
Invertivore Bentho-Pelagic Non-guarder	1.309	0.338	0.635	1.973	*
Invertivore Bentho-Pelagic Non-guarder Mobile	-0.211	0.339	-0.894	0.470	
Invertivore Chordate Sedentary Bearer	-0.108	0.676	-1.436	1.232	
Invertivore Mobile Bearer	-0.158	0.822	-1.848	1.409	
Invertivore Pelagic	0.636	0.492	-0.304	1.600	
Other	-0.038	0.456	-0.939	0.862	
Piscivore Benthic	0.160	0.430	-0.677	1.004	
Piscivore Bentho-Pelagic	1.063	0.414	0.271	1.900	*
Piscivore Pelagic	0.258	0.389	-0.475	1.019	
Planktivore	0.531	0.655	-0.792	1.876	
Scraper Benthic	0.390	0.338	-0.278	1.084	
Scraper Bentho-Pelagic	0.194	0.346	-0.495	0.876	
Zooplanktivore Benthic Guarder	-0.317	0.410	-1.145	0.480	
Zooplanktivore Benthic Non-guarder	-0.022	0.441	-0.892	0.849	
Zooplanktivore Bentho-Pelagic Guarder	-0.010	0.379	-0.759	0.719	
Zooplanktivore Bentho-Pelagic Non-guarder	-0.657	0.377	-1.415	0.066	
Zooplanktivore Pelagic	0.148	0.766	-1.364	1.662	
Zooplanktivore Pelagic Coral associated	-0.779	0.451	-1.699	0.092	

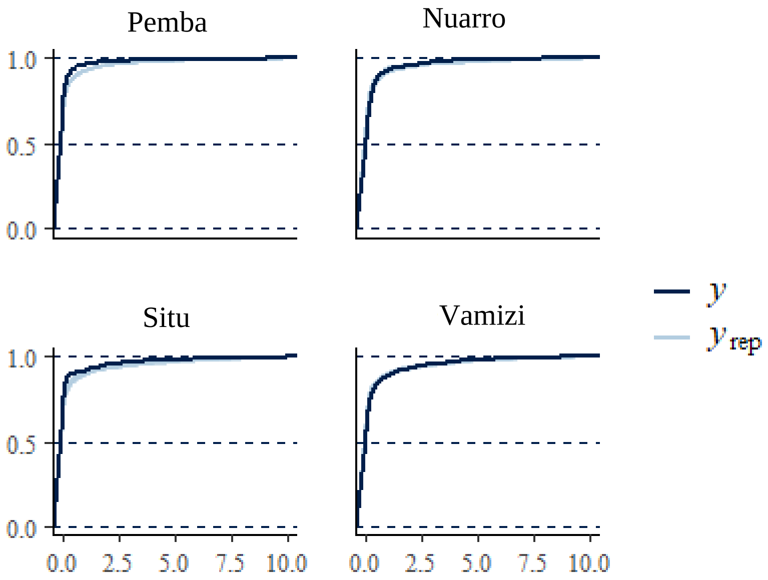

Figure IV-5: Posterior empirical cumulative distribution function (ECDF) plots grouped by site of the Bayesian model of functional group biomass using site and habitat variables grouped by functional group as predictors. X-axes are limited in these plots to allow better visualization of the section of the plot where most of the data exists.

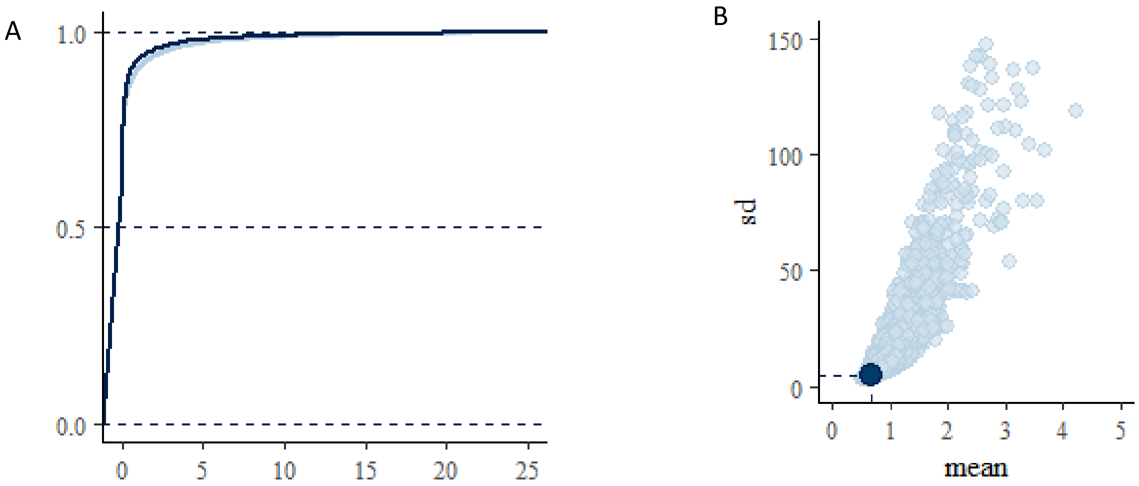

Figure IV-6: Posterior prediction ECDF of 10 random model estimates (light blue) and the data (dark blue) of the functional group biomass model using total Pemba fishing catch (A) and posterior predictions of mean and SD from the model (light blue) and data (dark blue) (B).

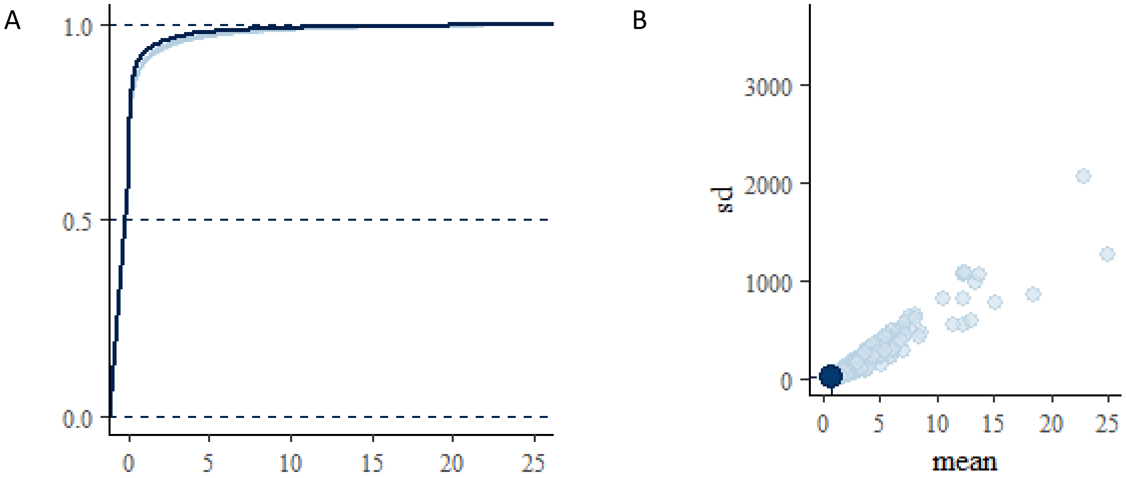

Figure IV-7: Posterior prediction ECDF of 10 random model estimates (light blue) and the data (dark blue) of the functional group biomass model using method specific Pemba fishing catch (A) and posterior predictions of mean and SD from the model (light blue) and data (dark blue) (B).

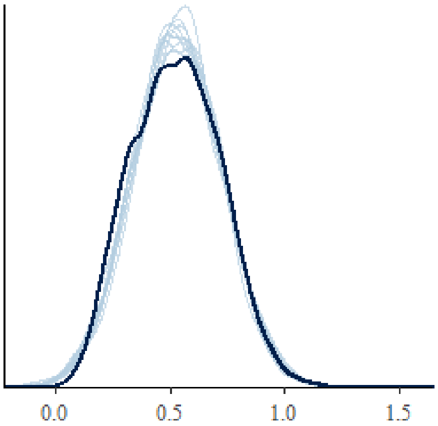

Figure IV-8: Posterior predictive density overlay of ten random model runs (light blue) and the data (dark blue) of the mode of proportional maximum length of each species in each sample.

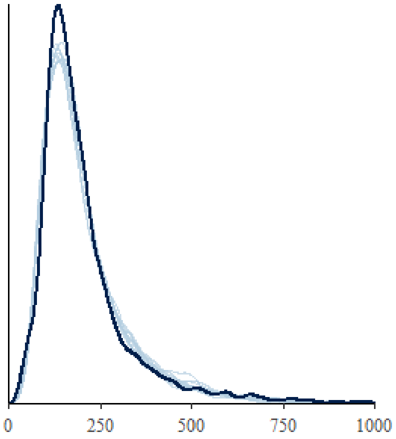

Figure IV-9: Posterior predictive density overlay of 10 random runs of the model (light blue) and the data (dark blue) of preferred species length.

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