Mangroves, fisheries and community livelihoods

Rachel Claire Orger Seary

St Catharine's College

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UNIVERSITY OF CAMBRIDGE

Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text. It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. I further state that no substantial part of my thesis has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. It does not exceed the prescribed word limit for the relevant Degree Committee.

Summary

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Mangroves are thought to provide vital ecosystem services to coastal fishing communities through the enhancement of fisheries production. Ongoing loss of mangrove extent globally is therefore of societal concern given that communities living near mangroves rely on mangrove-fishing for income and subsistence. Whilst research and conservation efforts have successfully advocated mangrove restoration, and promoted the importance of mangroves in climate mitigation and coastal protection, knowledge of how people use mangroves for fishing is less well developed (Chapters 1 and 2). To date, most quantitative estimates of the value of the presence of mangroves to fishing have been limited to single fishing sectors, gear types or species groups and therefore fail to capture the full diversity of fishing practices, and thus the true socio-economic benefits of mangrove-fishing.

The thesis first develops a definition of what mangrove-fisheries can encompass. A case study which investigated the fishing activities associated with mangroves through interviews with fishers was conducted in the Perancak Estuary, Bali, Indonesia. A framework based on this case study was developed as a flexible tool for identifying the characteristics of a mangrove-fishery in a local context (Chapter 3). Using this framework, Chapter 4 measured the all-encompassing value of mangrove benefits to fishing in the Peam Krasaop Fishing Community (PKFC), Koh Kong Province, southwest Cambodia. The ecosystem service value of mangroves for fishing to households in the PKFC was arrived at using daily landings volumes and market values provided through interview surveys with fishers. Both chapters highlight the highly diverse nature of mangrove-fisheries.

To what extent are the benefits of mangrove purely local phenomena or are these benefits reflected in global catch datasets? Chapter 5 investigates the spatial relationships between mangrove extent and fisheries catches at the global scale. For the period 2000-2012, small-scale (artisanal and subsistence) catch data, from the Sea Around Us fisheries catch database, was matched against high resolution mangrove extent maps from the Global Database of Continuous Mangrove Forest Cover for the 21st Century revealing that contrary to much of the previous literature, variation in mangrove-associated species catches is better explained by proximity to the mangrove than by mangrove area. Finally, Chapter 6 considers how new and emergent technologies, such as real-time vessel tracking, are likely to improve our ability to estimate mangrove-fishery value, assesses the potential of restored mangroves in providing ecosystem services, and reflects on how communities will need to respond to pressures on mangrove-fishery livelihoods from global environmental change.

For Grandad, one of life's greatest characters, who always had a good story to tell and after all of this I would have loved to have told him mine.

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Table of Contents

List of figures

List of tables

List of abbreviations

AIS - Automatic Identification Systems

BPOL – Bali Institute for Marine Research and Observation

CGMFC-21 - Global Database of Continuous Mangrove Forest Cover for the 21st Century

Chl a – Chlorophyll a

CPUE – Catch Per Unit Effort

DIVA-WCM - Dynamic Interactive Vulnerability Assessment Wetland Change Model

DoE – Department of Environment, Koh Kong Province, Cambodia

EEZ – Exclusive Economic Zone

FAO – Food and Agriculture Organisation of the United Nations

GAM – Generalized Additive Model

GDP – Gross Domestic Product

GEBCO - General Bathymetric Chart of the Oceans

GT – Gross Tonnage

IFA – Inshore Fishing Area

KK – Koh Kong

MIC – Mangrove Information Centre, Sanur, Bali

MoE – Ministry of Environment, Cambodia

NPK – New Peam Krasaop

OPK – Old Peam Krasaop

PA – Protected Area

PKFC – Peam Krasaop Fishing Community

PKWS – Peam Krasaop Wildlife Sanctuary

PMMR – Participatory Management of Mangrove Resources Project

RCP - Representative Concentration Pathway rp – Indonesian Rupiah

SAU – Sea Around Us project

SD – Standard Deviation

SDG – Sustainable Development Goals

SLR – Sea Level Rise

SST – Sea Surface Temperature

UN – United Nations

US$ - United States Dollar

1 - Introduction

1.1 Mangroves and their ecosystem services

Protecting coastal ecosystems is considered central to achieving one of the greatest challenges the world faces, of maintaining the ocean resources relied upon by billions of people for food and economy in the face of continued overfishing, pollution, habitat destruction and climate change (Millenium Ecosystem Assessment 2005, United Nations 2015). As such, nations have pledged by 2020 to conserve at least 10% of coastal and marine waters under the United Nations Sustainable Development Goals agreed in 2015 (United Nations 2015). The effective regulation of harvesting of resources through fishing, along with environmental restoration, are necessary steps in meeting these goals, and are thought to be essential to meeting other global goals such as ending poverty, achieving zero hunger and decent work and economic growth (Nippon Foundation Nereus Program 2017). Understanding how coastal and marine ecosystems are linked to people through ecosystem services, the range of benefits that people gain from ecosystems (Millenium Ecosystem Assessment 2005), is crucial in guiding the actions taken to meet these goals and monitor them in future years (Selig et al. 2018).

Ecosystem services can be divided into 4 functional groupings: 1) provisioning services, those where products are obtained, such as food, water or materials; 2) regulating services which provide benefits through regulation of ecosystem processes; 3) cultural services, which provide non-material benefits such as cultural, aesthetic or educational value; and 4) supporting services, which are required for the provision of other ecosystem services, such as primary production or habitat provision (Millenium Ecosystem Assessment 2005, JNCC 2014). Mangrove forests, groups of trees and shrubs that occupy the land-sea barrier of coastal environments, have important roles in all 4 types of ecosystem services.

Mangrove forests occur in 115 countries and territories and cover an estimated 137,760 km^2 across tropical and sub-tropical regions, based on a 2000 estimate by Giri et al. (2011). More than 100 million people live within 10 km of a mangrove forest and benefit from the various ecosystem services they provide (UNEP 2004). The most recent estimate of their combined ecosystem service value, measured in 2014, suggest a value of $200,000/ha/yr (Costanza et al. 2014). This figure is 20 times the estimate of $9,900/ha/yr made in 1997 (Costanza et al. 1997). However, it can be argued that mangrove ecosystem services are still undervalued. Considerable research efforts have been made in the past 10 years to remedy this underestimate, largely focussing on the regulatory services that mangroves provide. Most dominantly, the carbon storage capacity of mangrove forests has been explored (Sharma 2018), finding that mangroves are among the most carbon rich forests in the tropics and responsible for 14% of carbon sequestration in the global ocean (Donato et al. 2011, Alongi 2012). As such, mangroves are recognised as having an important regulatory role in offsetting greenhouse gas emissions and subsequently mitigating against climate change (Duarte et al. 2013, Atwood et al. 2017, Cameron et al. 2019, Sani et al. 2019).

Mangroves also have an important regulatory role in coastal protection. The physical structure of mangroves can attenuate wind and swell waves, storm surges caused by cyclones and in some cases provide protection from tsunami waves (Alongi 2008, McIvor et al. 2012a, McIvor et al. 2012b). For communities living at the coast, mangroves therefore have a vital role in preventing loss of human life, property damage and loss of wealth in the occurrence of extreme events (Dahdouh-Guebas et al. 2005, Kathiresan and Rajendran 2005).

Tourism in mangroves is a cultural ecosystem service that can also be an important source of revenue and job opportunities (Kairo et al. 2010, Uddin et al. 2013). There are however additional non-marketable cultural ecosystem service associated with mangroves, for instance traditional, spiritual or religious links to mangroves, as well as education and research and social and wildlife recreation (Kairo et al. 2010, Uddin et al. 2013, Richards and Friess 2015). From a community perspective, cultural services such as maintenance of traditional ecological knowledge, creation of social relationships, personal satisfaction and freedom as well as mental health and relaxation have also been linked to mangroves (Queiroz et al. 2017).

Additionally, and the focus of this thesis, mangroves are important for fisheries. Mangroves are host to a high biodiversity of fish and invertebrates (Sheaves 2005, Ellison 2008). The mangrove ecosystem therefore serves an important provisioning ecosystem service in providing fish and invertebrates for direct capture fisheries (Hutchison et al. 2014). Moreover, mangroves have a supporting function in fisheries production outside of the mangrove through nursery habitat provision (Beck et al. 2001, Mumby 2005, Sheaves 2005, Faunce and Serafy 2006, Chong 2007, Hutchison et al. 2014). Thus, coastal fishing communities where mangroves are present benefit from, and rely upon, mangroves in providing food and economy (UNEP 2004, Hutchison et al. 2014). Chapter 2 reviews in more detail the current knowledge of how mangroves, fisheries and communities are linked together.

1.2 Issues of mangrove degradation and fisheries decline

All 4 types of ecosystem service have been used in the argument to protect mangrove forests. This has been necessary as mangrove forests are one of the most threatened tropical environments, on a par with coral reefs and tropical forests which have been the focus of significantly more attention

(Valiela et al. 2001). Within 2 decades (early 1980's-2000), an estimated world average of 35% of mangrove forest cover was lost, at an average rate of 2.1% per year (Valiela et al. 2001). The deforestation rate has since decelerated, to a world average of 0.16-0.39% between 2000-2012 (Hamilton and Casey 2016). However, there are large disparities in rates of loss between countries. While some regions of the Americas, Africa and Australia have reached almost zero mangrove loss rates, other regions still exhibit worrying deforestation rates. In particular, countries in the SE Asia region, which holds half of the world's mangrove cover, showed 3.58-8.08% mangrove loss between 2000-2012 (Hamilton and Casey 2016). Loss of mangrove area and subsequent loss of ecosystem service function threatens increased carbon emissions from deforestation (Hamilton and Friess 2018, Cameron et al. 2019), increased risk for coastal communities from the impacts of extreme events (Dahdouh-Guebas et al. 2005, Kathiresan and Rajendran 2005) and reduction in fisheries production (UNEP 2004, Duke 2007).

Much of the mangrove deforestation has been driven by conversion for other human uses such as aquaculture, agriculture and coastal development, as well as degradation from activities such as damaging fishing practices, extraction of other goods such as timber, damming and tourism (Hall 2001, Alongi 2002a, Creel 2003, Vázquez-González et al. 2015, Richards and Friess 2016). This is problematic as land use decisions are often made without full consideration of the implications on resource use by local people.

A stand out example of these pressures is the boom in conversion of mangrove areas to shrimp pond culture which began in the 1980's. This process has sacrificed the multiple ecosystem services provided by mangrove forests to communities for reliance on a single commodity. Moreover, shrimp pond culture often fails after 5-10 years due to issues of self-pollution and disease, thus offering only short-term profits (Primavera 1997). Shrimp pond conversion typically leads to declines in nearshore fish and invertebrate catches for artisanal fishing communities as a result of the mangrove deforestation incurred (Dewalt et al. 1996, Primavera 1997, Dahdouh-Guebas et al. 2006). While loss of mangroves has slowed overall, this pattern of destruction for other uses still exists, as well as the impact of an acceleration in the development of new commodities such as oil palm, which poses similar threats (Richards and Friess 2016).

Lacking recognition of the value of the environmental input of mangrove ecosystems into fisheries enhancement is one problem that can lead to mangroves being converted to other uses, particularly for directly marketable products such as from aquaculture and agriculture (Spaniks and van Beukering, 1997, Barbier, 2000). Many studies have reported positive correlations between mangroves and fisheries catches to support the importance of mangroves in fishery enhancement, across much of the distribution of mangrove forests on local and regional scales (Pauly and Ingles 1986, Lee 2004, Loneragan et al. 2005, Manson et al. 2005b, Aburto-Oropeza et al. 2008, Carrasquilla-Henao et al. 2013). Despite these efforts, fundamental information is still lacking on how mangroves and fisheries are linked together and, furthermore, how they are connected to community livelihoods.

Surprisingly, no definition of what constitutes a mangrove-fishery exists. This is a problem for the management of mangroves and fishery resources as it risk the interests of some groups of fishers being invisible and under-represented and their connection to mangroves being overlooked by decision makers. This is commonplace for small-scale fisheries, particularly where perceived smaller-scale resource users are overshadowed by larger scale or industrial fisheries (Carvalho et al. 2011, García-Flórez et al. 2014, De Vos and Kraan 2015, Jadhav 2018). This is an issue particularly for mangrove ecosystems due to their location between land and sea, which adds increasing complexity to their management (Walters et al. 2008). This locality creates ambiguity between government departments over whose mandate it is to protect and sustainably manage all of the aspects of mangrove use, and confusion over mangrove use by different users (Walters et al. 2008). Standardized collection of information on how local people use mangroves over space and time has therefore been suggested as a step towards ensuring that resource management and policy is routed in local socio-economic and environmental issues (Kaplowitz 2001, Dahdouh-Guebas et al. 2006, Walters et al. 2008).

1.3 Thesis structure and research questions

In order to address these issues, this thesis first explores how people use and benefit from mangroves through fishing and aims to develop a definition of what mangrove-fisheries can encompass. Chapter 3 therefore asks: 'What is a mangrove-fishery?'. This is addressed through a case study of fishing communities living around the Perancak Estuary, Jembrana Regency, Bali, Indonesia. A framework is then developed to be used as a tool in identifying the characteristics of a mangrove-fishery in a local context. This framework is intended as a first step within research or planning for management or conservation to ensure measures of mangrove-fishery value arrived upon reflect the full benefits that fishing communities receive. Following this approach, the objective of Chapter 4 is to measure the all-encompassing benefits of mangrove-fishing to the Peam Krasaop Fishing Community, Koh Kong Province, Cambodia.

Research thus far has reported links between mangroves and fisheries observed on the local and regional scale. As the relationship linking mangroves to fisheries production remains unclear, it can be questioned whether any such relationship can be observed at the global scale. Studies linking mangrove cover to enhanced fisheries production on local and regional scale have been treated cautiously due to this lack of information on the underlying mechanisms linking the two. One reason for this lack of information is that little is known regarding the home range or movement of fish that use mangroves. Moreover, studies that have linked mangroves to fisheries production have rarely recorded any spatial information on fishing locations. As such, accurate information regarding how mangroves as habitats for juvenile fish contribute to adult fish stocks, and therefore fisheries catches, has been difficult to obtain (Faunce and Serafy 2006). Deducing the 'effect distance' that mangroves have on fisheries production is therefore equally challenging. Ambiguity in this relationship thus hinders the effectiveness of mangrove-fishery enhancement being used as an argument in mangrove conservation and management (Beck et al. 2001).

The second aim of this thesis is therefore to explore whether relationships between mangrove extent and fishing reported on the local and regional scale can be seen at the global scale. Chapter 5 uses global fisheries catch data and high resolution continuous mangrove extent information for the 2000-2012 period to investigate the spatial relationship between mangrove extent and small-scale fisheries catches.

The next big, and uncertain, threat to mangroves and mangrove-fishery livelihoods is climate change (Gilman et al. 2008, Cummings and Shah 2017). Aspects of climate change such as sea level rise, increased storminess and changing ocean temperature are expected to force changes in mangrove distribution and function (Gilman et al. 2006, 2008, Cummings and Shah 2017). Research will be required to understand how changes to the provision of ecosystem services will affect community livelihoods for people living in and around mangroves. While a fundamental understanding of the mangrove-fishery-community linkages in their current state is missing how the system will change under future pressures is difficult to predict. Moreover, monitoring change in the state of these linkages in the absence of baseline data of the current relationship between mangroves and fisheries will not be possible. This thesis, aimed at developing a sound understanding of i) how people use mangroves for fishing, and ii) how mangroves and fisheries productivity are linked across a range of spatial scales, works towards developing this baseline knowledge. Chapter 6 re-evaluates the state of knowledge on mangrove-fishery-community linkages in the light of the research undertaken in this thesis and reflects on the future research agenda. Whether trends observed in Chapter 5 agree with the socio-economic information collected at the local scale in Chapters 3 and 4 is discussed. Chapter 6 also addresses how these trends are expected to change under future environmental change and how advances in technology, such as vessel tracking systems, might aid in monitoring these trends. Strengthening the knowledge of the relationship between mangrove extent and fisheries productivity, as well as its importance in community livelihoods, is important in order to generate a strong standpoint on which to promote the connection between mangroves and fishing.

2 - Literature review: What is the current state of knowledge on mangrove-fishery-community linkages?

Summary

This chapter provides an overview of the current state of knowledge of how mangroves, fisheries and coastal communities are linked together. It begins with an introduction to the current hypotheses of how mangroves are thought to enhance fisheries, both directly through the provision of fish and invertebrates for direct capture fisheries and indirectly through the nursery function, in providing adult recruits to offshore fish stocks. It then reviews the context dependent variables which are thought to influence the potential and actual fishable biomass from mangrove systems, following the structure of the conceptual framework provided by Hutchison et al. (2014). First, it reviews the breadth of literature describing how mangrove state influences potential fisheries catches, investigating which characteristics of mangrove ecosystems are thought to contribute to fisheries production. Secondly, it reviews how human activities that change mangrove state impact upon potential fisheries production. Thirdly, it explores how social drivers influence fishing effort. Additionally, it reviews how climate change as an overarching influence on mangrove ecosystems and fishing communities is currently influencing, or is expected to influence, the links between mangroves, fisheries and fishing communities.

2.1 Introduction

It is a widely held argument that mangroves enhance fisheries production. The underlying mechanism that is thought to link mangroves to fisheries production is the provision of habitat for fish and invertebrates (Beck et al. 2001, UNEP 2004, Sheaves 2005, Faunce and Serafy 2006, Hutchison et al. 2014, Nagelkerken et al. 2015). In particular, mangroves have been described as an important nursery habitat. Nursery habitats, as defined by Beck et al. (2001), are a subset of juvenile habitats that contribute a greater than average number, or biomass, of individuals to the adult population on a per-unit area basis than other habitats that are used by juveniles. Mangroves have a number of characteristics that make them a good habitat for juvenile fish or invertebrates. Firstly, mangroves provide a physically complex structure of aerial prop roots, trunks and overhanging branches (Sheaves 2005, Hutchison et al. 2014). This structure provides shelter from predation and disturbances. Increased complexity of mangrove root structure has been experimentally shown to reduce predation of juvenile fish (Laegdsgaard and Johnson 2001). This complex physical structure also has a role in the initial settlement of juveniles, as the friction of the mangrove structure slows water flows and retains fish and invertebrate larvae (Alongi 2002b, Hutchison et al. 2014).

Secondly, mangroves are highly productive environments and therefore provide food for juveniles, which contributes to the growth and survival of fish or invertebrates (Laegdsgaard and Johnson 2001). Juvenile fish and invertebrates make ontogenetic migrations away from the mangrove to other habitats or offshore, where they are caught by fishers, thereby contributing to adult fish stocks (Beck et al. 2001, Kimirei et al. 2013, Hutchison et al. 2014). This relationship has been inferred indirectly via correlations between mangrove habitat extent and fisheries catches (e.g. Pauly and Ingles 1986, Manson et al. 2005, Aburto-Oropeza et al. 2008, Carrasquilla-Henao et al. 2013, Lee et al. 2014, Carrasquilla-Henao and Juanes 2017). In reality, however, there is little direct evidence of the nursery hypothesis for mangroves as it requires information on the movement patterns of fish and invertebrates that is difficult to obtain (Beck et al. 2001).

However, the use of stable isotope signatures and stomach content analyses have provided information on the movements of mangrove-associated fish within coastal seascapes (Morinière et al. 2003, Huxham et al. 2007, Nakamura et al. 2008, Kimirei et al. 2013). As most mangroves are only intermittently inundated by tides, few species can occupy mangrove habitats all of the time (Sheaves 2005). As such, many species do not just use one habitat but move daily between connected habitats (such as mangroves, seagrass meadows and coral reefs) between tidal cycles, for foraging or seeking shelter, as well as longer term ontogenetic shifts when food resources and shelter needs change (Mumby 2005, Nagelkerken et al. 2015). This mosaic of habitats in the coastal zone has been referred to as the ‘seascape nursery’ (Nagelkerken et al. 2015). Field studies in the southern Ryukyu Islands, Japan, Curaçao, Netherlands Antilles and the Dar es Salaam region of Tanzania using stable isotope signatures have provided evidence that fish using mangroves as juveniles move to coral reef habitat during young adult and adult stages (Morinière et al. 2003, Nakamura et al. 2008, Kimirei et al. 2013). The coral reefs in these studies were located up to 2, 4 and 9 km from the mangrove respectively (Morinière et al. 2003, Nakamura et al. 2008, Kimirei et al. 2013).

Also in the Netherlands Antilles, densities of adult fish of selected mangrove-dependent species were higher on coral reefs where mangroves and seagrass were present in the bay than when they were not (Nagelkerken et al. 2002). It has also been suggested that mangroves provide an intermediary habitat, between seagrass and reef habitat, for juvenile fish, and therefore increase the biomass of fish on reef habitats by reducing the risk of predation (Mumby et al. 2004).

Mangrove habitat use is however not limited to juvenile fish and invertebrates. Mangroves typically show an abundance of bivalves, such as oysters and cockles. Mangroves provide ideal environments for bivalves as aerial roots provide solid attachment points, soft sediments are used for burying and they are areas of high primary production (Hutchison et al. 2014). There are also a number of crab species that are resident within mangrove forests during adult stages and feed on mangrove detritus (Hutchison et al. 2014). Capture of mixed species of fish and prawns also occur within the nearshore areas in proximity to mangroves (Primavera 1997, Marschke 2012). The direct harvesting of fish and invertebrates such as oysters, cockles and crabs from mangroves make up an important part of fisheries production, particularly within artisanal fishing communities (Ocampo 2006, Beitl 2011, Marschke 2012). As such, mangrove-associated fishing is most commonly discussed as having two strands: 1) direct capture fishing within mangroves or inshore; and 2) an indirect benefit to offshore fishing.

There are a number of contextual factors which also contribute to the ecosystem service function of mangroves, and therefore influence mangrove-associated fisheries production from place to place. These include ecosystem drivers, human impact drivers and socio-economic drivers (Hutchison et al. 2014). A conceptual model which describes the various factors influencing the potential and actual fisheries catch and value associated with mangroves was developed by Hutchison et al. (2014) (Fig. 2-1).

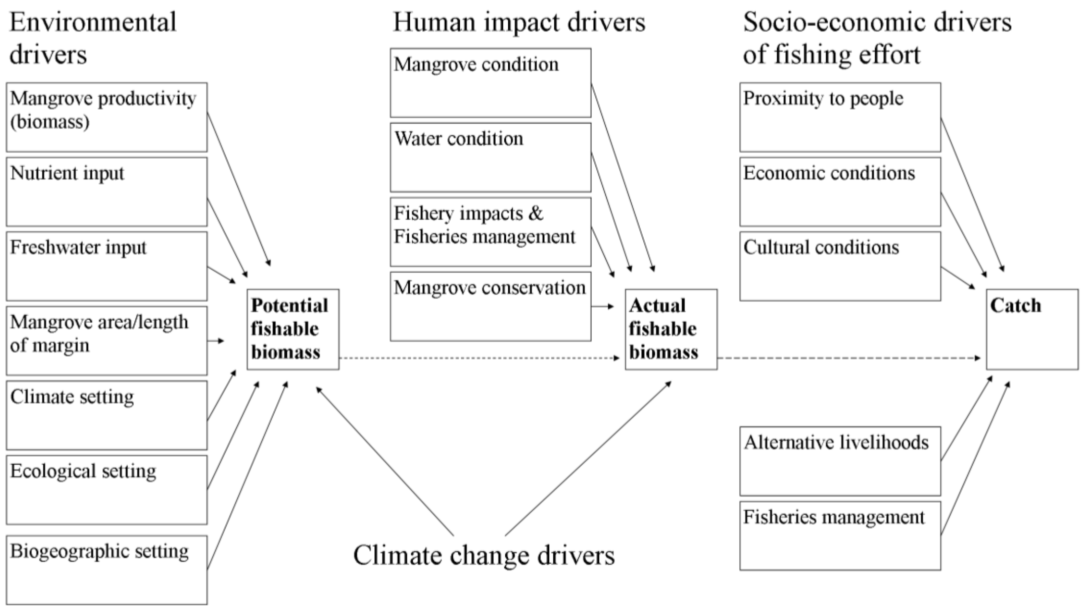


Figure 2-1. Conceptual model from Hutchison et al. (2014) describing the drivers of mangrove-fishery catch and value. Potential fishable biomass is determined by the environmental conditions of the mangrove-forest under natural conditions. The actual fishable biomass is then derived from the potential fishable biomass modified by human impacts on the environmental state of the mangroves and fish stocks, which can be mitigated by management and conservation. The catch then depends on the actual fishable biomass and the socio-economic drivers which influence fishing effort. The model has been adapted to include climate change impacts on mangrove state which may also influence potential and actual fishable biomass through modifications to the contextual environmental state.

Following the structure laid out in this model, this literature review summarizes the current state of knowledge regarding the following questions:

- what are the mangrove attributes that contribute to potential fishable biomass?;
- what are the human pressures on mangroves that influence fishable biomass?;
- what are the social drivers of fishing effort within mangroves?;
- and how is future climate change expected to influence fishable biomass within mangroves?

2.2 What are the mangrove attributes that contribute to potential fishable biomass?

A number of studies have explored mangrove area present in a particular area as an explanatory variable in fisheries catches (Pauly and Ingles 1986, Kenyon et al. 2004, Loneragan et al. 2005, Manson et al. 2005a, Aburto-Oropeza et al. 2008, Carrasquilla-Henao et al. 2013, Vázquez-González et al. 2015). Bringing these local and regional scale analyses together in a meta-analysis, Carrasquilla-Henao and Juanes (2017) suggest that globally mangrove cover has a positive influence over fisheries catches, and is a good predictor of fisheries catches overall. It has also been argued that the area of mangrove-fringe (approx. 5-10 m on the seaward edge) is more important than the total area of mangrove vegetation (Aburto-Oropeza et al. 2008). This is thought to be explained by the disproportionate use of the mangrove edge for feeding and shelter by some marine species, rendering this area most valuable for mangrove-fishery production (Arbuto-Oropeza et al., 2008). While studies of the influence of mangrove area over fisheries catches do range widely, including the Indo-West Pacific and the American Caribbean and Eastern Pacific, there are certainly hotspots of research that are represented in more detail, such as Australia, the Philippines, Malaysia and Mexico (Carrasquilla-Henao and Juanes 2017). Other mangrove abundant regions, such as the coast of West Africa, are almost entirely absent from studies of mangrove fish and fisheries (Faunce and Serafy 2006, Carrasquilla-Henao and Juanes 2017). Further, a large proportion of these studies have demonstrated the relationship that mangrove area has with catches of penaeid prawn species only.

Following the hypothesis that fisheries production is correlated with mangrove area, losses of mangrove area are therefore expected to result in losses from fisheries production (Barbier and Strand 1998, Duke 2007, Vázquez-González et al. 2015). Changes to fisheries production have rarely been reported quantitatively following mangrove clearance. This is probably due to lack of baseline measures of fisheries production for artisanal fisheries prior to disturbance on which to measure change. However, a number of studies have attempted to estimate losses from fisheries production associated with a loss of mangrove area. Barbier and Strand (1998) produced a model of mangrove-fishery linkages to simulate the relationship between mangroves, fishing effort and shrimp production over time in the State of Campeche, Mexico. Model results indicated that during a period of local mangrove area loss in 1980-1990, a more than proportional decline in the Campeche fishery catch ensued (a 6.5% loss in fishery output following a 2.3% loss of mangrove area) (Barbier and Strand 1998). In the Alvarado Lagoon System, western Gulf of Mexico, based on the inverse of the relationship estimated to exist between mangrove area and fisheries catch, a decrease in value of 5,882 US$ was estimated for every hectare of coastal mangrove converted for production of sugarcane (Vázquez-González et al. 2015). Sampled empirically in Gazi Bay, Kenya, however, abundance of fish at sites cleared of mangrove by human activity was higher compared with sites within the mangrove forest. This finding must therefore represent other site-specific factors that influence fish abundance in mangroves (Huxham et al. 2004).

Local scale attributes such as mangrove productivity, related to the availability and quality of nursery habitat have been suggested as important factors influencing potential fisheries production (Chong 2007, Sheaves et al. 2014). Connectivity between habitats allows maximal nursery ground value to be reached as different habitats meet particular functional requirements, for example the availability of necessary resources and ideal physical conditions (Sheaves et al. 2014). Connectivity of habitats also facilitates ontogenetic, diurnal or tidal migrations (Sheaves et al., 2014). The ecotone (the transition area between two biomes) distance is therefore important as the boundary between habitats is often the area of greatest risk of predation (Sheaves et al. 2014). Some studies however have found no correlation between fisheries productivity and the presence of habitat other than mangrove, for example seagrasses in the Gulf of California (Aburto-Oropeza et al. 2008).

Ecological setting of a mangrove forest also influences potential fishable biomass. Thus, for example temperature or salinity tolerances may restrict certain species or life stages from utilising particular habitats (Sheaves et al. 2014). There is also seasonal variation associated with the ecological setting and therefore fish community structure within mangroves will inevitably result in variation in seasonal fisheries catch (Lugendo et al. 2007, Tsai et al. 2015). Lugendo et al. (2007) suggested temporal variation in fish community structure in Chwaka Bay mangroves, Zanzibar could be attributed to seasonal variation in rainfall and subsequent changes to local salinity. They argued that decreased abundance of fish in mangroves during the rainy season due to lowered salinity conditions caused fish to move elsewhere for more preferable conditions. Measures of mangrove-fishery enhancement should therefore take seasonality into account.

Physical characteristics and species composition of the mangrove forest itself may also influence fish species diversity and density. The geomorphic type of mangrove forest, whether it be riverine, fringing or basin, may also influence its function as a habitat for fauna, its productivity and amount of nutrient outwelling (Ewel et al. 2019). Geomorphic variation within mangroves of the same type may also influence fishing. Thus, for example, variation in fish catches has been observed between closed or intermittently open estuaries (Saintilan 2004). Blaber (2007) linked spatially heterogeneous mangroves with highest fish densities, further suggesting that large bodied schooling fish showed preference for open water areas within fragmented mangroves. Furthermore, some bottom dwelling species, such as gobies, differed with the proportion of mud in the surface sediments of the mangrove forest. Diversity of mangrove plant species has also been positively linked with associated faunal species diversity within the mangrove forest. As mangrove plant diversity is also directly correlated to the size of the mangrove forest, loss of mangrove area due to human activity could result in the reduction of faunal species biodiversity and subsequent undesirable effects on potential fishable biomass (Duke 2007).

2.3 What are the human pressures on mangroves that influence fishable biomass?

It has been shown that mangrove area has been correlated on local scales with higher fish abundance and diversity, and therefore fish catch. The loss of mangrove area through human induced deforestation or degradation could therefore have negative impacts on fishable biomass.

The human activities which lead to mangrove loss and degradation have been well studied and are detailed in Table 2-1. However, less focus has been placed on investigating the implications of mangrove loss for fisheries production and the mangrove-fishing communities which rely upon this production.

The social impacts of conversion of mangroves for shrimp ponds have been described by Primavera (1997). These impacts are numerous, and include the expropriation and privatisation of mangroves, salinization of water and soil, declines in food security, marginalisation of communities and unemployment, migration to cities and social conflict. While conversion for shrimp farms is perceived as a higher profit use of land than keeping mangroves in their natural state, the economic benefits of conversion are typically not received by communities (Primavera 1997). Jobs created in shrimp farming for local communities are low paying, and fishing communities become “refugees” of aquaculture when ponds fail and private companies move on to land elsewhere. Conversion of shrimp ponds also has implications for fishing itself, through reduction of catches from nearshore fishing and gathering of crustaceans. This is also an issue for food security of coastal fishing communities, exacerbated by the fact that yields from shrimp culture are exported to luxury markets and therefore do not contribute to local food needs (Primavera 1997).

The economic impacts of mangrove conversion for shrimp farming have been estimated for fishing communities in Thailand (Barbier 2003). A bioeconomic model used to simulate the relationship between mangrove loss and its effect on fisheries production has suggested that conversion of 30 km^2 of mangrove for shrimp aquaculture could cause a financial loss of as much as 408,000 US$ annually for the artisanal fishing community (Barbier et al. 2002). It was also noted that economic impacts of mangrove loss were greater for shellfish products than for demersal fisheries (Barbier et al. 2002). Further, an economic valuation conducted in the Surat Thani Province, Southern Thailand found that mangrove conversion for shrimp farming was not economically viable, when losses to fisheries production and other extractive uses, the costs from water pollution as well as the cost of mangrove rehabilitation were taken into account (Sathirathai and Barbier 2001).

How fishing itself forces mangrove-fishery productivity decline has also been discussed, using the Sundarbans fishery in Bangladesh as an example of observed catch declines following ongoing fish, crab and prawn over-exploitation (Islam and Haque 2005). The socio-economic drivers of fishing effort in mangrove-fisheries and the impacts of over-fishing should therefore not be excluded as a driver of fishable biomass in mangrove ecosystems.

Table 2-1. Description of the human activities which impact mangrove forests and their influences on mangrove condition.

Activity	Impact	Sources
Aquaculture	- Large scale clear cutting causes immediate loss of mangrove forest - Groundwater withdrawal and alteration of river flows - Post-collapse coastal erosion, intrusion of saltwater and coastal flooding - 30% of global annual mangrove loss is due to aquaculture	(Sathirathai and Barbier 2001, Barbier et al. 2002, Richards and Friess 2015, van Wesenbeeck et al. 2015)
Agriculture (Rice and oil palm plantations)	- Degradation of mangrove forest density - Subsequent flooding into the forest causes coastal erosion - Rice and oil palm plantations are thought to be the second largest threat to mangroves in SE Asia	(Mazda et al. 2002, Richards and Friess 2015)
Agriculture (Sugarcane plantations)	- Loss of mangrove forest causes reduction of habitat for harvested species and loss of ecosystem function - Water pollution caused by sugarcane mills has been reporting to cause fish death in rivers and lagoons	(Vázquez-González et al. 2015)
Conversion for livestock pastures	- Loss of mangrove forest causes reduction of habitat for harvested species and loss of ecosystem function - Impacts on water condition are thought to be less than for sugar cane as cattle provide nutrients in the form of organic matter - Wetland function can be maintained if livestock is only present in small numbers	(Vázquez-González et al. 2015)
Fishing practices	- Damaging practices such as trawl-fisheries can cause habitat loss and environmental stress - Harvesting of mangrove oysters often involves the cutting of mangrove roots with the oysters attached which causes damage to the mangrove forest - Mangrove wood is sometimes used to construct fishing gear (e.g. fishers construct platforms on which to fish, producing brush piles or wooden frames for fishing nets) - Overfishing to meet consumer demand can deplete species or change biological structure of the ecosystem and result	(Bandaranayake 1998, Blaber et al. 2000, Alongi 2002a, Creel 2003, UNEP 2004, Islam and Haque 2005)

	in reduced mangrove-fishery productivity - Ballast waters of large fishing boats by fishers migrating between countries can introduce non-indigenous flora and fauna which can alter community structure	
Damming	- Alteration of tidal cycles caused by damming has been linked to declining fish abundance in mangrove areas - River damming has been linked to reduced landings of estuarine-dependent species such as mangrove oyster	(Alongi 2002a, Baisre and Arboleya 2006)
Unsustainable commercial exploitation (e.g. logging for timber)	- Felling of wood products can cause unsustainable rates of mangrove loss - Reduced mangrove biodiversity due to preference for harvesting particular species - Loss of carbon stock	(Alongi 2002a, Malik et al. 2015)
Coastal development	- Growth of cities and ports in coastal areas is often correlated with mangrove loss - Urban development at the coast brings increasing demand for clean water and sewage treatment; when sewage exceeds available sewage treatment it can enter the coastal waterways untreated from land based sources - Construction of human developments such as bridges and levees cause modifications to waterways which are key areas for gathering and cultivation of shellfish, finfish and crustaceans by coastal communities - Contaminants from developments seep into groundwater and therefore end up in mangrove waters	(Alongi 2002a, Creel 2003, Shahbudin et al. 2012)
Tourism	- Additional infrastructure built on the shoreline to accommodate tourists - Clearing of mangroves to build marinas and coastal resorts - Boats bringing tourists are a source of solid waste pollution to coastal zones	(Hall 2001, Creel 2003)

2.4 What are the social drivers of fishing effort within mangroves?

Fishing effort within mangrove forests can be driven by a number of socio-economic variables, including proximity, size and demand of human populations; the cultural, political and economic conditions of the local population; access to alternative livelihoods; and varying levels of fisheries management (Hutchison et al. 2014). Fishing and related activities are a dominant source of income for the majority of people living in close proximity to mangrove forests (Walters et al. 2008). Greater population density is therefore likely to equate to greater demand for products. Fishing effort and fish catch is thus expected to be highest for mangrove forests close to large human populations (Creel 2003, Hutchison et al. 2014). Coastal populations are growing faster in many parts of the world than non-coastal populations, with consequences for increasing pressure on coastal wetlands (Creel 2003). It should be noted that fish catch does not linearly increase with fishing effort. In some cases dense human populations cause degradation to mangrove ecosystems through over-fishing. Such practices render mangrove-fisheries less productive in areas of high demand and fishing effort than areas of more sparse human populations (Hutchison et al. 2014). This problem can however be mitigated by levels of conservation and fisheries management which influence fishing effort within a mangrove-fishery (Hutchison et al. 2014).

Beitl (2011) provides an example of artisanal fishing in Ecuador's mangrove forests in which cultural and political processes influence the nature of human-mangrove interactions; in this case catch rates and daily decision making regarding cockle fishing is governed by both formal and informal institutional arrangements. Cockle fishers are constrained by institutional closure periods within the managed fishing area. However they also use an optimal foraging strategy in decision making, using the previous day's catch as a determinant of where to fish next, on a daily basis. Cultural constructs also influence fishing effort allocation and behaviours. Cockle fishers in Ecuador accept that all fishers have the right to harvest fish from mangroves, with the exception of those who destroy or damage the mangroves (e.g. shrimp farmers); for this reason while fishers have preferred fishing areas, they do not actively defend them. These social and political constructs in mangrove-fisheries in Ecuador help mitigate against a free-for-all, tragedy of the commons situation where there is open access.

The method of fishing activity can vary according to ecological and social conditions and therefore influence number/weight of fish caught or catch per unit effort (CPUE) within a particular mangrove-fishery. Dehghani (2019) compared traditional fishing methods in the mangrove forests of the Hara Biosphere Reserve, North Persian Gulf, finding clear differences in catch weight between fishing methods used by different communities. Trawling methods retrieved catch 1.5 times the weight of stake net and gill net methods, despite no substantial differences in the fish diversity between fishing methods being observed. Although not necessarily driving the fishing effort within mangroves by a community, traditional fishing methods used by a community may be an indirect social driver of catch within a local mangrove-fishery.

Collection of particular mangrove products or target species can also be determined by levels of wealth or poverty. Thus, for example, in the Caeté Estuary, North Brazil, more wealthy families in the community will not collect products of no commercial value which poorer families will collect for subsistence. Further, for poorer families certain subsistence products are collected only when in need of emergency food provision, for example the collection of snails and molluscs as a last resort where families would otherwise go hungry (Glaser 2003). Alves and Nishida (2003) also provide an example of socio-economic status of a community driving fishing effort for a particular product, suggesting that in Mamanguape River Estuary, Northeast Brazil, gathering of mangrove crab is only conducted by the extreme poor communities living around the mangroves and not by traditional fishermen.

Access to alternative livelihoods or alternative resources are also socio-economic drivers of fishing effort in mangrove systems (Badola et al. 2012, Hutchison et al. 2014). Those communities with the most livelihood options are expected to put less pressure on mangrove systems. Badola et al. (2012) noted that while local communities living around mangroves on the east coast of India had a positive attitude towards mangrove conservation and use of alternative resources, those who were too poor to afford these alternative resources admitted that they would continue to take mangrove products even from protected areas. In Bangladesh, Ahmed and Troell (2010) observed that environmental stressors caused coastal fishers to carry out illegal practices, such as using fine mesh nets to collect shrimp, in the absence of ample adaptation opportunities.

2.5 How is future climate change expected to influence fishable biomass within mangroves?

As well as direct impacts of human activities on mangrove forests, several studies have attempted to project the future impacts of various aspects of climate change such as sea-level rise (SLR), increased storminess and changes to temperature, precipitation, atmospheric CO_2 and ocean circulation (Gilman et al. 2006, 2008, Lovelock et al. 2015). All of these components of climate change are expected to alter the productivity of mangroves and their associated biological community to some degree, along with their links with adjacent systems (Godoy and Lacerda 2015). However, according to the IPCC 2018 report on the impacts of global warming and human and natural systems, the risk associated with rising sea surface temperature (SST) is much lower for mangroves than for other coastal habitats (e.g. coral reefs and seagrasses) (Hoegh-Guldberg et al. 2018). For example, detectable to moderate risks only emerge with a projected rise of 1.3°C relative to pre-industrial SST levels for mangroves, compared to corals, which have been at high risk of severe impacts since the 1980’s. Moreover, projections show low certainty over higher than moderate risks from climate change being observed for mangroves as we reach 2 °C relative to pre-industrial SST levels, whilst seagrasses are projected to reach high risks (of severe and widespread impacts) at 1.8°C, and corals will reach very high risks (of severe and irreversible impacts) at an increase of 1.2°C.

Whilst very little research has directly addressed the indirect impact climate related changes to mangroves may have on fisheries productivity, the projected risks of severe and irreversible impacts ecosystem services from fisheries in low latitudes, with an increase in SST of 2°C from pre-industrial levels, are very high (Hoegh-Guldberg et al. 2018). The biological and ecological changes which are expected to be brought about to marine ecosystems and resident fish populations through climate variability and change are therefore very likely to force changes in fisheries productivity and thus impact fishing community livelihoods (Badjeck et al. 2010).

Whilst mangroves are projected to be relatively resilient to changes in SST, sea-level rise is projected to be the greatest climate change related risk to mangrove forests (Gilman et al. 2006, 2008, Ellison 2015, Lovelock et al. 2015, Ward et al. 2016). The decline or degradation of mangrove area driven by SLR could impact mangrove-fisheries production through the reduction of critical coastal habitat for fish and invertebrate species (Badjeck et al. 2010). The ability of mangrove areas to keep up with rising sea level through surface elevation gains will determine their regional vulnerability (Gilman et al. 2008, Ellison 2015). Gilman et al. (2008) grouped the site-specific responses of mangroves to SLR into 3 categories: 1) stable sea-level rise, in which sea level is not rising relative to mangrove surface elevation; 2) sea-level rise falling relative to mangrove surface elevation; and 3) sea-level rise greater than mangrove surface elevation change. It is in this third category in which mangrove margins may begin to retreat landward, driven by increased erosion pressure, weakened roots which leads to trees falling, increased salinity and excessive durations of inundation (Gilman et al. 2008).

Responses to SLR will differ between forests of varying species composition, as rates of surface elevation gain and rates of colonization vary amongst mangrove vegetation species and zones (Gilman et al. 2008). Regional responses to SLR will also vary by geomorphic setting (Sasmito et al. 2016, Ward et al. 2016). Relating mangrove surface elevation change to the SLR scenarios provided by the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5), Sasmito et al. (2016) concluded that surface elevation gains of mangroves in both basin and fringe mangroves will be able to cope with the IPCC's low SLR scenario (Representative Concentration Pathway (RCP) 2.6) within a 100 year projection period. However, under the high SLR scenario (RCP 8.5), SLR is projected to exceed surface accretion rate by 2070 and 2055 for basin and fringing mangroves respectively. Using the Dynamic Interactive Vulnerability Assessment Wetland Change Model (DIVA-WCM) which considers the three key influences of regional vulnerability to SLR: 1) rate of relative SLR, scaled by tidal range (Kirwan and Guntenspergen 2010); 2) lateral accommodation space and 3) sediment supply, Spencer et al. (2016) also confirmed that micro-tidal (< 2 m tidal range) settings are more likely to be vulnerable to future SLR than macrotidal settings (> 4 m spring tidal range). However, also using the DIVA-WCM model, Schuerch et al. (2018) present a more optimistic view, with model simulations suggesting that if 37% of wetlands are given sufficient accommodation space, wetland gains of up to 60% are possible by 2100.

Lovelock et al. (2015) modelled vulnerability of mangroves using surface-elevation table-marker horizon table records from around the Indo-Pacific, finding that 69% of Indo-Pacific mangrove areas studied are not keeping pace with regional SLR and are largely controlled by availability of suspended matter (as estimated through satellite-derived suspended sediment concentrations). The impacts of SLR are often compounded by limitations placed on sediment supply by human activity. Both Raha et al. (2012) and Shearman et al. (2013) report drowning of mangroves on deltaic islands in the Sundarbans due to subsidence and decreasing sediment transport coming from the Ganges, the latter driven by human activity and compounded by SLR. Accommodation space (lateral space for expansion of vegetation) for landward migration in light of SLR can also limit response to SLR forcing. Thus, for example, the low lying Pacific Islands with developments built on narrow plains are both physically and economically restricted from retreat (Gilman et al. 2006). Di Nitto et al. (2014) simulated landward migration of mangroves in Gazi Bay, Kenya, finding that under a low SLR scenario projected for 2100 (IPCC 2001), shift of mangroves landward could occur with no significant loss of mangrove area. However under a projected high SLR scenario (IPCC 2001), landward migration is expected to be obstructed by the topographic gradient of the region and therefore would result in a decline in total mangrove area.

Human responses to climate change, for example adaptation actions such as construction of sea walls, water irrigation activities or managed retreat, may also have impacts on mangrove response to climate change which may in turn impact upon mangrove-fisheries productivity (Gilman et al. 2008). Armoured shorelines have been found to have a negative impact on mangrove fish communities in Australian estuaries. Fish diversity and abundance was lower in mangroves that were in closer proximity to urban structures (Henderson et al. 2019). Further, the construction of armoured regions behind mangroves in response to SLR, or the development of urban infrastructure in the coastal zone, restricts accommodation space, therefore hindering the mangroves ability to adapt to SLR and leading to loss of mangrove area (Schuerch et al. 2018).

Other climate-related environmental variability and change, such as temperature, precipitation, atmospheric CO_2 and ocean circulation, are expected to have some influence of mangrove ecosystem function. These factors are, however, less well studied and, even less so, the subsequent impact on mangrove-fisheries. Global increases in temperature, atmospheric CO_2 and precipitation have potential to increase mangrove productivity and provoke expansion into higher latitudinal ranges (Gilman et al. 2008, Omo-Irabor et al. 2011, Ward et al. 2016). Precipitation in particular may cause mangroves to colonize areas which were previously occupied by salt marsh habitat (Ward et al. 2016, Saintilan 2018). Precipitation could also induce increased river overflow and therefore sediment transport, which may mediate the effects of SLR in some areas (Ward et al. 2016).

Brown et al. (2010) simulated the impacts of climate related changes in primary productivity on fisheries in a number of Australian marine ecosystems, finding that projected increased primary productivity over the next 50 years brought about positive changes in regional fisheries landings and catch value. However, in some regions the rate of fishery landings showed a quicker increase in response to increased primary productivity compared to fisheries catch value, indicating that some higher valued species had been replaced in the model by lower value species in response to changing primary productivity (Brown et al. 2010). Furthermore, simulations by Brown et al. (2010) showed that despite increasing regional primary productivity overall, loss of mangrove (and therefore loss of mangrove primary productivity) can change fisheries catches by reducing community biodiversity evenness (the representation of each species in a community).

Predicted increased frequency and intensity of storm events in some regions, and accompanying increases in the frequency of extreme high water events, are expected to have mixed impacts on mangrove forests (Gilman et al. 2008, IPCC 2013, Ward et al. 2016). Depending on mangrove position, storm characteristics and levels of exposure, increased frequency and intensity of storminess can cause defoliation, tree mortality and alter soil elevation, all of which could lead to loss of mangrove area (Gilman et al. 2008). Conversely, sediment coming from outside sources and nutrient inputs related to increased storminess could in some areas increase mangrove productivity, growth and surface elevation, which could increase resilience against the negative impacts of SLR (Lovelock et al. 2015). Assumed climate related flooding however in many regions can be the result of both the impact of changing climate confounded by pressures exerted on coastal resources by human populations (Zhang et al. 2018, Murray et al. 2019). As such, disentangling these two impacts and understanding global threat of climate change as a factor in controlling storm events and subsequent flooding in coastal areas is challenging (Naylor et al. 2017).

Additional climate change aspects which are not well understood in terms of their potential impacts on mangroves are changes in ocean circulation. However changes to ocean circulation are expected to influence propagule dispersion and therefore have potential to change mangrove distribution (Gilman et al. 2008). The response of other coastal habitats, such as coral reefs and seagrass meadows, to climate may also impact mangrove forests due to alterations in the connectivity and exchange of nutrients between adjacent habitats (Gilman et al. 2008).

There are also aspects of climate change which may impact fish and invertebrates directly, which may influence fisheries productivity in mangrove forests. In the tropics, changing ocean temperature is expected to cause latitudinal shifts in distribution of temperature sensitive fish, species extinctions and changes to larval transport through changing tropical currents. As such, these changes are expected to change the species composition of fisheries catches (Booth et al. 2017).

Given that the impacts that climate change will have on mangrove ecosystems are uncertain, how fishing communities relying on mangroves for their livelihoods will be impacted is mostly undetermined. Direct climate impacts to fisheries yields or indirect impacts through mangrove ecosystem degradation could reinforce or drive communities in low-elevation zones, particularly in developing countries, into poverty (Barbier 2015). Impacts of higher atmospheric CO_2 are already being felt in the Sundarbans mangrove forest, Bangladesh. Lowering of salinity in marine and estuarine waters as a result of increased CO_2 dissolved into the ocean creating carbon acid (acidification) is thought to be responsible for lowered oyster (*Saccostrea cucullata*) shell weights (Choudhury et al. 2019). Interviews with fishers in the Rufijii district of Tanzania also suggested a number of climatic impacts felt by the community in the past 10 years. Impacts included loss of mangrove cover due to soil erosion, colonisation of new mangrove species, beach erosion, increased river and ocean water temperature, water pollution caused by flooding and storm surges (Yanda et al. 2019). Subsequent impacts to fishing livelihoods have included reduced fish catches, destruction of fish breeding sites and relocation inland by the community. These impacts, based upon perceived impacts by the fishing and farming community conveyed through interview surveys, are assumed to be climate related within this study. In the absence of study into the causes of these impacts (e.g. from erosion, storm surges and reduced fish catches), the possibility of direct human, social or political impacts that could also be causing an effect perhaps have been overlooked. These pressures felt by the community (whether they are indeed caused by perceived climate impacts or other impacts) have led some to abandon fishing activities and move to nearby towns. Those not able to move have switched to other activities, such as the illegal selling of mangrove poles, changing fishing gears or fishing in deeper seas (Yanda et al. 2019). This leads to the further question as to whether or not these and other adaptive changes, to climatic or other pressures, will be sustainable in the longer-term. Developing an understanding of how people use mangroves for fishing is therefore a necessary first step in order to understand both the pressures on mangrove ecosystems by fishers and conversely how communities will have to adapt their fishing practices and livelihoods under future environmental change.

3 - Defining mangrove-fisheries

Summary

Efforts in mangrove management so far have focussed upon slowing mangrove forest loss, restoration and climate mitigation, to the detriment of a consideration of the social dimensions of mangrove use for fisheries. Mangrove-fisheries globally are data poor, and no ubiquitous definition for what constitutes a mangrove-fishery currently exists. Subsequently, a confusing picture of mangrove-fishing is found in the literature, which on one end describes the traditional view of fishers collecting directly from the mangrove and on the other includes studies that limit mangrove-fishery enhancement measures to mangrove-associates caught offshore. This risks the interests of some groups of fishers being under-represented in fisheries or mangrove management plans where their connection to mangroves is overlooked, particularly where they are overshadowed by larger scale or industrial fisheries.

This chapter therefore aims to develop a definition of what mangrove-fisheries encompass which incorporates a broad scope of their possible characteristics. First, an analysis exploring how mangrove-fisheries are currently defined or measured in the literature was conducted. A detailed case study, which investigated the fishing activities associated with mangroves through interview surveys, was conducted in the Perancak Estuary, Bali, Indonesia. This case study demonstrated the complexity that a mangrove-fishery can encompass, where fishing is connected to the mangrove forest by fishers of multiple sectors, functions, locations and temporal scales. The case study also highlighted that mangrove-fisheries are variable even in close proximity. With particular reference to this case study, a framework was developed as a flexible tool for identifying the multiple dimensions of a mangrove-fishery in a local context. Following this framework should encourage researchers and managers to look outside of the groups of fishers traditionally expected to benefit from mangrove fishing. This will enable the development of a broader definition of mangrove-fisheries in a site specific way. Identifying the full scope of fishers that contribute to or benefit from a mangrove-fishery is the first step towards building management measures that reflect the interests of groups of fishers that are otherwise under-represented.

3.1 Introduction

At present there is no ubiquitous definition of mangrove-fisheries; studies so far have used broad and sometimes vague descriptions of mangrove-fishing. On one hand, research has described traditional fishers collecting directly from the mangrove (Ocampo 2006, Rondinelli and Barros 2010, Côrtes et al. 2014). On the other hand, other studies have solely linked offshore catch to mangrove presence inshore. Fisheries data where mangroves occur are also notoriously poor. Small-scale fisheries are often under-represented in data collection, fishery reports and management plans where they coexist with larger scale fisheries. Calls for a better definition of small-scale fishing sectors are therefore not uncommon as a tool to improve representation or clarify the characteristics of a fishery within the reporting and management of fisheries. These re-definitions have strived for more holistic and flexible definitions to remove generalisations which can lead to inappropriate management measures, such as through misrepresentation of a group or sector or it being missed out entirely (Carvalho et al. 2011, García-Flórez et al. 2014). This has therefore been referred to as an "un-defining" process (Jadhav 2018).

Examples of the problem of generalisation can be seen in two regions. The first example comes from the governance of small-scale fisheries in The Netherlands, where pelagic and demersal trawl fleets are the focus of data collection and management. As a result, all other fleets are amalgamated into a "rest category" of coastal fishers whose small-scale activities are omitted from data collection and who thus remain under-represented by fishery organisations (De Vos and Kraan 2015). This issue should be considered in the case of mangrove-fisheries where some fishing activities, especially those where the catch is not commercially sold, are unlikely to be reported in fisheries catch statistics. Secondly, in India, generalisation that all small-scale fisheries are synonymous with poverty has resulted in management plans that have unnecessarily focussed on capitalising and modernising fishing fleets (Jadhav 2018).

It has also been argued that socio-economic parameters, such as employment, ownership, trade and cooperation, should be included in the descriptors of small-scale or artisanal fisheries (Carvalho et al. 2011). This can be important in identifying the contribution of those fisheries mistakenly perceived as being of less importance. Thus, for example, socio-economic surveys of seabass anglers in England and Wales revealed that annual catch landings of sport fishing for seabass equal that of the commercial fishing fleet, and revealed that this activity involves 1.44 million people (Pawson et al. 2006, 2007). Similarly, small-scale fishing was found to employ more people in the Azores and contribute to higher catch landings and value than larger scale fishing in the region (Carvalho et al. 2011). Mangroves are known to contribute greatly to the livelihoods of coastal fishing communities, however with limited quantitative data on their contribution, it is difficult to be sure how their social or economic importance compares to larger industrial fisheries. The socio-economic importance of varying fishing sectors should therefore be incorporated into research and management to ensure recognition of all sector contributions.

Redefinition of a fishery or sector can also be useful in putting an end to confusion over what the group includes, or does not include, and in re-evaluating the importance of previously excluded elements to its totality. For instance, a systematic redefinition of fisheries bycatch was conducted to incorporate all of its possible elements globally following confused perception of the term. As a result, an additional 40% of global bycatch was identified that had previously been invisible and therefore unmanaged (Davies et al. 2009). The redefinition of what mangrove-fisheries can encompass could also be a useful tool in exposing further value.

3.2 What is a mangrove-fishery? An analysis of the current literature

The term 'mangrove-fishery' is generally used by researchers to describe a small community of artisanal fishermen who forage within the mangrove, using traditional tools, or no tools at all. However, studies which have measured the ecosystem service value that mangroves contribute to fisheries production, typically attribute mangrove benefits to a much wider frame of reference with regard to the types of fishing included. A list of 23 research articles, which represents all the studies which have quantitatively measured the mangrove enhancement value to fisheries production, has already been identified (Carrasquilla-Henao and Juanes 2017). Using this list, the characteristics used to describe each fishery when measuring the value of mangrove-fisheries have been drawn out here from each of these articles. Descriptors in these measurements included a variety of fishing locations, fishing sectors, gears used, target species included and spatial scales (Table 3-1). A summary of these descriptors is used below to describe:

- where mangrove-fishing takes place;
- what catch is considered mangrove-associated; and
- who is doing the fishing?

3.2.1 Where does mangrove-fishing take place?

There is no agreement in the literature regarding at what distance from a mangrove a fish caught is the result of some mangrove effect (the effect distance). As such, the fishing locations included as 'mangrove-associated fishing' ranges in the literature from fishing that is exclusively conducted within the mangrove forest itself (Martosubroto and Naamin 1977, Staples et al. 1985) to fishing that has taken place up to 30 nautical miles (approximately 55.6 km) offshore (Manson et al. 2005a, 2005b). In between these extremes are studies that have focused on fishing within rivers, estuaries or the coastal zone in the vicinity of mangrove forests (Gedney et al. 1982, Jothy 1984, Camacho and Bagarinao 1986, Loneragan et al. 2005, Lee et al. 2014, Vázquez-González et al. 2015).

The spatial scale over which mangrove-fisheries are studied is often influenced by the fisheries-dependent data available (Manson et al. 2005a, 2005b). As such, the spatial scale is set at the furthest distance known to be travelled by fishermen, and not based on any site specific ecological parameters (Aburto-Oropeza et al. 2008, Carrasquilla-Henao et al. 2013). Further, catch associated with mangrove habitat is often coarsely described, such as estuarine or riverine, onshore or offshore (Turner 1977, Gedney et al. 1982, Barbier and Strand 1998, de Graaf and Xuan 1998, Kenyon et al. 2004, Loneragan et al. 2005, Meynecke et al. 2007). This is because secondary fishing data rarely includes specific fishing ground locations. Others have used fishery independent surveys of juvenile abundance in the mangrove as a proxy of mangrove-associated catches offshore (Ley 2005, Sheaves et al. 2012). In such cases, no information is available regarding the location that the mangrove-associated fishing takes place.

Studies of mangrove-fishery value also range in their scope from measures of mangrove-fishery value at the local community level (Carrasquilla-Henao et al. 2013) to a small number of studies that have measured the relationship worldwide through an aggregation of regional studies (Turner 1977, Pauly and Ingles 1986, Lee et al. 2014). The majority of studies however are pitched at a large regional level, such as the East Coast of Australia (Manson et al. 2005a), the Western Peninsula of Malaysia (Gedney et al. 1982, Sasekumar and Chong 1987, Loneragan et al. 2005) or the Gulf of Mexico (Aburto-Oropeza et al. 2008, Vázquez-González et al. 2015). Regional studies are often bound by management areas as this is the scale at which fisheries data is collected. Worldwide studies (which are based on an aggregation of regional studies) of mangrove-fishery linkages exist only for prawn species (Pauly and Ingles 1986, Lee 2004).

As pointed out by Carrasquilla-Henao and Juanes (2017), quantitative research on mangrove-fishery linkages has been concentrated in just 6 countries out of the possible 105 countries in which mangroves are present (Table 3-1; Hamilton and Casey 2016). It is therefore likely that there is much further variation in how mangrove-fisheries can be described in the remaining countries that are not represented in Table 3-1.

3.2.2 What catch is considered mangrove-associated?

Most commonly, studies linking mangroves to fish catches only include known mangrove-associate species (Turner 1977, Jothy 1984, Camacho and Bagarinao 1986, Aburto-Oropeza et al. 2008, Carrasquilla-Henao et al. 2013). However, positive relationships between mangrove extent and fisheries catches have been reported that include estuarine dependent species (Manson et al. 2005a, 2005b, Meynecke et al. 2007) and general marine fish or invertebrate species (de Graaf and Xuan 1998, Lee 2004, Ley 2005, Loneragan et al. 2005, Vázquez-González et al. 2015).

Both fish and invertebrate species are targeted within mangrove-fisheries. However studies of mangrove fisheries enhancement have frequently focused exclusively on penaied prawn or shrimp catch (Martosubroto and Naamin 1977, Staples et al. 1985, Sasekumar and Chong 1987, Barbier and Strand 1998, Kenyon et al. 2004, Lee 2004, Loneragan et al. 2005, Manson et al. 2005a, Sheaves et al. 2012). The connection of prawns/shrimps with mangrove areas during juvenile life stages has been well documented compared to other invertebrates or fish. It is, therefore, unsurprising that they have been the focus of most mangrove-fishery value measures (Turner 1977, Pauly and Ingles 1986, Barbier and Strand 1998, Kenyon et al. 2004, Lee 2004, Loneragan et al. 2005, Sheaves et al. 2012).

Where fisheries data used is not species specific, studies have typically used measures of total catch volume. As a result, the proportion of species that have an association with mangroves is not known (de Graaf and Xuan 1998). Much of the literature surrounding mangrove-fisheries, particularly the grey literature, has stated that 75% of fisheries catches are mangrove-associated, without any ecological evidence for this statement (Sheaves 2017). This assumption has been criticized on two fronts: 1) that the proportion of species that use mangroves is much less than this figure, and 2) that the statement is too generalised for what is a site-specific relationship (Sheaves 2017). Taking these criticisms into account, only catches listed as known mangrove-associates in FishBase (Froese and Pauly 2017) or SeaLifeBase (Palomares and Pauly 2016) are included within the development of a definition of mangrove-fishing within this chapter .

3.2.3 Who is fishing?

Although mangrove-associated small-scale, artisanal, subsistence and recreational fishing have been mentioned in the quantitative literature (Table 3-1), measurements of mangrove-associated fishing have predominantly been concerned with the commercial fishing sector. Smaller scale fishing, such as artisanal and subsistence fishing, has been better addressed in the qualitative literature (Glaser 2003, Islam and Haque 2005, Beitl 2011). Overall, therefore, this division means that the contribution of smaller scale fisheries is not represented in quantitative measures of mangrove-fishery value.

A few studies have included more than one fishing sector in their analysis of mangrove-fisheries (Camacho and Bagarinao 1986, Pauly and Ingles 1986, Barbier and Strand 1998, Ley 2005, Vázquez-González et al. 2015). Even so, a maximum of two fishing sectors has been studied in a single location (Table 3-1). As a wide range of fishing sectors are reported to use mangroves (Table 3-1), it is possible that additional groups of mangrove users exist in a location where just one or two sectors are being included analytically. These additional sectors are likely being excluded from measurements of mangrove-fishery value, particularly in data poor areas.

Mangrove-associated fishing is conducted using a range of techniques from traditional cast nets and hand-lines to large-scale trawlers (Table 3-1). It should also be noted that those fisheries associated with mangroves, particularly within the quantitative literature, are rarely described using the term "mangrove-fisheries". Fisheries are most often identified by their target species, sector or location (Table 3-1), for example the commercial shrimp fishery (Martosubroto and Naamin 1977, Pauly and Ingles 1986, Sasekumar and Chong 1987) or the Gulf fishery (Staples et al. 1985). Stakeholders in a mangrove-fishery (groups benefiting from mangrove presence) should therefore be looked for outside of those sectors that are specifically identified as mangrove-fishers or mangrove-fisheries.

Table 3-1. Analysis of how mangrove associated fisheries are defined in the quantitative literature by fishing location, spatial scale, species included, fishing sector, gear and identity. The list of papers explored, representing studies which have quantified mangrove-fishery linkages, were compiled by Carrasquilla-Henao and Juanes (2017).

	Fishing location	**Scale**	**Study location**	**Species association**	**Sector**	**Gear**	**Identity**
(Manson et al. 2005a, 2005b)	Half degree sections of the coast (30 nautical miles)	Regional (> 1000 km)	East Coast of Australia	Mangrove Estuarine Other	Commercial	Trawl Line Net Pot	By gear
(Carrasquilla-Henao et al. 2013)	0-4026.81 m from mangrove	Local ($280\ km^2$)	San Igancioe Navachiste-Macapule Lagoon system, Mexico	5 selected species of mangrove associates	Artisanal	Hooks Rings Spear Cast net Gill net Clam digging	By gear By sector
(Meynecke et al. 2007)	Estuary Offshore Coastal	Regional	Coast of Queensland, Australia	Estuary	Commercial	Trawl Net Pot Line	By gear

(Jothy 1984)	Coastal	Regional	Peninsula Malaysia	Mangrove	Commercial	Not specified	By sector
Yanez-Arancibia (1985)	No access						
(Paw and Chua 1991)	Sites including coral reefs and seagrass	Regional	Coastal provinces of the Philippines	Mangrove	Artisanal Commercial	Not specified	By sector
(Saintilan 2004)	Estuary	Regional (55 estuaries)	New South Wales, Australia	All except exclusively oceanic species	Commercial	Not specified	Not specifie d
(Ley 2005)	Estuary	Regional (1400 km)	East Australia	All	Commercial Recreational	Research gill net	Not specifie d
(Turner 1977)	Inshore Offshore	Worldwide	27 regional locations	Mangrove	Commercial	Trawler	Not specifie d
(Martosubroto and Naamin 1977)	Within mangrove Adjacent offshore areas	Regional	Indonesia by province	Penaeid shrimp	Commercial	Within mangrove: tidal traps Offshore: Not specified	By target By sector
Staples et al. (1985)	Mud-mangrove banks	Local (14 km river) and regional (200 km^2 grid cells)	Embley River, NE Gulf of Carpentaria, Australia	5 penaeid prawn species	Commercial	Small beam trawl via fisheries independen t survey	By region
(Pauly and Ingles 1986)	Not specified	Worldwide	37 countries	All penaeid shrimp : Mangrove	Commercial Artisanal	Not specified	By target

				Other			
Sasekumar and Chong (1987)	Offshore Coastal Mangrove inlets	Regional	Peninsula Malaysia	Penaeid prawns	Commercial	Not specified	By target
(Lee 2004)	Nearshore	Global	37 countries	Marine prawns	Not specified	Not specified	Not specified
(Loneragan et al. 2005)	Coastal Estuary	Regional (2000 km)	Western Peninsula of Malaysia,	All prawn species: Mangrove Other	Commercial	Trawler Bag net Paired trawl Drift/gill net Trammel net	By target By location
(Barbier and Strand 1998)	Offshore	Regional	Campeche State, Mexico	Shrimp only: Mangrove	Commercial Artisanal	Not specified	By location By target
(Gedney et al. 1982)	Coastal	Regional (Approx. 1 10 000 ha)	The West Coast of Malaysia mangrove area	Mangrove	Artisanal	Not specified	By target By sector
(Kenyon et al. 2004)	Estuarine research survey (Fishery occurs: Offshore Estuary Mangrove)	Regional (500 km)	Joseph Bonaparte Guld, NW Australia	2 prawn species: Estuary	Commercial	Not specified	By fishing location
(Sheaves et al.	Within mangrove	Regional (650 km)	Mangrove estuaries on	Single prawn species:	Commercial	Research cast net	By fishing

2012)	sampling regarding offshore fishery		the coast of NE Australia	Mangrove			location By target
(de Graaf and Xuan 1998)	Nearshore Offshore	Regional	Southern Region of Vietnam	All	All	Not specified	By fishing location
(Aburto-Oropeza et al. 2008)	Within 50 km of mangrove incl. Mangrove Offshore reefs Sandy bottoms	Regional	Gulf of Mexico	Mangrove	Small-scale	Hand line Gill net	By sector By practice
(Camacho and Bagarinao 1986)	Coastal shelf area bordering mangroves	Regional (by province, including approx. 226,000 ha, up to 200 m depth)	Philippines	Species observed in the mangrove	Subsistence Commercial	Commercial: Beach seine Muro-ami Gill net Otter trawl Subsistence: Not specified	By sector
(Vázquez-González et al. 2015)	Riverine	Regional	Alvarado Lagoon System, Gulf of Mexico	6 species: No information	Commercial Recreational	Not specified	By location By sector By cooperative

3.3 Study site selection and description

Indonesia has the largest area of mangrove of all countries worldwide, but has also seen the largest total mangrove area loss (Hamilton and Casey 2016). Bali, and specifically the Perancak Estuary, has been at the centre of several studies reporting rapid mangrove loss due to aquaculture conversion and subsequent replanting (Rahmania et al. 2015, Viennois et al. 2016, Gusmawati et al. 2018, Proisy et al. 2018). Despite this, the importance of the mangrove-fishing that exists in the area has yet to be studied. The fieldwork reported here took place in 3 locations in Bali. The main study site was the Perancak Estuary and its surrounding villages, situated within the Jembrana Regency of West Bali, Indonesia (8°23'42.3"S, 114°37'39.2"E) (Fig. 3-1B). For comparison of the mangrove-fishing activities across Bali, shorter visits were made to Benoa, in South Bali (Fig. 3-1C) and Gilimanuk, West Bali (Fig. 3-1D) where mangroves are also present. These locations were chosen based on local knowledge which pointed to the existence of mangrove-fishing communities in these areas.

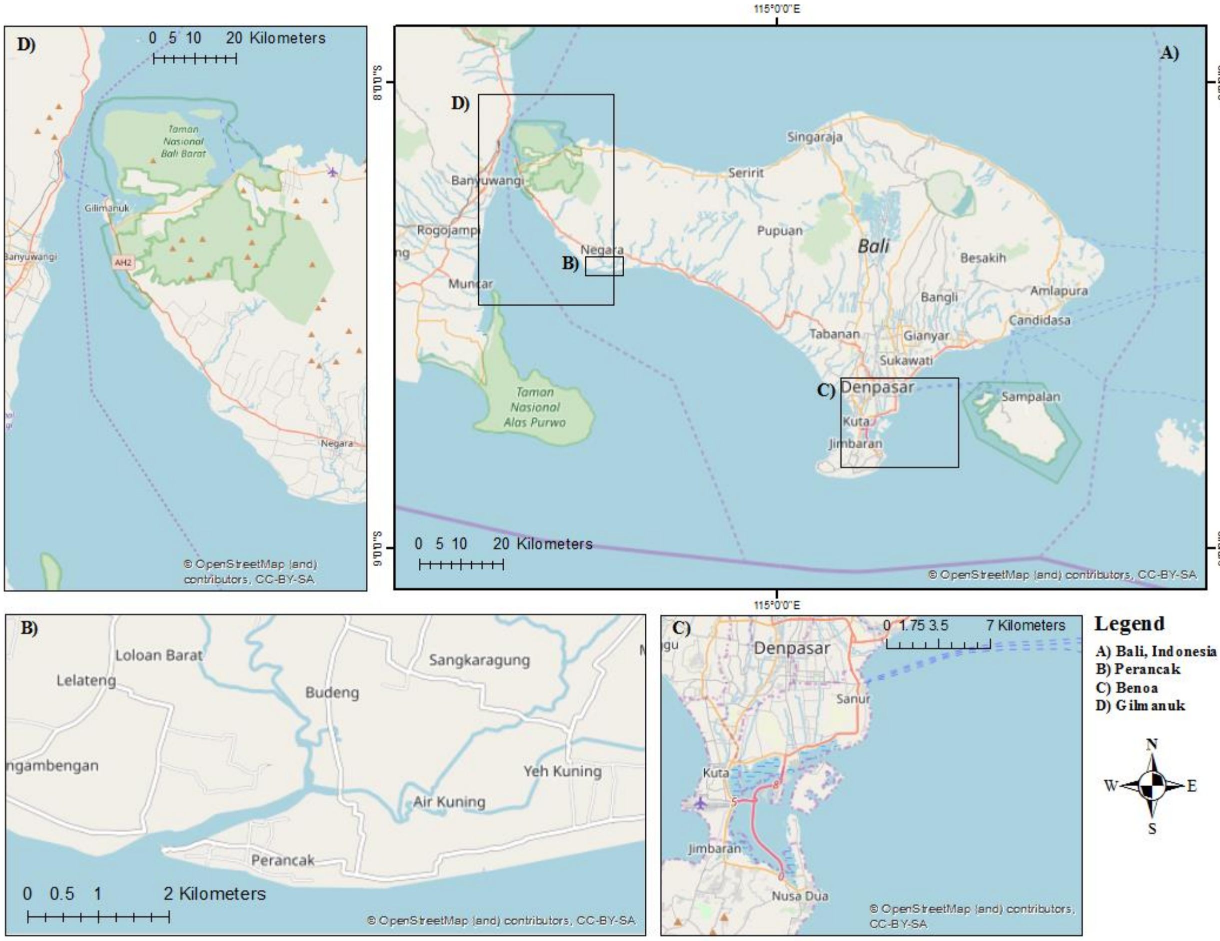


Figure 3-1. Location of case study sites showing A) Bali, Indonesia, B) The Perancak Estuary, Jembrana Sub-district, Jembrana Regency, West Bali which was the primary study site, C) Denpasar City, South Bali, the location of the Benoa Fishing Village and D) Gilimanuk, West Bali.

3.3.1 Geological and ecological setting

The main Perancak Estuary covers an area of approximately 7.55 km^2. The estuary has 4 main branches, fed by mountain catchments at its northern boundary and terminating at its southern limit in the Indian Ocean. The estuary exhibits a semi-diurnal tide, with an estimated tidal range of 2 m (Rahman 2015). However as the nearest tidal gauge sits at Penambengen Fishing Port, 6 km west of the estuary, no accurate tidal range measurement exists for the estuary (Proisy et al. 2018). The land areas surrounding the estuary can be submerged by 0.5-1 m of water from the estuary at high tide, particularly on spring tides (Rahman 2015). The region experiences a dry season between April and October and a rainy season from November to March, with an annual average rainfall total of 1500 mm per year. There is an average annual temperature range of 26-31°C (Viennois et al. 2016).

The Perancak Estuary has been the subject of several studies focussed on mapping land use change, due to the prevalence of aquaculture development and failure in the area, and subsequent changes in mangrove extent (Rahmania et al. 2015, Viennois et al. 2016, Gusmawati et al. 2018, Proisy et al.

2018). In the late 1970s almost the entirety of the mangrove area surrounding the Perancak Estuary was converted to ponds for fish or shrimp aquaculture, establishing a thriving industry in the 1980s which began to decline in productivity in the 1990s (Proisy et al. 2018). This location is representative of the pattern of aquaculture establishment and subsequent land cover change which occurred along the same timeframe in many areas of Indonesia (Gusmawati et al. 2018, Proisy et al. 2018).

Following a period of decrease caused by mangrove cutting from 2001 to 2003, total mangrove extent around the Perancak estuary then increased from 40 ha in 2003 to 125 ha in 2015 (1.25 km^2) (Proisy et al. 2018). This included an increase in mangrove extent, both in natural areas and through replanting efforts on aquaculture pond walls and floors (Proisy et al. 2018). Of the 125 ha of mangrove area, approximately 35 ha was replanted mangrove while the remainder was naturally colonized or recolonized areas (Proisy et al. 2018). Mangrove species composition varies considerably between natural and replanted mangrove species surrounding the Perancak estuary; in natural forest plots in 2015, Proisy et al. (2017) found that *Avicennia alba* (70% of plots) was the most commonly occurring species, followed by *Sonneratia alba* (50%) and *Avicennia officinalis* (37.5%). Meanwhile planted plots were dominated by *Rhizophora* spp. *(Rhizophora apiculata* (53%), *Rhizophora mucronata* (40%) and *Rhizophora stylosa* (33%) which were not found in natural plots (Proisy et al. 2018).

There are 1,546 aquaculture ponds surrounding the Perancak estuary covering 360 ha (Gusmawati et al. 2018). However, only 369 ponds are currently (2018) active and 70% have been abandoned (Gusmawati et al. 2018). Ponds in the area include fish culture, intensive, semi-intensive and polyculture ponds (Gusmawati et al. 2018).

Fish culture ponds in Perancak culture milkfish (*Chanos chanos*), are shallow (<1 m of water), feed is dispersed manually (or sometimes via an automatic feeder) and one aerator (used to enrich the pond water with oxygen) is sometimes used. These ponds were referred to as traditional ponds by respondents from the aquaculture sector. Traditional aquaculture ponds (sometimes referred to as extensive aquaculture), sometimes rely on water brought in from currents and tidal exchange for free (FAO 2019). Culture of shrimp in traditional ponds is an additional type of aquaculture in the area identified during interviews.

Semi-intensive aquaculture ponds do not rely on water flow, as nutritional inputs through commercially formulated shrimp feeds are made to the ponds themselves (FAO 2019). These semi-intensive ponds around the Perancak Estuary are earthen banked (built directly into the soil), rectangular in shape and with 0.6 to 1.2 m water depths. These ponds have 1-3 aerators and one gate for both water inflow and outflow. Semi-intensive and intensive ponds are larger than traditional ponds, ranging from 0.1 to 0.5 and 0.4 ha respectively.

A higher stocking density of shrimp distinguishes intensive from semi-intensive ponds, as well as a larger number of aerators (4 or more per pond) and higher feeding inputs. Intensive ponds are either earthen banked or built with a liner, or built from concrete, with a water depth of 1.0 to 1.5 m. Intensive ponds have separate inlet and output gates (they do use water inputs from the river, but outputs are released there through a separate drainage system). Polyculture ponds (those culturing more than one product) in the area cultivate shrimp together with algae (Ulva spp.) and have characteristics similar to intensive ponds.

Pond abandonment, following periods of low production, has been linked to the spread of disease through closely linked and densely populated ponds in the central Perancak Estuary area and specifically to the incidence of white spot disease. White spot disease is a viral infection that causes mortality of shrimp that has been prevalent in Indonesia since its introduction to Java in 1994, and can be passed on through water sharing between ponds.

3.3.2 Population

In a 2013 estimate, the Jembrana Regency had 321,008 inhabitants, divided between 5 districts. The central Perancak Estuary lies within the Jembrana Sub-District (62,790 residents) which has 4 main villages neighbouring the estuary named Perancak, Air Kuning, Yeh Kuning and Budeng. These were the main locations in which interview respondents were sought (Fig. 3-1B).

Agriculture, particularly rice farming, and fisheries are the most prominent economic sectors in the Jembrana Regency (Jembrana Regency 2014). The Jembrana Regency has a 604 km^2 marine area and is the largest producer of marine fish in Bali. According to the Jembrana Regency Government Fisheries and Forestry Services, the potential marine fish production is 57.9 tonnes annually, split between pelagic (93%) and demersal (7%) catch (Jembrana Office for Marine Fisheries and Forestry 2014). Most commercial fishing at sea uses purse seines or lift nets while small scale fishing uses gill nets or hook and line in small boats called Jukung (< 5 GT) (E Susilo, pers. comm. 2017). Pelagic catch targeted within the Bali Strait (the channel between Bali and Java Islands) is prominently Bali sardinella (*Sardinella lemuru*), as well as scad and frigate tuna while demersal catches include grouper and snapper (Jembrana Regency 2014). Traditional fishing within the Perancak Estuary also exists but their activities are not specified within reports of commercial or small scale catches.

Regional statistics from the Regional Government Fisheries Agency state that the Jembrana Regency as a whole supports 10,022 fishermen; for three quarters of this group fishing is their main job and for remainder it is the secondary option (Jembrana Office for Marine Fisheries and Forestry 2014). Within the Jembrana sub-district of the Jembrana Regency, it is reported that there are 1532 fishermen and 80% have fishing as their primary occupation. In the sub-district there are 627 active fishing boats, consisting of 611 with outboard motors, 9 motor boats and 7 Jukung/boats without motors (Jembrana Office for Marine Fisheries and Forestry 2014). However, these statistics do not take into account the traditional fishing occurring within the Perancak Estuary and the surrounding mangrove forest and are therefore likely to be an underestimate of the small scale fishing boats and fishing activities that are conducted without boats within the sub-district. No mention of mangrove-fishing is made within the regional fishing reports for the Jembrana Regency.

Average fish consumption in 2014 across the Jembrana Regency was 29 kg/capita/year (Jembrana Office for Marine Fisheries and Forestry 2014). However no further information regarding breakdown of fish consumption by sub-district is available. It seems reasonable to assume that fish consumption is likely to be higher than the Regency average in the coastal villages, including those bordering the Perancak Estuary.

3.4 Methods

3.4.1 Interview surveys

Fieldwork was conducted between February-March 2017. This time frame was chosen due to its position during the rainy season, being a less busy time for fishermen, therefore allowing better access to interview respondents. The primary method of data collection was through detailed semi-structured interviews with members of the community who were directly or indirectly are involved in fish production and thus potentially derive benefit from the mangrove presence in Bali. Prior to fieldwork, a number of potential respondent groups were identified, using relevant government reports and academic publications describing the resident population of Jembrana and wider Bali (Polunin et al. 1983, Jembrana Office for Marine Fisheries and Forestry 2014). The groups identified comprised those conducting the following activities: 1) traditional (artisanal) fishing, 2) small-scale fishing, 3) commercial fishing, 4) recreational (tourist) fishing tours and 5) aquaculture farming. An additional category of traditional fishers who self-identified as recreational fishers, due to their perception of fishing as a hobby rather than an occupation, were also interviewed. This group had not been identified prior to fieldwork.

Respondents were first identified for each of the categories by “gatekeepers” in the community. The gatekeepers themselves were found through introduction by researchers and other staff at the host institution (Bali Institute of Marine Research and Observation, BPOL), who were themselves members of the community in surrounding local villages. Further respondents were then identified through snowballing, with initial respondents suggesting other members of their community who might provide additional information. Snowballing was more prevalent within the traditional fishing sector than the small scale or commercial fishing sectors as respondents in these sectors often suggested that the fishing was so similar within their sector that other fishers would not be able to provide any additional information and were therefore reluctant to pass on further connections. Traditional fishing was more varied in its methods and therefore respondents were willing to point out members of the community with different specializations to their own.

While the majority of interviews were pre-planned and arranged to take place at the home or workplace of the respondent, some interviews were opportunistic, approaching fishers during the fishing activity. Opportunistic interviews were mainly conducted with respondents of the recreational fishing category, as these fishers were land-based, or with traditional fishers who were gathering products around the local mangrove area. Attempts at opportunistic interviews proved unsuccessful with fishers within other sectors, for example small-scale or commercial fishers, especially if attempted without a familiar gatekeeper present to make an introduction. Opportunistic interviews were also restricted to those fishing activities operating on land, as those fishing within the river/out at sea were only accessible during transit and therefore were reluctant to stop and talk.

Thirty-two interviews were conducted in total. In Jembrana, 8 semi-structured interviews were conducted with traditional fishers, 6 with recreational fishers, 3 with small-scale fishers, 2 with "fish masters" (managers) of commercial fishing boats and 4 with aquaculture workers or owners. Semi-structured interviews were also conducted for comparison within wider Bali. These included an interview with 1 small-scale fisher in Denpasar and 1 in Gilimanuk. In the case of Denpasar, the respondent was also conducting mangrove fishing tours on behalf of a mangrove fishing tour company, and therefore the interview took place during a tourist fishing trip.

Less structured interviews were also conducted with members of the community who were identified as individuals who might be able to offer a summary of the activities in the local mangrove area. For example, gathering information on small-scale fishing included discussion with a small-scale fishing agent, who was the agent of a group of fishers accounting for 50 small-scale fishing boats. Information on fishing in the estuary were also sought from a government official from the local government fisheries office and by consulting documents provided by The Office of Marine Fisheries and Forestry of Jembrana Regency (Jembrana Office for Marine Fisheries and Forestry 2014).

These less structured interviews were a useful tool in identifying further respondents in each area, and also for gathering information beyond that specifically asked for as part of the interview schedule, under the time constraints of the fieldwork period. This activity also highlighted additional themes that might have been missed by semi-structured interviews alone. Seven interviews were conducted in this fashion, comprising 2 interviews in Jembrana, 4 in Denpasar and 1 in Gilimanuk. These unstructured interviews were conducted with various members of the community, contacted through local connections. In Jembrana, one unstructured interview was conducted with a

Government Officer of the Fisheries Sector in the Jembrana Office and one with a small-scale fishing agent. In Denpasar, a pre-organised unstructured interview was conducted with the Director of the Mangrove Information Centre (MIC) which led to further unstructured interviews which involved a discussion with 3 representatives of the Forest Police, with the head of a fishing community in Benoa Village and a fourth interview with the owner of the mangrove fishing tours company and worker within mangrove crab culture, along with the community secretary. In Gilimanuk, an unstructured discussion with 5 members of a fishing community took place. The semi-structured interview schedule can be found in Appendix 3-1.

3.4.2 Transcription

Interviews were translated instantaneously throughout the interview from Bahasa Indonesian to English, allowing the primary interviewer to steer the discussion as it progressed through the interview schedule. In some cases, a second translator was required to translate from Bahasa Bali (the Balinese local language) to Bahasa Indonesia, after which the primary translator repeated the translation in English. However, this second translator was only required in a minority of interviews. Taking reflexivity into account during interviews, translators were asked to directly translate the questions asked by the interviewer. However some differences in tone or choice of wording were out of the control of the interviewer.

Interviews were immediately transcribed (using pen and paper) throughout the interview and duplicated in an electronic document immediately afterwards. On one occasion, due to absence of an English speaking translator, the interview was conducted primarily in Bahasa Indonesian, delivered via a list of questions written in Indonesian, voice recorded, and translated later.

3.4.3 Participatory mapping

Participatory map annotation was conducted throughout the interview, using a simple map of the Perancak Estuary (see Appendix 3-2a) where appropriate, as a tool for respondents to identify fishing locations and discuss geographical and temporal changes to both fishing and mangrove areas. For fishing in areas outside the Perancak Estuary, a map of Bali and its surrounding coastal waters was used for the same function (See Appendix 3-2b). The appropriate map was used for each respondent depending on the information given during the discourse of the interview. Thus, for example, a traditional fisher who claimed only to fish within the estuary was only asked to annotate the local estuary map. By contrast, a small-scale fisher who stated that they change their fishing location seasonally, was asked to annotate both the estuary and the wider Bali maps. When a respondent was particularly enthusiastic to share knowledge about fish within the mangrove area, a fish identification guide was used as a resource for the respondent to identify the fish they catch and/or observe in the mangrove area. This fish identification guide was based on a list of species found in Bali provided in Polunin et al. (1983). A list of the known mangrove-associated fish were selected and compiled from this source, along with photographs from FishBase (Froese and Pauly 2017) (See Appendix 3-3). This resource was only used for selected interviews rather than for every interview so as not to lengthen the interview schedule and lose the attention of the respondent.

3.4.4 Analysis

Fishing locations drawn on paper maps by respondents were transferred onto digital maps in ArcGIS. First, the satellite image of the Perancak Estuary used for interview surveys was georeferenced to a map of the Perancak Estuary. The fishing locations were then traced onto the georeferenced map in ArcGIS to form point, polygon and line features. The mid-point of all of these features were displayed on the final map. Fishing locations visited by fishers of different sectors were distinguished on the map.

The interview transcripts were analysed through categorization within Atlas.ti qualitative coding software, using an interpretive indexing approach. Interpretive indexing followed the methods detailed in Cope (2010), first by outlining descriptive codes based on the overarching research questions. At a second stage, analytic codes were derived, based on themes and patterns identified throughout the process for both interview transcripts and the annotated maps. The descriptive codes followed the questions outlined in the interview transcript. Thus, for example, one process highlighted extracts of discussions based on fishing history, target catches, gears used and mangrove use. Following the decision that descriptions of the mangrove-fishing within the region could be best separated by fishing sector, descriptors of mangrove-fishing were drawn out for each sector respectively across 4 themes, as in the next section.

3.5 Results

Four dimensions distinguished mangrove use by fishers: firstly, the relationship or connection that the fisher has with the mangrove; secondly, the function that fishing has for that fisher; thirdly, the location where fishing takes place; and fourthly, the timescale over which mangrove-associated fishing takes place. The variable characteristics which can exist for each of these four dimensions, based on all the characteristics observed within the Perancak Estuary Mangrove-Fishery as a whole, are mapped out in Figure 3-2. This framework can be used as a procedure for teasing out the existing stakeholders and their interactions with the mangrove, by fishing sector, through each of the four subsequent dimensions. Information regarding the characteristics of each fishing sector observed in the region which led to the formation of this framework are laid out in the following section.

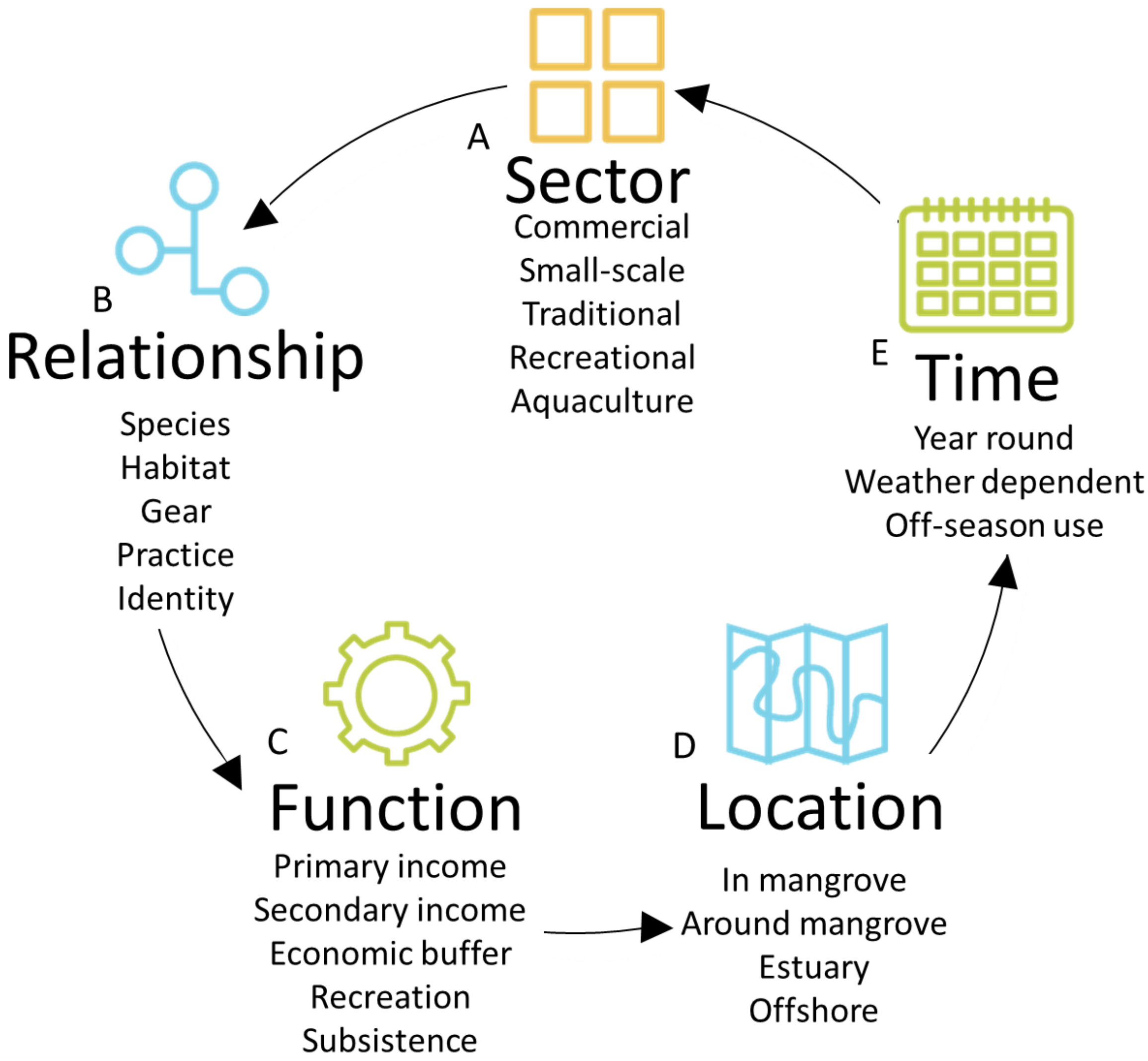


Figure 3-2. A procedure for defining the characteristics of a mangrove-fishery through dimensions of A) fishing sector, B) relationship with the mangrove, C) function, D) location and E) time, based on the characteristics of the Perancak Estuary Mangrove-Fishery.

3.5.1 Mangrove use by sector

The sectors identified were traditional, recreational, small-scale and commercial fishing as well as aquaculture. Fishing sectors presented represent the sector that the fisher perceived themselves to primarily belong to (the sector that they stated they belonged to during interview). Generally, the commercial sector refers to large-scale industrial fishing, which comprise large motorized boats with several workers employed by a fishing master. The small-scale sector is generally characterised by fishing that is conducted by smaller (sometimes motorized) boats where catch is primarily for sale. Traditional fishing is usually conducted by individual fishers who use small artisan (non-modern) tools or no tools, and is for sale or for subsistence but not usually sold in formal markets. Recreational fishing is as the category name suggests. Sectors in this framework however refer to the people within that sector, and their use of the mangrove, rather than the activities of the fishing sector itself. For instance, the framework refers to the mangrove-associated activities conducted by a fisher whose main job is commercial fishing, but not to their (non- mangrove associated) commercial fishing activities.

3.5.1.1 Traditional fishers

Traditional fishers (those using artisanal techniques) are referred to as "people who go to the mangrove" or "traditional fishers" within the community. The respondents conducting traditional fishing activities ranged from 30-63 years of age and included both male and female fishers. Respondents within the traditional fishing sector had a long history of fishing, between 3 and 37 years, with the majority suggesting they had been fishing for "*all of their life*". Traditional fishing is a skill passed down through families or communities. However traditional fishing can also be taken up as a retirement occupation by fishers from other fishing sectors. Mangrove use by traditional fishers in the Perancak Estuary is summarised in Figure 3-3.

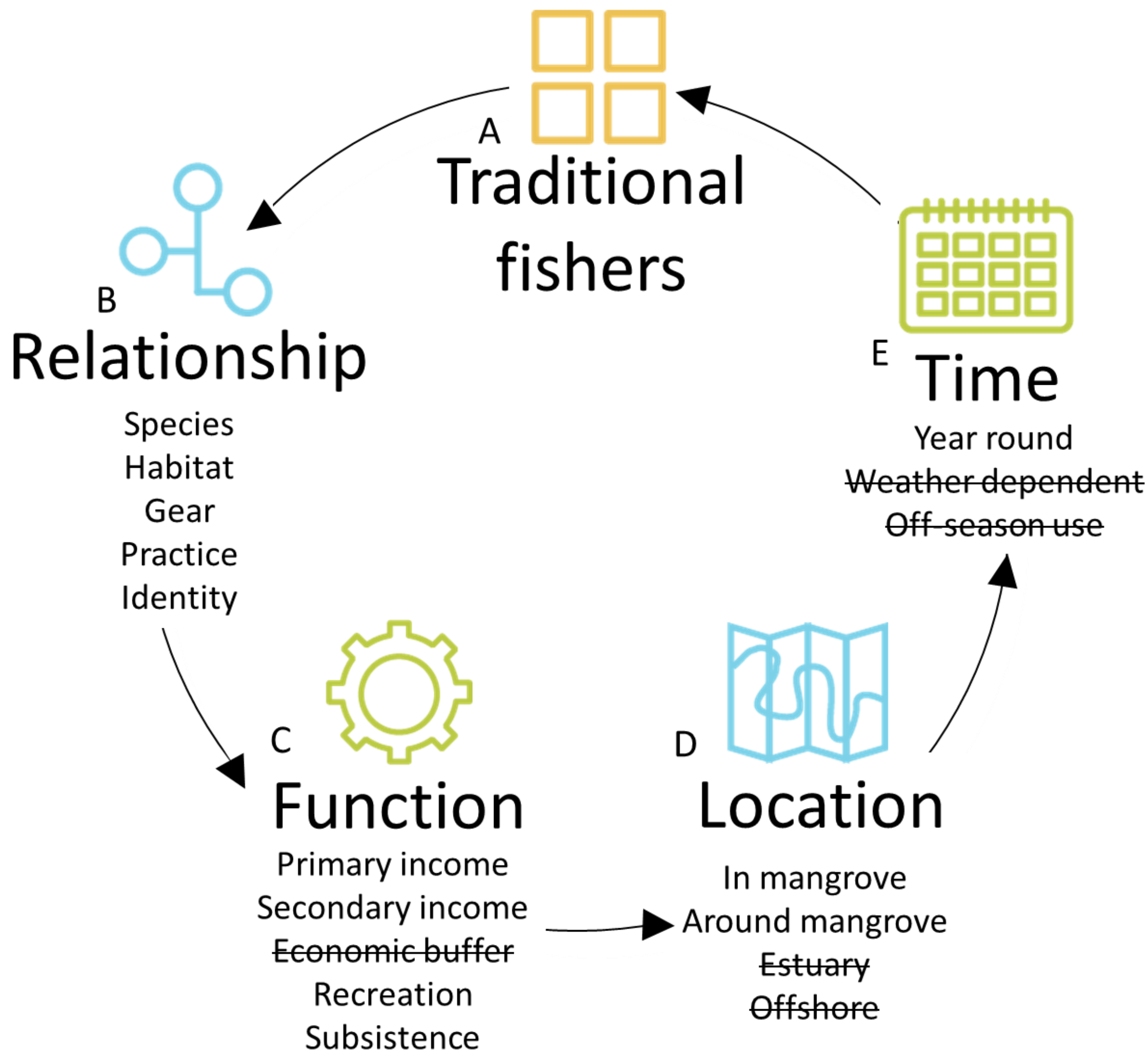


Figure 3-3. Mangrove use by traditional fishers in the Perancak Estuary, Jembrana Sub-district, Bali, following the framework for defining the characteristics of a mangrove-fishery through dimensions of A) sector, B) relationship or connection with the mangrove, C) function of fishing and D) location of fishing and E) temporal scale of fishing. Crossed out attributes do not apply to the group of fishers described.

Connection with mangrove: All species of fish and invertebrates targeted by traditional fishers that were either known mangrove-associates or were caught in the mangrove are listed in Table 3-2. However, target catches by individual fishers within the sector were variable compared to other sectors. Moreover, each traditional fisher appeared to fulfil their own niche within their particular locality or community and in some cases appeared reluctant to stray from their own specialization. For instance, one respondent who only catches fish suggested *"[I catch] only fish, no crabs or mussels etc. I just catch fish with nets, everyone knows their specialization. There is another guy that catches crab in the mangrove"*. The respondent also suggested that he was the only fisher using a particular specialized gear to catch fish in his village. Fishers also showed reluctance to change gear specialization, even when there was a financial incentive to do so (e.g. where another product was in abundance but would require a change to a different gear).

Fishing gears used by traditional fishers were therefore individually specified towards catching a particular species in the mangrove. This specialized equipment was also variable amongst fishers who target the same product. Thus, for example, of the 3 mangrove crab fishers that were interviewed, the mangrove crab was harvested in 3 different ways: either by using a "Sangtek" (a long iron pole with a hook on the end); or by utilising a "Jaring" (a very small net on the end of a pole); or by using a "Perminthan" (crab trap). The first two methods are used to scoop crabs out of holes in mangrove mud banks whereas the third equipment is placed within the mangrove. Bivalves, such as mussels, oysters and scallops, are harvested either by hand using a small knife or by using an "Arit" (a metal rake scraped across the bottom). For fish, cast nets are used, with the nets having different mesh sizes for different fish species. Alternatively, a less selective fishing method named "Go-go" is used, a term which means simply to gather by hand. One respondent suggested that he uses go-go to catch "*anything behind the mangrove; fish, shrimp, crabs*". An additional non-selective method uses a "Sahu", a small net with a handle. The same respondent suggested that his wife uses this method *"to catch little fish and shrimp, anything little"*. Within the traditional fishing sector, gear used is therefore specialised towards fishing in the mangrove habitat.

Traditional fishers were therefore also connected to the mangrove through the practice of going to the mangrove for fishing. Almost all of the fishing activities conducted by traditional fishers took place in the mangrove and as such traditional fishers in the region identify as mangrove-fishers.

Table 3-2. Species caught by fishers of all sectors in the Perancak Estuary Mangrove-Fishery, Bali, along with the fishing sectors of respondents who caught them (by self-identified sector) and the locations in which they have been caught across all sectors. N= number of respondents who reported catching the species.

Group	Species name	Common name	Local name	Primary sector of respondents	Known mangrove associate?	Locations caught	N
Fish	*Lutjanus argentimaculatus*	Mangrove red snapper	Kakapmerah/ Mengarrat	Artisanal Recreational Small-scale	Y	Mangrove Estuary Offshore	9

Fish	*Rasterlliger brachysoma*	Short bodied mackerel	Putian/ Kembung/Suluk	Artisanal Recreational Small-scale	N	Mangrove Estuary Offshore	5
Fish	*Lates calcarifer*	Barramundi	Kakapputih / Bangkuku	Artisanal Recreational Small-scale	Y	Mangrove Estuary	6
Fish	*Caranxsex fasciatus*	Big-eye trevally	Lakalaka	Artisanal Recreational	Y	Mangrove Estuary	4
Fish	*Mugil cepahalus*	Mangrove mullet	Blanak	Artisanal	Y	Mangrove	4
Fish		Grouper (general)	Kerapu	Artisanal Recreational Small-scale	Y	Mangrove Estuary Offshore	5
Fish	*Oreochromis mossambicus*	Mozambique tilapia	Mujair	Artisanal	Y	Mangrove	3
Fish	*Oreochromis niloticus*	Nile tilapia	Nila	Artisanal	Y	Mangrove	1
Fish	*Leithognathus equulus*	Common ponyfish		Artisanal Recreational	Y	Mangrove	2
Fish	*Lutjanus grisius*	Grey snapper		Artisanal	Y	Mangrove	1

Fish	*Lutjanus russellii*	Russel's Snapper		Artisanal Recreational	Y	Mangrove	2
Fish		Snapper (general)	Kakap	Recreational		Mangrove Estuary	3
Fish	*Saurida nebulosa*	Clouded lizardfish		Artisanal	Y	Mangrove	1
Fish	*Chanos chanos*	Milkfish		Artisanal Small-scale	Y	Mangrove Offshore	2
Fish	*Siganus lineatus*	Goldenlined spinefoot		Artisanal	Y	Mangrove	1
Fish	*Siganus guttatus*	Orange-spotted		Artisanal	Y	Mangrove	1
Fish	*Siganus vermiculatus*	Vermiculated spinefoot		Artisanal	Y	Mangrove	1
Fish	*Upeneus tragula*	Freckled goatfish		Artisanal Recreational	Y	Mangrove	2
Fish	*Terapon jarbua*	Jarbua terapon	Kerong-Kerong	Recreational	Y	Mangrove	1
Fish	*		Benghulu	Recreational		Estuary	1
Fish	*		Japris	Recreational		Estuary	1
Fish	*		Lemuju	Recreational		Mangrove Estuary	2
Fish	*		Mudoc	Recreational		Mangrove	1

Fish	*Lethrinus atkinsoni*	Pacific yellowtail emperor		Recreational	Y	Mangrove	1
Fish	*Epinephelu srivulatus*	Halfmoon grouper		Recreational	Y	Mangrove	1
Fish		Grey shark		Recreational		Estuary	1
Fish	*Auxis rochei*	Bullet tuna	Tongkol	Small-scale Commercial	N	Offshore	6
Fish	*Leptura canthussavala*	Savalai hartail	Layur	Small-scale	N	Offshore	4
Fish	*Sardinella lemuru*	Bali Sardinella	Lemuru	Small-scale Commercial	N	Offshore	3
Fish		*Short-bodied mackerel*	Suluk	Small-scale		Offshore	1
Fish	*Decapterus macrosoma*	Short-fin scad	Layang	Small-scale, Commercial	N	Offshore	3
Fish		Small fish		Commercial		Mangrove	1
Crustaceans	*Scylla serrata*	Mangrove crab	Mangrove crab	Artisanal Recreational	Y	Mangrove	5
Crustaceans		Red mangrove crab		Artisanal		Mangrove	1
Crustaceans		Crab (general)		Recreational Small-scale		Mangrove Estuary	3

				Commercial			
Shrimp		Shrimp (general)		Artisanal		Mangrove	2
Gastropods		Snails (general)		Artisanal		Mangrove	1
Bivalves		Shells (general)		Recreational		Mangrove	2
Bivalves		Scallops (general)		Small-scale		Mangrove	1
Bivalves		Oysters (general)		Artisanal		Mangrove	1
Bivalves	*Perna viridis*	Green mussels	Green mussels	Artisanal Commercial	Y	Mangrove	3
Bivalves	*Polymedosa expansa*	Broad geloina/Marsh clam	Kerang toc toc	Artisanal	Y	Mangrove	1
Cephalopods	*Loligo vulgaris*	Common squid	Cumi-cumi	Small-scale	N	Offshore	1

* Species corresponding to local name given that could not be identified.

Location: Traditional fishing was concentrated around the mangrove-lined areas of the Perancak estuary and its smaller tributaries, which run throughout the villages in Jembrana (Fig. 3-4) (See Appendix 3-2 for original annotated maps). All respondents indicated that they visit the mangroves for fishing activities every day, unless the weather prevents them from fishing. Depending on the catch being targeted, fishing takes place directly within the mangrove forest or on its muddy banks at low tide (e.g. mangrove crabs or mussels), or in the estuary within 1-6 m distance of the mangrove (e.g. fish or shrimp). Fishers have 1-4 fishing sites that they either visit throughout the day or alternate between on separate days; these sites are always in or near the mangrove (Fig. 3-3). An exception to these two patterns of activity is the use of inactive aquaculture ponds as a secondary fishing site. One respondent mentioned using an aquaculture site only when he was initially unsuccessful in catching anything from the mangrove.

Without spatial information on the distribution of replanted and natural mangroves, whether fishers use the replanted mangrove areas for fishing could not be determined. However, one fisher indicated a preference for natural mangrove as fishing site for bivalves, suggesting that from the replanted mangrove *"the taste is no good".*

Fishing locations were also suggested to be chosen based on convenience, with fishers opting first for mangrove areas closest to their houses, and moving further afield throughout the day. This was reiterated by one fisher in Budung, a village located furthest away from the mouth of the estuary, who suggested that in his community "*mainly they are fishing in the mangrove, nobody goes to the sea"* whereas in the villages closer to the mouth of the estuary, there is a much larger presence of small-scale and commercial fishers that fish at sea.

Figure 3-4. Fishing location by sector based on participatory mapping by fishers and other stakeholders in the Perancak estuary area of the Jembrana Sub-district, Jembrana Regency, Bali. Sectors included are traditional, small-scale, commercial and recreational fishing. For the location of the Perancak estuary in Bali see Figure 3-1. Note: Sectors refer to groups of fishers who identify as belonging to the sector, as opposed to representing activity of the sector itself.

Time: The location of traditional fishing grounds is not influenced by seasonality, with fishers suggesting that they visit the same mangrove areas all year round, and further suggesting that fishing grounds have not changed for several years. One respondent suggested *"he has fished in the same area since 1987".* However, whilst the area of the mangrove that is used for fishing remains the same, fishers will switch between target catches depending on consumer demand and profitability. Thus, for example, one respondent indicated that mussels (which he gathers on the muddy bank in the mangrove) are most profitable between April and July and fish (which he catches in the river next to the mangrove) between July and August.

Fishing effort by traditional fishers ranges from 3-9 hours per day under normal conditions where fishing is not limited by the weather. In particularly good weather, some fishers are inclined to increase their fishing effort, while in heavy rain or very hot temperatures, the majority of fishers will either drastically shorten their fishing trip or decide to not go fishing at all. Thus whilst under normal conditions traditional fishers will visit the mangrove daily, in the bad season, fishing is typically reduced to two days per week.

Function: Fishing comprises the sole or primary occupation of most traditional fishers. Some fishers however also have additional seasonal or part time work that acts as a secondary occupation. These activities are generally secondary to fishing in bringing household income although in some cases, such as respondents who worked in construction or aquaculture, this seasonal work can form the dominant proportion of monetary income. Traditional fishing offers a low income but is a year round occupation. For example a respondent whose daily activity is traditional fishing but who works seasonally in the rice fields stated that *"his daily work is catching fish, he gets money, maybe 15,000 rp (1.1 US$) but in the rice field he can get 100,000 rp (7.5 US$) in one day, but it's seasonal so in one year he only works in the rice field for one month"*.

Income from traditional fishing per trip (one day's work) ranges from 0.75 US$ to 15.74 US$. As target catch is very variable amongst traditional fishers, and as each product has a different market value, monetary returns and fishing effort required is wide ranging amongst fishers of this sector. Traditional fishers sell the majority of their catch, which is dispersed locally. Products are sold directly to local customers, directly at the local market or restaurants, or sold to an agent who sells it at the local market. Both male and females are involved in fishing activities. However in the majority of households the female spouse is not involved in fishing and sometimes has an alternative occupation, such as office work or retail. It should be noted therefore that while fishing is the primary income of the fisher, other household members may have alternative incomes.

While the primary objective of traditional fishing is monetary income, traditional fishers keep some of their catch for subsistence purposes. Most traditional fishers only keep a little of their catch for their family every day and these are often the products of lowest quality. Fish and seafood catch therefore forms an important part of the daily diet for traditional fishers but the proportion of fish or seafood in the diet can be influenced by the productivity of the fishery. One respondent suggested that *"in the good season people eat fish every day, but we're having a bad season in the past year due to the weather, there is less fish so people don't eat as much seafood anymore".* In contrast, a respondent who keeps some of her bivalve catch for the family each day suggested that fishing makes an important contribution to the diet, saying *"you don't need to buy because you can find your food in nature".* On the other hand, some fishers do not consume any of their catch and buy seafood elsewhere. Use of mangrove-fishing for subsistence therefore varies in relation to individual behaviour. Some traditional fishers also partake in additional recreational fishing on weekends or evenings with their family. This catch is kept only for subsistence.

3.5.1.2 Recreational fishers

Recreational fishing, fishing activity conducted as a hobby rather than an occupation, is a popular activity undertaken by people living in communities near the Perancak Estuary in Jembrana. Whist sometimes conducted alone, recreational fishing is an activity which is usually carried out by groups of friends. It is also an activity which all of the family can be involved in, with fishers often taking small children with them. Likewise, recreational fishers recounted taking part since childhood, being taught by elder members of their family. As such, the age of respondents in this fishing sector was at its most wide ranging, from 22 to 77 years old. Mangrove use by recreational fishers in the Perancak estuary is summarised in Figure 3-5.

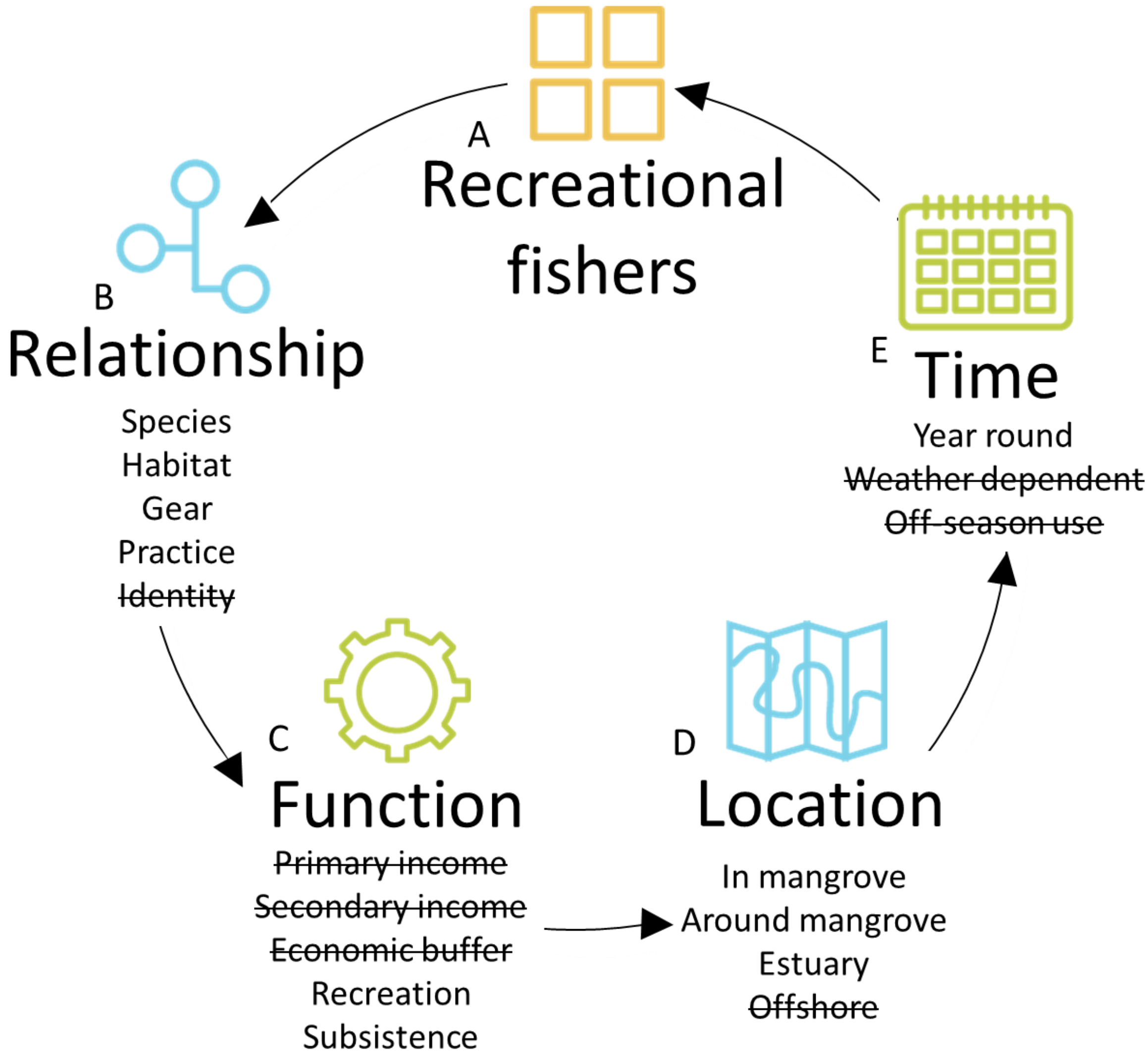


Figure 3-5. Mangrove use by recreational fishers in the Perancak Estuary, Jembrana Sub-district, Bali, following the framework for defining the characteristics of a mangrove-fishery through dimensions of A) sector, B) relationship or connection with the mangrove, C) function of fishing and D) location of fishing and E) time of mangrove-associated fishing. Crossed out attributes do not apply to the group of fishers described.

Mangrove connection: All species caught by recreational fishers are known mangrove associates (Table 3-2). Recreational fishers in Jembrana mainly targeted demersal fish found in the Perancak estuary or smaller tributary rivers (see Table 3-2 for a full list of species caught). Snappers (*Lutjanus* spp.), in particular mangrove red snapper (*Lutjanus argentimaculatus*), are the most sought after target catch amongst fishers and are targeted by all respondents of this sector. Grouper (*Epinephelus* spp.) and trevally (*Carangidae* spp.) are also popular target catch. Fishers also occasionally collect invertebrates such as crabs and bivalves, although these are generally kept for use as bait.

Other than for bait collection, recreational fishers rarely carry out the practice of going directly to gather from the mangrove. Instead, recreational fishing is conducted from land using techniques that are common with some fishers of the traditional fishing sector. These are mostly variations of hand lines, which are configured with varying materials and lengths for use with different bait or with a particular target catch in mind. Some fishers have more than one type of hand line that they take on each fishing trip, in order to catch more than one target species. Also used is a type of hand line without a pole, locally named a “Jorang” or a “Gulangan”.

Recreational fishing takes place in close proximity to the mangrove and therefore recreational fishers are also connected to the mangrove through use of the mangrove habitat. Mangrove areas are consciously chosen as a preferred location by recreational fishers, with one respondent confirming this; “[the mangrove] *is important because where there is mangrove there is fish*”. Even so, recreational fishers do not self-identify as mangrove-fishers, or as fishers at all, as fishing is not their occupation.

Function: Recreational fishing is not perceived as an occupation by fishers in Jembrana because the catch is not for sale. Respondents of the recreational fishing sector were either retired from other occupations or currently have work in occupations not related to fishing and therefore the function of fishing is for recreation only.

Catch is kept entirely for personal consumption and thus has subsistence value. Fishers usually take home between 1 up to 13 fish per fishing trip. The exception was one fisher, who was the only respondent who fished recreationally by boat. He indicated that he can catch 25-30 kg of fish per trip. For some households, the fish caught during recreational fishing activities fulfils all of the families intake of fish in the diet, with one fisher stating that one fishing trip is “*2-5 days’ worth of fish for the family*” and another respondent that “*he never buys fish from the market because they eat what they catch and if it’s too much they keep it in the freezer*”. Others do not fulfil their subsistence needs from recreational fishing and therefore also buy fish or seafood from the market.

The amount of fish and seafood consumed by those who conduct recreational fishing varies between households. Some catch fish to eat fish every day, with one fisher suggesting “*They eat fish every day in the family. His house is only 100 m from the river*”. Within other families, fish consumption is more seasonal. One respondent stated; “*[Diet] depends on the season, during the season they eat a lot of fish/seafood. Now [March] is not the season. They buy different foods from the market instead*”. In contradiction to the seasonality conveyed by this respondent, another fisher suggested that March to April is the good season for fish; "*There are lots of fish in March and April. Sometimes lots in the morning, sometimes in the afternoon, he cannot predict it. This is because of climate change*". The first of these respondents may have been be referring to the seasonal nature of the pelagic fishery in the Bali strait that determines whether or not they buy fish at the market, as the price of buying these species may fluctuate along with the commercial fishery. The second respondent may have been discussing the seasonality of recreational fishing within the estuary.

Other fishers are more reluctant to buy fish from the market, preferring to eat their own catch or buy from small grocery stalls. One respondent stated that while his family do buy from the market *"he is afraid to buy fish from the market because sometimes in Indonesia they put formalin in to preserve it and that's not good for you".*

As most recreational fishers use hand lines, they must also use bait. This bait is either sourced through fishing for it themselves, such as small fish, crabs, shrimp, bivalves or worms, or by buying bait at the market. Fish bought from the market to be used as bait include Bali sardinella (*Sardinella lemuru*), named locally as "Lemuru", which costs around 0.37-0.75$ per fishing trip (using half a kilo per fishing trip). An alternative bait is fringescale sardinella (*Sardinella fimbriata*), known locally as "Tembang", which was reported to currently (2017) cost 1.87$ per kilo, with the respondent noting that this fish is "*more expensive right now because there is big wind and the fishermen don't go to fish*".

Location: Recreational fishing trips are conducted near the mangrove forest along the Perancak Estuary (Fig. 3-4) with a concentration of activity centred on one bridge crossing the estuary. When fishing from the bridge, fishers are no more than approximately 30 metres away from mangrove habitat. Some fishers also stand in the river or on the river bank, between 2 and 12 metres from the mangrove but rarely within the mangrove forest itself. Fishers choose their distance from the mangrove for logistical reasons related to gear configuration. One fisher explained his choice of fishing site as follows: "*6-10 metres from the mangrove. When there is a lot of mangrove there is a lot of fish also. In the roots of the mangrove there is a lot of fish but it's hard to get fish there because the line gets stuck*". Another fisher suggested that he stops 12 metres from the mangrove, *"as he is looking for fish in the roots*".

Time: Recreational fishing does not appear to be restricted by seasonality of the target catch and occurs year round, only being influenced by changeability in the weather. Time spent fishing is variable amongst recreational fishers, ranging between 1-5 hours per trip and between 2-7 trips per week. With some fishers therefore spending as much as 14 hours fishing per week, recreational fishing, while not as frequent as by those who fish as an occupation, makes up a large proportion of leisure time. Being a recreational activity, fishing effort does not follow so rigid a pattern as those who conduct fishing as an occupation, with fishers stating that they stop fishing "*when they feel they have had enough*" and opt for fishing trips only when the weather or water conditions are good.

3.5.1.3 Small-scale fishers

Small-scale fishing is conducted using small wooden boats called "Jukung", and more modernized versions made from fiberglass called "Fiber" (Fig. 3-6). Fishing is mainly conducted at sea, seasonally targeting both pelagic and demersal fish. The number of small scale fishing boats is not distinguished from the commercial fishing vessels within government statistics of fishing in Jembrana, totalling 627 boats in the Jembrana sub-district. 620 of these vessels use a motor with just 7 units of non-motor boats/Jukung (Jembrana Office for Marine Fisheries and Forestry 2014). (Jukung can be sailed without a motor, but most small scale fishers do incorporate a small engine). However, numerous observations of Jukung along the Perancak estuary along with information sought through interviews suggest this total of 627 is a large underestimate of the traditional boats present.

Respondents of the small scale fishing sector were between the ages of 38-40. Small-scale fishing, similarly to traditional fishing in Jembrana, is an occupation passed through generations, with fishers recounting having been fishing all their lives (between 15 and 25 years), since being taught by family during childhood or learning through seasonal work on fishing boats. Fishing in the Jukung can be conducted alone or including up to two people per boat. Mangrove use by small-scale fishers in the Perancak estuary is summarised in Figure 3-7.

Figure 3-6. Small wooden fishing boats, Jukung, used by small-scale Balinese fishers in the Jembrana sub-district. Photograph taken in February 2017 at Air Kuning Beach, Air Kuning Village, where many fishermen launch their fishing boats.

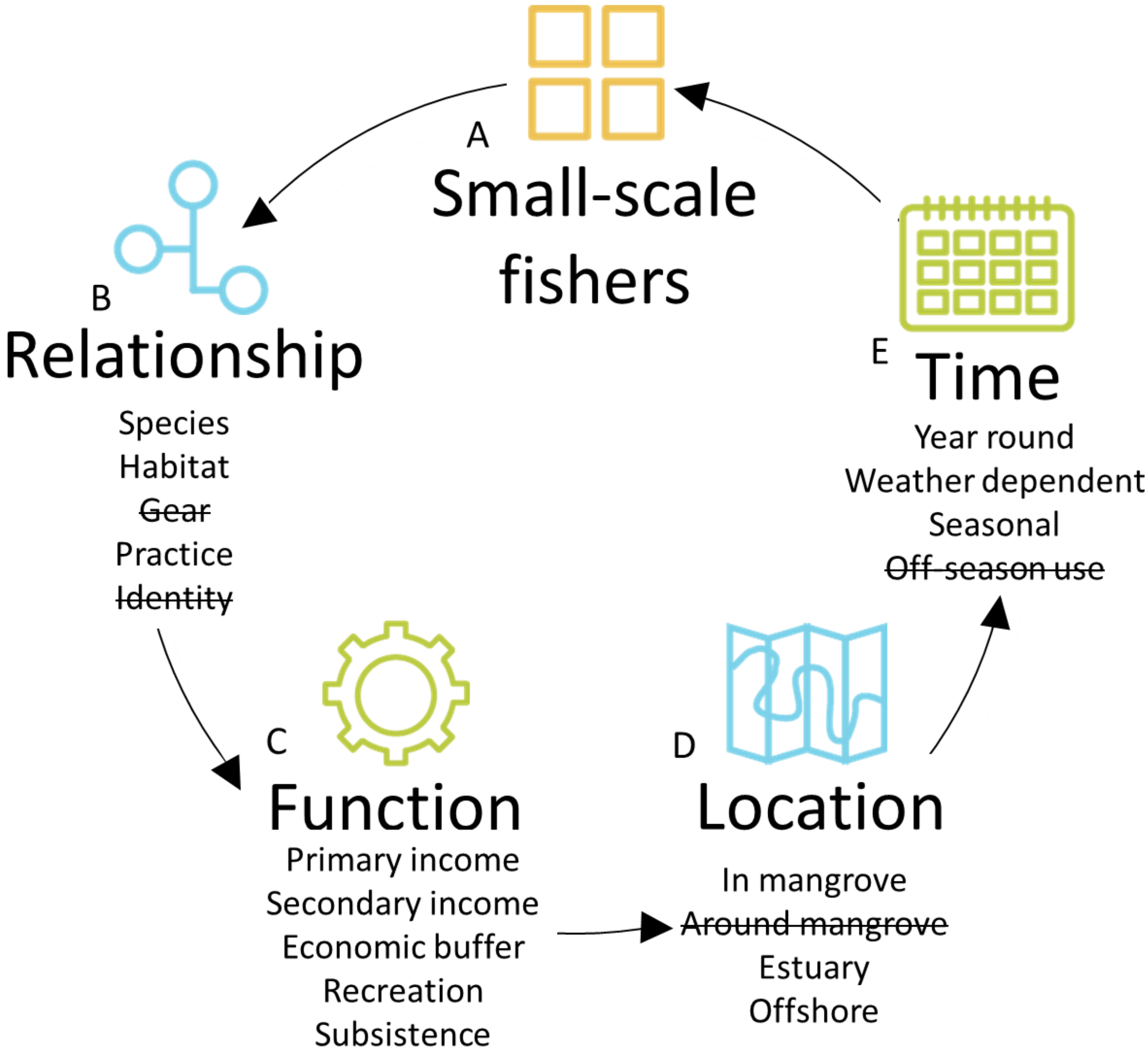


Figure 3-7. Mangrove use by small-scale fishers in the Perancak Estuary, Jembrana Sub-district, Bali, following the framework for defining the characteristics of a mangrove-fishery through dimensions of A) sector, B) relationship or connection with the mangrove, C) function of fishing and D) location of fishing and E) time of mangrove-associated fishing. Crossed out attributes do not apply to the group of fishers described.

Connection with mangrove: Mangrove-associated species are not the primary target species for small-scale fishers. The main target species for small-scale fishers is Bali sardinella (*Sardinella lemuru*) which is caught offshore. However, catches of Bali sardinella are seasonal and therefore small-scale fishers intermittently target demersal fish. These demersal fish species, also caught offshore, include known mangrove-associated species such as grouper species and red snapper (*L. argentimaculatus)* (Table 3-2). Demersal species are grouped as an "other" category within fish landings reports in Jembrana and therefore the proportion of mangrove-associated species could not be calculated (Jembrana Office for Marine Fisheries and Forestry 2014). Nonetheless, demersal species provide a year round option, likely providing a buffer to the seasonality of the pelagic species which are predominantly targeted. The seasonality of small-scale fishing targets is detailed in Table 3-3.

Small-scale fishers do not directly use the mangrove during their normal activities. However when the weather prevents fishing activities at sea, small-scale fishers fish within the mangrove-estuary. During this time they catch mangrove associated fish species (Table 3-2). Small-scale fishers do not practice mangrove gathering or use gear associated with mangrove fishing during this time and they therefore do not identify as mangrove fishers.

Table 3-3. Seasonality and market value of target catch by small scale fishers. Seasonality of mangrove associated catch is also indicated (Mangrove associated = Yellow, Non-mangrove associated = Black). Species names that correspond to common names listed are detailed in Table 3-2.

Target (Local name)	**Common name**	**Price per kg (rp)**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mangrove associate?**
Karapu	Grouper	80,000													Yes
Kakap merah	Red snapper	50,000													Yes
Layur	Hairtails	25,000 - 30,000													No
Kembung	Island mackerel	25,000													No
Putian/Suluk	Short-bodied mackerel	15,000 - 25,000													No
Layang	Scad	18,000													No
Tongkol	Frigate tuna	15,000													No
Lemuru	Bali sardinella	7,000-8,000													No

Function: The primary purpose of small-scale fishing is for monetary income. Income from small-scale fishing fluctuates with seasonal catches. This is because seasonality influences both the potential catch volume and the market value of the catch species. For example, a fishing agent who buys from 50 small-scale fishing boats suggested that during a good season for pelagic fish, the catch can be 100-200 kg per boat but only 20 kg in the off season. For demersal catch, which is not seasonal, fishers bring in 10-20 kg per boat. Yields reported by small-scale fishers themselves were consistent with that of the fishing agent, suggesting that in the off season, they can catch between 20-35 kg of pelagic fish, with this figure increasing substantially in the good season for fishing.

Expenses involved in small-scale fishing include fuel, subsistence and bait costs. Agreements between agents and fishers generally involve the costs of equipment (boats, engines, gear and bait) being provided by the agent, while fishers must provide fuel, subsistence and repairs themselves. The fishing agent interviewed suggested that the fishers therefore achieve around 20% profit after expenses. One respondent suggested that for overnight fishing trips (e.g. for catching Suluk, short-bodied mackerel), he will spend 11.24 US$ on fuel and 5.24 US$ on subsistence (food/water and cigarettes), while for a shorter trip during the morning, he will spend on average 3.37 US$ on fuel and 1.5 US$ on subsistence.

The majority of the catch is sold to the agent, who sells it either at local markets or to markets in Denpasar, the largest city in Bali. Here the price for demersal fish is higher than locally. The quality of fish determines whether it is sold in local markets, local restaurants or is exported internationally.

The fishers do however keep back some of the catch (for example between 2-5 fish per day) for their family, giving small-scale fishing a secondary subsistence role. One respondent suggested *"They keep a few for their consumption. Only keep about 5 fish per day, only 5 because tomorrow they will get it again"*. Some small scale fishers also partake in more traditional fishing such as crab fishing, which is kept for their family's consumption, or is sold to local families at their houses. One respondent suggested that he fishes for scallops every two days, selling between 3-3.75 US$ of products per trip to local people, while another respondent reported that "*If he goes to the mangrove he catches fish for the family but when they go to the sea the fish is for selling and some is for his family*". Fish therefore is an important part of the diet of families who conduct small-scale fishing, well-illustrated by one small-scale fishing respondent:

"It's the main diet, there's no side effect like there is with chicken and pork. Fish is fresh and it's good for your health and they know that they catch it themselves, so it's good. They don't go to the market for fish, just for vegetables/sauce/spices. They don't buy fish from the market because they don't know if it is fresh, it's funny when a fisherman goes to market to buy fish."

Within some villages in Jembrana, small-scale fishing is also popular as a seasonal occupation. One respondent indicated that in his village (Perancak Village, which sits at the mouth of the Perancak Estuary), "*80 % of the village is a fisherman" and "if there is a fish season, everybody goes to sea*". A fishing agent from the neighbouring village, Air Kuning Village, also suggested that everybody in his village owns a Jukung. Furthermore, during the period of this study (2017), out of the 50 Jukung which he manages, just 20 are currently active, suggesting that some fishers are active only in the most profitable season (May – June). Despite this finding, other respondents of the small-scale fishing sector suggested that they do continue to fish outside of this most profitable season, unless there is bad weather that prevents them from doing so. Small-scale fishers also occasionally use the mangrove area for recreational fishing activities, keeping the catch for subsistence purposes.

Location: Small-scale fishing primarily takes place at sea (Fig. 3-8). According to regulation, small scale fishing can take place between two zones which are bound at a minimum of 4 nautical miles (7.4 km) and 8 nautical miles (14.8 km) respectively from the Balinese coast (Jembrana Office for Marine Fisheries and Forestry 2014). Small scale fishers from Jembrana often frequent 2 popular fishing spots in South Bali, named Jimbaran and Tabanan, taking a route east out of the Perancak estuary and fishing along the coast within these zones (Fig. 3-8). Fishers had difficulty specifying their distance from shore when fishing, but it is noted that when fishing for demersal fish, they are closer to shore than when targeting pelagic fish. An additional fishing sites are Muncar, within the Bali Strait and in North of Bali, although the latter is only used when fishers are unsuccessful elsewhere (Fig. 3-8). Mangrove associated demersal fish detailed in Table 3-2 are therefore caught offshore within locations shown in Figure 3-8, although the exact location in which these species are targeted, and their distance from the mangrove forest was not specified. When small-scale fishing cannot be conducted at sea, small-scale fishing respondents report using the Perancak Estuary or mangrove forest areas (Fig. 3-3).

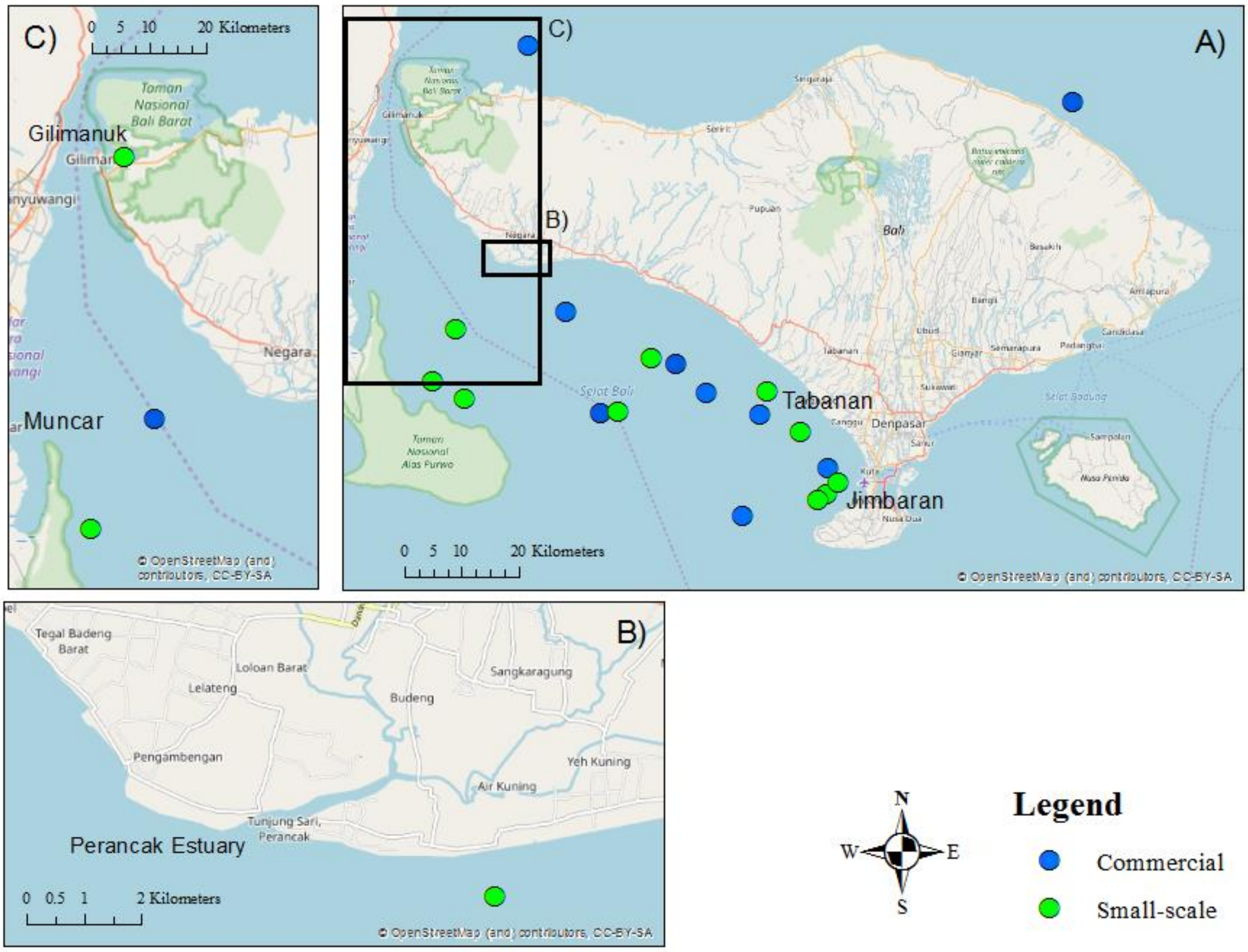


Figure 3-8. Offshore fishing sites as annotated by small-scale and commercial fishers in the Jembrana sub-district, Jembana Regency, Bali. Fishing sites are marked as the mid-point of polygons and lines drawn by fishermen. Map includes showing A) Bali, Indonesia, B) The Perancak Estuary, Jembrana Sub-district, Jembrana Regency, West Bali which was the primary study site and C) Gilimanuk, West Bali.

Time: Target catches of small-scale fishers are seasonal (Table 3-3). However switching between seasonal catches means small-scale fishing can be a year-round occupation. A government official discussing the seasonal nature of fishing in Jembrana made this point: *"For Jukung it does not depend on the season because of the target, they target demersal and Tongkol and they change the fishing gear so they change according to what fish is there and they can go anytime. Maybe only the weather delays them".*

The frequency of direct mangrove use by small-scale fishers is therefore weather dependent, using the Perancak Estuary as a fishing ground when weather is unsuitable for fishing at sea. Some fishers use this secondary option for collecting products for sale, while others just collect products in the estuary to keep for their family. One small-scale fisher highlighted that *"mangrove is not the main* *site for fishing, the main fishing is in the sea*". However, another respondent whose primary fishing occurred at sea when prompted as to how often he visited the mangrove stated "*often, when the weather is too bad to go to the sea, about 4 times per week*". This response suggests that the secondary option of using the estuary is frequently used by some small scale fishers.

3.5.1.4 Commercial fishers

Commercial fishing is the largest fishing sector in the Jembrana Regency (Jembrana Office for Marine Fisheries and Forestry 2014). Commercial fishing boats have a maximum gross tonnage of 30 GT and primarily use purse seines to catch Bali sardinella and other pelagic species. Mangrove use by commercial fishers in the Perancak estuary is summarised in Figure 3-9.

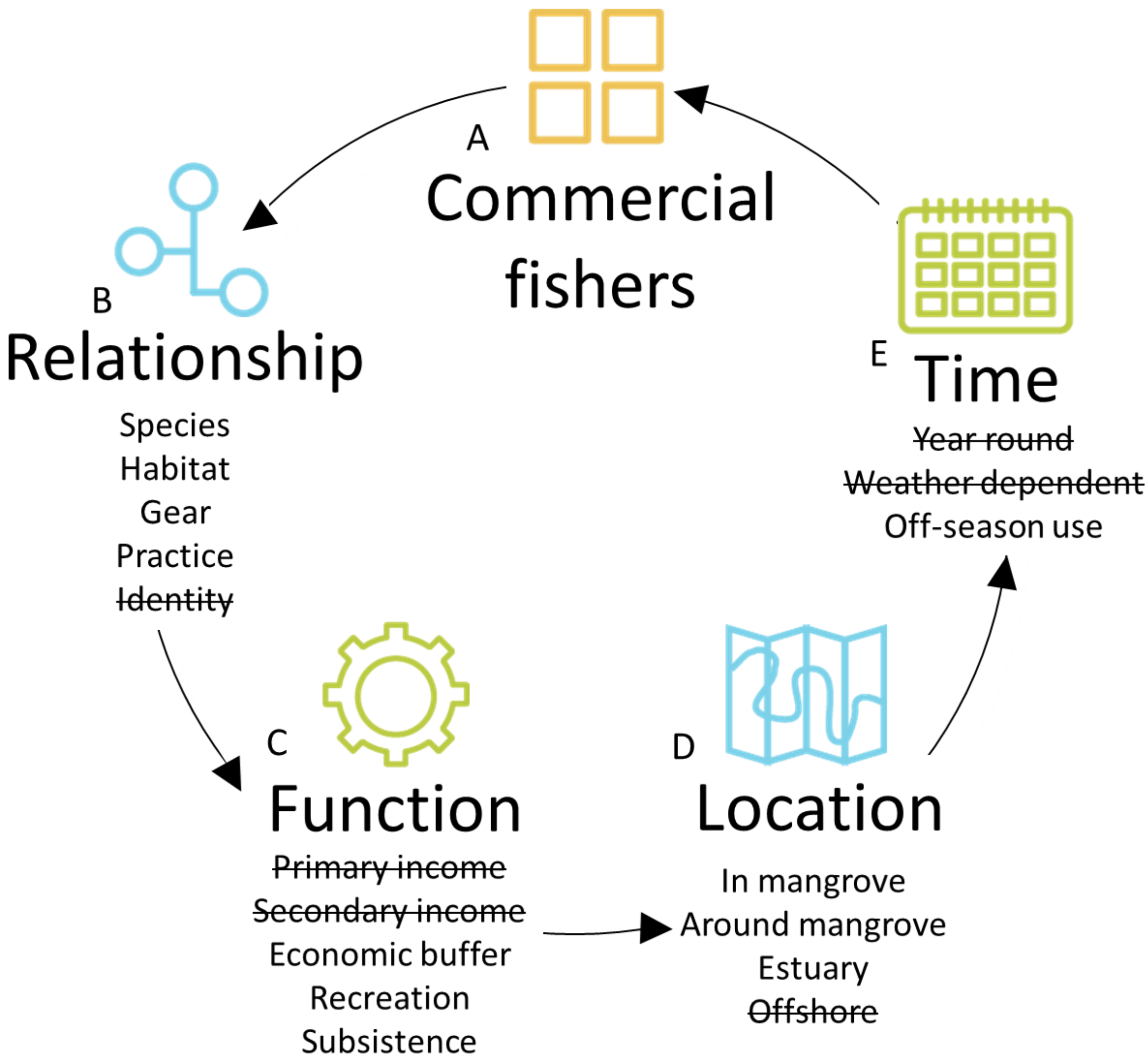


Figure 3-9. Mangrove use by commercial fishers in the Perancak Estuary, Jembrana sub-district, Bali, following the framework for defining the characteristics of a mangrove-fishery through dimensions of A) sector, B) relationship or connection with the mangrove, C) function of fishing and D) location of fishing and E) time of mangrove-associated fishing. Crossed out attributes do not apply to the group of fishers described. Note: "Commercial fishers" refers to the fishers belonging to the sector, and their other non-commercial activities, rather than commercial fishing activity itself.

Mangrove connection: Normal commercial fishing activity does not target mangrove-associated species. The main species targets for commercial fishers are Bali sardinella (*Sardinella lemuru*), locally named “Lemuru”, bullet tuna (*Auxis rochei*), or “Tongkol” and shortfin scad (*Decapterus macrosoma*), known as “Layang” (Table 3-1). Conducted offshore, commercial fishing does not use the mangrove habitat. However, commercial fishing activities are seasonal and those fishers on commercial boats require secondary options during the off-season. During this time, fishing in the Perancak Estuary can provide a secondary option for both subsistence and income, as discussed below. When using this option, commercial fishers adopt traditional practices of fishing in the mangrove and target mangrove-associated species, such as small fish and bivalves (Table 3-1). Some commercial fishers are therefore connected to the mangrove through the practice of going to the mangrove and using typically mangrove associated fishing techniques. Notwithstanding this behaviour, commercial fishers did not identify themselves as mangrove fishers or traditional fishers.

Function: Commercial fishing during the good season provides the primary income for fishers and is the sector which brings in the largest monetary income. Two commercial fishing boat managers - or “fish masters” - were interviewed, representing boats with 33 and 40 fishers respectively. The fishing masters suggested that the total catch per day ranges from 300 kg in the bad season to the best catch they have experienced of 20,000 kg. On average, catches fall between 2,000 - 5,000 kg per day. This equates to an income of around 150-225 US$ per month per worker. The commercial fish catch is mainly sold to an agent who then sells the catch to one of two local fish processing factories (for Lemuru) or to local markets (for Tongkol). Fishers obtain fish for subsistence needs during the commercial season, as during this time workers on the commercial fishing boats are allowed to take 1-2 kg of fish home per trip. Primary income and subsistence derived from normal commercial fishing activities is however not from mangrove-associated species. However, during the bad season commercial fishers obtain products from the estuary either for subsistence or income. One respondent, when asked if he used the mangrove area for fishing, suggested that the function of this activity is for collecting products for consumption only “*"Never, fishing in the mangrove is not for livelihood but for recreation. They go to fishing and collect the crab and serve it at the dinner table*”.

Due to the seasonality and unpredictability of the Lemuru catch from year to year, in some years there is no work for commercial fishers. At the time of the surveys described in this thesis (2017), there had been no fishing for 9 to 12 months. Many commercial fishers had taken alternative employment (such as drivers, or workers in restaurants or hotels), or were living off of the income generated in the previous year, depending on the fish and the season; “*If he has income for one year, the next year the fish will be gone and he uses the savings from the previous year”.*

Time: The good season for commercial fishing is from October to April (peaking December-April) and the bad season is from May to October. During the bad season, traditional fishing activities are conducted by fishers whose occupation is usually in the commercial fishing industry. These traditional fishing activities are located within the Perancak Estuary (Fig. 3-3) and commercial fishers use the mangrove for fishing during this time. It was unclear how commonly or frequently the mangrove is used as an economic buffer by commercial fishers and further investigation is required. A government official in the regional fisheries office, discussing traditional fishing by commercial fishers suggested "*they use several different fishing gear, net, trap, hand line or cast net (this is all traditional) but from this office they do not have data about the number because it is the secondary option for the fishermen when they do not have money. It is a recreational activity also".* This respondent suggested however that this secondary option of fishing in the mangrove is more frequently used by fishers from the commercial sector than by those from the small-scale sector, due to small-scale fishing being less seasonal, and therefore more stable year round, than commercial fishing.

As the bad season can span from 6 months to an entire year, therefore it represents a wide time period through which fishers may be dependent on this secondary option for subsistence or income from fishing. As some fishers do have other secondary work during the bad season, frequency of use of mangrove areas is variable amongst fishers, and also variable from year to year, depending on the duration and frequency of bad seasons within the commercial sector.

Location: Commercial fishing takes place at sea within 2 popular fishing grounds in South Bali (Figure 3-8). Fishing grounds used by commercial fishers, according to regulation, should be > 12 nautical miles (22.2 km) from shore. However there is no monitoring in place to regulate this practice and therefore small-scale and commercial fishing sectors occupy largely similar fishing grounds. The fishing areas used for traditional fishing by fishers from the commercial sector in the bad season are displayed in Figure 3-3.

3.5.1.5 Aquaculture

Respondents for the aquaculture sector in the Jembrana sub-district included 2 owners of active aquaculture farms, an owner of an aquaculture farm that has ceased production and 2 employed in aquaculture work, 1 of whom is also an aquaculture consultant. Respondents were aged between 27 and 45 years old and included 1 female. Aquaculture farms are often family run businesses in the Jembrana sub-district, in which both the husband and wife are involved in management, and farms are subsequently passed on through generations.

Aquaculture in the sub-district uses mostly traditional technology although wealthier pond owners use manual (semi-intensive) technology. Semi-intensive aquaculture was sometimes referred to by workers as manual technology because it also involves pumps that circulate water in the ponds. Aquaculture production currently includes white leg shrimp (*Litopenaeus vannamei*) known locally as "Vannamei", black tiger shrimp (*Penaeus monodon*), known as "Windu" or "Butang", and milkfish (*Chanos chanos*). Shrimp and fish from the ponds are sold via a middleman to local markets or restaurants in wider Bali as well as being exported to the neighbouring island (Java) or internationally. Mangrove use by aquaculture workers in the Perancak Estuary is summarised in Figure 3-10.

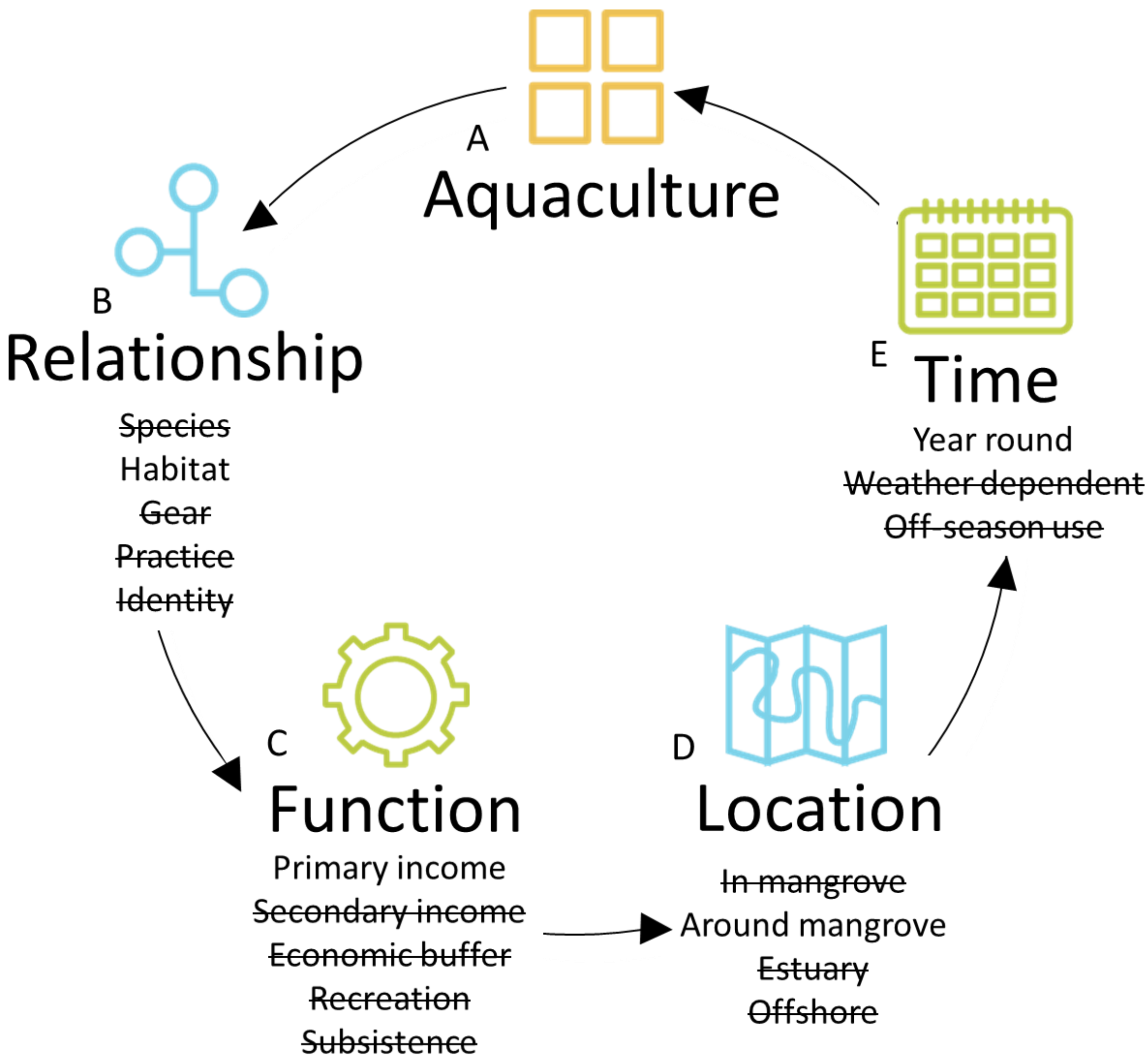


Figure 3-10. Mangrove use by aquaculture owners or workers in the Perancak Estuary area, Jembrana Sub-district, Bali, following the framework for defining the characteristics of a mangrove-fishery through dimensions of A) sector, B) relationship or connection with the mangrove, C) function of fishing and D) location of fishing and E) time of mangrove-associated fishing. Crossed out attributes do not apply to the group of fishers described.

Connection to the mangrove: Aquaculture production derives no direct benefit through mangrove-fishery enhancement. However, aquaculture workers unanimously suggested that the presence of mangrove habitat was indirectly linked to successful production of fish and shrimp within aquaculture ponds. Aquaculture workers therefore actively plant mangrove, or rehabilitate mangrove habitat, on the periphery of their ponds. The value of the presence of mangrove is thought to be through the filtering properties of the trees, preventing pollution from river water from entering the ponds. One aquaculture pond owner suggested "*the mangrove around this area is a profit to his farm, he cannot explain the numbers, but the mangrove filters the water coming from the river into the farm*" and another owner stated "*the water quality affects the production and the mangrove affects the water quality that comes from the river*".

Disease sharing between ponds is thought to be the largest risk to production in the sub-district, with traditional farms all using the same water channels as inlets and outlets for their ponds; "*The problem is from the river, the water comes in. It means that if one aquaculture has a disease, all the others will have it too*". Suggested causes of poor river water quality also include damaging fishing practices, human waste, rubbish, sediment dredging, flooding and run off from agriculture. It was highlighted that "*nowadays, they try and move from traditional to technology*", for reasons of river water pollution. However the modern technology is expensive to implement and therefore is not a viable option for everyone.

This benefit from mangrove presence does not apply to intensive ponds (modern ponds) as they do not rely on clean water sources from the river, instead using water from a well. Nonetheless, respondents using modern technology still perceived the mangrove to be important for other functions, such as stabilizing the borders between ponds.

Location: The location of aquaculture ponds around the Perancak Estuary are detailed in Figure 3-11. It can be observed that ponds line the estuary and the surrounding rivers and their tributaries. Those ponds that use water inputs from these waterways (traditional aquaculture ponds) are bordered by mangroves. Both traditional and semi-intensive ponds also have planted mangroves around the barriers of ponds for structural support of the earthen banks.

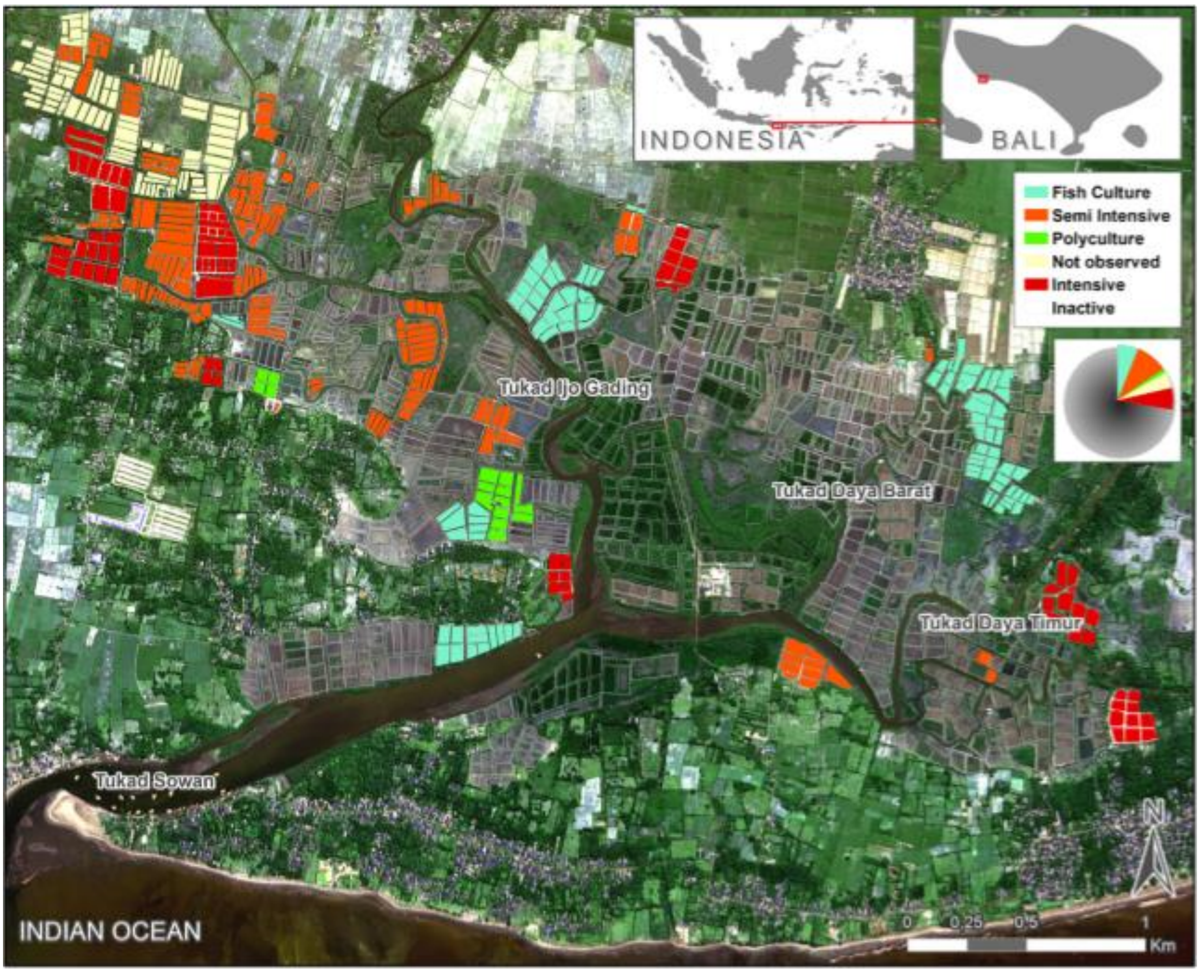


Figure 3-11. Map of aquaculture pond locations around the Perancak estuary in 2014 from (Gusmawati et al. 2018). The pie chart represents the proportions of types of aquaculture production represented within the 1546 ponds present: fish culture, polyculture, semi-intensive, intensive, not observed and inactive ponds.

Time: Aquaculture ponds are active all year round. However there have been notable changes in annual production since the establishment of aquaculture in the 1980s in the Jembrana sub-district. In particular, aquaculture workers recounted a widespread drastic reduction or halt to production in 2005. According to respondents, *"30% [of ponds] were still active at that time, 70% were not".* Respondents linked this episode to the introduction to the ponds of poor quality river water (from pond effluent), enabled by both mangrove cutting (and thus the loss of filtration function) and dredging of sediments from the watercourses which polluted the water through sedimentation and caused mangrove degradation. The introduction of this water to ponds then facilitated the spread of disease. Production from the ponds was halted for several years (until 2014 in some cases) or resulted in a switch to other more disease resistant culture species such as milkfish, or from black tiger shrimp to white leg shrimp, which is now the most popular species farmed in the area.

This halt in production triggered mangrove replanting. This began less than a year after the episode, and has been ongoing ever since, as described by one respondent *"BPOL [The institute for Marine Research and Observation, Bali] and government, they replanted mangrove and the situation is getting better for the aquaculture, there are mangroves here now. They replanted 5 months after the mangrove died. All the mangrove areas that died have been replaced, now it is full of mangrove".*

However, not all respondents agreed that the situation is resolved, with some suggesting that the situation is still not good enough to culture the preferred species, for example suggesting *"There has been no improvement to the water quality. They are hoping at some point it will get better. The mangrove is very good for shrimp aquaculture, the river was more polluted when the mangrove was cut and the conditions meant they could no longer culture shrimp. The replant has not improved the water conditions enough yet to grow shrimp again but they hope that it will".*

Another halt to production occurred in 2010. Interviewed aquaculture workers suggested that this halt was linked to potassium fishing in the rivers. A respondent, whose farm shut down after 2010, suggested that potassium fishing is linked to the decline of the offshore fishery: "*The amount of fish is decreasing because of the people itself. In 2010, there was a problem that they could not find any fish (for almost 2 years), usually there is a lot of fish. Because there is no fish in the ocean anymore, they start looking in the river. The problem is the people use the potassium to catch the fish and the small fish die. It also affects the aquaculture. The quality of fish is an indicator of whether the water is good, and if the water is good, the aquaculture is good*". Respondents attributed changes in production to agricultural run-off, sharing of disease between ponds, changing regulations regarding culture species and use of antibiotics. It should therefore be noted that changes to mangrove area are not the only influence on aquaculture production. Nonetheless, respondents from the aquaculture sector appeared to hold the strongest perception of mangrove presence importance to their own financial wellbeing of all the sectors interviewed.

3.5.2 How do mangrove-fisheries in wider Bali compare?

A description of how all the fishing sectors identified in the Perancak Estuary use mangroves, and therefore a description of what the Perancak Estuary Mangrove-Fishery encompasses overall is summarised in Figure 3-12. To discuss whether this description fits the characteristics of other mangrove-fisheries in Bali, this section compares the Perancak Estuary Mangrove-Fishery to the mangrove-fishing activities observed in Benoa, South Bali and Gilimanuk, Southwest Bali.

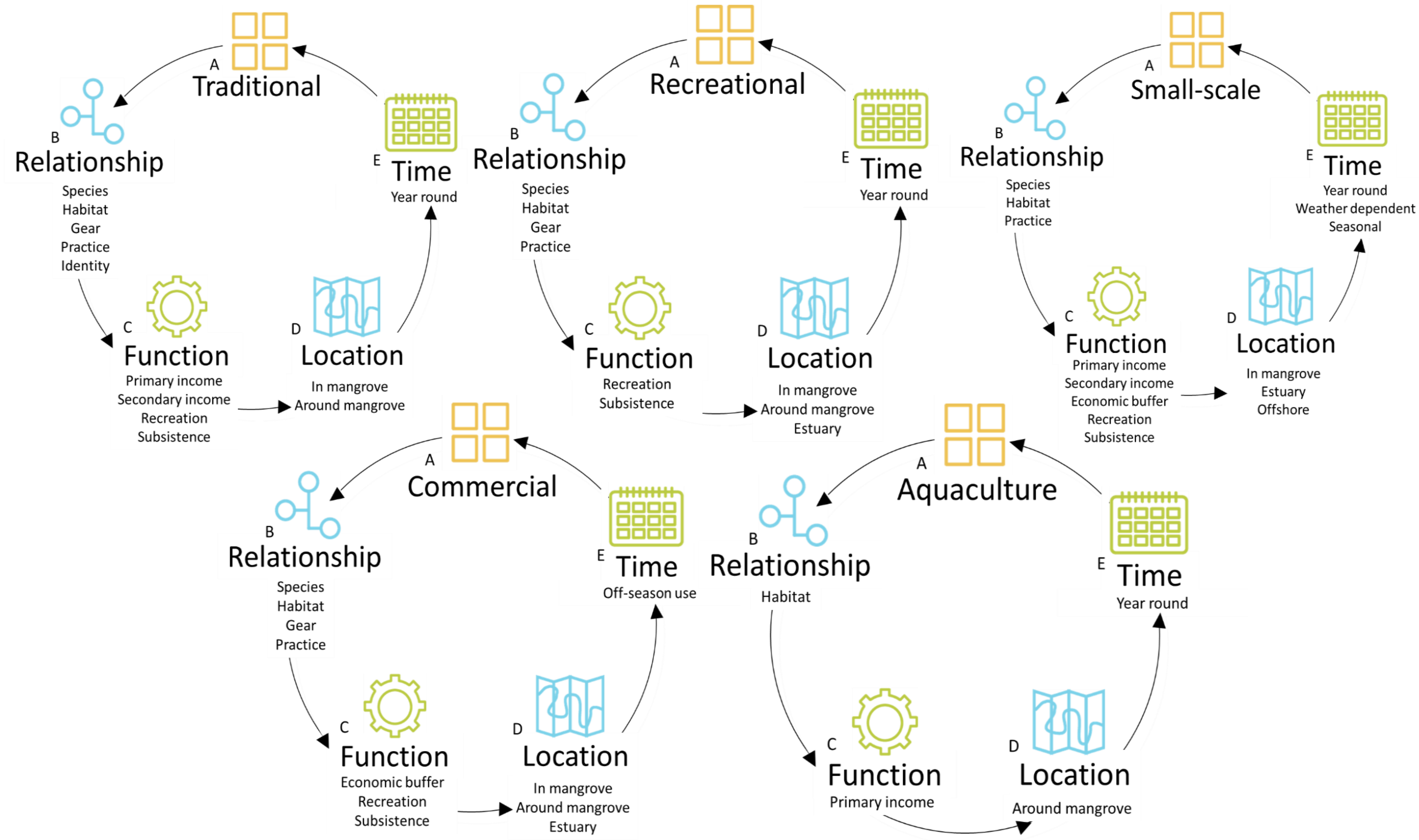


Figure 3-12. The typology of the Perancak Estuary mangrove-fishery, describing how fishers use mangroves through dimensions of A) sector, B) relationship or connection with the mangrove, C) function of fishing and D) location of fishing and E) time scale of mangrove-associated fishing.

3.5.2.1 Benoa Fishing Community, South Bali

The fishing community in Benoa Village, Denpasar, South Bali (Fig. 3-1) is made up of 96 fishermen and their families. Benoa has a 13.73 km^2 expanse of fringing mangrove forest which runs along Benoa Bay, a 25-30 km^2 tidally influenced lagoon (Bach et al. 1998, Hendrawan 2014). Approximately 1 km^2 of the forest is run as a governmental ecotourism centre, with a tourist boardwalk running throughout. Compared to the mangrove-fishing in Perancak, there is more unified fishing community organisation regarding mangrove use in this community which is made up of fishermen of all specifications and their families which operate as one unit. The community, which was established in 2009, is centred around a community owned and managed restaurant, which buys products collected from the mangrove (crab and fish) by the community and sells them within a tourist-targeted restaurant built on a boardwalk within the mangrove forest. Within the community, men carry out the various fishing activities while women manage the community and the restaurant, as well as producing products such as lotions and snacks from the fruit of *Sonneratia* spp.

As in the Jembrana Regency, a mismatch between government and fishing community regarding the importance of mangrove for fishing activities is evident in the area. As in Jembrana, numbers of traditional and small scale fishers are not recorded in government statistics and therefore government level managers are unaware of the extent or variability of mangrove related fishing occurring at Benoa. For instance, a representative of the governing body (the forestry police) of the mangrove area in Benoa stated that *"they have no data about how many people fish there but mostly there is about 5-10 people there every day for the fishing (recreational fishing)"*. Meanwhile, interviews that followed with community members revealed a community of 96 fishers exists in the area.

Sectors identified: Fishing activities in the Benoa Mangrove-Fishing Community included traditional fishing, small-scale fishing, recreational fishing (for tourists) and crab mariculture. There is no commercial fishing sector operating from this community comparable to the large-scale fishing fleet in Perancak. Traditional fishing includes mangrove gathering and use of crab traps. Small-scale fishing was conducted in small-wooden boats with small outboard motors, similar to the Jukung used in Perancak. Small-scale fishers in Benoa mostly fish with hand-lines. There are approximately 50 small-scale fishers in the community. Small-scale fishers also partake in traditional fishing activities, such as catching shrimp by foot with a small mesh named a "Sawukekot". Ten of the small-scale fishers in the community also conduct recreational tourist mangrove-fishing operations, an activity which was not observed in Perancak. These trips entail tourists accompanying fishermen during their usual fishing activities by small-scale fishing boat, or by canoe. The Benoa Fishing Community do not partake in any other recreational fishing activities. However within the tourist mangrove-boardwalk, which is outside of the community, some recreational fishing by individuals fishing with hand lines from the boardwalk, was observed.

In addition, the community conducts crab mariculture within the mangrove forest, where juvenile crabs are bought and incubated, then fenced into natural mangrove habitat where they are fed and harvested. Forty-five community members are employed in mariculture. Benoa is the only place that mangrove-crab mariculture occurs in Bali.

Mangrove connection: All sectors of the Benoa Mangrove-Fishery target mangrove-associated species (Fig. 3-13). Traditional fishers target shrimp and mangrove crab. The main targets of small-scale fishers include giant trevally (*Caranx ignobilis*), known locally as “Kue”, as well as grouper species and rays. Mariculture activities only produce mangrove crab. However the juveniles are bought in from elsewhere and are not collected from the local mangrove. All sectors are also connected to the mangrove through use of the mangrove habitat for all or some of their fishing activities. Most fishers also directly use traditional mangrove gathering techniques for some of their activities. As such, the fishers identify themselves as a community closely connected to the mangrove for income and subsistence. The community is also actively involved in mangrove replanting and educational outreach activities concerning the importance of mangroves to the ecosystem and their livelihoods.

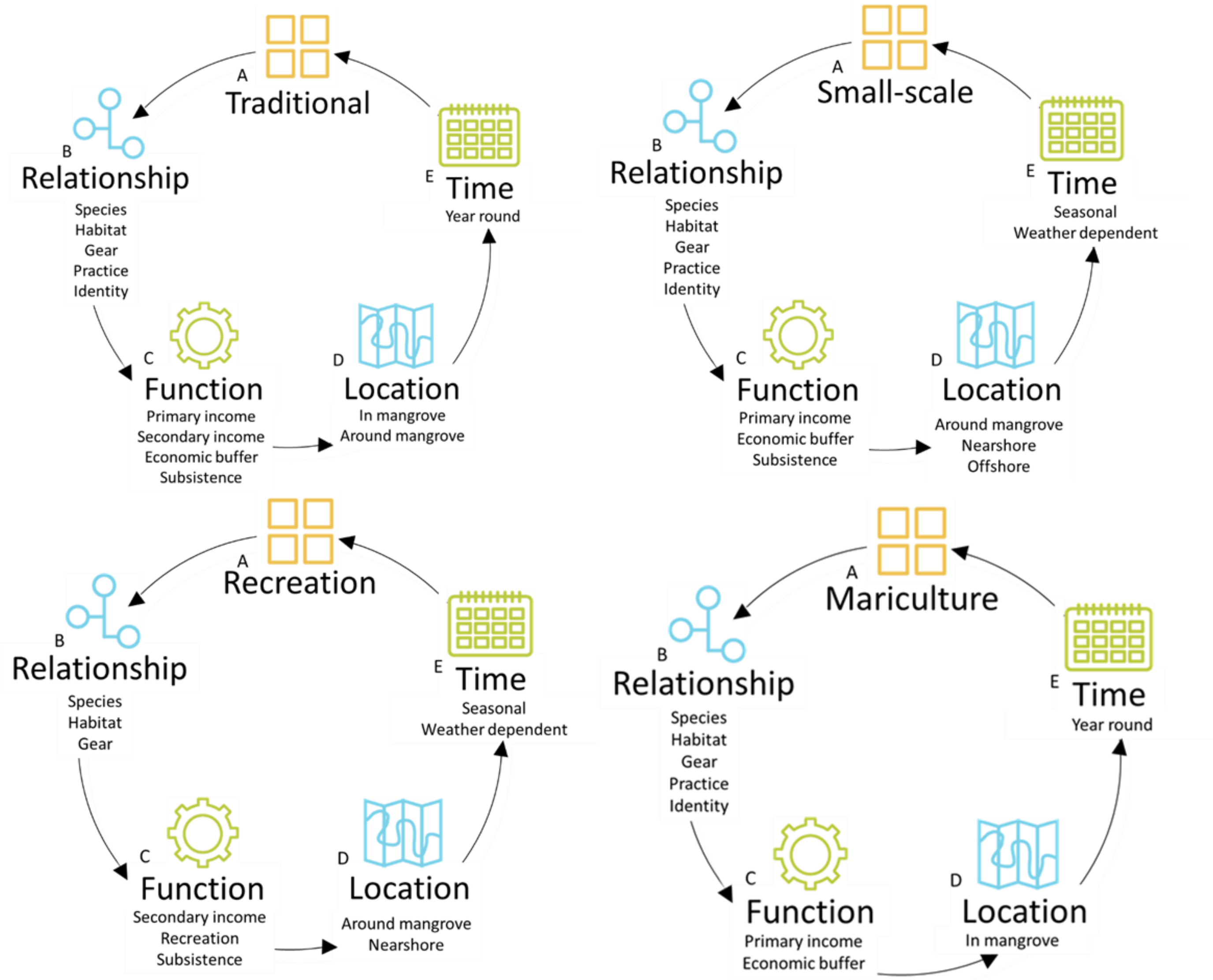


Figure 3-13. Typology of the Benoa Mangrove-Fishery, following the framework for defining the characteristics of a mangrove-fishery through dimensions of A) sector, B) relationship or connection with the mangrove, C) function of fishing and D) location of fishing and E) time of mangrove-associated fishing.

Function: Fishing and mariculture activities are the primary occupations of the Benoa Mangrove-Fishing Community. Crab aquaculture is the occupation with highest income in the area. Crab mariculture was established in Benoa in 2009 due to reductions in fish catch at sea. According to the community head, each member earns a minimum 2.6 million rp (183.60 US$) per month conducting crab aquaculture. One hundred crabs (approximately 40 kg) are bought by the community restaurant each day. Crab production is also seen to present an economic buffer against pressures in the fishery. One respondent suggested "*here if they cannot go to the sea, they have the aquaculture so if there is no fish they can still live from the aquaculture. They also make money from tourism*". Fishers also work in the community restaurant during off seasons or days that they are not fishing.

According to one small-scale fisher, the income from one day of small-scale fishing using 4 hand lines is 100,000-200,000 IDR (7.05-14.11 US$) (but sometimes nothing). He considered this to be his main job, selling the fish to the community restaurant. This fisher noted however that expenses of small-scale fishing trips are high, suggesting 150,000 rp (10.58 US$) is spent on fuel, bait, gear, food and cigarettes for each trip. The community restaurant stated a preference for buying grouper from the fishers but they rarely meet the demand of the restaurant and therefore grouper are also bought elsewhere. Shrimp caught by fishers are sold directly to local customers, local stores or in neighbouring towns such as Kuta.

Traditional fishing in the village also includes collecting crabs from the mangrove using crab traps, which are sold to the community restaurant. Fishers also gain subsistence value from their fishing trips, keeping fish for their families on days where yield is not enough to sell.

Recreational tourist fishing trips make up a secondary income for some fishers, charging approximately 750,000 rp (52.90 US$) per person (and include up to 6 people), 20% of which is given to community restaurant. Any fish caught during these trips is offered to tourists but is often declined and gifted to the fisherman.

Location: Small-scale fishing takes place mainly within the Benoa Bay area. One fisherman suggested that the closest he will fish to the mangrove is 50 m, and 5 km being the furthest away, although the latter is rare. However, other small-scale fishers were also observed fishing within 2 m of the fringing mangrove. Recreational tourist fishing activities take place in the same fishing locations that small-scale fishers frequent in Benoa Bay. Fishers from other communities, such as Kuta, Legian and Denpasar also use Benoa Bay for fishing, but fishers of the Benoa community suggest that these fishers are only there for recreational purposes and that their catch is not for sale.

Crab mariculture takes place within the mangrove forest itself, with workers placing mesh around the mangrove trees to restrict crabs to the area; *"He doesn't want the mangrove cutting, so he makes a prototype of how to make the crab aquaculture without cutting. It will not be a square, the shape will depend on the trees. 50 cm deep, they use bamboo and nets so the crabs will not walk outside the nets they make the nets slippery and simple. Inside the nets they put the crabs inside".* The community has facilities to incubate juveniles before placing them in the mariculture area. Traditional gathering also takes place inside the mangrove or around the mangrove edges in Benoa Bay. There was not sufficient time to carry out participatory mapping to gain more detailed fishing locations in Benoa. However fishing effort appeared more concentrated in one area than the Perancak Estuary Mangrove-Fishery, which was more widely spread by comparison.

Time: Small-scale fishing is a seasonal activity due to weather conditions. One fisher suggested that October-December is the time of particularly bad weather and therefore during this time he does not fish by boat at all, instead working in the community restaurant and conducting traditional shrimp fishing by foot. Tourist mangrove-fishing trips follow small-scale fishing schedules. During the small-scale fishing season, each participating fisher receives tourists approximately twice per month.

Traditional fishing activities in the mangrove are conducted all year-round and are not weather dependent. However it is suggested that the yield is less during the rainy season. Crab mariculture is also active year-round.

3.5.2.2 Gilimanuk, West Bali

The Gilimanuk fishing community lies just outside the bounds of the Bali Barat National Park, Southwest Bali (Fig. 3-1), which has a 3.1 km^2 of fringing mangrove forest (Doherty et al. 2013). Unlike the locations of the two other study sites, the coastal zone of Bali Barat National Park also exhibits seagrass and coral reef habitats (Polunin et al. 1983). The area includes 0.4 km^2 of seagrass habitat and 8 km^2 of coral reef (Doherty et al. 2013).

A rapid assessment revealed that the fishing community in Bali Barat has changed from a community conducting fishing as a primary occupation to one centred on tourism. A community member stated there are "*78 fishermen, but not really fishermen*". Some small-scale fishing still exists within the area, with approximately 30 members of the community still actively fishing. However, the majority of fishermen now use their boats as tourist rentals, with tourists visiting the neighbouring Menjangan Islands. As such, interview respondents who were currently involved in fishing were limited. A description of mangrove use by the remaining fishing community is summarised in Fig. 3-14.

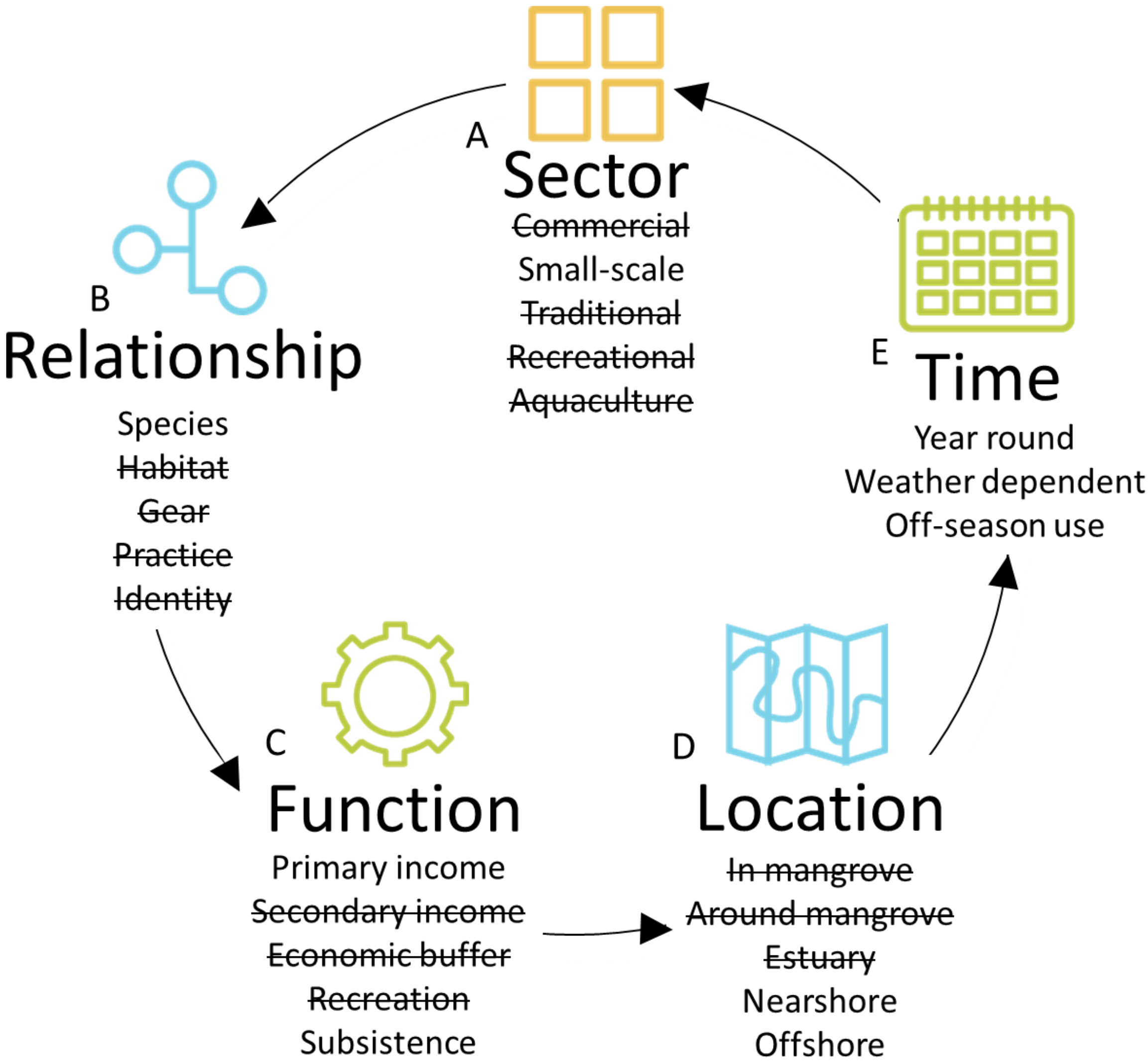


Figure 3-14. Mangrove use by the Gilimanuk Fishing Community, following the framework for defining the characteristics of a mangrove-fishery through dimensions of A) sector, B) relationship or connection with the mangrove, C) function of fishing and D) location of fishing and E) time of mangrove-associated of fishing. Crossed out attributes do not apply to the group of fishers described.

Sectors identified: Small-scale fishing was the only fishing sector identified in Gilimanuk. Fishers in Gilimanuk operate similarly to small-scale fishers in Jembrana and Benoa, fishing with small wooden boats and using the "Bulu" (a line with feathers) to fish offshore.

Tourist activities on fishing boats do not include any fishing activities as they do in the Benoa Fishing Community, being used for transport only. Fishers suggested that tourist fishing operations do not occur because fishing in the mangrove is not allowed in the Bali Barat Nature Reserve.

Mangrove connection: Small-scale fishers in Gilimanuk seasonally target Layang (*Decapterus macrosoma*) and Tongkol (*Auxis rochei*) which are not mangrove-associated species. However, outside of the season for pelagics, fishers also target species that are potentially mangrove-associated, such as shrimp which are caught offshore, or target demersal fish, such as snapper and rabbitfish around the coral reef or seagrass habitats. They also target typically coral reef associated fish such as parrotfish, triggerfish, barracuda and needlefish. These fish were not mentioned as target catch by the Jembrana and Benoa fishing communities. As fishers in Gilimanuk also use coral reef areas for fishing it is difficult to separate the fishery enhancement value provided by mangrove v. coral reef presence.

Fishers in the Gilimanuk community do not directly use the mangrove area for fishing and as such do not conduct any traditional gathering practices. Fishers in Gilimanuk therefore do not identify as mangrove-fishers.

Function: For those who are still fishing, it is their primary occupation, selling the majority of their catch to a local fishing agent. Fishers also have additional occupations in tourism, renting their boats to tourists for trips to Menjarran Island and therefore fishing is not the only income.

As was observed in Jembrana and Benoa, fishers in Gilimanuk keep some of the catch for personal consumption, deriving some subsistence value from their fishing activity.

Time: Small-scale fishing is seasonal, with one fisher suggesting that the good season starts in February and ends in May, switching between Layang and Tongkol during this time. Outside of this time, shrimp or demersal fish can be targeted. As in the other communities, small-scale fishing also depends on the weather.

Location: Small-scale fishing takes place offshore. One fisher suggested that fishing is 15 km offshore over sandy habitats. Others suggest that fishing is near the coral reef and seagrass habitat. Further interviews would be required to understand the extent of fishing grounds used by the community. Fishing does not take place within the mangrove forest in Gilimanuk; "*It's rare that they catch fish near the mangrove area so they go out to the ocean, nobody fishes in the mangrove anymore*".

3.6 Discussion

3.6.1 Defining the Perancak Estuary Mangrove-Fishery

The study has highlighted the complexity of the fishing community in the Perancak Estuary, identifying its 5 self-identified sectors of traditional, recreational, small-scale and commercial fishing, as well as aquaculture activities. The sectors, and their associated fishing grounds, are fluidly moved between by fishers seasonally, year to year or during a lifetime. Identifying this fluidity in sectors shows that each of these groups of fishers in the region, even those with less obvious connections with the mangrove, do derive some benefit from the mangrove in some or all of their activities. The mangrove-fishery in Bali is multi-dimensional through how fishers are connected to the mangrove, the function that fishing has, the time during which fishers are conducting mangrove associated fishing and locations of fishing. The connection individuals within that sector have with the mangrove is also variable and complex. The complexity of these sectors, their interaction with the mangrove and with each other can be linked to form a framework which represents the full complexity of how the mangrove-fishery can be defined. The framework developed (Fig. 3-2) therefore shows that mangrove-fisheries can be far more complex than represented in the existing quantitative literature.

Interviewing fishers in Bali uncovered groups of fishers which are not identified in the available official fishing reports. Commercial and small-scale fishing activities are detailed in fishing reports of the Jembrana Regency, but interviews identified additional traditional and recreational fishers using the area. This finding reinforces studies elsewhere which have documented how smaller scale fisheries or groups of fishers can be "invisible" to managers when such groups co-exist with larger scale or industrial fisheries (Carvalho et al. 2011, García-Flórez et al. 2014, De Vos and Kraan 2015, Jadhav 2018). These studies have found that perceived smaller scale fisheries have social or economic values that is higher than that provided by their larger scale counterparts. Interview surveys also allowed for identification of fishers who would not easily be observed during a snap-shot view of the existing activities. For instance, fishers that use the estuary only during bad seasons or when the weather is unsuitable for their primary mode of fishing would not be accounted for if surveyed only during the good season.

Furthermore, it is clear that mangrove habitat use can provide an important economic buffer to offshore fishing activities. Reports that commercial fishers from the region have endured a 9 month period of no fishing suggest that the offshore fishery is not in a stable position. Further, the number of active offshore fishing boats far exceeds the maximum number of vessels permitted by Regency management targets. Under the Government of East Java and Bali, just 83 Balinese vessels operating purse seines are permitted, however in 2014 2,464 active vessels (with outboard motors) were counted (Jembrana Office for Marine Fisheries and Forestry 2014). This discrepancy suggests that the offshore fishery is not being sustainably managed at a governmental level. Subsequent continued periods of low production in the commercial fishery could result in fishers more regularly turning to this economic buffer option of using the mangrove estuary resources as an alternative occupation. Consequently, the importance of mangrove-fishing for the small-scale and commercial fishing sectors could increase with increasing pressure on offshore stocks. This is important to monitor, as increased resource within in the Perancak Estuary could have implications for other fishers, such as traditional and recreational fishers, who are already relying on resources there.

Mangrove-fishing also has subsistence value for fishers of all sectors. Mangrove-associated catches in Perancak Estuary Mangrove-Fishery (including mangrove-associated species caught in the mangrove, estuary or offshore) are mostly dispersed in local markets or kept for personal consumption. In comparison, fish caught offshore which are not mangrove associates, for example Bali sardinella, are sold to factories, which then sell products to restaurants and markets in the city or internationally. The mangrove-fishery therefore likely plays a larger role in the local markets and in local diets than that of the industrial offshore fishery despite its much smaller scale. While interviews indicated that fishermen mostly catch enough fish and seafood to sustain their own families, further interviews would be required with families who do not conduct fishing in the region, in order to identify the contribution of mangrove-fishing to the wider community.

Aquaculture activities were included within the framework, despite not having a direct link to mangrove-fishery enhancement through fishing. This is because aquaculture workers demonstrated a strong perception that mangroves were essential to fish or invertebrate production. Respondents attributed this link to the filtering property of mangroves in preventing polluted river water from entering the ponds and causing disease that can halt aquaculture production. Testing this function ecologically was outside the scope of this study. However, the capacity of mangroves to filter pond effluent entering rivers, which contains high nitrogen and phosphate loads, has been confirmed elsewhere (Robertson and Phillips 1995). This function may explain how planting of mangroves in aquaculture pond periphery in Jembrana decrease the severity of river water pollution by ponds themselves, which is one of the main causes of cross-contamination among ponds using the same waterways.

However, recent disease spread events recalled by aquaculture workers in the Jembrana sub-district suggest that the filtering function of mangroves is not yet sufficient to prevent cross-contamination of ponds entirely. Semi-intensive ponds export more contaminant in their effluent than traditional technology per hectare, and therefore a shift from traditional to semi-intensive aquaculture technology which is currently beginning in Jembrana, and is observed in wider SE Asia (Robertson and Phillips 1995), may worsen the situation further. This could increase reliance on the mangrove filtering function by those working in the aquaculture sector. Of course there are also aspects of shrimp aquaculture that might negatively impact fisheries production, from the removal of mangrove area and therefore habitat for fish and invertebrates, as well as pollution of waterways from pond effluent. The success of aquaculture ponds, or otherwise, in the region therefore might influence the success of mangrove-fisheries.

No comprehensive landings data, other than for the commercial fishing sector, exists for the Jembrana sub-district. Therefore, while the study was able to identify the wide ranging stakeholders who are linked to the mangrove through fishing, it was not possible to quantify the contribution of mangrove-associated catch within sectors. It was also difficult to clearly define the number of actors in each sector, due to the dispersion of fishers among the 4 villages around the Perancak Estuary and reluctance of some sectors to suggest further respondents. Following this study, which has provided a baseline of information regarding mangrove use by each fishing sector, future research would be in a better position to quantify the mangrove-associated contribution to each sector.

3.6.2 How does the Perancak Estuary Mangrove-Fishery compare to others?

Three different typologies described mangrove use by fishers in Perancak, Benoa and Gilimanuk. These communities are located just 20-80 km apart and therefore it can be argued that a single definition of what mangrove-fisheries encompass cannot, and should not, be applied from one location to another even in close proximity. There were similarities between communities, for example traditional and small-scale sectors in Perancak and Benoa carried out similar activities for similar functions. However, interviews in Benoa uncovered an additional sector, mariculture, which uses mangrove, which was not observed in Perancak. Further, interviews in Benoa suggested that recreational fishing, when used for tourism, can be used as an income source, whereas it was used only for recreation and for subsistence in the Perancak community. It is therefore important to look at the function that mangrove-fishing has within sectors, as well as the presence of the sectors themselves, to understand the societal importance of various fishing activities.

Connection to the mangrove within the Gilimanuk fishing community appeared less multi-dimensional than that of fishers in Jembrana and Benoa, being limited to catching mangrove-associated fish species offshore and around other coastal habitats (Fig. 9). The activities of the Gilimanuk fishing community in the past, as described in 1983, were much more diverse. Previously, the activities involved fishing using traditional fishing gears that was primarily for local consumption, as well as fishing focused towards the ornamental fish trade, and collection of larval milkfish (*Chanos chanos*), a mangrove-associated species, for use in brackish water fish ponds (Polunin et al. 1983). Mangrove use by fishers in Gilimanuk has therefore changed over time in the region. Changes are likely to have been influenced by extension and zonation of the Bali Barat marine reserve in the area, which focussed on reducing damage to mangroves as well as ceasing destructive fishing methods (Polunin et al. 1983). In comparison, no specific governance regarding mangrove-use for fishing (other than direct cutting of mangroves) appeared to exist in Perancak or Benoa. Levels of governance of a mangrove area might therefore influence what mangrove-fisheries can encompass.

It can be argued therefore that the Perancak Estuary Mangrove-Fishery does represent the typical complexity of mangrove-fisheries elsewhere, when compared to others in Bali. However, considering the results of the analysis of the quantitative literature (Section 3-2, Table 3-1), mangrove-fishing in Bali appears much more complex than mangrove-fishing has been described elsewhere. Compared to many of the quantitative studies included in Table 3-1, especially where only a single dimension (or fishing sector) of mangrove-fishing has been measured, the Perancak Estuary Mangrove-Fishery, which involves fishers from 5 different sectors, represents the upper end of complexity of what a mangrove-fisheries can encompass. This also applies to the complexity of functions that mangrove-fishing has for fishers in the Perancak Estuary, compared to the prior literature which has stated only incomes or biomass generated through mangrove-fishing, not distinguishing its contribution to secondary or economic buffer incomes, subsistence or recreation. Moreover, the temporal and spatial variability in mangrove-fishing displayed in the typology developed was not conveyed in the literature regarding other mangrove-associated fisheries examined earlier in this chapter, where information on fishing locations and seasonality has been vague or lacking entirely. As such, the analysis of the current quantitative literature, aimed at summarizing how mangrove-fisheries are currently described, did not capture the nuance of what mangrove-fisheries can encompass, when compared to the typology developed in this chapter.

Of course, this initial analysis of mangrove-fishery literature was limited to exploring only quantitative studies. Studies from the qualitative literature on mangrove-fisheries have described additional sectors that benefit from mangroves, for example those involved in processing and trading in the Sundarbans, Bangladesh (Islam and Haque 2005). In the Caeté Estuary, Brazil, mangrove-fishing has an additional function in emergency food provision (Glaser 2003), which was not observed in Bali. Whilst complex, the Perancak Estuary Mangrove-Fishery cannot represent all of the possible characteristics and interactions that mangrove-fisheries can exhibit, as identified in descriptions of other mangrove-fisheries in Bali and elsewhere. The mangrove-fishery studied in the Perancak Estuary therefore might not demonstrate the upper end of complexity of all mangrove-fisheries.

3.6.3 Implications for managing mangrove-fisheries

Justifications for mangrove-fishery management, or simply mangrove conservation, have been attempted through many mangrove-valuation studies (Costanza et al. 1997, Spaninks and Beukering 1997, Vázquez-González et al. 2015). However, these studies often focus upon a single dimension of mangrove use by a community. Ronnbaack (1999) suggests that the under-valuation of mangroves is one of the leading causes of mangrove conversion to other land uses. This case study of a relatively small mangrove-fishery suggests that a mangrove-fishery can encompass much more complex interactions and therefore social importance than represented in many measures of mangrove-fishery value. A framework such as that developed here should encourage managers to look outside of the groups of fishers traditionally expected to benefit from mangrove fishing to develop a broader definition of mangrove-fisheries in each local context. This is particularly pertinent where offshore fisheries are declining and smaller-scale fisheries may be offering an economic and ecological buffer which is invisible or underestimated when it comes to fisheries or mangrove management strategies.

Suggestions for management of mangrove-fisheries have included key habitat restoration, stock enhancement in mangrove habitat and coastal rehabilitation (Baran and Hambrey 1999, Islam and Haque 2005). Development of community-based mangrove management and bottom up approaches have also become increasingly popular. Datta et al. (2012) stress that knowledge of the actual uses of mangroves in a community, rather than the assumed uses of mangroves, are essential to sustainable community-based management. The framework in this study therefore presents a first step in the direction of mangrove-fishery management, encouraging the holistic and site-specific definition of the full scope of activities that mangrove-fisheries encompass. This social perspective, together with assessment the ecosystems value as a whole, and the other ecosystem services it provides, would put managers in a better place to make optimum and informed trade-off decisions over resource use. As such, as would be the next step in this process, the following chapter will use this framework developed to conduct a thorough quantitative analysis of the benefits received from the mangrove by a mangrove-fishing community in a local context.

4 - Measuring mangrove-fishery benefits: A case study of the Peam Krasaop Fishing Community, Koh Kong Province, Cambodia

Summary

Whilst previous studies have applied economic value to the ecosystem services mangroves provide to fisheries, most quantitative studies in the peer reviewed literature have limited their measurements to the value provided through a single fishing sector, gear or particular target species group. As such, it can be argued that present research into mangrove-fisheries has not yet represented the full complexity those mangrove-fisheries can encompass in terms of the wide range of people and activities that benefit from the mangrove. The reported values of mangroves to fishing livelihoods are therefore likely falling short of a full valuation. The study set out to provide an all-encompassing value of mangrove benefits to fishing, i.e. purposefully investigating the value gained from mangroves through all fishing sectors, fishing activities and target species existing in a particular fishing community.

The study focussed on the Peam Krasaop Fishing Community (PKFC), Koh Kong Province, southwest Cambodia. This is a newly formed fishery, with a history within the past 40 years of mangrove destruction for charcoal production, its illegalisation, and subsequent mangrove restoration, followed by changing uses of mangrove by the community.

Quantitative and qualitative information was collected via semi-structured interviews with fishing households in the PKFC, as well as from a number of identified key informants in the community and its governing bodies. Average daily catch volumes, species and market prices were detailed by fishers for each of their household fishing activities. To calculate the ecosystem service value of mangroves for fishing to households in the PKFC, daily landings volumes were scaled to approximated annual catches based on estimated days fishing per activity. These catch figures were then converted to economic value, based on the local market prices given by respondents. Finally, the proportion of mangrove and mangrove-associated species in catch landings and subsequent gross income was then calculated. Results estimated that the PKFC derive approximately 90% of fishing catch, and 85% of gross income, from mangrove-associated species. Fishing activities are diverse within households, with households conducting between 1-8 different seasonal fishing activities, across mangrove gathering, fishing by boat and mariculture.

This study provides a higher estimated proportion of mangrove-associated catches than many studies of fishing communities elsewhere. While the PKFC is highly dependent on mangrove-associated fish and invertebrate catches, it may be the case that the PKFC does not have higher levels of dependency than other mangrove-fisheries. Rather, this study may provide a better quantification of mangrove value than has previously been achieved. Further studies along the same lines as the one presented here, taking a holistic approach to mangrove-fishery valuation, are necessary to test this proposition.

4.1 Introduction

Using the framework devised in Chapter 3, this chapter aims to provide a more holistic overview of the value of mangroves to a local fishing community in Cambodia. Specifically, the study considers a wide range of sectors and activities within which the fishing community operates. It evaluates the connection between each activity, its target species and the presence of mangroves. The study also describes the locations used for fishing and the seasonality of mangrove use. These relationships and patterns are discussed in relation to the income generation and subsistence needs of the local community, as well as the social, historical and political contexts driving mangrove-fishing in the local area. Such contextual information is often excluded in quantitative measures of mangrove ecosystem services (Cormier-Salem 1999, Saint-Paul and Schneider 2010). In taking this approach, the study is able to measure the current importance of the mangrove-fishery to various aspects of community livelihoods and to understand what might drive mangrove use in the future.

An increase in human activity on the 435 km coastline bordering the Gulf of Thailand, particularly in the past 2 decades, along with fishery expansion, has put pressure on coastal resources in Cambodia. As such, both declines in fishing productivity (catch per unit effort) and declines in mangrove extent have been observed (Srean 2018). Mangrove extent in Cambodia has fallen from 94,600 ha in 1976 (Srean 2018) to 46, 477 ha in 2012 (Hamilton and Casey 2016, Richards and Friess 2016). The main drivers have been, and continue to be, conversion for aquaculture (27.7%), oil palm plantations (8.9%) and rice cultivation (1.5%). Mangrove conversion for oil palm is currently of particular concern (Richards and Friess 2016). In the context of these losses, it is important to note that the direct use value of mangroves per household in the coastal provinces of Cambodia has been estimated at close to 10,500 US$ per year, of which more than half is attributed to fishing (Sopheak and Hoeurn 2016). Furthermore, it is likely that this figure does not represent the true value of the mangrove-fishery. Estimates of what is being caught, and by whom, are simplified to provide statistics on a broad scale, encompassing a number of fishing communities over a large geographic scale and failing to accurately represent the full complexity and magnitude of mangrove-fishing in the region.

As fisheries management in Cambodia has focussed mainly on inland fishing thus far (Teh et al. 2014), there are large gaps to fill in fisheries statistics for inshore marine fishing. National fisheries statistics under-represent small-scale fisheries (which includes artisanal and subsistence activities) as landings statistics only consider catches taken by taxable vessels (Teh et al. 2014). Boats with engines of 30 horse power or below, which are characteristic of those used by mangrove-fishers, do not appear in such returns. Reconstructed Cambodian fish catches for the 1950-2010 period suggest catches were 200% higher than that reported, with the largest proportion of this shortfall made up of unreported small-scale fish catches (Teh et al. 2014). Such gaps in knowledge are not only an issue of economy, but also of food security, with fish and aquatic animals providing, on average, 80% of protein to the diet (Joffre et al. 2010). Ignorance of the fishing pressures on inshore marine areas, and the importance of such pressures for the livelihoods of coastal communities is likely to cause further declines in fisheries production and have socio-economic implications if regulation is not put in place (Teh et al., 2014).

This study focusses on the Peam Krasaop Commune, Koh Kong Province, southwest Cambodia. The Peam Krasaop Fishing Community is highly dependent on mangroves for fishing, and conducts direct mangrove gathering, inshore fishing and offshore fishing (PMMR team 2000). The site provides an ideal location for the quantification of full mangrove-fishery value. This is because social studies have already provided some baseline qualitative information about the mangrove-fishing community present in the area (PMMR, 2000). This enabled this study to rapidly identify the key respondents in the community and, through them, to gain a full picture of current fishing activities, including mangrove use. This subsequently permitted the collection of quantitative information about fish catches (an activity not possible within the timeframe of the study reported in Chapter 3).

4.2 Site description

4.2.1 Location, hydrology and climate

The Koh Kong Province, southwest Cambodia accounts for more than half of Cambodia's mangrove area. As a result, the Peam Krasaop Wildlife Sanctuary (PKWS) in Koh Kong Province was designated as one of 23 Protected Areas (PA's) in Cambodia in 1993 (Dara et al. 2009 estimate from map approved in 2003 in Taing et al. 2017). The protected area covers 25,897 ha and includes 23,750 ha (237.5 km^2) of mangrove forest. It also makes up 60% of the Koh Kapic and Associated Islets Ramsar Site, as a Wetland of International Importance under the Ramsar Convention, established in 1999 (Pillai 2003).

The Koh Kong Mangrove-Estuary is fed by the Tatai River originating in the Cardamom Mountains. Mangroves line the small islets within the estuary and fringe the mainland at the landward edge of the estuary. Sediments from river inlets have contributed to a number of alluvial sediment islands within the PKWS, which lie 0-2 m above sea level (Pillai 2003). Tides are semi-diurnal, with a tidal range between 0.7-2 m, inundating the islands during spring tides (PMMR team 2000). Other than mangrove forest, other coastal and terrestrial habitats in the PKWS include upland evergreen forest, coastal mangrove peatland, seagrass beds and coral reef habitats (Pillai 2003, Lo et al. 2016, Taing et al. 2017). No fishing is conducted by the fishing community in coral reef habitat or seagrass beds.

The air temperature in the Koh Kong Province ranges from 22-33°C. Rainfall occurs year-round, although there is a dry season (November-May) and a rainy season (June-October) due to the SW monsoon. Rainfall thus varies significantly from less than 20 mm per month in January to almost 900 mm per month in July (Thoeun 2015). Rainfall significantly changes water salinity between seasons (Pillai 2003). During the rainy season, offshore winds blow from the northeast to the southwest, and there are large waves which make boat travel difficult, while during the dry season waters are calm.

4.2.2 Mangrove ecology

The PKWS hosts 64 mangrove species. Along the estuary mangrove fringe the forest is characterised by *Rhizophora* spp., in which *Rhizophora apiculata* is the dominant species (PMMR team 2000, Pillai 2003). Zonation of mangrove species occurs away from the mangrove fringe. Lo et al. (2016) observed mangrove and mangrove-associated communities in 4 clusters within the PKWS: 1) *R. apiculata* only, 2) *Ceriops tangal* only, 3) *R. apiculata, C. tangal* and *Lumnitzera littorea* and 4) *Xylocarpus granatum* along with two non-mangrove species, *Hibiscus tiliaceus* and *Melaleuca cajuputi*.

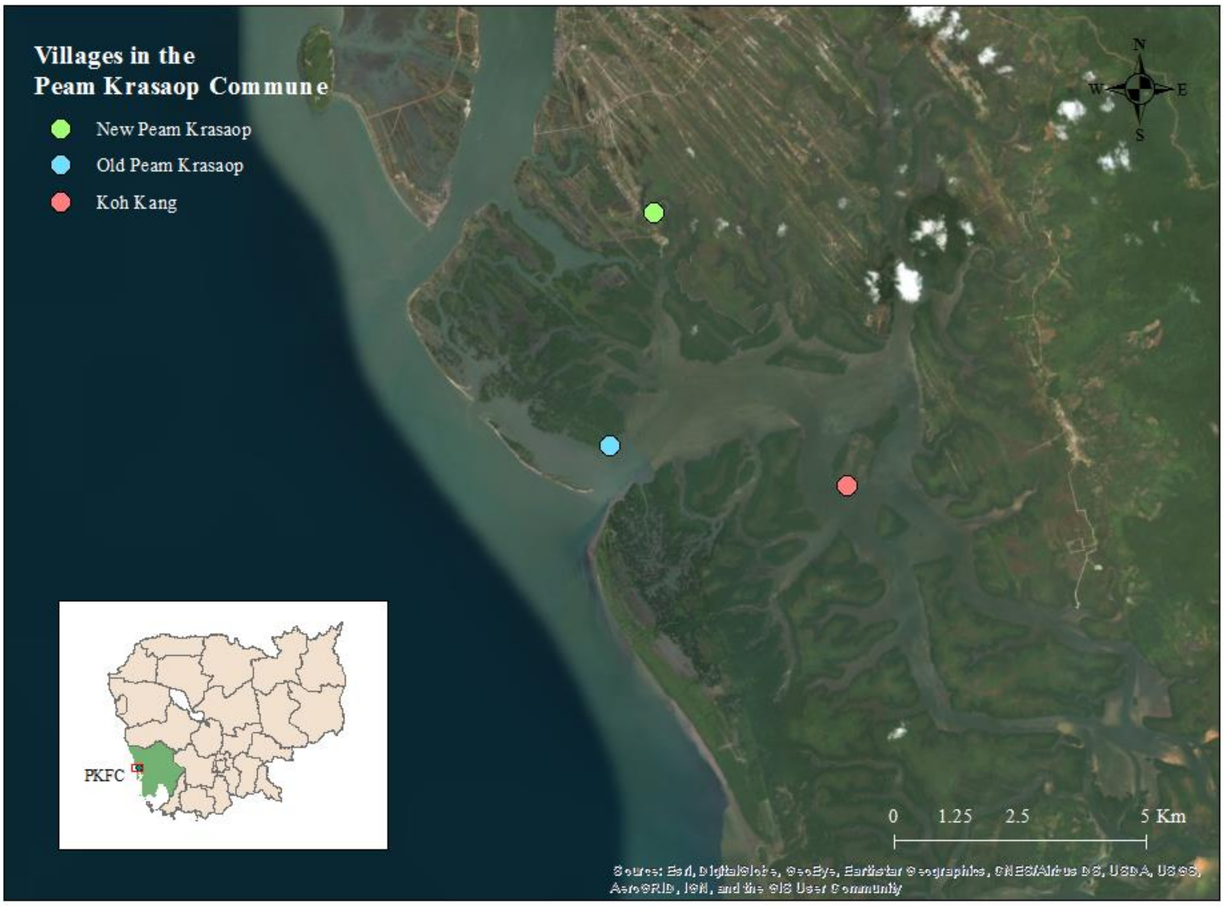
4.2.3 Population and settlement

The Peam Krasaop Wildlife Sanctuary (PKWS) has a population of approximately 9,000 people, living within 6 communes, which include 13 village settlements in total (Dara et al. 2009, IUCN 2009). The settlements are mostly built on wooden stilts around the island boundaries and along the mangrove-lined channels. This study focuses on the Peam Krasoap Commune, which includes 352 households across 3 settlements.

The three villages within the commune, shown in Fig. 4-1, are New Peam Krasaop Village (NPK) (102°59'38.877"E 11°34'3.105"N), also known locally as Boeng Kayak, Old Peam Krasaop Village (OPK) (102°59'12.687"E 11°31'34.975"N) and Koh Kang (KK) (103°1'42.685"E 11°31'11.646"N). The Peam Krasaop Fishing Community (PKFC) includes fishers from all 3 villages.

There are currently 170 active fishing households in the Peam Krasaop Fishing Community (PKFC) according to local fishery reports from 2016. This makes up 57% of the Peam Krasaop Community as a whole, and comprises approximately 46% of households in NPK, 86% in OPK and 86% in KK. These active fishing households, referred to as the Peam Krasaop Fishing Community (PKFC), were the target of the semi-structured interviews carried out in this study.

The Peam Krasaop Commune lies approximately 7 km from Koh Kong Province Town Centre which can be accessed by road from the NPK village. The NPK village also has a port, which is used by villagers on the islands to access Koh Kong town and to land fish. The port is also used by tourists to access neighbouring islands. Tourists also visit the PKWS 1 km long mangrove boardwalk, which is located near NPK village. This was established in 2008 to boost ecotourism in the region. It provides employment in ecotourism, selling snacks and souvenirs as well as boat, motorbike and tuk-tuk driving to the community. In NPK, many households conduct these occupations, as well as work in factories, offices and government departments in Koh Kong Town. By comparison, just a few households in OPK and KK have jobs other than fishing.



Cambodia Basemap (2014), Copyright: Office for the Coordination of Humanitarian Affairs stores the data on HDX website: https://data.humdata.org/dataset/cambodia-admin-level-1-boundaries (Level 1).

Figure 4-1. Map of the Peam Krasaop Commune in the Koh Kong Province, SW Cambodia, home to the Peam Krasaop Fishing Community (PKFC). The commune includes 3 settlements, New Peam Krasaop (NPK), Old Peam Krasaop (OPK) and Koh Kang (KK). The Cambodia Basemap (2014) is from Office for the Coordination of Humanitarian Affairs HDX website: http//data.humadata.org/dataset/Cambodia-admin-level-1-boundaries (Level 1).

4.2.4 Management structure

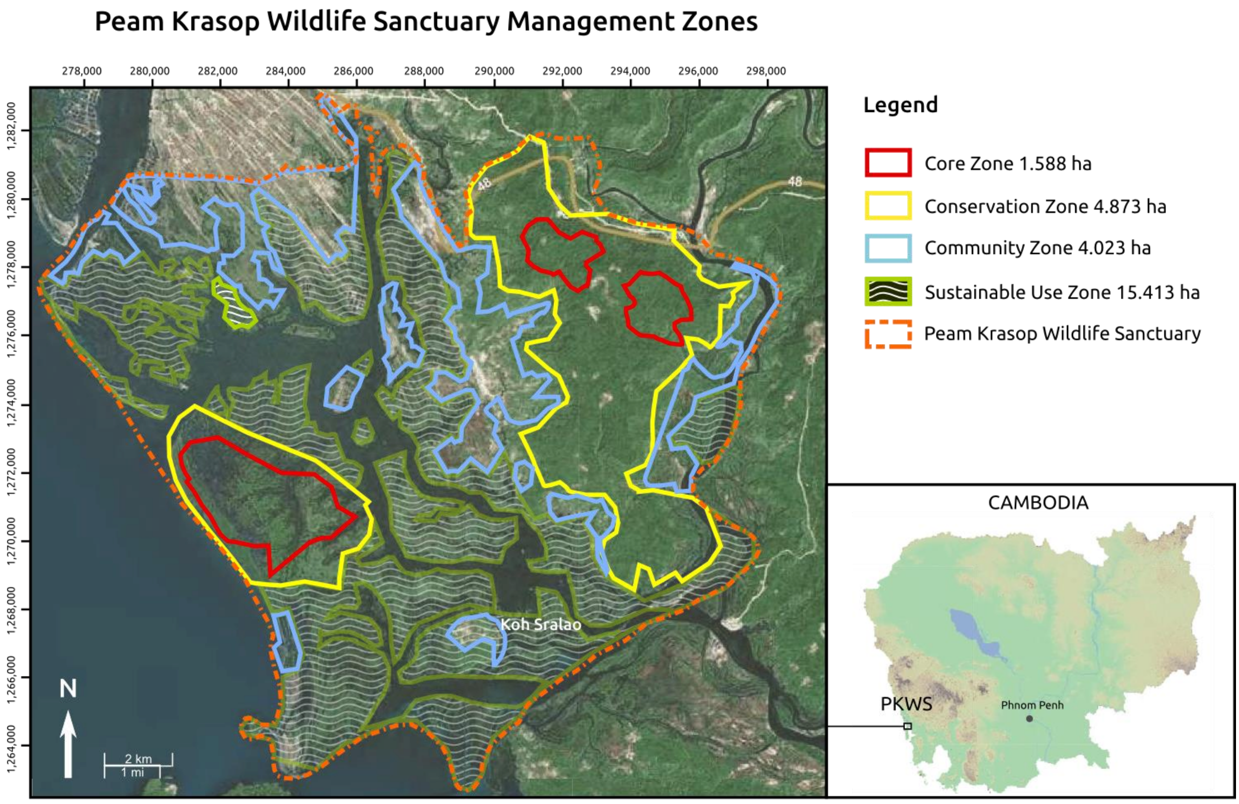
Use of the PKWS for extractive activities, under the Royal Decree on Designation and Creation of Protected Areas, is managed through zonation. The zones include a 1) core zone, in which key features or values are protected through prohibited development or exploitation, 2) a conservation zone which falls adjacent to the core zone to protect ecosystems and natural resources of high conservation values, 3) a sustainable use zone which are areas of high economic value for development and community livelihoods and can be used sustainably, and finally 4) a community zone in which community development activities are permitted to continue (Fig. 4-2) (Dara et al. 2009). The immediate surroundings of all 3 villages are community zones, allowing fishing to be conducted by the community in these areas (Fig. 4-2).

Environmental management of the PKWS is the responsibility of the provincial Koh Kong Department of Environment (DoE), on behalf of the National Ministry of Environment (MoE). Determination of the protected area boundaries, research and data collection on animal, plant and socio-economics and prevention of illegal activities therefore lies with the DoE (PMMR team 2000).

Community-based coastal resources management has also been promoted within the PKWS by the Participatory Management of Mangrove Resources Project (PMMR), an initiative involving provincial technical departments (environment, fisheries, women's affairs, and rural affairs) and local communities, supported by the International Research Centre, Canada (PMMR team 2000). The PMMR project was carried out two phases of work between 1997-2000 and in 2004, involving the establishment of village management committees, educational workshops on participatory planning and sustainable livelihoods and creation of community by-laws. A village management committee was set up on Koh Kang, but not on Old Peam Krasaop. The New Peam Krasaop Village had not yet been established at the time of this initiative.

It is unclear whether these village management communities or community by-laws still exist or to what extent they are enforced in the Peam Krasaop Fishing Community. However, there is some active presence of PKWS rangers (24 within the PKWS area) who are members of the local villages. One of the ranger stations is based in NPK. These rangers are employed to ensure compliance with prohibited mangrove damage and are involved in enforcing the zonation boundaries of the PA. Although fishing in the PKWS should be compliant with Fisheries Law 2006, no local law restrictions or enforcement of particular fishing targets, yields or gear specification appeared to be in place in 2017. Rangers in the area during the research period suggested their role only entailed ensuring that all fishers were in possession of a fishing licence. The PKWS as a protected area is however prohibited to trawlers in areas < 20 m in depth (PMMR team 2000).

Despite efforts by the PMMR in the PKWS, there are many constraints to the management of resources (PMMR team 2000). Those highlighted by the PMMR team include lack of human resources, equipment and communication between provincial departments and absence of a formally established committee (PMMR team 2000). Management is also constrained by the lack of appropriate alternative employment and poverty in the PKWS (PMMR team 2000).



Adapted from: An Dara, Kong Kimsreng, Hout Piseth, and R.J. Mather (2009). An Integrated Assessment for Preliminary Zoning of Peam Krasop Wildlife Sanctuary, Southwestern Cambodia. Gland, Switzerland: IUCN 52p.

Figure 4-2. Zoning of the Peam Krasaop Wildlife Sanctuary. The rationale behind zoning, and a description of permitted activities in the core, conservation, sustainable use and community zones are detailed in (Dara et al. 2009). This English language adaptation of the map was created by (The Cambodia Fishing Cat Project 2017).

4.3 Methods

4.3.1 Data collection

Qualitative and quantitative fishery data was collected through semi-structured interviews. Interviews were conducted with fishing households only and were chosen opportunistically, stopping at households where somebody was home. This process continued until all occupied homes that could be accessed had been interviewed. Interviews were therefore conducted with whichever adult family member(s) were at home and willing to participate in the exercise. Interviews included males and females over a wide range of ages from approximately 19 to 90. However the majority of those interviewed were between 30 and 60 years old. Interviews were conducted with 45 households (approximately 27% of the PKFC) including households in NPK village, KK village and OPK village. The interviews took place between July-August 2017 and corresponded with the rainy season when fishing intensity is low.

4.3.1.1 The semi-structured interview

Fishers were asked to detail their household fishing activities, their chosen target species and the seasonal differences in their fishing strategies. They were then asked to provide information about the typical daily catch volume, market price, economic income and frequency (number of days fishing) of each activity in each season. Respondents were also asked about volume of landings and species that are used for subsistence, along with discussion of importance of fish and seafood in the household diet. Fishing locations were recorded through participatory mapping, with fishers drawing and annotating fishing sites on paper maps of the area during interviews. General discussion about household fishing history, pressures on fishing and mangroves, and mangrove importance was also generated during interviews. A fish and invertebrate species key was used as in Chapter 3, based on a list provided in PMMR team (2000) and can be found in Appendix 4-2.

Interviews were transcribed in real time, with paper and pencil, and put into electronic copy later the same day. The interviews were conducted with an additional research assistant and an interpreter. During the interview, the research assistant followed the planned interview schedule, conveying the questions to the interpreter, whilst the primary researcher transcribed the interview and also steered the conversation in response to the respondents' answers as they saw fit. The interview schedule along with the annotated maps, are included in Appendices 4-1a, 4-1b and 4-2.

Interviews were first facilitated through introduction by the deputy of the provincial Department of Environment along with the homestay family, who were a well-regarded family of a former village head and provincial government worker. Thereafter, participants were approached by the researchers and interpreter alone. No interviews were refused from fisher households and participants were generally open to discussion. Limitations to the interview survey and influence on the results due to researcher presence in PKFC are discussed in the following section.

Interviews lasted between 30 and 120 minutes and allowed participants to elaborate on new topics and stories as they wished. Interviews did not therefore always follow the same structure, and not all questions were answered by each fisher. Of the interviews conducted, 36 were completed to a standard that could be used for quantitative analysis, representing 23%, 19 % and 16% of the fishing households in NPK, KK and OPK. A further 26 less structured interviews were conducted with more targeted key informants, which included middlepersons (those who buy and sell fishery products), fishing community committee members, community leaders, rangers, managers and government workers. All fisher household and key informant interviews were used qualitatively to provide general information about the fishery. Observations of fish landings were also made throughout the study period and recorded where possible to supplement information provided by interview surveys. Port visits were made during known popular landings times, during early mornings or early evening. However, researchers were present in the village throughout the day to conduct interviews with those who remained in the home.

4.3.1.2 Limitations to fieldwork in Peam Krasaop: On being a "barang"

Being a foreigner (or "barang") in Peam Krasaop had both negative and positive aspects on the access to and depth of discussion with fishers. Whilst not the first foreigner to be conducting research interviews in the region, following the work of Melissa Marshcke in the 1990's-early 2000's (Marschke 1999, 2012, Marschke and Sinclair 2009), the presence of a young, white female was a subject of curiosity, particularly among the women in the village. Peam Krasaop villagers are familiar with tourists passing through the port in the peak season, where they are welcome due to the jobs in transportation they generate. However tourists are less likely to enter the village.

This unusual state of affairs resulted in a friendly welcome into homes in the village by resident women, who wanted to ask questions about the purpose of the visit to the village and about being away from our homes and our families. On being assured that the researcher (and the research assistant, who was even a few years younger than the researcher) were unthreatening, women in the village were happy to be interviewed about their household fishing activity, with discussions lasting for as long as 1-1.5 hours, often whilst they performed household tasks, such as net mending, fish processing and looking after children. This was a positive influence on the research outcomes, as often the women of the household, who take care of the processing and selling (and sometimes also take part in the fishing), have more breadth of knowledge of the goings on in the household than the fishermen themselves. Interviews with men, were sometimes less detailed and they were less interested, sometimes seeming too busy and wandering away mid-interview. Interviews with men were also more difficult to become engaged in as the researcher, with the conversation often happening between the translator (who was male) and respondent alone. The researcher's attempts at the Khmer language, simple phrases to introduce the researcher and the research, which were well meaning but terrible in delivery, suited a function as an ice breaker but also in asserting the presence of the researcher in the conversation, creating an interaction between the respondent and researcher rather than between the respondent and the translator. The researcher's character as a young student (and therefore unthreatening stakeholder) may have been favourable in discussions with people in positions of authority within the village such as village and commune heads, who were happy to share documents on the management of the commune/ village community and fishing community with the researcher.

The presence of an interpreter also had influence, on the instigation of the interview, interview topics and their depth of discussion. The interpreter for the project was a worker from the Cambodian National MoE, negotiated as a prerequisite for being given permission to conduct interviews in the area. The translator, whilst a Cambodian national, was an outsider himself being from the city in Phnom Penh, recently graduated from University, fluent in English and far from having the upbringing of a fishing village. Whilst the presence of a MoE worker, which appeared to be a respected occupation within the community, granted access to interviewing members of the village, there was some clear bias in the subjects of discussion which villagers were willing to have in his presence. Entering into discussion of mangrove damage, for the most part, was met with textbook answers such as "*there is no damage, the people know that the mangrove belongs to the community/MoE*" which had a negative influence on the depth of conversation that was possible on this subject, as villagers were unlikely to disclose any knowledge of illegal activity by themselves, or their neighbours, to a government worker. Further, discussions of the perception of mangrove importance were answered with book learnt knowledge of the importance of mangroves. This response may have been the result of educational activities conducted by the participatory mangrove management team in the early 2000s (PMMR team 2000) and a clear case of "telling you want you want to hear". Bias in the information translated to the researcher also came from the translator himself, who admitted that his position as an MoE worker prompted fishers to disclose issues they are facing in the fishery (believing him to have influence on these issues within the governance of the area), which he did not always translate, believing it to be uninteresting to the research objective. Caution and less weight has been given issues of mangrove damage, illegal fishing and other fishing pressures within analysis as a result of particular limitation to information in these subject areas.

4.3.2 Analysis

Analysis of qualitative information was conducted in Atlas.ti (a software for qualitative data analysis software) using the method of qualitative coding detailed in Chapter 3, Section (3.4.4). Annotated maps were georeferenced and visualised in ArcGIS using the method described in Chapter 3. Quantitative information was organised and analysed in R, a language and environment for statistical computing (R Studio Team 2016). Household annual fishery statistics were estimated from daily catch, frequency and seasonal information. Initial estimates based on fishing 7 days per week provided unrealistic overestimates of catch and income per household due to overestimated number of days fished, derived from "fishing is everyday" responses by participants which do not account for the number of days when fishing is prevented by bad weather. The variability in fishing activities and locations used by the PKFC means that each household and fishing activity within that household is affected differently by different weather conditions. For this reason, fishing frequency estimates based on rainfall records were considered too simplified. The number of days fishing were therefore estimated based on observations during surveys, expert opinion by two researchers who have previously worked in the area and on regional patterns in the peer reviewed and grey literature (Teh et al. 2005, 2007, Lunn and Dearden 2006, Zamroni and Yamao 2011, Mualil et al. 2014, Anticamara and Go 2016), as well as local fisheries community reports from the 2016-2017 period. Days fishing per activity were therefore capped at 25 days per month in the dry season and 15 days in the rainy season. Annual catches and incomes quoted in the results have been calculated using this adjusted effort. The original values based on 7 days fishing (unless specified otherwise by the fisher) are detailed in Appendix 4-3. The rules and assumptions made for the estimation of total catch volumes are detailed in Appendix 4-4.

4.3.2.1 Calculating mangrove benefits

To calculate the ecosystem service use value provided by mangroves for fishing to households in the PKFC, daily landings volumes were scaled to approximated annual catches based on the adjusted estimated days fishing per activity and converted to economic value based on local market prices given by respondents. This followed a method which has previously been used to calculate the use value of mangrove-ecosystem services to fisheries via local market prices in Mexico by Aburto-Oropeza et al. (2008). A full cost analysis was not possible due to lack of consistent information on household fishing expenses. Household incomes calculated therefore represent estimated gross incomes before expenses are deducted. Some information gathered on household expenses for each of the fishing activities is however provided for reference in Appendix 4-5.

Household catch and income values were scaled first to whole village catch landings level (for each of the 3 villages) based on catch composition in that village and the proportion of the village interviewed and later combined to give the estimated total catch and value of the whole fishery landings. The proportion of mangrove and mangrove-associated species in catch landings subsequent gross income was then calculated.

Mangrove-associated catches were calculated including known mangrove-associated fish and invertebrate species only, using information provided in the FishBase database (Froese and Pauly 2017) and the SeaLifeBase database (Palomares and Pauly 2016). Those species caught within the mangrove but not recorded as known mangrove-associates in FishBase or SeaLifeBase were not coded as mangrove-associates. Mangrove-associated species caught outside the mangrove were included. Groups of mixed species recorded which included non-mangrove species of any proportion were recorded as non-mangrove associated catches, unless the proportion of each species was specified by the fisher. A typology to characterize the PKFC mangrove-fishery was drawn using the framework developed in Chapter 3.

4.3.2.2 Checking for inter-community mangrove-use variability

Following the conclusions of Chapter 3 regarding the variability of mangrove-fishing communities in close proximity, efforts were also made to investigate inter-village differences in fishing livelihoods within the community prior to analysis of the community as one entity. Analysis of variance and post-hoc testing was conducted to compare annual catch volume (kg) and gross income (US$) per household in the 3 villages. Analysis of dissimilarity in catch composition between households in the three villages was conducted using R's vegan package, using non-metric multidimensional scaling ordination to visualise dissimilarity using a Bray-Curtis distance (Oksanen 2009, 2015, Letten 2017). Further analysis of dissimilarity between the 3 villages was conducted using a Permanova test (a multi-variate ANOVA based on dissimilarities) with the R vegan package Adonis function, followed by Simper analysis to identify the species groups responsible for any dissimilarity (Seaby and Henderson 2007, Oksanen 2015). Data were not transformed prior to analysis as outliers were considered interesting to the outcomes of the analysis.

4.4 Results

This section will first summarize the information gathered regarding the social, political and historical context of the fishing community. It will then move on to the quantitative approximation of current mangrove benefits to the fishery as a whole. It will then report on household level landings, incomes and livelihood strategies as well as comparing household fishing strategies between villages. Finally it will discuss the contribution of the various fishing activities and target species to the overall benefits households in the PKFC obtain from the mangrove. Throughout this section, unless stated otherwise, "N" refers to the number of respondents interviewed who participate in and gave information on a particular activity discussed, as a proxy measure of the thoroughness of the information obtained.

4.4.1 Social, political and historical context of the Peam Krasaop Fishing Community

4.4.1.1 A history of charcoal production

The lucrative charcoal production industry in the 1980's and early 1990's attracted families to the area due to the jobs it created, with people moving from other provinces in Cambodia or Cambodian nationals returning from Thailand. Migration coincided with the end of the Khmer Rouge regime in 1979, a time in which Cambodians had been displaced from their home villages. Koh Kang, and neighbouring Koh Sraloa, were the largest areas of mangrove cutting for charcoal production, which was exported to Thailand and Singapore. This created jobs in cutting and transportation which attracted several members of the community who still reside in Peam Krasaop. The following statements, made by older community members that were interviewed, describe the state of the mangrove forest during the period of charcoal production:

"It was all gone, all you could see was roots"

"It was near Koh Kang, it was like a factory for charcoal"

"If the place had mangrove, they would go there to cut the tree".

Respondents suggested that after mangrove cutting for charcoal production was banned in the early 1990's, those who had moved to the area for jobs in charcoal production were left unemployed and, unable to afford to migrate back to their hometown, took up fishing as an alternative occupation. During charcoal production, there were few active fishermen in the PKWS. The market value of charcoal was much higher than that of traditional fishery products and therefore offered a more appealing occupation. While some suggest fishing was the primary industry for families in Old Peam Krasaop Village, only around 10 families were fishing during that time from Koh Kang. For this reason there is not a long generational history of fishing in the Peam Krasaop Fishing Community and few original inhabitants prior to the 1980s.

Fishers recount that during the time of charcoal production, fishery products were more available than they are currently because there were not many people fishing and therefore any adverse effects of mangrove destruction that may have occurred were not felt by the fishing community. Villagers have experienced a reduction in catch since the end of charcoal production which is attributed by villagers to the increase in the number of fishers.

4.4.1.2 Changes to mangrove extent through destruction and rehabilitation

According to the villagers, the period of mangrove cutting for charcoal production destroyed approximately 80% of the existing mangrove forest pre-charcoal production. Villagers recount that the only mangrove remaining was composed of those species not useful for producing charcoal. During charcoal production, it was *R. apiculata* which was favoured to be burnt to produce charcoal (PMMR team 2000). It was suggested that mangrove replanting efforts, along with natural regrowth, have restored the mangrove forest to approximately 95% of its original pre-charcoal production state between the illegalisation of cutting and now (2017). The most recent estimate by the community in 2016-2017 suggests that there is a total of 1,326 ha of mangrove within the community area. No information could be given regarding how this figure was calculated.

Replanting began in 2001 and still continues through efforts by the Peam Krasaop Protected Area Community. They have planted 310 ha of mangrove (71 ha between 2014-2016), reserved 60 ha of land for natural mangrove regrowth and established a mangrove nursery with capacity to produce 200,000 seedlings per year. PKWS rangers report very little illegal activity related to mangrove cutting has occurred in recent years. However some cutting persists as permission is granted by the community for mangrove wood to be cut and used as material for house building. Villagers reiterate that they no longer observe mangrove damage and therefore do not attribute any current fishing pressures to mangrove damage.

4.4.1.3 Relocation and job diversification

Prior to 2004, all households of the community were on OPK and KK (the two island communities). New Peam Krasaop Village, nicknamed “Boeng kayak”, was established in 2004 when the Royal Cambodian Government offered previously uninhabited mangrove bordered shrub land on mainland Koh Kong Province to the communities living on the former floating villages.

Land was requested from the government by the communities due to the various challenges faced by living on the islands. The new upland village (NPK) offered an opportunity for better education for their children and better access to health care. In addition to this, upkeep of stilted houses on the islands was expensive and some families had suffered large costs replacing the wooden poles which hold the houses in place. Further, living in stilted houses did not allow for agricultural practices. Moving to the mainland offered the option of permanent land on which to undertake farming. In reality, few houses in the new village currently (2017) have access to agricultural land as the majority of houses in the village are on stilts and lie within a mangrove-fringed channel. Houses near the road (built on land) do have some agricultural land. However many families who were originally offered this land sold it on and opted for land within the channel where they could have access by boat directly to the house.

The Ministry of Environment (MoE) incentives for donating the land were different to those of the villagers themselves, being concerned by the erosion of the beach barrier protecting OPK and increased storminess (Kong et al. 2013). These concerns were not reiterated by fishers as significant reasons for moving upland. The MoE were also concerned about the potential for continued mangrove damage and resource depletion following the rehabilitation efforts and believed that there would be opportunities for new jobs outside of fishing.

These job options however were not readily available during the initial relocation and many families returned to fishing. Some therefore returned to their previous homes on the islands having failed to find alternative occupations on the mainland. Around 80 households stayed on at the old villages or made the decision to return back to the old villages after 1-3 years in the new village. One fisher from OPK, who returned from the new village to OPK to continue fishing, stated: *"First, the government moved people to the mainland, people were happy to move to the mainland. It's the habit of people who always live close to the sea and easy to go fishing, that's the reason they came back to the old island. At first the government wanted to move all but they couldn't find new jobs and the people know about fishing so they don't mind that people want to live in the old island, but they already gave them land".*

Since the initial relocation there is now a school and a road which provides access to the town. Several families who don't have their own land on the mainland, rent small apartments for their children to go to school or send them to live with relatives in the upland village while the family members who are fishing remain on the old islands near the fishing grounds. The number of active fishers in the community has decreased from 95% of the community being involved in fishing prior to migration upland, to 67% in 2015 and 57% in 2016/2017, according to an estimate by the Peam Krasaop Commune Committee. Prior to relocation to the new village, and after the ban on mangrove cutting for charcoal production, fishing was the only occupation available to people in the community.

Non-fishing jobs within households are much more common in NPK than the other villages as here there is access via road to Koh Kong town, where there are opportunities for work in factories and offices. Those in KK and OPK have to travel by sea to take up these opportunities. Families on OPK and KK do take seasonal work in boat driving for tourists but to a lesser extent. Some jobs that can be taken year round, such as factory work, often are taken seasonally by those in NPK, returning to fishing intermittently.

Not all households have equal opportunity for job diversification on NPK. Fishers suggested that households must have enough family members to carry out fishing activities while others go to work, otherwise all family members must be involved in fishing. Modern jobs, such as factory work, are also seen as occupations for young people. They are mostly taken by young females, and therefore older fishers believe themselves barred from such occupations.

In recent years, a shift from fishing to mariculture activities has also begun in the PKFC, in particular involving the culture of green mussel (*Perna viridis*). The current trend in green mussel culture began approximately 10 years ago, reaching its peak of popularity in the PKWS in the period 2015 – 2017.

Mariculture activities and how they contributes to mangrove-fishing livelihoods in discussed in more detail in section 4.4.3.3.

4.4.2 Current mangrove use value

The total estimated annual landed catch volume for the Peam Krasaop Fishing Community is 1015.8 tonnes, bringing in a gross income of an estimated 1.2 million US$ to the community. This estimate was made based on a plausible evaluation of the interview data which was adjusted to reflect a reasonable number of days fished. The upper bound estimate, going by the data prior to adjustment, is 1244.1 tonnes caught by the PKFC as a whole and 1.5 million US$ in annual gross income. The estimated catch volume and value derived from the three individual villages (based on the adjusted estimate) is detailed in Table 4-1. Of this catch, 90% of total catch volume and 85% of value in US$ is of known mangrove-associated species.

Table 4-1. Estimated total annual catch landings in volume and gross monetary value, according to market prices conveyed by respondents in August 2017, for the Peam Krasaop Fishing Community (PKFC) and for the three villages within the community, New Peam Krasaop (NPK), Old Peam Krasaop (OPK) and Koh Kang (KK).

Village	Estimated annual catch (tonnes)	Estimated annual catch value (Thousand US$)	No. fishing households
NPK	735.6	755.8	102
KK	93.7	126.1	32
OPK	186.5	302.7	36
Community total	1015.8	1184.5	170

Fishing in the PKFC comprises a number of fishing practices, which include traditional gathering in the mangrove, inshore fishing by boat, offshore fishing and mariculture activities, with a variety of activities and targets within each of these groups. Mangrove-use for fishing by the PKFC is summarised in Fig. 4-3. Compared to the communities studied in Chapter 3, the fishing community does not separate distinctly by sector, as all of the community partake in a number of different activities and do not identify themselves by sector. Mangrove use is therefore partitioned instead by fishing, gathering or mariculture activities in Fig. 4-3.

Fishing livelihoods in the PKFC are also highly diverse, with households targeting between 1-8 different species groups, which require a number of different gear specialisations and seasonal activities. Catch information separated by species targeted and by household therefore reveals more about household fishing livelihoods than can be communicated through total fishery catch landings figures. As such, the following section describes fishing livelihoods at the household level.

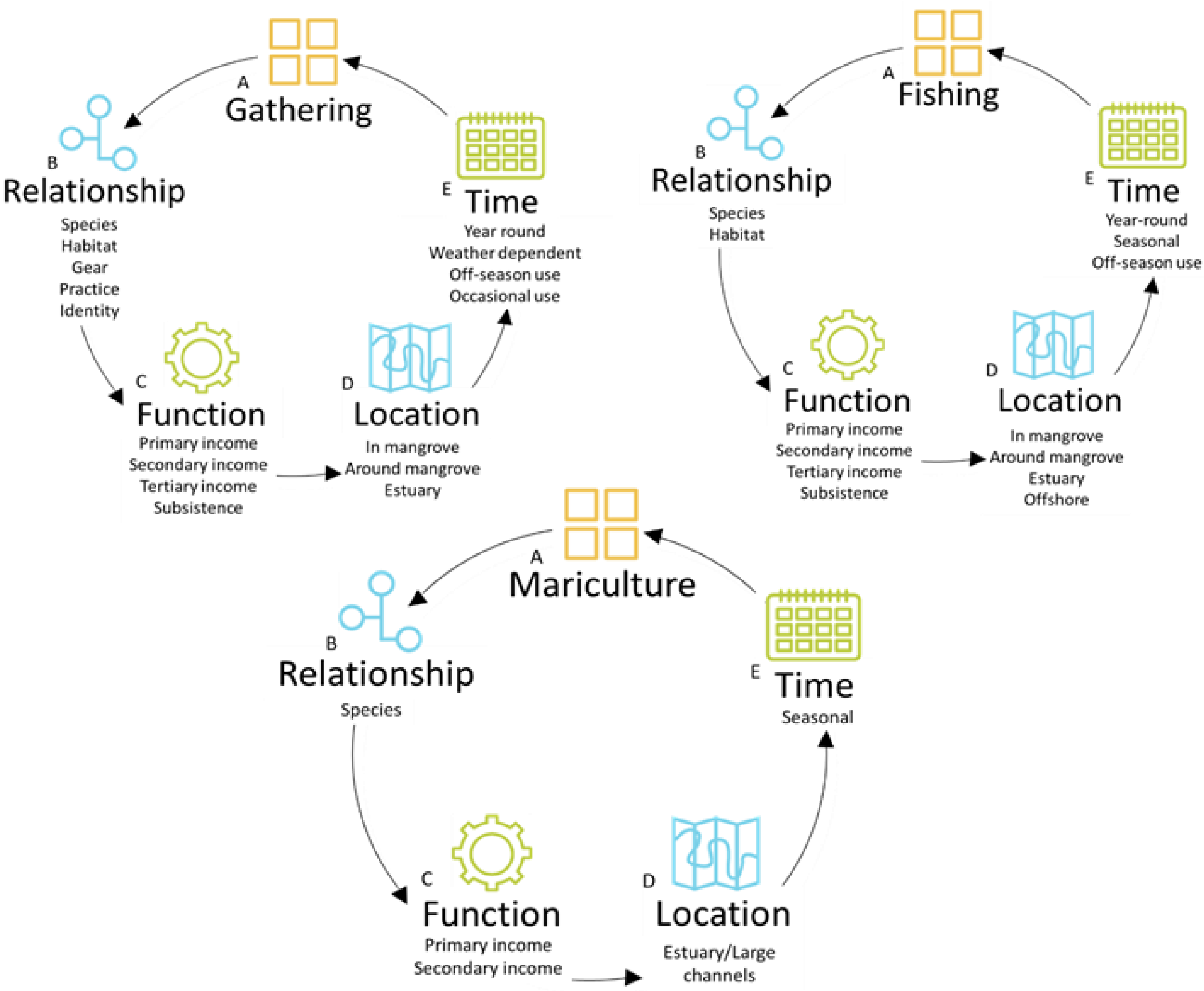


Figure 4-3. A description of the characteristics of the Peam Krasaop mangrove-fishery. This diagram follows the framework presented in Chapter 3 in which the typology of a mangrove-fishery in a local context is mapped out in order to identify all the groups who use or benefit from the mangrove. The ways in which the mangrove is used by each activity (A) is divided into dimensions of B) relationship with the mangrove, C) function of fishing, D) fishing location and E) time of mangrove-associated fishing.

4.4.2.1 Fishing livelihoods by household

Households in the PKFC catch an average of 6.2 (SD 9.2) tonnes of fish and invertebrates and obtain 6,934.9 (SD 6,137.4) US$ in gross income per year. Average household size is 5 (SD 2) family members (N = 40). Due to the diverse nature of fisher livelihoods, it was not possible to calculate individual expenses involved with fishing for each household. However details collated regarding the fuel, bait, equipment and worker costs attributed to particular fishing activities are detailed in Appendix 4-5. Expenses involved with fishing can vary from none, for activities such as gathering, to 100% of gross income for high investment activities such as green mussel culture. Expenses incurred therefore depend on activity choice. For instance, fishers who employ workers expend at least 20% of total catch value and those that travel by boat use at least 2-3 litres of fuel per trip, which can reach 40 litres during the dry season if fishing takes place offshore, at approximately 0.86 US$ per litre. Set up and equipment costs, for green mussel culture and grouper culture in particular, can be very high and may require a number of years to generate profit. It should be noted therefore that total annual catch volume and value quoted can be vastly different (and usually much higher) than the net income generated by fishing families.

Fishing activities, targets and therefore catch volume and income also differ seasonally. The average catch landings per household is 5 (SD 7.9) tonnes in total for the dry season (over 7 months) and 1.1 (SD 2) tonnes in the rainy season (over 5 months). Gross income is therefore considerably higher for fishing households during the dry season than the rainy season, at an average season total per household of 5,408.6 (SD 4,669.4) US$ versus 1,526.2 (SD 1,918.6) US$. As a result, a few fishing households stop fishing during the rainy season. This was the case for 7 of the 36 fishers interviewed (6 from NPK, 1 from OPK), whilst just 1 fisher (from OPK) interviewed opts to fish in the rainy season but not during the dry season.

Households in the PKFC also derive the majority of their fish and seafood that they consume from mangrove-fishing, although the exact proportion of seafood in the diet was not clear. However if households in the PKFC kept just 5% (a conservative estimate) of their annual catch landings for consumption, average consumption per person (in an average household of 5 people) would be 62 kg of fish or seafood products annually, putting seafood consumption higher than the national average of 38 kg per person.

4.4.2.2 Inter-village variability in household fishing strategies

One-way ANOVA and Tukey's post-hoc analysis showed no significant difference in mean annual catch landed (kg) or total gross income (US$) per household between the 3 villages ($F(2,33) = 0.667$, $p = 0.52$). Observations made during interview surveys however suggested that livelihood strategies (the species targeted and the methods used seasonally) by households in the three villages showed some variable traits. Further ecological community analysis was therefore used to elucidate any differences not picked up by comparison of total catch or income values. Non-metric multi-dimensional scaling ordination (NMDS) showed no strong pattern in community structure of catches between the 3 villages but did indicate some outliers from each of the villages (Fig. 4-4).

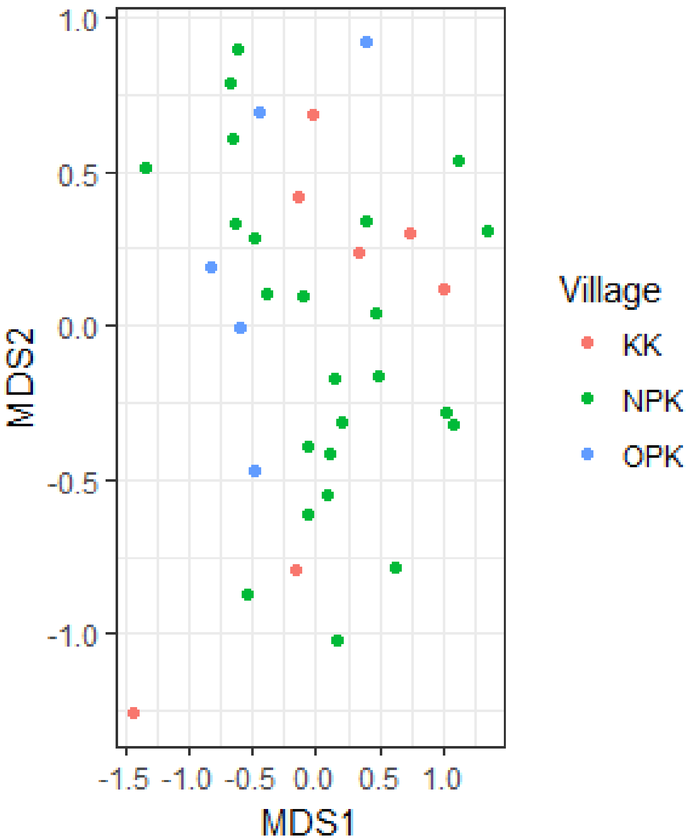


Figure 4-4. Non-metric multi-dimensional scaling ordination using Bray Curtis distance for catch species composition by household within Koh Kang (KK), New Peam Krasaop (NPK) and Old Peam Krasaop (OPK) Villages. Data points are arranged in two dimensions (axes 1 and 2), with similar samples plotted close together and dissimilar samples plotted further apart. Direction on the axes, and numbers on the axes, are arbitrary. Data was not transformed or standardized prior to analysis due to interest in outliers in the dataset. Stress value = 0.17. The vegan package was used in R to produce this analysis.

A Permanova test using the R's adonis function suggested that 8% of dissimilarity in catch composition can be explained by the village affiliation of the fisher (R^2 = 0.08). A simper analysis was then conducted to highlight the species groups responsible for this dissimilarity in catch composition between villages. The cumulative percentage influence of species caught between the villages in the PKFC, calculated using Simper analysis, are detailed in Table 4-2.

Table 4-2. Results of simper analysis conducted to investigate dissimilarity in catch composition between 3 villages in the Peam Krasaop Fishing Community. Only species with the top 3 highest cumulative contribution to dissimilarity are shown here. Average abundance denotes mean volume (kg) of daily catches of a particular group per household. Percentage contribution and cumulative percentage refer to the percentage dissimilarity calculated by simper analysis.

Contrast:	Name	Av. Abundance (kg)	Av abundance (kg)	Av. dissimilarity	% Contribution	Cumulative %
KK_NPK	Average Dissimilarity: 8.6	KK	NPK			
	Common mangrove clam	1406.65	3259.11	0.27 (SD 0.3)	30.86	30.86
	Green mussel	380.40	2449.13	0.23 (SD 0.29)	26.34	57.20
	Blue swimming crab	125.00	467.93	0.10 (SD 0.14)	11.66	68.86
KK_OPK	Average Dissimilarity: 8.9	KK	OPK			
	Green mussel	380.40	2800.00	0.26 (SD 0.23)	29.31	29.31
	Whitefish	0.00	1500.00	0.17 (SD 0.17)	19.08	48.39
	Common mangrove clam	1406.65	0.00	0.17 (SD 0.26)	18.87	67.26
NPK_OPK	Average Dissimilarity:	NPK	OPK			

	8.8					
	Green mussel	2449.13	2800.00	0.29 (SD 0.27)	33.48	33.48
	Whitefish	0.000	1500.00	0.14 (SD 0.15)	16.00	49.48
	Common mangrove clam	3259.11	0.00	0.13 (SD 0.26)	13.81	63.29

Table 4-2 shows that four species groups contribute most to dissimilarity in catch composition between villages, namely common mangrove clam, green mussel, whitefish and blue swimming crab (Table 4-2). Dissimilarity between NPK and KK can be mostly attributed to higher average catches (kg) of common mangrove clam, green mussel and blue swimming crab on the former than the latter, while the species groups are caught by some households in both villages. Average harvest of green mussel proved higher on OPK than KK and NPK, contributing most to dissimilarity with both villages. Absence of mangrove gathering activity for common mangrove clam in OPK in contrast to its popular activity in NPK and KK also contributed to dissimilarity. Likewise, catch of whitefish solely in OPK, offered dissimilarity with both other villages.

4.4.2.3 Fishing site variability between villages

The locations visited by fishers from the 3 villages are shown in Figure 4-5. As also conveyed anecdotally by fishers, this map confirms that while some village specific fishing occurs within the proximity of each village, fishers of NPK do travel to their original fishing grounds prior to relocation which are mainly within the channel close to OPK; *"The people come back to the same place, just change the house, because there is no new place for fishing"*. As such, fishers from the 3 villages utilize many of the same spaces for fishing. Whilst acknowledging some differences in target catches, livelihoods are similar throughout the PKFC and therefore results are now discussed for the PKFC combined where appropriate.

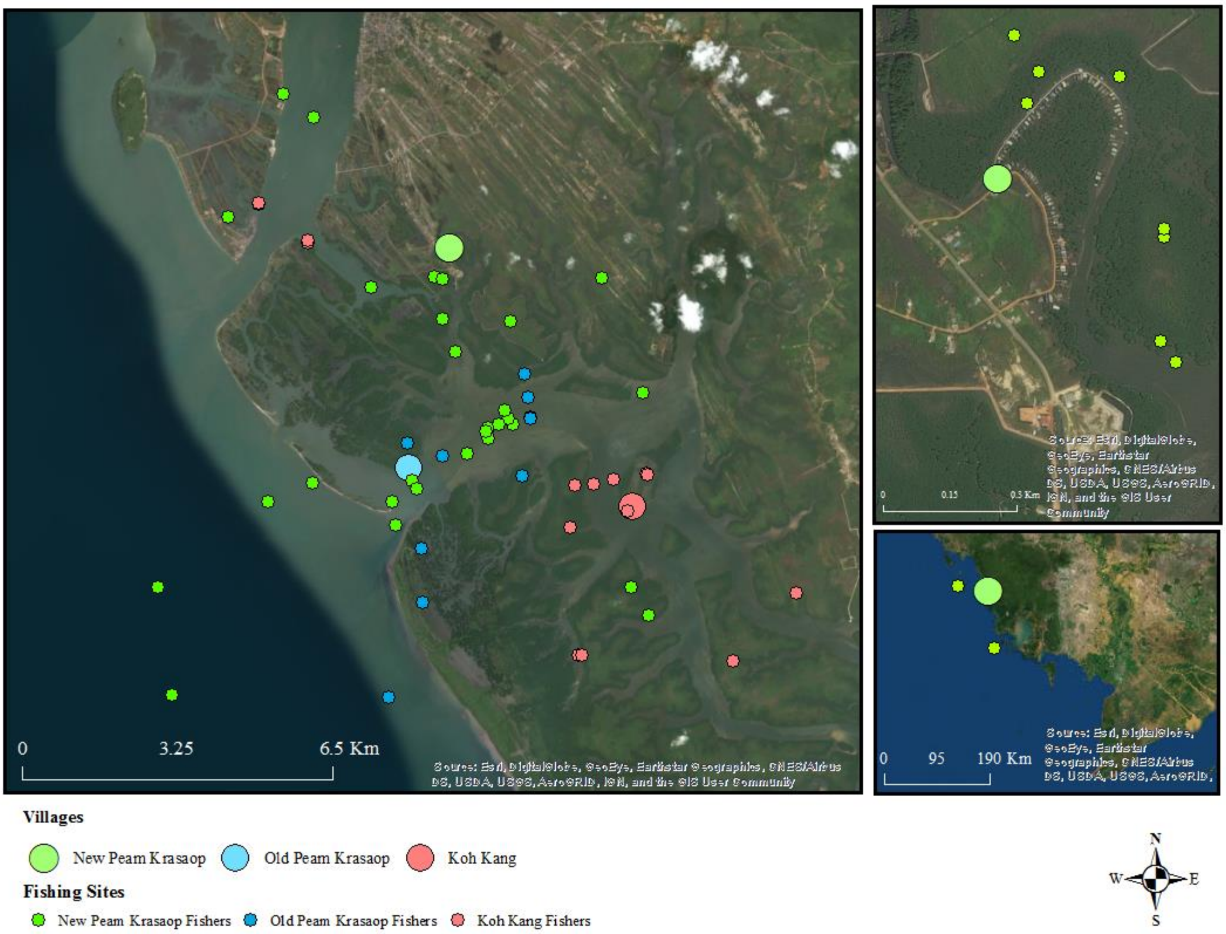


Figure 4-5. Fishing sites frequented by fishers from 3 villages, New Peam Krasaop (NPK), Old Peam Krasaop (OPK) and Koh Kang (KK). Data points represent mid-points of polygons drawn by individual fishers or household representatives during interview surveys. The map panels displayed show the regions that were annotated by fishers (from 3 maps used depending on respondent answers) within the Peam Krasaop Wildlife Sanctuary (left), zoomed in on the mangrove surrounding NPK (top right) and the coastal zone adjacent to the Peam Krasaop Wildlife Sanctuary (bottom right).

4.4.2.4 Catch species composition

Interviews identified 74 species of fish and invertebrates which are landed by the PKFC. A full list of the species caught, their mangrove association, the fishing gears used to catch them and the estimated number of households currently targeting these species groups are detailed in Table 4-3.

Table 4-3. Species groups targeted by the Peam Krasaop Fishing Community (PKFC) according to interviews with the community. The species included in each group and their known mangrove association from the FishBase or SeaLifeBase databases (Palomares and Pauly 2016, Froese and Pauly 2017) are detailed in the table. The estimated number and proportion of households in the community who target these species groups along with examples of the fishing gears used to fish them are also included. Khmer sounds are derived mostly from interview surveys, those missing were supplemented by those detailed in PMMR team (2000) and may differ locally.

Species group name	Khmer Sound	Species included	Mangrove associated	No. house holds	% of PKFC house holds	Gears used
Blue swimming crab	Kdam ses	*Portunus pelagicus*	Y	86	51	Crab net, Crab trap, Pong-pang
Common mangrove clam	Neeoo	*Polymedosa erosa*	Y	54	32	Gathering
Dollfus octopus	Meuk pingeang	*Octopus dollfusi*	N	4	3	Shells
Fourfinger threadfin	Karav	*Eleutheronema tetradactylum*	Y	9	5	Fish net
Green and giant tiger shrimp	Kong lay	*Penaeus monodon* *Penaeus semisulcatus*	N N	6	4	Shrimp net, Pong-pang
Green mussel	Chong kamputer	*Perna viridis*	Y	69	40	Culture poles
Grouper culture	Trey takai	*Epinephelus tautina* *Epinephelusawoara*	Y N	13	8	Fish traps, Culture cages
Longlegged crab	Kdam cheung ven	*Possible identity: Episesarma mederi (mangrove associate)*	N	9	6	Crab traps
Mangrove oyster	Chon krolduc/ Chong	*Crassostrea sp.*	Y	21	13	Gathering using small knives

	tadet					
Mangrove snail	Chat chmay	*Cerithidea sp.*	Y	26	15	Gathering
Mantis shrimp	Prokang	*Oratosquilla nepa*	N	4	3	Shrimp net, Pong-pang
Mixed fish	Trey do-angkar	*Gerres filamentosus*	Y	71	42	Crab traps, Fish traps, Fish net, Pong-pang, Hook and line
	Trey sleuk-beus	*Drepane punctata*	Y			
	Trey takai	*Epinephelus tautina*	Y			
	Trey takai	*Epinephelus awoara*	N			
	Trey kontang phleung	*Siganus javus*	N			
	Angdeng poy	*Plotosus anguillaris*	Y			
	Trey andat chhke	*Cynoglossus macrolepidotus*	N			
	Trey Kobai	*Buffalo fish (sp. identity not found)*	N			
	Borbelsporn	*Himantura imbricate*	N			
	Borbel ruy	*Himantura gerrardi*	N			
	Trey kachi	*Plectorhynchus pictus*	N			
	Trey kbork angkam	*Valamugil seheli*	N			
	Trey ke	*Leiognathus equulus*	Y			
	Karav	*Eleutheronematetradactylum*	Y			
	Trey proluos	*Sillago sihama*	Y			

	Trey krohorm	*Lutjanus malabaricus*	N				
	Trey angkeuy Krohorm	*Lutjanus johni*	Y				
	Borta	*Lutjanus russelli*	Y				
	Trey sleuk-beus	*Drepane punctata*	Y				
	Chram trouy khmoa	*Rhizoprionodon acutus*	N				
	Spong	*Lates calcarifer*	Y				
	Trey kmaw	*Dussumieria elopsoides*	N				
	Trey proluos	*Sillago maculata*	Y				
	Trey anger	*Sphyracna obstusata*	N				
	Trey kontuy krob ekba lsruoch	*Cociella crocodilus*	N				
	Trey kbork kmuk	*Liza vaigiensis*	Y				
	Trey kontangp hleung	*Siganus canaliculatus*	N				
	Trey ok	*Arius maculatus*	Y				
	Trey chor	*Caranx sexfasciatus*	Y				
	Trey kamkach	*Gnathanodonc speciosus*	Y				
	Trey andat krobei	*Pseudorhombus arsius*	Y				
	Trey	*Ephippus oprbis*	N				

	trocheak domrei					
	Trey pruy-veng	*Pentaprion longimanus*	N			
	Trey kantuy-reung	*Megalaspis cordyla*	N			
	Trey chab-sar	*Pampus argenteus*	N			
	Trey kborkangk am	*Valamugil seheli*	N			
	Trey phtong prort kheiv	*Ablennes hians*	N			
	Trey phtong prort khmoa	*Strongylura leiura*	Y			
	Trey phtong phka	*Hemirhamphus far*	Y			
	Trey ke	*Gazza minuta*	Y			
	Trey chang kombei	*Otolithes ruber*	N			
	Trey sompane	*Scomberaides lysan*	Y			
	Trey krorb khnor	*Lethrinus nebulosus*	Y			
	Trey chab-khmoa	*Parastromateus niger*	N			
Mixed molluscs	Khchang dekkaul	*Telescopium telescopium*	Y	9	5	Gathering

	Neeoo Kreng chheam Krengteuk -chhroav Chon krolduc/ Chong tadet	*Polymedosa erosa* *Tegillarca granosa* *Cucullaco labiata* *Crassostrea sp.*	Y Y N Y			
Mixed shrimp	Kompeus Konglay Konbraun e Bangkeani long Bang kang	*Macrobrachium lanchesteri* *Penaeus semisulcatus* *Macrobrachium equidens* *Melicertus latisulcatus* *Macrobrachium rosenbergii*	N N N Y N	26	16	Shrimp net, Pong-pang
Serrated mud crab	Kdam kmoh	*Scylla serrata*	Y	80	47	Crab trap
Spotted catfish	Andeng barang	*Arius batrachus*	Y	6	4	Hook and line, Crab trap, Crab net, Fish trap
Striped sea catfish	Angdeng poy	*Plotosus anguillaris*	Y	15	9	Hook and line
Telescope creeper	Khchang dekkaul	*Telescopium telescopium*	Y	4	3	Gathering
Whitefish	Trey so	*Opisthopterus tardoore* *Ilisha melastoma* *Sardinella gibbossa*	N N N	19	11	Fish net

4.4.3 Catch landings volumes and values

Yield, market value and seasonality vary between target catches. Some products, such as mangrove oysters, have no formal market value and are gathered just for subsistence all year-round, whereas others, such as whitefish, have large market value but are only available for one month during the year. The mean yield and catch value for each of the target species, per trip (1 days' catch) and annually are detailed in Table 4-4. A summary of the fishing activities, species groups targeted and their contribution to mangrove-fishery livelihoods in the PKFC are detailed in this section.

Table 4-4. Average daily catch of target species groups and associated gross income per household, in the Peam Krasaop Fishing Community, in the dry season, rainy season and total per household annually. "NA's" denote that fishing for the species group does not occur during a particular season.

	Dry season				Rainy season				Annual			
Species group	**Av. Daily catch kg**	**SD**	**Av. Daily income US$**	**SD**	**Av. Daily catch kg**	**SD**	**Av. Daily income US$**	**SD**	**Av. Total catch kg**	**SD**	**Av. Total income US$**	**SD**
Blue swimming crab	6.70	7.91	37.75	53.89	3.33	2.72	25.28	21.36	780.45	676.83	4320.69	3906.98
Common mangrove clam	42.99	59.87	6.39	7.75	43.33	43.02	6.44	5.24	7338.75	13428.79	1080.69	1758.28
Dollfus octopus	5.60	NA	16.00	NA	NA	NA	NA	NA	895.23	NA	2557.36	NA
Fourfinger threadfin	31.50	9.19	104.90	61.73	25.00	NA	61.25	NA	2000.00	141.42	6286.15	1613.82
Green and giant tiger shrimp	5.71	NA	8.35	NA	0.71	NA	1.04	NA	310.71	NA	453.80	NA
Green mussel	NA	NA	NA	NA	NA	NA	NA	NA	5803.22	7949.71	1882.12	2358.64
Grouper	NA	NA	NA	NA	NA	NA	NA	NA	138.57	NA	1000.00	NA
Longlegged crab	12.50	10.61	4.59	3.90	12.50	10.61	4.59	3.90	2875.00	3005.20	1056.56	1104.41

Mangrove oyster	3.40	1.14	NA	NA	3.75	0.96	NA	NA	103.20	64.96	Not sold	NA
Mangrove snail	11.07	15.29	3.88	0.61	7.09	12.12	2.59	1.74	488.30	983.91	127.45	148.13
Mantis shrimp	1.08	NA	8.17	NA	0.54	NA	4.08	NA	71.51	NA	543.08	NA
Mixed fish	6.24	10.24	11.75	18.45	3.27	2.31	7.36	12.27	481.06	583.78	766.12	1118.75
Mixed molluscs	1.00	NA	1.27	NA	1.00	NA	1.27	NA	19.98	22.66	45.86	NA
Mixed shrimp	6.96	2.21	37.39	20.52	3.79	3.22	27.29	26.61	467.27	308.62	2898.18	2700.51
Serrated mud crab	4.24	3.68	32.69	27.27	2.89	2.85	22.38	21.06	571.03	628.85	4461.45	4705.30
Spotted catfish	NA	NA	NA	NA	1.25	NA	0.74	NA	93.75	NA	55.13	NA
Striped sea catfish	2.75	1.39	2.53	1.63	3.50	0.71	3.43	0.69	675.00	106.07	661.50	103.94
Telescope creeper	0.10	NA	NA	NA	0.10	NA	NA	NA	3.60	NA	Not sold	NA
Whitefish	100.00	NA	122.50	NA	NA	NA	NA	NA	2500.00	NA	3062.50	NA

4.4.3.1 Fishing

The most commonly targeted species by the PKFC, using crab traps or nets, are blue swimming crabs (N=19) and serrated mud crabs (N=18). Mixed fish catches were also common (N=14), usually being caught incidentally within traps or nets during crab fishing rather than being sought as a target. Fishing for blue swimming crab takes place offshore or within larger mangrove-lined channels (Fig. 4-6). Thus the weather dictates blue swimming crab fishing seasonality, as fishers fear storms, windy conditions, large waves and lightning. Conversely, fishing for serrated mud crab, which takes place within the protection of the mangrove forest, either inside it or within smaller channels (Fig. 4-6), takes place all year-round, particularly during the rainy season when weather restricts fishing for blue swimming crab. Both species bring in larger catch volumes and gross income per day in the dry season than the rainy season. These two mangrove-associated species combined bring in the largest average gross income per household than any other target species group. The average annual gross income from blue swimming crab and serrated mud crab was 4,320.7 (SD 3,907.0) US$ and 4,461.5 (SD 4,705.3) US$ respectively (Table 4-4).

A less selective fishing method, that is popular in OPK, is the use of equipment named "Pong-pang" (N = 3). The pong-pang is a long net attached to a stationary tall wooden pole in the water column, which uses water flow to herd fish, shrimp and crab into the net (see Table 4-3 for target species). This equipment is only used when the water level is high and therefore is intermittently used, just during the rainy season, between June-August.

Pong-pang fishing is not the primary income of fishers in OPK, but more of a rainy season option used in the between seasons for other activities. It was suggested that pong-pang fishing is a third occupation or income, after green mussel and grouper culture for families in OPK. However, it does form an important livelihood strategy available to those living in OPK, whereby three seasonal activities (mariculture of green mussels, mariculture of grouper and pong-pang) provide income year-round.

The only activity described which solely targets non-mangrove associate species by PKFC fishers is octopus fishing (N=1). This targets Dolffus octopus (*Octopus dollfusi*), 5 km offshore, using natural shells as traps, which are bought in Vietnam. As this activity neither utilizes mangrove-associated target species nor bait, and takes place offshore, no mangrove association can be drawn from this activity. Just two families conduct octopus fishing in the PKFC. Octopus fishing comprised the primary income of the fisher interviewed where other household members of this respondent take part in mangrove gathering for common mangrove clam as a secondary income.

Lower quality fish catches are also kept for subsistence by households in the PKWS, sold among the community for eating or as bait. Shrimp are dried, mainly by women, so that they can be sold at a better price than by wet weight to the middleperson (Table 4-3). The community are not entirely dependent on seafood products, especially in NPK as there is easy access to outside markets to buy meat and vegetables. In OPK and KK the market is more limited to seafood, while there is some opportunity for buying meat from small shops in the village. Fishers suggested however that seafood was an important component of their diets, with most families eating seafood every day.

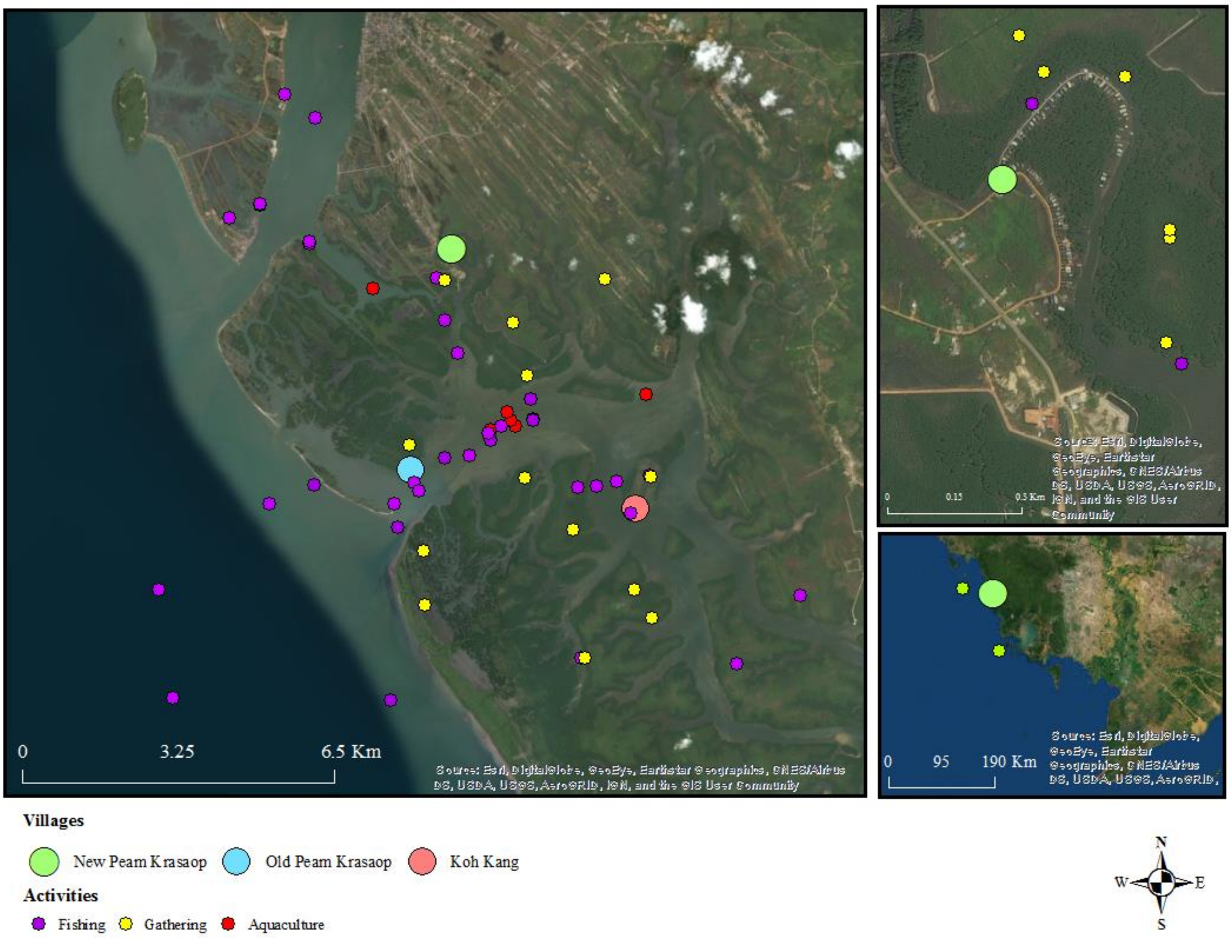


Figure 4-6. Fishing sites by activity, by fishers of the Peam Krasaop Fishing Community (PKFC). Maps are derived from hand drawn annotations by fishers in participatory mapping included in semi-structured interviews with PKFC households in 2017. Fishing sites represent the mid-points of polygons drawn by fishers. "Fishing" includes all wild-capture fishing activities conducted by boat, "gathering" involves those activities conducted within the mangrove by hand and "aquaculture" includes green mussel and grouper culture activities. The map panels displayed show the regions that were annotated by fishers (from 3 maps used depending on respondent answers) within the Peam Krasaop Wildlife Sanctuary (left), zoomed in on the mangrove surrounding NPK (top right) and the coastal zone adjacent to the Peam Krasaop Wildlife Sanctuary (bottom right).

4.4.3.2 Gathering

Gathering for common mangrove clam, or "mud clam", is only conducted by fishers from NPK and OPK (N=12). Clam gathering is an activity which directly uses the mangrove area, targets a mangrove dependent species, *Polymedosa erosa*, and uses a traditional mangrove gathering practice.

Gathering for mangrove clam occurs all year round. Gathering of common mangrove clam is also carried out during the time in which other fishing gear, such as crab traps, are left in the water during fishing trips. Gathering is therefore rarely the primary fishing activity by households, but an activity which is widely used by families who also conduct other forms of fishing, particularly in times where weather prevents other fishing. It can however contribute 1,080.69 (SD 1,758.28) US$ to gross income per household. This is not an insubstantial contribution given that the annual Gross Domestic Product (GDP) per capita in Cambodia is 1,385.3 US$ (World Bank Group, 2017). There are 2 middlepersons who buy common mangrove clam in the PKFC, which are then collected from the NPK port by traders who sell to Phnom Penh or Vietnam and who therefore influence local price.

Gathering in the mangrove is also used for collecting of food products for the household. The collection of these products is not a daily activity, more an activity conducted for specific products "*just when the family want to eat*" a few times per month. Products such as mangrove oysters and mangrove snails and sometimes also common mangrove clam are collected for the sole purpose of eating, with no intent to sell (Table 4-3). Subsistence gathering takes place the mangrove near to the village (NPK and KK) where locations can be reached on by foot or by small boat (Fig. 4-6). Collecting for subsistence purposes is often a job done by women, children and the elderly of the household and is also carried out within groups of neighbours. The role of women however is not limited to such activities, as women were also observed conducting other fishing activities with their spouses, although never alone.

Fishers and middlemen reported declines in common mangrove clam catches during the previous 1-3 years (2015 – 2017), attributed by respondents mainly to large numbers of fishers in previous years. One fisher suggested for example, "*The mud clam has decreased because so many people go to collect. Before he could get at least 100kg, now only 5-10kg. It started decreasing about 3 years ago. They talk about the size, the size has not changed, but sometimes you can get big ones that are 1/2 kg, but it's hard to find them".* This is also attributed by some fishers by numbers of fishers coming from other villages to collect mud clams; *"A lot of people from other areas (like Koh Sraloa / the town) come to collect mud clam".*

The number of fishers conducting gathering of mud clam has declined in recent years, as has the frequency of trips for those who do; "*The number of people gathering has decreased, now about 20 families that go to collect the clam. He doesn't know how many used to go, before: 20 boats of 7-8 people, now: 10 boats of 2-3 people".* Fishers suggest that previous low prices and high abundance caused fishers to deplete supplies, while current price is now higher than before; *"Less clam [now]. Low price, so people collected too much, now it's high price but there's no more to collect".*

4.4.3.3 Mariculture

Culture of green mussel (N=18), *Perna viridis* (referred to as aquaculture by the community), involves cutting poles from trees in the upland forest, or sometimes from mangrove trees. These poles are then wrapped in plastic sheeting (Fig. 4-7) and installed vertically in the water column where they are naturally colonised by the mussels over a period of approximately 1 year. As there is a perception that large annual gross incomes from this activity are possible at the present time (2017), many families have stopped their usual fishing activities (seasonally or indefinitely) in favour of putting their efforts into green mussel culture harvest. However, while green mussel harvesting can bring large yields, several households reported having experienced years of no profit or no yield from their green mussel poles. Despite this risk, several households are beginning to invest in green mussel culture activities and during the time of interviews were anticipating their first yield, having planted the poles in the past year. The typical incentives and concerns conveyed by newcomers to aquaculture in the community are stated by one household; *"They saw the neighbour who got much money, but she's not sure if they'll make much money. They loaned some money from microfinance to buy the poles. Her concern is whether the yield will be high or not"*.

Green mussel culture has displaced other fishing activities during the harvest period for the mussels, between December to March, in which fishers intensely work until all poles have been harvested, also employing those from families who do not own aquaculture poles for diving, harvesting and boat work. Those who own aquaculture poles are also busy with pole cutting, preparation and placing during most of the rainy season; previously they would have been fishing prior to investing in mariculture.

Estimates based on interview participant numbers actively involved in green mussel culture suggest that 69 households (40% of households) in the PKFC own green mussel culture poles. Discussions with middlemen however, who buy green mussels from families in the village, suggest that up to 80% of households in the PKFC are involved.

Figure 4-7. A woman in Koh Kang Village, Peam Krasaop Commune, prepares poles for green mussel culture (left) and green mussel culture poles in the channel between Old Peam Krasaop village and neighbouring Koh Sraloa in the Koh Kong Mangrove-Estuary (right). Photographs taken during fieldwork in August 2017.

The channel between OPK and the neighbouring island of Koh Sraloa is where the majority of poles used to culture the species are placed (Fig. 4-6). The channel is approximately 1.9 km in width at its widest point and therefore poles within the channel are no further than approximately 950 m from the nearest point of mangrove forest (Fig. 4-6). Fishers however suggest that it is the water depth and velocity which determine pole placement location, rather than distance from the mangrove.

Households own between 100 to 2,000 poles, and add more approximately every 3 years when the poles start to degrade and are no longer viable for mussels to grow on them. The channel is therefore densely filled with wooden poles (Fig. 4-7). Annual harvest brings in an average of 1,882.1 (SD 2,359.6) US$ during a short 4 month harvest period. However, establishment of green mussel culture costs upwards of 1,000 US$. Entry to green mussel culture is therefore restricted by wealth.

Poorer households are also disadvantaged in gaining financial loans to enter green mussel culture compared to wealthier households, as microfinance loans offered are larger for those with more money. A fisher discussion of wealth levels related to aquaculture access stated *"All of them [the community] also have aquaculture but the middle scale, also a boat. Can also loan more money than* *the poor people because they have land, the poor people only have a house. E.g. poor people could loan $1000 whilst people in the middle could loan $12,000".*

Entry to green mussel culture is also restricted by space. This is illustrated by one fisher who has chosen to move away from OPK due to lack of opportunity for green mussel culture; *"He doesn't have space to do aquaculture in the old village so they moved here to find other jobs to do. Some families still were there because they have aquaculture if they have a big space. There is no space because there is already so many".* Space limitation has also caused conflict between those who are involved in green mussel culture and those who are not, as the location for green mussel poles is also a popular location for fishing (Fig. 4-6), particularly for blue swimming crab. Some fishers suggest that this restricts access for fishing, forcing fishing to take place in less favourable shallower waters where yields are lower. Others (those involved in aquaculture) suggest this conflict is only an issue for the minority, given that only a small number of families are not involved; "*The area that you can do aquaculture has some conflicts with the families who don't have aquaculture, only nets. All the people in the village want them to do aquaculture but they complain to the people that have a big aquaculture that there is no space for fishing. But actually the people with fish nets can put the nets around the poles*".

Profit from green mussel harvest for the PKFC is closely linked to demand from Thailand. Mussels are sold either directly to Thai buyers or via local middlemen, who then sell to buyers in Thailand. As a result, the PKFC have experienced episodes of lost income due to lack of demand in Thailand; *"One time because the green mussels are imported to Thailand, in 2013 Thailand had floods so the factories could not process so the demand for mussel decreased. All the people in the village had this problem, it reduced the income".* Despite this, green mussel culture continues to be a popular activity amongst the PKWS as annual income from green mussel can be similar to that of other fishing activities, while requiring less time and effort; *"He thinks it's still the same [the income] but for fishing you work hard, for aquaculture you just put the poles and check two times. Fishing you go every day and if you don't, you don't catch crab".*

Grouper culture (N=2), like green mussel culture, brings high yields and incomes to those who can afford its high investment costs (see Appendix 4-5 for expenses). Grouper culture involves catching fish using specific grouper traps and placing them in stationary cages where they are fed until reaching the marketable size of 0.7 kg. Fishing for grouper, using species specific fish traps, takes place within the channel between OPK and Koh Sralao, around the green mussel culture poles and in and around the mangrove (Fig. 4-6). Grouper culture is actively pursued only in OPK, as only OPK has the necessary environmental conditions of deep water and high salinity. It also requires consistent maintenance during the active season and therefore only those individuals that live nearby can take up this occupation. Target species described by fishers included both mangrove and non-mangrove associated grouper species (Table 4-3) and therefore as a group, grouper have not been coded as mangrove associated catch in this study.

The gross income from grouper culture in the past year (2016-2017) for one household was 1,000 US$. However fishers suggested that the potential yield was reduced by 1/3 due to red spot disease in the previous year. Fishers also suggested that the size of grouper being caught for culture is smaller than previously. Incomes from both green mussel culture and grouper culture are also subject to weather dependent losses; "*The main incomes are (difficult to define which one is first) green mussel and fish aquaculture, it also depends on the weather. That year when there is a lot of rain, mussels decrease but the fish is good, if the temperature is high the fish is decreas*ed".

4.5 Discussion

The PKFC is highly dependent upon mangrove-associated fish and invertebrate catches. The estimate of 90% of the total fishery catch landings of mangrove-associated species is a conservative one, as species groups with any non-mangrove associated species, regardless of proportion in that group (such as grouper and shrimp species), were coded as non-mangrove associated species. Thus it is likely that mangrove-associated species make up more than 90% of catches by volume within the community. There is, however, a large range of catch volumes and gross incomes between households in the PKFC. This estimate of mangrove-association, which was derived from catch landings from the fishery as a whole, may therefore not be equally representative of individual households. Dependent on livelihood strategies, which were variable within and among villages, mangrove-associated catches could be more important for some households than others.

Those activities that are most accessible to people of all wealth levels, and therefore the most frequently used methods, such as crab fishing or gathering, are those which directly or indirectly benefit from the mangrove forest. Meanwhile, many of the non-mangrove associated groups included, such as grouper culture and octopus fishing, are derived from high investment activities which are not available to less wealthy families in the community. The estimate of an average of 85% of gross income from fishing per household may be an underestimate for the poorest households in the PKFC. Conversely, those wealthy households who do not target mangrove species as their primary, or even secondary income, may derive considerably less benefit from the mangrove. No households in the PKFC, however, can be assumed to be entirely detached from the mangrove-fishery, given the subsistence use of mangrove products even by households that conduct non-mangrove activities for their primary income.

Compared to other studies of mangrove-fishery value, this study provides one of the higher estimates of the importance of mangroves to fishing. Examples elsewhere include 71.9% of municipal catches in the Philippines (Paw and Chua 1991), 60% of commercially sold catch in Fiji (Aksornkoae et al. 1984 in Ronnbaack 1999) 67% of commercial catches in Eastern Australia (Aksornkoae et al. 1984 in Ronnbaack 1999), 32% of small-scale fisheries catch in the Gulf of California (Aburto-Oropeza et al. 2008) and 80% of commercial catch in Florida (Aksornkoae et al. 1984 in Ronnbaack 1999). While the PKFC are clearly very strongly linked to the mangrove through fishing, it may be that the PKFC does not derive more value from the mangrove than other fishing communities. Rather, it may be the case that this study was further reaching in evaluating mangrove-fishery benefits. Where other quantitative studies have traditionally been limited in their quantification of mangrove ecosystem services to one or two fishing sectors, activities, gears or species, this study conducted a thorough analysis of all the groups who may derive benefit from the mangrove through fishing.

The study provides higher estimates of indirect and direct value of mangroves to fishing household incomes than have been suggested in Cambodia. Estimates made in 2014, using a production-function approach, have suggested that fishing communities in Cambodia gain an average of 5,076.95 US$ of use value from mangroves (including fuel wood and mangrove poles as well as fishing and gathering snails) and an indirect value of just 44.82 US$ from the nursery and breeding function of mangroves (Sopheak and Hoeurn 2016). This study of the PKWS approximated that households earn a gross annual income of 6,934 (SD 6,134) US$ from fishing activities alone. Much of this catch is caught outside of the mangrove, for example swimming crabs and green mussel culture which are dominant fishing activities in the PKFC. This highlights the importance of the indirect value that mangroves provide to fishing PKFC, which is likely higher than has previously has been estimated for fishing communities in Cambodia.

Catches of many of the species targeted by the PKFC are however reportedly declining. Pressure on fish and invertebrate stocks in the PKWS is also high through fishing, and may be exacerbated due to the “boom and bust” strategy that appears to operate in the PKFC. This trend occurs when a profitable activity is taken up by many, and exacerbated until no longer profitable and a new more profitable activity is identified. This pattern has long been observed within the community since its establishment the 1990s (Marschke, pers. comm. 2017). An example of this dynamic is the rush of intense common mangrove clam gathering by the community, followed by its decline and current response by the community to move into green mussel culture, which already shows signs of instability as a sustainable activity due to lack of space for expansion. The community also reported lower catches of other products such as grouper species, suggesting the current fishing activities may be unsustainable.

However, in following this strategy, it might be argued that the PKFC is an adaptable fishing community, through its ability to switch between activities, acquire new skills and follow profitable trends. This could be a result of the PKFC being a relatively newly formed fishery, having been active only for approximately 30 years. The kind of cultural value associated with mangrove-fishing which has been observed in other mangrove-fisheries of longer history (Costanza et al. 1997, James et al. 2013) may thus not have developed here. Cultural value associated with particular fishing practices or targets, often passed on as learned skills from generation to generation, can be a barrier to adaptation even where fishing is no longer profitable (Adger et al. 2013, Blythe 2015, Miller et al. 2018). The current adaptation strategy could help the PKFC in being resilient to future changes, such as impact on the mangrove through continued sand dredging (Larson 2018), erosion of the protective beach barrier (Kong et al. 2013) and/or potential future climatic changes to the mangrove ecosystem (Ward et al. 2016).

This ‘switching strategy’ does not, however, benefit everyone in the community. New activities are often pioneered by wealthier families in the community, while poorer families continue to exploit declining stocks. Those targets, such as common mangrove clam, continue to be depleted, possibly beyond bounce back capacity by those who have no other option, thereby not allowing the stock to recover. While boom and bust may serve as a successful option for wealthier families, it may be to the detriment of poorer families whose entry to the next new option is limited or delayed. The barrier to entry to green mussel culture through money and space is an example of this process. This also leads to poorer families relying on microfinance loans or loans within the community. These can be risky investments, as highlighted by the variable yield successes in green mussel over recent years. They could further indebt families and lead to more intense harvesting of other declining stocks due to the livelihood struggles that result. Debts such as these could also lead to conflict within the community, which is already being generated through competition over space.

Wealth aside, an additional limiting factor in this strategy is the reliance on external demand. Some of the largest income generating target species, namely green mussels and common mangrove clams, are profitable only when demand from international markets is high. Ceased demand from these markets may lead to these activities becoming obsolete. This has already been experienced with the temporary standstill in green mussel demand from Thailand. Under these circumstances, it is likely, given their history, that the PKFC would seek to use the mangrove for a new market or target. One question however is for how many cycles can this pattern continue - at what point will there be no “next option”?

The community is also adaptive in their diversification to new occupations. As a result, the number of fishing households has drastically reduced within the Peam Krasaop Commune in recent years, particularly in NPK where there is better access to other occupations. Households do however appear to continue prioritising fishing as the primary household occupation. Many return to fishing seasonally from other jobs, suggesting that in the good season, fishing can still generate a better income than modern jobs. Many households also feel restricted from diversifying to new jobs due to family size, suggesting that modern jobs can only be taken by members of families who have a large enough family to also perform all the fishing tasks required. Being employed in non-fishing work is also seen as a privilege for wealthier families who do not need to fish (because they can afford to buy their fish from others). Green mussel culture, however, has enabled some families to enter modern jobs due to the lower labour intensity involved with culture year-round rather than fishing. Nonetheless, it is the year-round, higher labour activities which provide food products to the community (e.g. crab, fish and bivalves) in comparison to mariculture products which are not kept for subsistence. It seems clear therefore that fishing, at least to support household subsistence needs, is likely to continue despite the diversification of occupations by the younger generation.

4.5.1 Limitations

Approximation of total annual yield was conducted based on estimates of fishing effort by the PKFC due to the absence of primary data. While fishermen often stated that fishing occurred every day, it was evident that fishing is often restricted or stopped entirely by bad weather, and therefore annual catch estimates had to be scaled based on estimated days fishing from participant observation, regional patterns and expert opinion. As such, some overestimates of annual catches may have been calculated as a result. An example is that of four-finger threadfin, which is unlikely to have been caught in such large quantities as recorded, but was likely recorded by a fisher using the higher end of the range of catch volumes experienced for that species. Equally, underestimates could have been given where fishing is possible more frequently than the estimates used. Use of log books to quantify fishing effort by fishers, or longer term observations, would allow for more accurate estimates to be made (McCluskey and Lewison 2008). As interviews took place only during the rainy season, data collection also relied on memory of the dry season by fishers and therefore some bias towards rainy season catches in the immediate memory of respondents. Return visits during the dry season would clarify seasonal differences in mangrove-fishing activities. Quantifying household subsistence value of mangrove benefits to the community was also restricted by time limitation of this study.

Taking these limitations into account, quantification of mangrove-benefits to fishing in the PKFC could not give definitive measures of mangrove-associated catches and incomes. However, this study has been able to give rough approximations of the value gained by the PKFC through mangrove-fishing using detailed local knowledge. It has been argued elsewhere that the use of fishers' knowledge is a vital step in the planning of management of fishery resources, particularly in understanding the history of a fishery (Johannes et al. 2008). In keeping with this argument, the complex history of mangrove use in the PKWS derived here is important information in understanding current and future uses of mangroves by the PKFC. It would not have been discovered through other, less socially focussed, methods of data collection.

Peam Krasaop also includes areas of previously degraded mangrove forest which have been restored, as a result of replantation efforts by local agencies and communities, and therefore could be providing ecosystem services that support the fishing community (Pillai 2003). It was not clear however whether replanted mangroves were directly used for fishing, as historical locational data on mangrove change was not available. Replanted mangroves in some cases have been shown to host similar levels of biodiversity and fish density as natural mangroves. However whether the fish and invertebrate communities remain the same as natural mangrove faunal communities after replanting or not requires further study. This is because different species groups respond differently to forest degradation (Bosire et al. 2008). Furthermore, whether biodiversity hosted by replanted mangroves therefore translates to fisheries production, fulfilling the same role to mangrove-fishing communities as natural mangroves, has not been investigated. Nonetheless, quantification of mangrove benefits to fishing communities where mangroves have been replanted, such as conducted here for the PKFC, may shed light on the future potential of mangrove replanting efforts which are happening in wider Cambodia, SE Asia and elsewhere in the Tropics in response to rapid mangrove loss.

4.6 Conclusions

The PKFC maintain year-round mangrove-fishing livelihoods through seasonal switching between gathering, fishing and mariculture activities. As such, the PKFC derive the majority of their fishing catch and income from mangrove-associated species. The complexity of mangrove-fishing activities, through varying target species, locations and seasons, and diversity of activities within households, makes definitive quantification of mangrove ecosystem service value challenging. Further research into seasonal fishing patterns is required in order to provide more accurate estimates of annual fish catches and incomes. What is presented here however gives a detailed insight and approximation of benefits that coastal mangrove-fishing household can receive from mangrove-fishing.

This case study also provides an example of the benefits a fishing community can receive from a region of previously degraded and restored mangrove forest. This is important in informing and promoting wider restoration efforts which are happening in wider SE Asia and worldwide in response to rapidly reclining mangrove forest extent. This study holds some promise for the future of sustained mangrove-fishery livelihoods, under the appropriate conservation, restoration and management measures.

The PKWS however is not entirely without pressures, with high fishing effort, illegal sand dredging and coastal erosion potentially threatening the mangrove ecosystem. The PKFC appear resilient to changes in ecosystem function through their adaptive and changeable fishing strategies, as well as diversification into other occupations. There are however leaders and followers in these strategies which potentially benefit the former more than the latter, which risks further degradation of resources by those left behind.

Inclusion of the historical, political and social context has given more information regarding the influencing factors of mangrove use in the PKWS which could not have been attained through higher level methods. Further local-scale monitoring into the activities, catches and incomes afforded to the PKFC through mangrove-fishing, along with the social, political and historical factors influencing them is necessary. This information will be vital in understanding and preventing potential human and climatic impacts on mangrove-fishing livelihoods in the PKFC, and similar communities, in future.

5 - Investigating the relationship between mangrove extent and small-scale fisheries at the global scale

Summary

A positive relationship between mangrove extent and fisheries catches has been widely reported. However, the relationships reported have been considered too generally stated and lacking in understanding of the underlying mechanisms to definitively link mangroves to fish catch. In particular, many studies lack geospatially located fishing data and are therefore bound by arbitrary parameters or locations. Geospatially located fishing data is difficult to obtain at the small local and regional scales that studies of mangrove-fishery linkages have been conducted. This chapter aims to investigate whether a relationship between mangrove and fish catches can be detected at a global scale. Catch data was obtained from the Sea Around Us (SAU) global fisheries catch database, along with high resolution mangrove extent maps from the Global Database of Continuous Mangrove Forest Cover for the 21st Century (CGMFC-21). These were used to explore the relationship between subsistence and artisanal fisheries catches and mangrove forest extent for the 2000-2012 period. Spatial trends in mangrove extent and fish catches were then further explored via a number of potential explanatory environmental variables, using high resolution data sets available through Google Earth Engine. Finally, the chapter explores whether trends emerging in global data are representative of mangrove-fishing information collected at local scales. Contrary to much of the previous literature, results suggested that variation in mangrove-associated fishing catches is better explained by proximity to the mangrove than by mangrove area. Generalised additive models, used to explore the relationships observed were improved by the inclusion of additional biotic and abiotic variables, although explained just 11% of the variation. Further research which investigates additional potential factors influencing the distribution of mangrove-associated catch is therefore necessary. In particular, this chapter pointed to a need for research to determine to what extent trends in mangrove-associated fish and invertebrate catches can be explained by socio-economic and oceanographic factors. Nonetheless, trends in mangrove-associated fishing here provide information on the distribution of mangrove-associated resource use which may have implications for conservation efforts, spatial planning and sustainable fisheries management.

5.1 Introduction

Mangroves are widely believed to enhance coastal fisheries through their role as a nursery habitat, host to high biodiversity, and positive influence on recruitment to adult fish populations (e.g. Faunce and Serafy 2006, Hutchison et al. 2014, Sheaves et al. 2014). This hypothesis has been used for several years in the argument to protect mangrove resources for coastal communities. This relationship however has long been problematic due to a lack of quantitative testing of the underlying links between mangrove characteristics and fish catches (Sheaves 2017). At both local and regional scales, many studies have found positive correlations between the area of mangrove and enhanced fish catches (Kenyon et al. 2004, Ley 2005, Manson et al. 2005b, 2005a, Vázquez-González et al. 2015). Indeed, 23 publications, detailing 51 studies at various locations worldwide, have endorsed the hypothesis through a positive relationship between some aspect of mangrove ecosystems and volume of fish catches (Carrasquilla-Henao and Juanes 2017), such as between fish catch and the total mangrove area present, or in some cases also the area of the productive mangrove fringe (Barbier and Strand 1998, Loneragan et al. 2005, Aburto-Oropeza et al. 2008, Vázquez-González et al. 2015). Conversely, loss of mangrove area has been correlated with losses of fisheries yields (Barbier and Strand 1998, Vázquez-González et al. 2015).

Chapter 3 highlighted the lack of agreement in the literature on the spatial relationship between mangrove extent and fishing catch volumes. Progress has been hampered by knowledge gaps, both of the distribution and behaviours of mangrove-associated fish and of the spatial patterning of mangrove-associated fishing activities. These relationships are further complicated by the fact that the ecological parameters which may influence mangrove-fish and fishery relationships most likely vary from place to place, making the relationship between mangrove characteristics and fish catches probably non-linear (Nagelkerken et al. 2008, 2015).

A number of factors have discouraged analysis at broad (regional seas/global) geographical scales, such as underreporting of catch landings (often dis-incentivised by taxes), lack of information on species composition of catches and non-uniform accuracy of mangrove extent estimates (Turner 1977). National catch data in particular are prone to underestimates of catches in the small scale sector, such as artisanal, subsistence and recreational fisheries (Pauly and Zeller 2018). Geospatially located data on fishing activities is also difficult to obtain at the local level, the level at which most mangrove-fishery research is conducted, due to lack of resources. Spatial fishing data collection requires the use of vessel monitoring log-book systems, and is reliant on the goodwill and participation of respondents, for which fishing locations can be sensitive information, often held only by the fisher themselves (Johnson et al. 2017). Participatory mapping and interview surveys can be very useful in providing spatial information (as shown in Chapters 3 and 4), but these methods are time intensive for respondents and researchers alike and produce only coarse results.

However, it is now possible to ask if global data reveals any of the trends believed to exist between mangrove extent and fisheries catches. The potentialities of the availability of high resolution and continuous global mangrove cover data, reconstructed catch data at global scales offering improved national scale data and local data and satellite-based global datasets on other environmental parameters are considered in more detail below. Remotely sensed global mangrove cover data has been made use of over large spatial and temporal scales to explore global patterns in mangrove carbon stocks and emissions (Hamilton 2012, Atwood et al. 2017) as well as the drivers and distribution of mangrove deforestation (Richards and Friess 2016). This will be a first look at whether global data reveals any of the trends believed to exist between mangrove extent and fisheries catches.

5.2 Methods

5.2.1 Data acquisition and manipulation

5.2.1.1 Fisheries catches

Global fisheries catch data was provided by the University of British Columbia from the Sea Around Us reconstructed catch database (Pauly and Zeller, 2015). The Sea Around Us database provides time series data of all marine fisheries catches within Exclusive Economic Zones (EEZ's) since 1950 (Pauly and Zeller 2016). Catches are reconstructed from baseline source data, in the form of landings data, including time period and spatial coverage of catches, from the Food and Agriculture Organization (FAO) or other international reporting entities (Pauly and Zeller 2016). Missing components from the data are identified through the websites and publications of governmental departments of fisheries, from non-fisheries sources such as household or nutritional surveys, as well as a global network of local collaborating experts. On identifying anchor points in the data (catch estimates for a single year or sector), data is expanded and interpolated for missing time periods, giving an estimation of total catch time series (Pauly and Zeller 2016). Taxon information is also used to reconstruct the relative abundance of species within catches, including latitudinal and depth range of the taxon group, as well as general habitat preference. The Sea Around Us database does not currently contain information about mangrove habitat or species-association and therefore species distribution of catch data is not constructed on any assumptions related to mangrove presence. It should be noted that there are some implausibly small data points included in the dataset (as small as 0.1e-07 tonnes per grid cell) as a result of the reconstruction process which are likely to be from areas of underreporting. The Sea Around Us project justifies the estimates of catch where there is no data as preferable to an assumed “no catch” in areas where data is known to be missing (Pauly and Zeller 2016).

Data from the small-scale fisheries sector (artisanal and subsistence) were included for all years within the 2000-2012 period. The artisanal sector is defined within the database as fishers using small-scale (e.g. hand lines and gill nets) and fixed gears (e.g. weirs and traps), where catch is predominantly for commercial sale but may be consumed or given away. The subsistence sector is defined as fishing conducted for subsistence only, or the subsistence fraction of artisanal catches. Small-scale fisheries include only those that operate within the Inshore Fishing Area (IFA), which includes the area within 50 km of the coast or 200 m depth, whichever comes first. Observations are in the form of tonnes of fish or invertebrates landed per half degree grid cells covering the world’s oceans, and are separated by species and by year of catch observation. Only catch observations of fish or invertebrate species that are known to use the mangrove habitat for some of their life history were included in the analysis, referred to herein as “mangrove-associates”. A list of mangrove-associate species was compiled using the information provided in FishBase (Froese and Pauly 2017) and SeaLifeBase (Palomares and Pauly 2016), via the rfishbase programmatic interface package in R, downloaded from GitHub (https://github.com/ropensci/rfishbase). A total of 138 species of fish and invertebrates were selected as known mangrove-associates, of which 91 appear within the Sea Around Us catch database (see Appendix 5-1). Data was further subset to include only catches occurring in grid cells that lie within mangrove holding countries, based on a list of mangrove extents provided by Hamilton and Casey (2016). Mangrove-associated fish catch recordings were available for 83 of the 105 mangrove holding countries (see Appendix 5-2).

Species were classified by their position in the water column (demersal, benthopelagic or pelagic) and their most common behaviour (solitary, aggregating or schooling) based on information from FishBase (Froese and Pauly 2017) and SeaLifeBase (Palomares and Pauly 2016).

5.2.1.2 Mangrove area

Global mangrove layers for each year between 2000-2012 were downloaded in geodatabase format from the Global Database of Continuous Mangrove Forest Cover for the 21st Century (CGMFC-21) (Hamilton and Casey 2016). Other global mangrove layers are also freely available, such as those reported by Spalding et al. (2010) and Giri et al. (2011). However, earlier estimates of mangrove cover have been criticised for taking ‘snapshot views’ of mangrove extent and aggregating regional and national datasets derived from unclear methodologies (Hamilton and Casey 2016). As a result, mangrove cover estimates available so far have been variable and difficult to use in monitoring mangrove change over subsequent years (Hamilton and Casey 2016). The CGMFC-21 database was therefore preferred as it synthesizes information across three databases: the Global Forest Cover database (Hansen et al. 2013), the Terrestrial Ecoregions of the World database (Olson et al. 2001) and the Mangrove Forests of the World database (Giri et al. 2011). The final synthesis provides a continuous and high spatio-temporal resolution estimate of global mangrove cover annually in raster format for the years 2000-2012 inclusive (Hamilton and Casey 2016). The resolution of these spatial layers is 30 m within the tropics and it is estimated that 99% of all mangrove forests are included (Hamilton and Casey 2016).

Using Google Earth Engine (GEE) (Gorelick et al. 2017), mangrove area per half degree grid cell was calculated to match the spatial bounds of the fish catch data measurements. As each raster layer from the CGMFC-21 database was very large, around 618 GB per layer, they could not be configured to the format necessary for analysis with using local processing alone, at least within the time constraints of this project. Google Earth Engine, a cloud-based geospatial processing platform, provided the computing power necessary to manipulate such a large dataset efficiently. Even so, it was also necessary to aggregate the mangrove layers from 30 m to 900 m resolution prior to use in GEE, using ArcCatalog, as files were too large for handling in GEE. The geodatabase files of mangrove area were also converted from raster to Tiff format, using ArcCatalog, to suit the format required for upload to GEE. The total mangrove cover (m^2) per Sea Around Us database grid cell was obtained by applying a spatial reducer to each annual mangrove cover layer between 2000-2012. This transformation was conducted in GEE using code provided by UNEP-WCMC, with results later converted to km^2. Resulting mangrove extent measures were checked against the original values reported for the CGMFC-21 database, giving an average error of 104.8 ± 0.6 km^2 worldwide across the 13 annual layers. Total global mangrove area of the resulting measurements averaged 82,609.1 ± 555.1 km^2 for the years 2000-2012.

5.2.1.3 Distance to mangrove

To calculate the distance between fish catch observations and the nearest mangrove area, geolocated fish catch observations were spatially joined to the previously specified grid in ArcMap. The straight line distance from all pixels on each annual mangrove raster layer of the CGMFC-21 dataset to all points on the world map was calculated using the 'Euclidian Distance' tool in ArcMap, using a distance preserving projection. A mask was applied to land areas, using the 10 m resolution ocean layer from Natural Earth (naturalearthdata.com). This was used to prevent nearest distance measures taking routes over land, with the exception of a 56 km landward buffer (approx. 1 grid cell) to allow for mangrove areas which lie on the land-sea interface to be included. Distances were calculated with a 1 km output cell size, thereby giving distance measurements to approximately the nearest 1 km. Using the 'Extract by attributes' tool in ArcGIS, the distance from each fish catch point observation to the nearest point on the mangrove raster was extracted, thereby giving a distance measurement of the proximity between the fish caught and the nearest mangrove pixel. Fish catch observations were represented by the mid-point of the grid cell they were caught in; distances do not account for the possible variation in catch location within the half degree grid cell. Distances reported may therefore have an error of up to ± 0.35 degrees (approx. 39 km), in addition to the 1 km measurement error.

In order to measure the size of the nearest mangrove area to any fish catch observation (i.e. the area of the mangrove in closest proximity to where the fish was caught, rather than the area of mangrove within the grid cell the fish was caught in), grid cells that contained mangrove were recorded with a point feature. Point to point distances, using the ArcGIS 'Near' tool, were measured from fish catch point features to the nearest mangrove point feature, again using the mask and buffer layers to avoid land crossing as described earlier. Distances were calculated with the location option checked, giving an output which specified the grid cell code of the nearest mangrove point feature. These grid cell codes were then cross checked with the mangrove area per cell calculated in GEE to give the area of the nearest mangrove area (per half degree grid cell). It should be noted that most mangrove forests overlap more than one grid cell, particularly where mangroves fringe the entire coastline of countries or even continents, and therefore true mangrove extent could be under-represented in these cases. However, no information exists regarding the spatial relationship between mangroves and fish catches with which to constrain this relationship. The half degree cell is the largest unit for which a quantitative measure of mangrove-fishery productivity has yet been derived (Manson et al. 2005a). The mangrove area within the nearest half degree grid cell which contains mangrove was decided upon as a reasonable measure from which to explore this relationship. An alternative measure would be the area of continuous mangrove. However as no information exists thus far to suggest continuous rather than fragmented mangrove is better at enhancing mangrove, this unit would be redundant. Mangrove area per country is another unit which could be used. However this would likely say more about a countries fishing effort than its mangrove area, and would require fisheries data separated by country rather than by an equally sized gridded mapped as was used here.

The resulting measurements of mangrove area per grid cell (km^2), fish catch per grid cell (tonnes by species), distance from fish catch to nearest mangrove (± 40 km) and area of nearest mangrove (km^2 per half degree grid cell) were saved in csv file format to be used in analysis in R studio (R Studio Team, 2016).

5.2.1.4 Additional environmental variables

Sea Surface Temperature (SST) and Chlorophyll a concentration (Chl a) measures were obtained from the Ocean Colour SMI: Standard Mapped Image MODIS Terra Data. This includes ocean colour and satellite ocean biology data produced, or collected, under NASA's Earth Observing System Data and Information System (EOSDIS) (NASA Goddard Space Flight Center 2017). The dataset was accessed via the Google Earth Engine (GEE) data catalog (https://developers.google.com/earth-engine/datasets/catalog/) and a temporal reducer was applied to obtain data for each of the years between 2000-2012. The Ocean Colour SMI datasets include measures from 24th February 2000 to current (2019). As a full year of data was therefore not available for the year 2000, measures for 2000 were replaced with measures from 2001. A spatial reducer was then applied to obtain a mean annual measure of SST and Chl a respectively for each grid cell in the SAU database for each of the years included. Data were aggregated from 500 m to 1,000 m resolution during this stage due to computing limitations. Data was not available for some of the SAU grid cells and therefore SST and Chl a measures were missing for 9,456 (0.1%) of the fisheries data observations.

Measures of depth were obtained from the General Bathymetric Chart of the Oceans (GEBCO) gridded bathymetric data set, freely available through the British Oceanographic Data Centre (GEBCO 2014). Data from the GEBCO one dimensional grid in the one minute global grid format was used from the year 2014. Data values from this dataset represent elevation in metres, with negative values for bathymetric depths and positive values for topographic heights relative to mean sea level. Using the 3D analysis tools in ArcCatalog, an additional functional surface, "Z", was added to the SAU grid from the bathymetry data to calculate the mean elevation of each grid cell at 1,000 m resolution. As some grid cells included overlap the coast, some grid cells display positive mean elevation values.

Protected area extent was obtained from the World Database on Protected Areas (WDPA), the most up-to-date and complete source of information on protected areas, updated monthly and managed by the United Nations Environment Programme's World Conservation Monitoring Centre (UNEP-WCMC) (IUCN and WCMC 2019). The WDPA feature class including protected area boundary polygons, representing 91 % of the protected area extent included in the database, were obtained through the GEE catalog. The data layers were temporally reduced to give the global protected area extent for the most up to date version available for January 2019. The layer was then spatially reduced as described for SST and Chl a measures and extracted in 1,000 m resolution, resulting in protected area (km^2) per grid cell.

5.2.2 Data analysis

Data analysis tested the null hypothesis (H_0) that mangrove extent has no statistically significant influence on mangrove-associated fish catch volume, under the alternative hypothesis (H_1) that some measure of mangrove extent has a statistically significant influence on mangrove-associated fish catches. To test the influence of mangrove extent on mangrove-associated fish catches, relationships between catches and three measures of mangrove extent were first visualised graphically: 1) mangrove area within the grid cell where fish were caught, 2) distance to nearest mangrove from the catch position and 3) mangrove area in the nearest mangrove containing grid cell. The distinction between 1) mangrove area and 3) nearest mangrove area is that the latter allows mangrove influence to be investigated for catch observations that occurred in grid cells where there was no mangrove. This was achieved by measuring the area of mangrove within the nearest mangrove containing grid cell. Distance to nearest mangrove was therefore also an appropriate measure in understanding this relationship.

As the relationships observed were not linear, Generalized Additive Models (GAM) were used to examine whether measures of mangrove extent explain any variation of global mangrove-associated fish and invertebrate catch. Generalized Additive Models were preferred over linear models as the assumptions that the response variable is normally distributed and that the response variable depends linearly on the explanatory variables are relaxed (Wood 2006). Generalized additive models allow this flexible specification of the relationship between the response variable and a number of covariates in terms of smooth functions, rather than detailed parametric relationships (Wood 2006).

GAM analysis used the mgcv software package in R. Each of the three explanatory variables related to mangrove extent were investigated first. Next, a full model of a set of potential environmental explanatory variables was investigated. Environmental variables were first plotted against distance from the mangrove to check visually for autocorrelation of variables prior to GAM model testing. No obvious autocorrelation was observed. Variables included in GAM model testing were mean annual Chlorophyll a concentration (Chl a), elevation (m), mean annual sea surface temperature (SST), latitude (°) and year of observation.

The final model was reached through a backwards step-wise approach, in which non-significant model terms were systematically eliminated. Mangrove-associated fish catch was modelled via a Gaussian distribution and all model parameters were estimated using smoothing functions (except for year) as preliminary plotting of explanatory variables suggested that relationships with mangrove-associated fish catches were non-linear. Smoothing functions used thin-plate regression splines and the optimal number of knots (divisions within successive segments of the x-axis) was selected through an automated process of cross-validation. The optimum number of knots chosen for each of the variables was k = 9, to find the best model fit with minimum error. The fit of models to the data was evaluated graphically as well as via the Generalised Cross-Validation Score (GCV), the Akaike Information Criterion (AIC), which are standard tests for GAM's, as well as plots of the model residuals (Wood 2006). AIC is a measure of goodness of fit of a model, whereby a smaller number indicates a better fit of a model to the data than a larger number. The GCV score indicates the degree of smoothness of the smoothing function applied to the parameters. Lower relative GCV scores are optimal. The relative importance of each explanatory variable was evaluated by visually inspecting the response curves and their associated confidence intervals, a P value significant at < 0.001 and the adjusted r^2 value (the percentage of the variance in the dependent variable that the independent variables explains, adjusted for the number of independent variables in the model) of the model output (Wood 2006).

All additional environmental variables investigated had a significant influence on mangrove-associated fish catches. Year was not included in the final model, as it was not a significant covariate explaining catches of mangrove-associated fish. The final model included distance to the nearest mangrove, latitude, mean Chl a, mean SST and mean depth.

Control analyses were also conducted to confirm the relationships observed to be associated with mangrove-associated fish catches are different to those which can be observed for other non-mangrove associated catches. To control for the influence of other environmental factors, mangrove associated catches were compared with non-mangrove associated catches from the Sea Around Us database but only within grid cells in which mangrove-associated fish catches were recorded. The distribution of catches was compared via a two-sample Kolmogorov-Smirnov test and analysis of covariance (ANCOVA).

5.3 Results

The largest proportion of mangrove-associated fish catch observations (63%) (Fig. 5-1A) and the highest summed total by volume (68% of total catch tonnage) (Fig. 5-1B) occurred within grid cells which had no mangrove present.

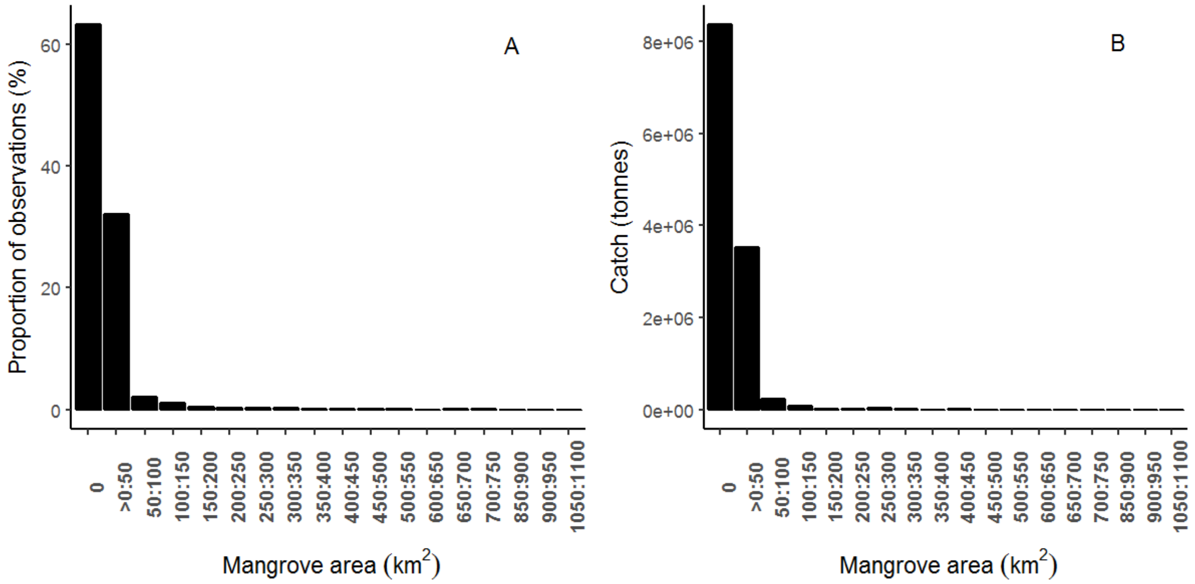


Figure 5-1. Summary statistics showing (A) the proportion of catch observations (% of grid cells) of mangrove-associated fish and invertebrates by mangrove area present (km²) in 50 km² categories and (B) the total sum of mangrove-associated catches observed within grid cells of each mangrove area (km²) category from subsistence and artisanal catches globally between 2000-2012.

There was also a decreasing trend in mangrove-associated catch volumes from smaller to larger mangrove areas in grid cells where mangroves were present, although this trend was not linear. Catches in grid cells which did not have any mangrove present exhibited a large range of catch volumes, from 0.2e-06–22,959.5 tonnes (Fig. 5-2A), whereas in grid cells of large mangrove extent, catch volumes were lower and considerably narrower in range (Fig. 5-2B). For instance, in grid cells where mangroves were present with an area up to 400 km², total annual catches per grid cell ranged from 0.1e-07–19,485.0 tonnes whereas in grid cells holding 400 km² of mangrove extent or greater, total annual catch per cell ranged only from 0.4e-02-470.9 tonnes. The relationship between mangrove area present and the volume of mangrove-associated fish catches therefore showed an overall negative trend (Fig. 5-2A-C). However, plotted as a log-log relationship (Fig. 5-2C), an increased range of catches per grid cell can be observed, as a result of a drop in the lower limit of catches with increasing mangrove area. In keeping with these results, the mean catch observed also decreased non-linearly with increasing mangrove area (Fig. 5-2D).

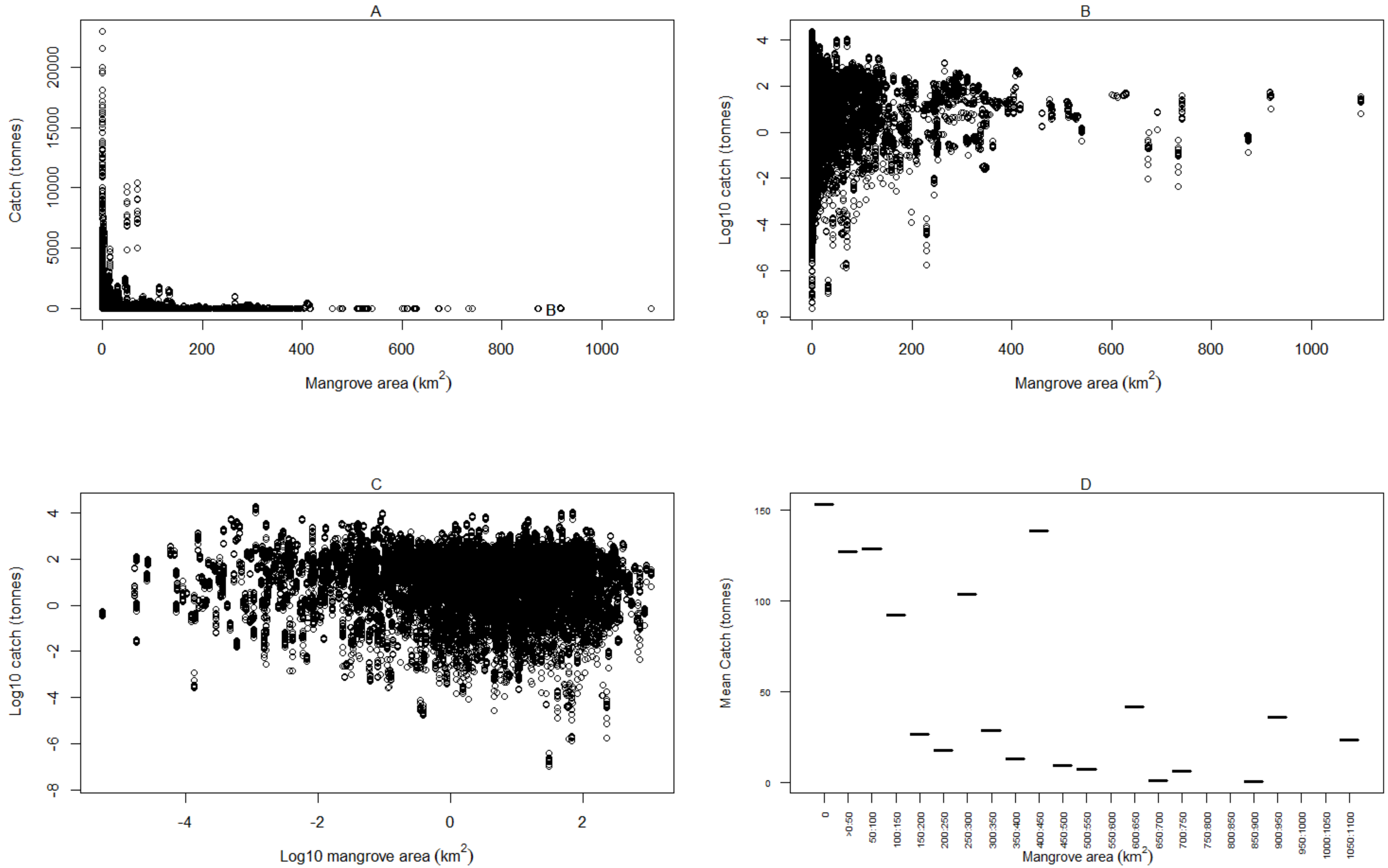


Figure 5-2. Graphical representation of (A) the untransformed relationship between the extent of mangrove area present and the volume of mangrove-associated fish and invertebrate species catches, (B) the log10 relationship and (C) the log10-log10 relationship, from the subsistence and artisanal fishing sectors globally. Individual scatter points (A-C) represent the total catch volume within one half degree grid cell for one year within the 2000-2012 period. Points in D represent the mean catch per grid cell within binned mangrove area categories.

There was also a decreasing trend in the number of species within catches with increasing mangrove area (Fig 5-3). Where no mangrove was present, or mangrove was present at an extent of less than 50 km^2 within a grid cell, 90 different mangrove-associated species were observed in catches. At the upper end of the range, where grid cells contained more than 850 km^2 of mangrove, barramundi (*Lates calicifer*) was the only species caught. With increasing mangrove area, catches of demersal, solitary species were more frequent relative to other species groups (39.7% of catch observations where mangrove area > 50 km^2). The frequency distribution of catches grouped by species environment and behaviour are plotted in Appendix 5-3. See also Appendix 5-4 for the distribution of catches by mangrove area for each individual species.

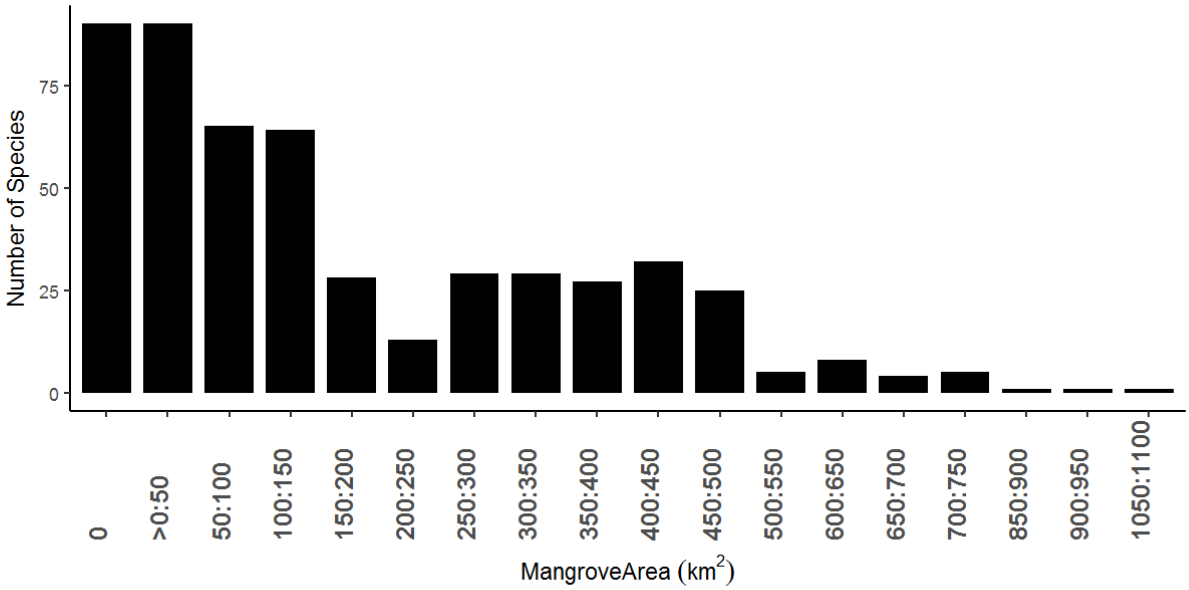


Figure 5-3. Species number within catches of mangrove associated fish and invertebrates, within global artisanal and subsistence fisheries catches, by mangrove extent within half degree grid cells. Catches are included for all mangrove-holding countries from 2000-2012.

A non-linear negative trend was observed in catches with increasing distance from the nearest mangrove location from the catch location (Fig. 5-4).

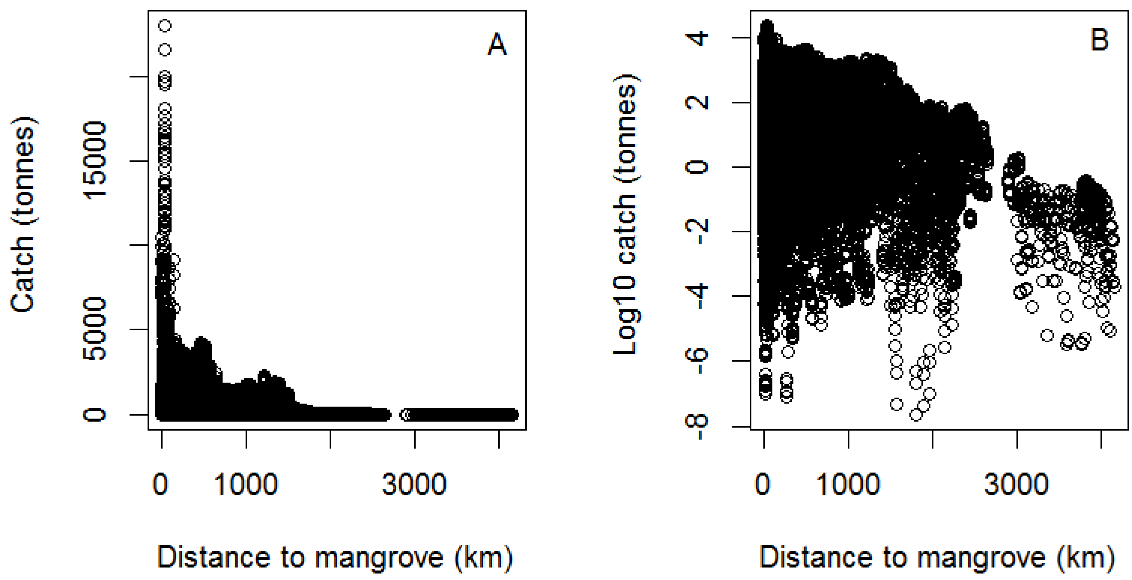


Figure 5-4. Graphical representation of (A) the untransformed relationship between the distance to mangrove and the volume of mangrove-associated fish and invertebrate species catches and (B) the log relationship, from the subsistence and artisanal fishing sectors globally. Individual scatter points represent the catch volume within one half degree grid cell for one year within the 2000-2012 period. Measures of distance to the nearest mangrove have a possible error of ± 40 km.

Catch frequency was highly skewed towards shorter distances to the mangrove, with 40.8% of mangrove-associated catch records occurring within 0-40 km from the mangrove, 16.9% between 40-80 km from the mangrove and 6.8% of catch observations between 80-100 km from the mangrove (Table 5-1). Catches of mangrove-associated species were however observed over a large range of distances from 0–4,200 km from the nearest mangrove. Nevertheless, the distance categories that account for the highest cumulative proportion (≥ 1%) of mangrove-associated catches (by tonnage) globally all occurred within 440 km of the nearest mangrove forest (Table 5-1).

Table 5-1. The proportion of catch records and proportion of total catches within 40 km categories of distance from the nearest mangrove, for artisanal and subsistence catches of mangrove associated species globally between 2000-2012. Only distance categories making up ≥ 1% of total catch records are included.

	Distance from mangrove ± 40 (km)	Proportion of catch records	Proportion of total catch tonnage
1	0:40	40.8	38.9
2	40:80	16.9	17.6
3	80:120	6.8	8.8
4	120:160	3.8	5.6
5	160:200	2.8	3.0
6	200:240	2.2	3.0
7	240:280	1.5	1.4
8	280:320	1.3	1.3
9	400:440	1.0	1.6
10	320:360	1.0	0.8

Examples of how these two trends coincide - namely decreasing catches with increased mangrove area, along with increasing catches with increased proximity to the mangrove - can be observed in Figure 5-5. This Figure gives examples from 4 mangrove forests (West Papua, Indonesia, The Sundarbans (across India and Bangladesh), The Gulf of California, Mexico and Peam Krasaop Wildlife Sanctuary, Cambodia). Figure 5-5 demonstrates how low or absent catches can be observed within grid cells containing mangrove, while clusters of mangrove associated fish catches occur in close proximity (within 0-120 km in these cases) to the mangrove forest (representing grid cells in which no mangrove is present).

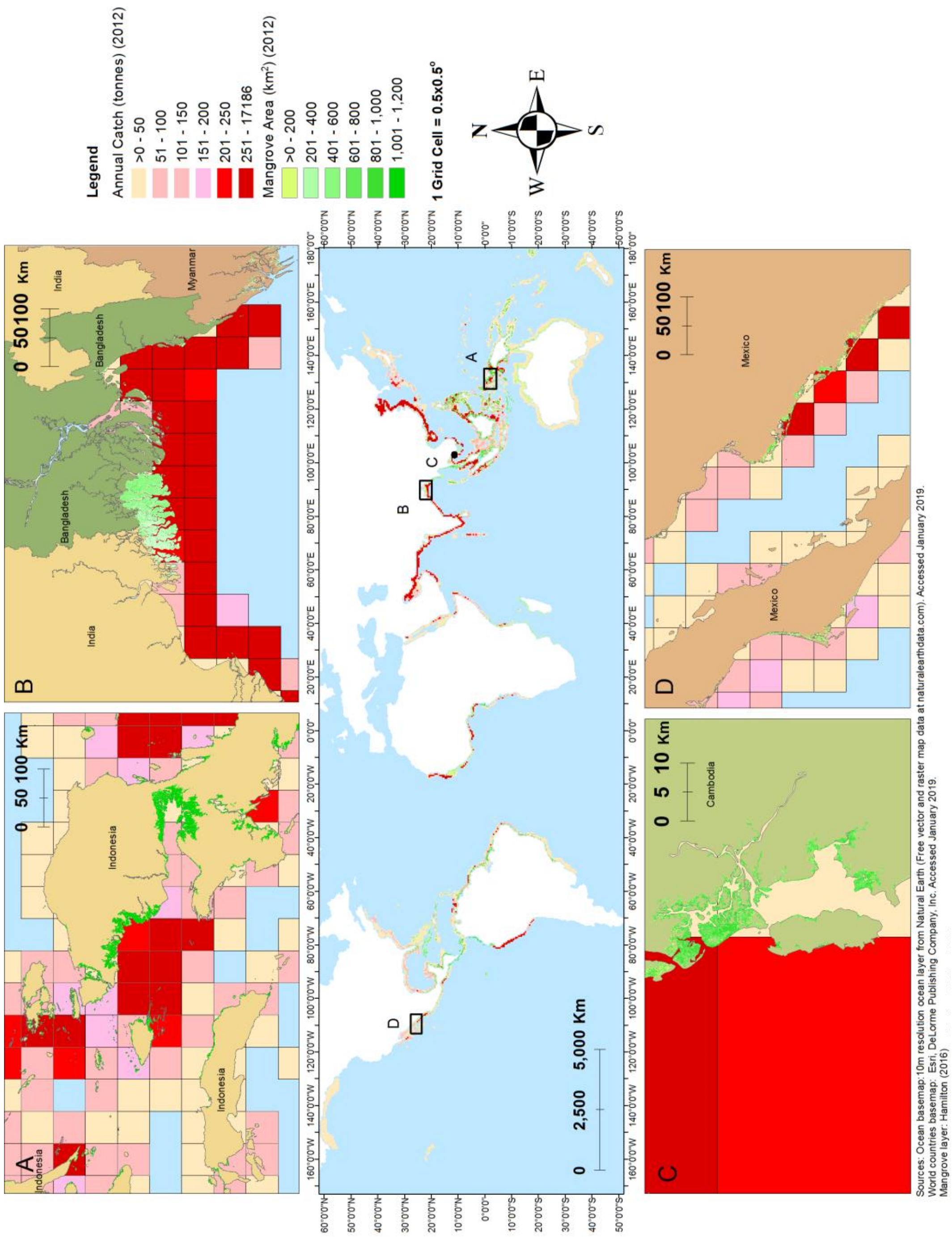


Figure 5-5. Mapped distribution of mangrove associated fish catches (tonnes caught per grid cell per year) and distribution of mangrove extent (km²) per grid cell globally for the year 2012. Inset maps represent 4 mangrove areas; A) West Papua, Indonesia, B) The Sundarbans Mangrove Forest (Bangladesh and India), C) The Peam Krasoap Wildlife Sanctuary, Cambodia and D) The Gulf of California, Mexico. In all maps, 1 grid cell represents half degree area.

The location of catches with increasing distance from the mangrove varied by species (see Appendix 5-5 for individual species plots). Species number in mangrove-associated catches decreased gradually from 89 species observed within 0-40 km from the mangrove to just 1 species observed at distances further than 3,080 km from the mangrove (Fig. 5-6). Catches observed at more than 3,080 km distance were made up of euchalon (*Thaleichthys pacificus*) only, and were small in volume, with all observations less than 0.38 tonnes annually per grid cell. All of these observations were located at the highest latitudinal location of mangrove-associated catches observed, between 54.75-61.25 N in the Gulf of Alaska (USA). The closest mangrove to this region is located in Hawaii or Mexico and thus a plausible mangrove affect seems highly unlikely.

At intermediate to large distances from the mangrove within the range observed (1,520-3,080 km), catches were also located in the North Pacific (USA), but also included catches in New Zealand at 2,900-3,080 km, around the coast of Japan at 1,520–2,680 km from the mangrove and at distances between 1,520–1,560 km on the west coast of China. Catches located at the highest latitudinal range of observations in the Southern Hemisphere (-43.00 to -44.74 latitude) in New Zealand were made up of Eastern Australian salmon (*Arrips trutta*) and flathead grey mullet (*Mugil cephalus*). In Japan, catches were made up 3 species, Japanese seaperch (*Lateolabrax japonicas*), flathead grey mullet (*Mugil cephalus*) and largehead hairtail (*Trichiurus lepturus*). Flathead grey mullet and largehead hairtail were also included in catches observed on the west coast of China, at 40.75 N, as well as milkfish (*Chanos chanos*) and blue swimming crab (*Portunus pelagicus*).

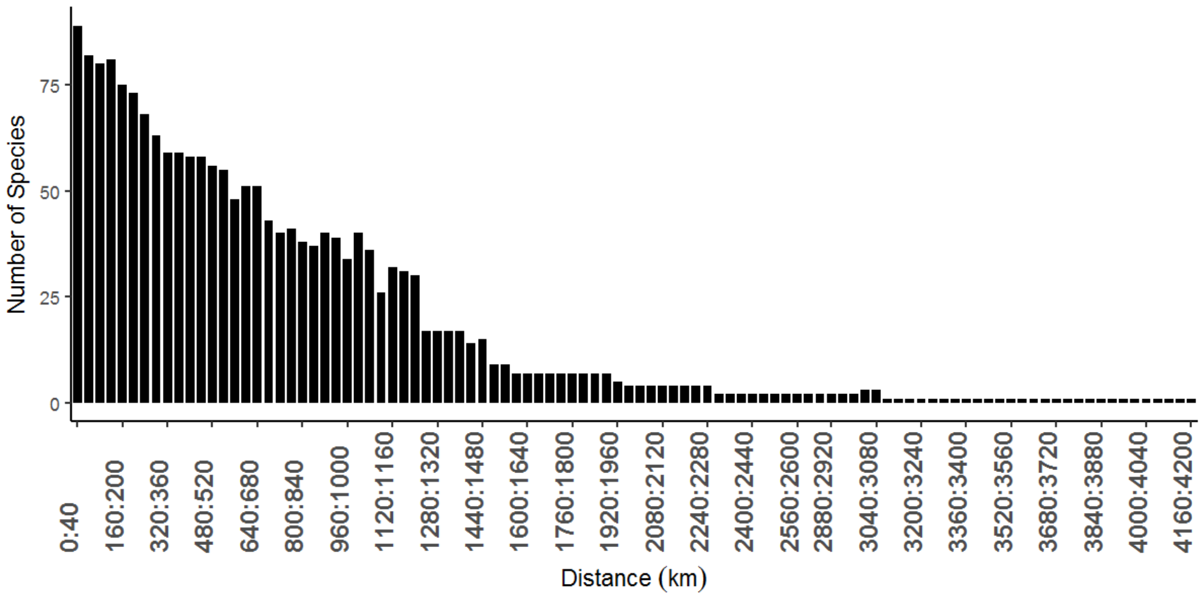


Figure 5-6. Number of mangrove associated fish and invertebrate species, within global artisanal and subsistence fisheries catches, by distance from the nearest mangrove in 40 ±40 km categories. Catches are included for all mangrove-holding countries from 2000-2012.

Species organised by the environment they inhabit in the water column (demersal, benthopelagic or pelagic) and by their schooling behaviour (mostly solitary, forming aggregations or schooling) showed distinct trends in catch locations relative to the mangrove (Fig. 5-7). Catches of demersal species were concentrated in close proximity to the mangrove, with 52.1% of demersal species catches occurring within 40 km of the mangrove (Fig. 5-7A). Demersal species were also limited in distance range compared to other groups, as no demersal species were caught further than 1,960 km from the mangrove. Benthopelagic species by comparison were persistent throughout almost the entire distance range within which mangrove-associated species were caught (0- 3,080 km from the nearest mangrove). However, the frequency and cumulative volume of catches of benthopelagic species also decreased with increasing distance from the mangrove (Fig. 5-7A). Pelagic species were the least represented group within mangrove-associated fish and invertebrate catches, accounting for just

20.7% of mangrove-associated catch volume. These however were highly skewed towards the mangrove, with 62.3% of pelagic species catches by volume occurring within 40 km of the mangrove. Catches of pelagic species had the largest distance range, extending from 0–4,200 km from the mangrove. However catches of pelagic species at large distances from the mangrove were small in volume and less common (Fig. 5-7A). Catches of pelagic species which occurred more than 900 km from the mangrove made up only 2.0% of pelagic species catch volume overall and those further than 3,000 km from the mangrove accounted for just 0.008%.

Solitary species, the majority also being demersal species, were also concentrated in close proximity to the mangrove (Fig. 5-7B). Species that form aggregations (snappers, perches, squirrelfish and barracuda species) were represented only by 13 species within catches. 47.2% of aggregating fish catches were caught within 40 km of the mangrove, decreasing in catch volume and frequency with increasing distance up to a maximum distance of 1,200 km from the mangrove (Fig 5-7B). Schooling species were caught in highest proportion at all distances from the mangrove and declined in volume more gradually with increasing distance from the mangrove, with 32.1% of catch volume caught within 40 km of a mangrove and 17.8% between 40 and 80 km (Fig. 5-7B).

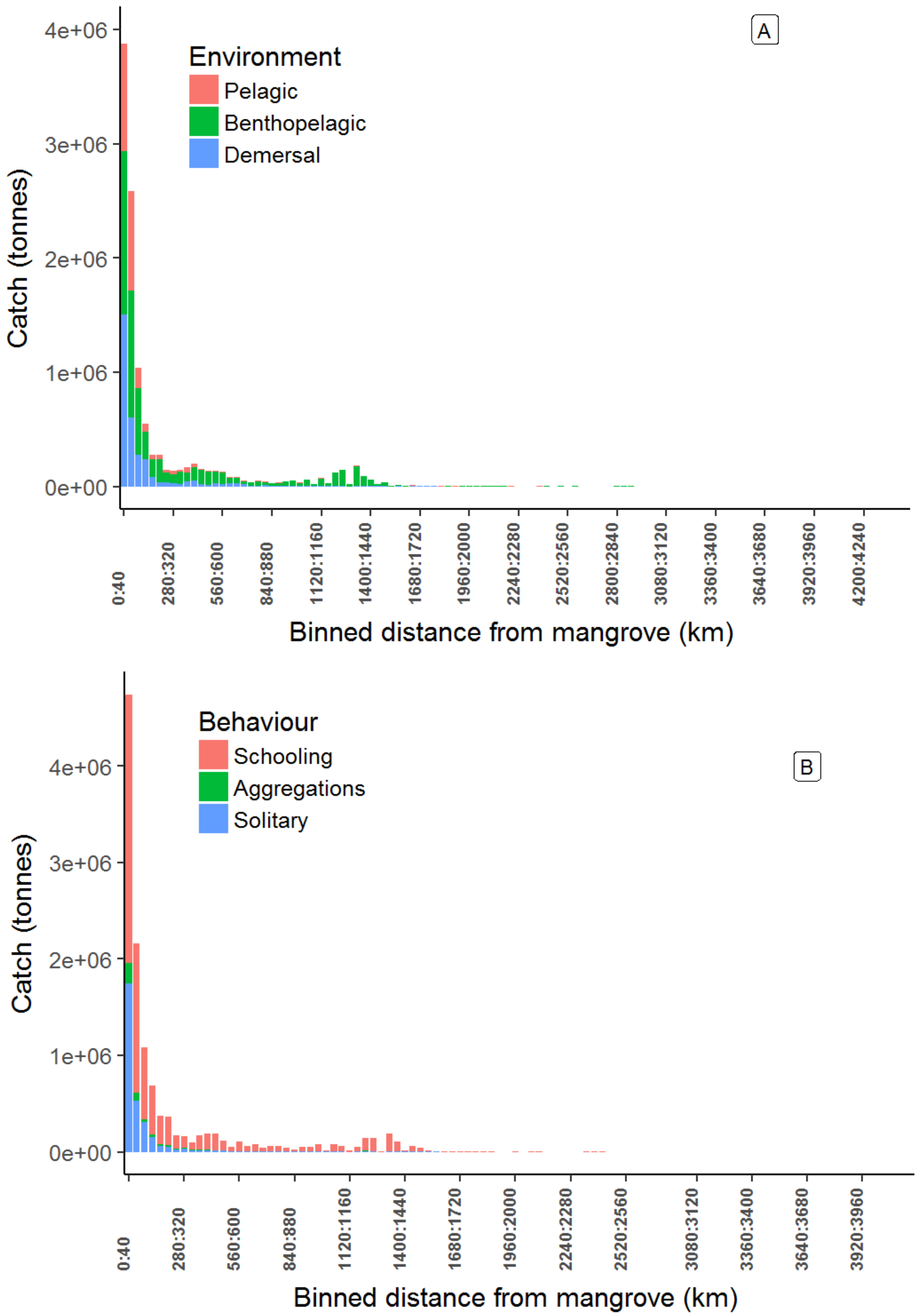


Figure 5-7. The distribution of mangrove-associated fish and invertebrate catches with increasing distance from the nearest mangrove forest (in 40 ± 40 km binned categories), grouped by (A) the environment inhabited by the species and B) schooling behaviour. Catches include subsistence and artisanal catches globally from 2000-2012.

Despite an overall decreasing trend in total catches with increasing distance from the mangrove, three peaks in catches were observed between 320-480 km, 1,960–2,200 km and at 2,320–2,440 km (Fig. 5-7). The first two peaks did not represent an increase in the frequency of fish catches at these distances, rather an increase in the magnitude of catches (Fig. 5-7). As such, median catches, displayed in Figure 5-8, formed peaks at these distances. The first peak included catches of 64 species, across a large latitudinal range from 42.75° S to 33.25° N, and were made up of 75.2% benthopelagic species, 16.1% demersal and just 8.7% of pelagic species. The second peak, at 1, 960-2,200 km represents catches observed only at the upper range latitudinal range in the Northern Hemisphere, from catches in Japan and the USA. This peak was made up of 4 benthopelagic and pelagic species. The four species, euchalon, flathead grey mullet, Japanese seaperch and largehead hairtail reiterate the spatial trend discussed earlier, of catches at the upper range of distances from the mangrove being concentrated in Japan and the Pacific Coast of North America. These catches were dominated by largehead hairtail, which made up 66.3 % of the catch volume within this peak and were all caught within the waters surrounding Japan.

A third peak in median catches was observed between 2,320–2,440 km as a result of a slight increase in both the frequency and magnitude of catches at this distance (Fig. 5-7). Catches within this peak were all concentrated between 43.25 to 45.75° N latitude and 140.75 to 147.25° E longitude (around the Japanese coastline). Again, catch volume was dominated by largehead hairtail (85.8%), the remainder being flathead grey mullet (14.2%).

Median catches, other than at these 3 peaks, were relatively constant with increasing distance from the mangrove, at less than 10 tonnes annually per cell (Fig. 5-7). The large skew in mangrove-associated fish catches at shorter distances to the mangrove can therefore be attributed to higher frequencies of mangrove-associated catches in the proximity of mangroves as opposed to increased catch volumes close to the mangrove. Large disparities between median and mean catches however, particularly within 0–1,520 km of the mangrove, suggest that outliers representing very large catches occur in low frequencies within this proximity to the mangrove. This placed annual mean catches per grid cell between 45-513 tonnes within distances up to 1,520 km from the mangrove whilst means were similar to median catches at distances further than this point.

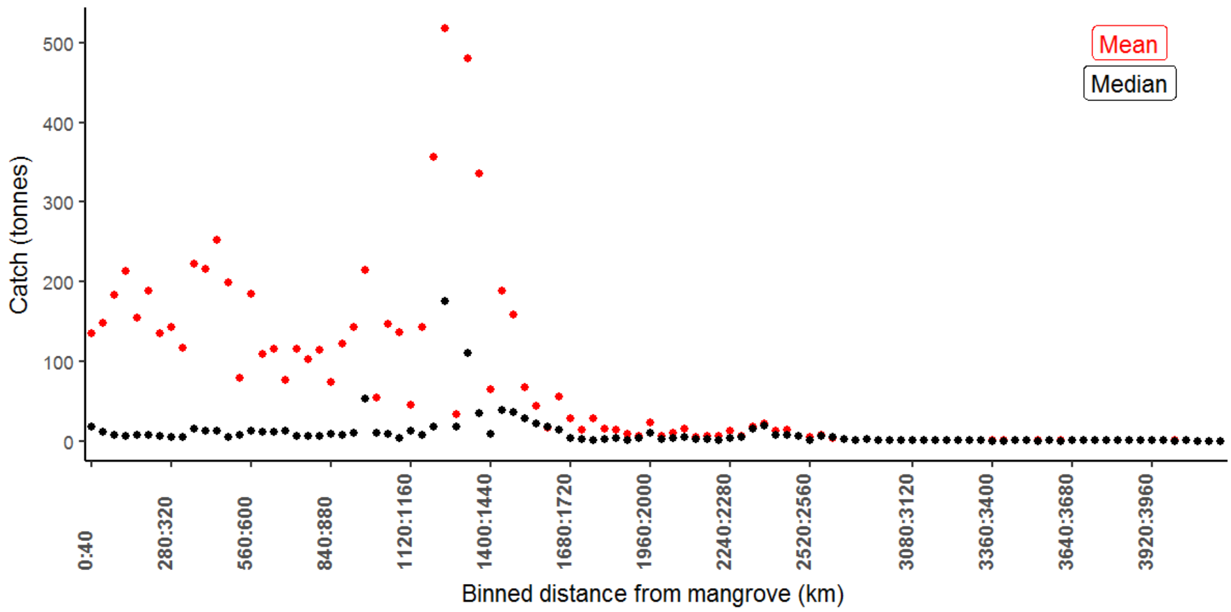


Figure 5-8. Mean and median annual catch volumes of mangrove-associates (tonnes per grid cell) at 40±40 km distances to the nearest mangrove globally for artisanal and subsistence catches between years 2000 to 2012. Box plots showing the full range of catches for each binned distance category are included in Appendix 5-6.

Median catches were more variable for catches grouped to represent the size of the mangrove area which was in closest proximity to the fishing site (Fig. 5-9). There was also no clear trend in the mean catches at the nearest mangrove size (Fig. 5-9). Catch frequency and summed catches globally were however highly skewed towards localities in the proximity of smaller mangrove areas, with 93.2% of catch observations and 94.1% of mangrove-associated fish catches (by tonnage) being in closest proximity to a mangrove forest of area >0-50 km^2. It is worth noting that grid cells holding small mangrove areas (>0-50 km^2) were much more common than larger extents, accounting for 87.3% of grid cells with mangroves present.

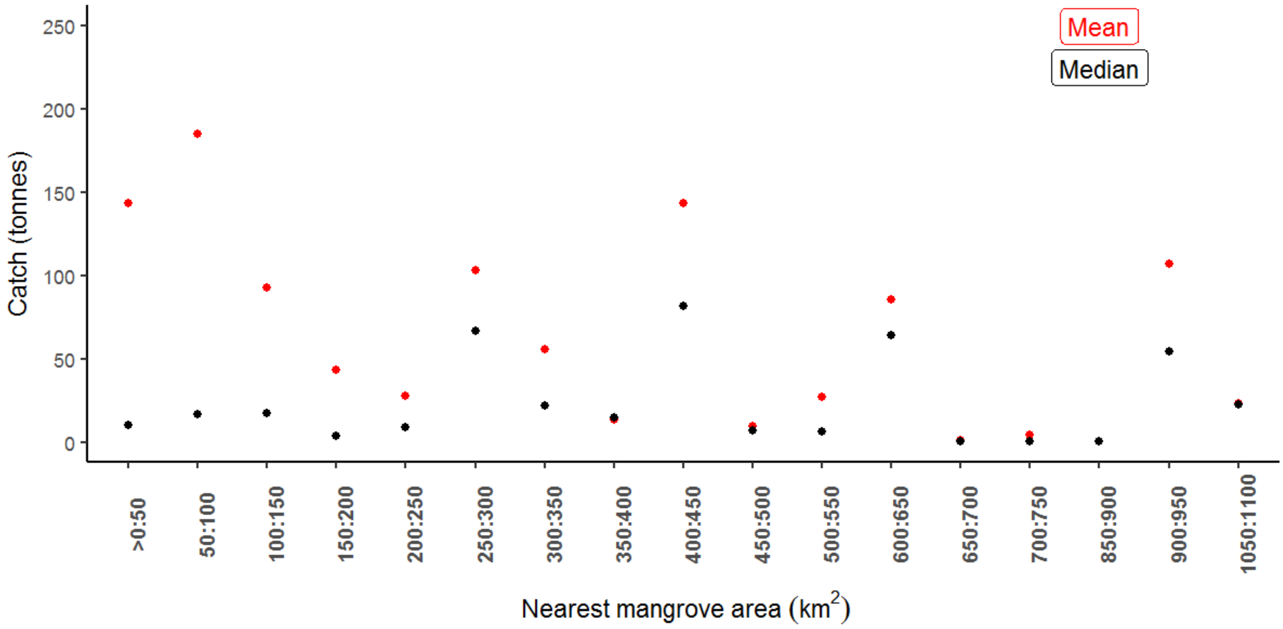


Figure 5-9. Mean and median annual catch volume of mangrove associates (tonnes per grid cell) at varying mangrove areas (km^2 within one grid cell) in closest straight line distance to the location fishing took place, globally, for artisanal and subsistence catches between 2000-2012.

5.3.1 Additional environmental parameters

Mangrove associated species were recorded in catches between 47.75° S and 61.25 N° latitude (Fig. 5-10A). Catches were most common (34.1%) and highest in median catch volume (a median of 28.0 tonnes per cell) across the equator, between 10° S and 10° N latitude, decreasing gradually in the northern hemisphere and more abruptly in the southern hemisphere (Fig. 5-10A). 86.0 % of catch volume was caught between 30° S and 30° N, the latitudinal range in which mangroves are found (Giri et al. 2011). Peaks in catches by latitude corresponded to trends exhibited by SST (Fig. 5-10 A and C). The mean annual SST in areas which mangrove associated fish were caught ranged from 3.4 - 39.9° C (Fig. 5-10C). However, 80.4% of catch observations were made at annual mean SST of 20-30°C, where median catches were also highest at 18.1 tonnes annually per grid cell. Catches were also relatively common (13. 9% of observations) between annual mean SST of 10-20°C (Fig. 5-10C). However median catch volumes in this category were just 1.8 tonnes annually per grid cell.

Mangrove-associated species were caught in waters of up to 5,134 m mean water depth (mean elevation ranging from -5,134 to 1,954 m due to some grid cells overlapping coast lines with high elevation areas within half degree inland) (Fig. 5-10B). Catches were most frequent (25.3%) and largest (median catch of 45.7 tonnes per cell) in grid cells of a mean elevation between 0 to -100 m. Catches were also frequent (16.1%) closer to the coast (at mean elevation of 0 to 100 m) but catches here were smaller, at a median of 6.5 tonnes per cell. It should be noted that elevation measures here represent the bathymetry of the location where the fish were caught, not the depth at which the fish were caught.

Mean Chl a concentration for grid cells in which mangrove-associated fish were caught ranged from 0.04-77.05 mg/m^3. Frequency of catches (98.2% observations) and total catch volume (98.9% of global catch in tonnes) was highest within areas of Chl a concentrations between 0.04 and 10 mg/m^3 (Fig. 5-10D). Catches were uncommon at Chl a concentrations higher than 10 mg/m^3.

Grid cells which contained a protected area of any size made up 55.2% of catch observations. However 53.8% of these cells contained less than 1 km^2 of protected area (within a half degree grid cell) (Fig. 5-10E). Grid cells which contained large protected area extents (>1,000 km^2) made up just 0.68% of catch observations in cells with protected areas, 0.37% of catch observations overall and had a median of just 0.2 tonnes per cell. Trends in catches where there are protected areas versus no protected areas are therefore likely to be a proxy for levels of governance (particularly representative of no take zones) where very low catch volumes have been observed, rather than a direct result of mangrove extent. Thus protected area extent was not explored further within the GAM models.

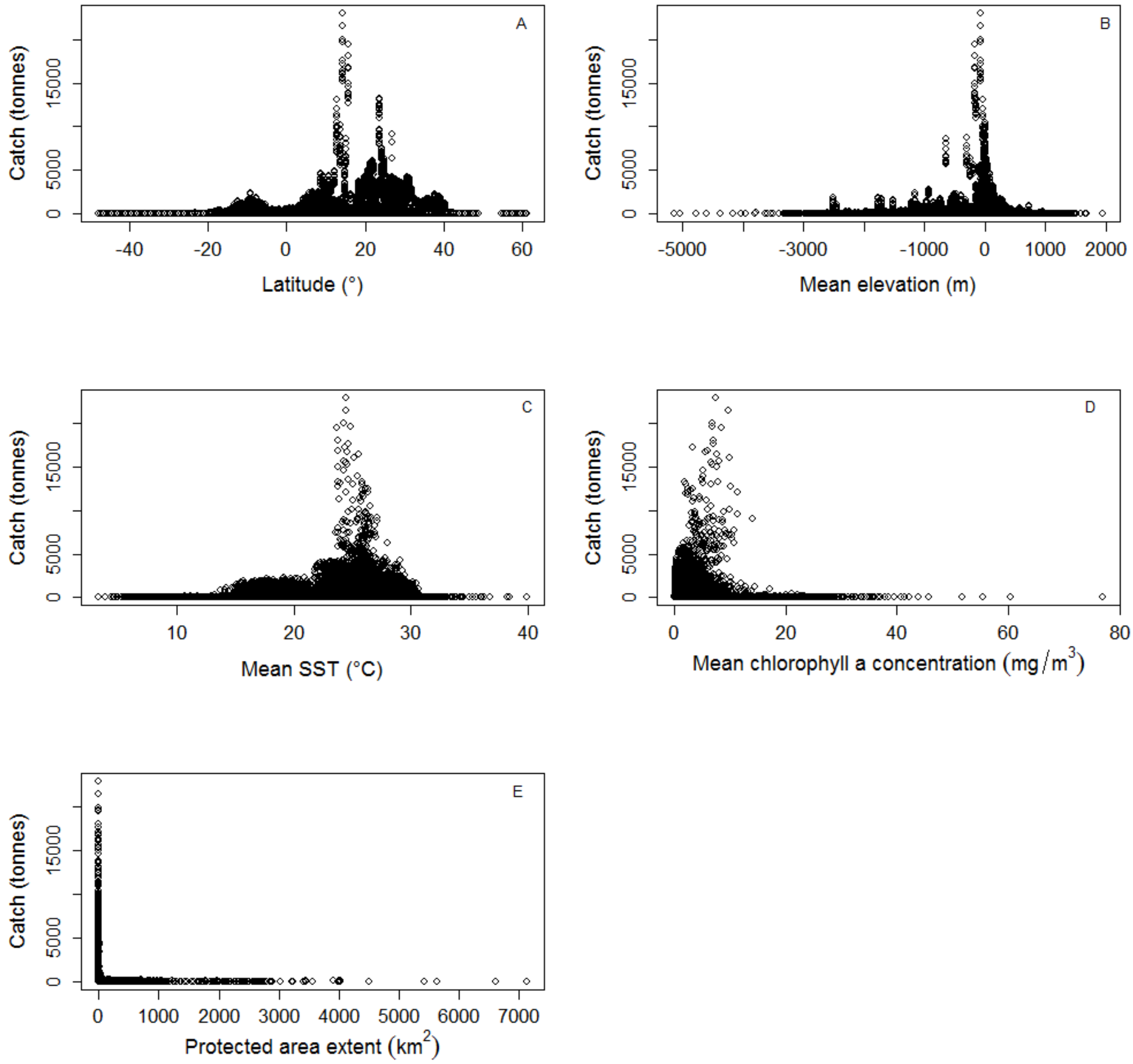


Figure 5-10. The relationship between mangrove associated fish and invertebrate catches (tonnes per grid cell annually) and a number of potential influencing factors of A) latitude at which fish was caught, B) mean elevation (depth), C) the mean annual sea surface temperature (SST), D) the mean chlorophyll a concentration and E) the extent of protected area. Catches include all subsistence and artisanal fishing sector catches in mangrove holding countries globally for the 2000-2012 period.

5.3.2 GAM results and interpretation

Results of the GAM selection process suggest that of the three mangrove extent variables tested, the distance to the nearest mangrove had the strongest relationship with mangrove-associated catches. The trend in mangrove-associated catches estimated by GAM models as a function of these three mangrove extent parameters are shown in Fig 5-11. The other two variables tested, mangrove extent within a half degree area, and the area of the nearest mangrove forest, also had a statistically significant influence on mangrove-associated fish catches (Table 5-2). The null hypothesis that no statistically significant relationship between mangrove extent and fish catches is rejected and the alternative hypothesis accepted. However, wide confidence intervals, demarked by the error bars in (Fig. 5-11A and C), for the two variables related to mangrove area, compared to the distance variable, suggest that more confidence can be attributed to measures of distance to the nearest mangrove to explain mangrove-associated fish catches than mangrove area. The deviance explained by mangrove-associated catches as a function of distance from the mangrove, and the model fit to the data (indicated by a lower GVC score relative to the other parameters tested), also support this assertion (Table 5-2). The AIC value of the smooth term fitted to the nearest mangrove area parameter was lowest, however its edf (effective degrees of freedom) value was the highest of all parameters suggesting its relationship was least linear, as can be observed in Fig. 5-11C.

The general trend estimated by the distance model suggests that mangrove-associate catch volume decreases with increasing distance from the mangrove (Fig. 5-11B). It should be noted however, that with increasing distance from the mangrove, confidence intervals widen, particularly past a threshold of 2,000 km from the mangrove (Fig. 5-11B). At distances further than 2,000 km from the mangrove, distance to the mangrove is not as reliable a predictor of mangrove-associated fish catches. Distance to the nearest mangrove as an explanatory variable for mangrove associated fish catches alone explained 0.59% of variability (Table 5-2). The addition of other environmental parameters, Mean Chl a concentration, mean SST, mean elevation and latitude improved the fit of the model to the data as well as the deviance explained by the model (Table 5-2). Year of observation did not have a significant influence on mangrove-associated catch volumes and was not included in the final model. The final model explained 11.5% of variance in mangrove-associated fish catches. The trends in mangrove associated catches (represented as changes from the mean catch volume centred on 0) estimated by the final GAM model as a function each of the parameters included are shown in Fig 5-13.

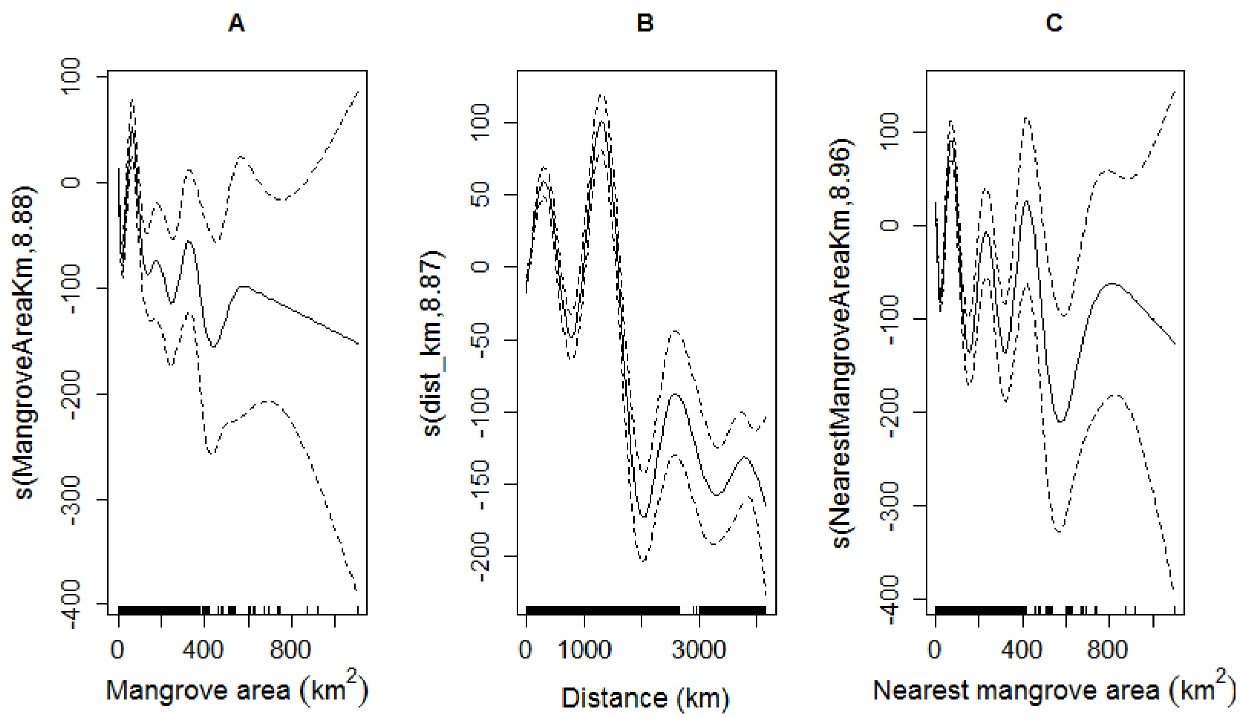


Figure 5-11. Estimated functions for the influence of mangrove extent parameters on mangrove-associate fish catches generated by Generalized Additive Models. Smoothing splines are fitted to the three parameters (A) mangrove area present, (B) distance to the nearest mangrove and (C) the area of the nearest mangrove, against mangrove-associated fish catches as the dependent variable. The y axis shows the smooth functions estimated by the model across each of the independent variables. The solid lines show changes to the response variable (catch volume) as a function of the explanatory variable, where all other variables are kept constant, therefore showing the general shape of the relationship, with the y axis units centred on 0. The number on the y axis caption shows the effective degrees of freedom (edf) of the term being plotted. The rug plot on the x axis shows the data points along each of the explanatory parameters (darker portions indicate higher frequency of data points). Dashed lines show the 95% confidence intervals above and below the estimated response of the smooth being plotted.

Table 5-2. Model results used to examine the fit of generalised additive models and estimate the deviance in mangrove-associated catches (the response variable) explained by various measures of mangrove extent and environmental factors globally for the 2000-2012 period. Deviance explained for the final model was 11.5 %, n=76970. Deviance explained by each individual covariate is indicated by the Adjusted r^2. The effective degrees of freedom for each model (edf) represents the "wigglyness" of the model, whereby edf=1 is a linear relationship. P values <0.001 suggest a significant influence of the smoothed covariate on the response variable. The Aikake's Information Criterion (AIC) and Generalized Cross Validation (GCV) scores indicate goodness of fit of the model to the data. Lower relative scores indicate better goodness of fit for both indices.

Smoothed model term	Adjusted r^2	GCV	edf	AIC	P
Initial models					
Mangrove area	0.00205	352228	8.878	1349104	<0.001
Distance	0.00586	350880	8.871	1348774	<0.001
Nearest mangrove area	0.00405	351320	8.962	1338689	<0.001
Final model	0.114	327210	46	1195826	
Distance			8.483		<0.001
Latitude			8.871		<0.001
Mean Chl a			8.762		<0.001
Mean SST			8.975		<0.001
Mean depth			8.904		<0.001

The model response to distance from the mangrove showed the most straightforward (or least wiggly) relationship with mangrove associated fish catches in the final model (Table 5-2, Fig 5-12). Mangrove-associated catches were estimated by the model to have more curved responses to the remaining parameters. Latitude as an explanatory variable for mangrove associated fish catch volumes showed a particularly strong trend, with a positive change in catch volumes at 30°S, again at 10°S, peaking at approximately 15°N and a negative trend thereafter. Further, Figure 5-12.B suggests that lower than average catches occur outside of 15°S to 25°N. Peaks in catches occurred between Mean Chl a concentration of 0-20 mg/m^3. However, large confidence intervals, and few data points above concentrations of 20 mg/m^3, suggest that Chl a is not an important predictor of catches, nor do many catches occur past this threshold. Similarly, the smooth term fitted to elevation as an explanatory parameter estimated a peak in catches at mean elevations of -500 to 500 m relative to mean sea level but flattened, with larger confidence intervals, at lower elevations (larger depths), suggesting that catches at > 500 m depth are small relative to catches in shallow waters but are more variable (Fig. 5-12E). Catches as a function of mean SST increased gradually to a peak threshold of 25°C after which there was a steep decline in catch volumes (Fig. 5-12D).

The environmental variables tested showed no distinct collinearity with distance from the mangrove (Fig 5-13). However, Figure 5-13C and Figure 5-13D show that catches at the extreme end of the distance range (3,000 - 4,000 km from the mangrove) did coincide with the extremes of the range of latitude and mean SST that mangrove associate species were caught. These regions of the GAM model outputs (very high latitude, very low mean SST and very large distances from the mangrove), all displayed large confidence intervals, suggesting a negligible relationship with mangrove-associated catches (Fig. 5-12).

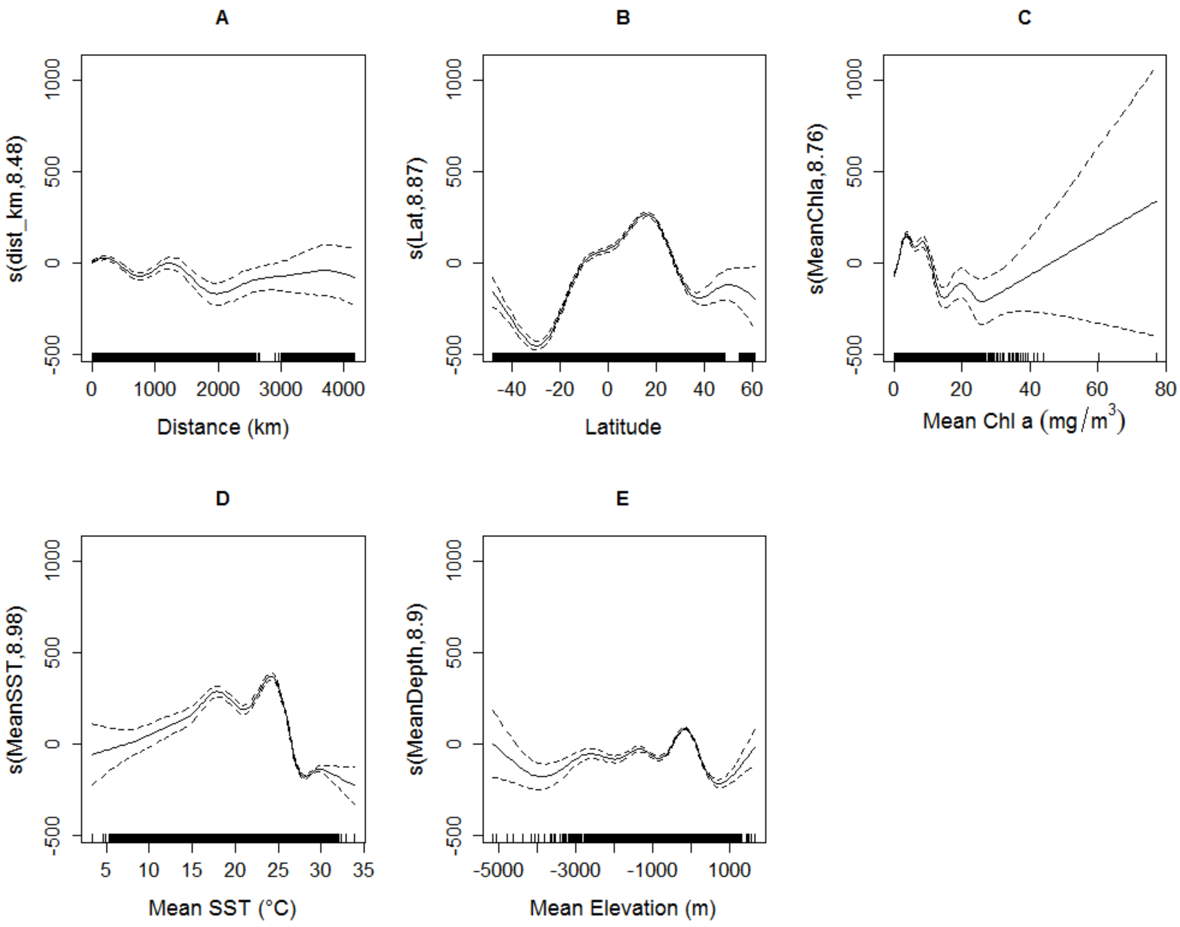


Figure 5-12. Estimated functions for the influence of environmental parameters on mangrove-associated fish catches generated by Generalized Additive Models. Smoothing splines are fitted to the explanatory parameters: A) the distance from the nearest mangrove (km), B) latitude, C) mean annual chlorophyll a concentration (mg/m3), D) mean annual sea surface temperature (°C) and E) mean elevation (m). The y axis shows the smooth functions of the model across each of the independent variables, thereby showing the general shape of the relationship between the response and the explanatory variable after smoothing, with units on the y axis centred on 0. The number on the y axis caption shows the effective degrees of freedom (edf) of the term being plotted. The rug plot on the x axis shows the data points along each of the explanatory parameters (darker portions indicate higher frequency of data points). Dashed lines show the 95% confidence intervals above and below the estimated response of the smooth being plotted.

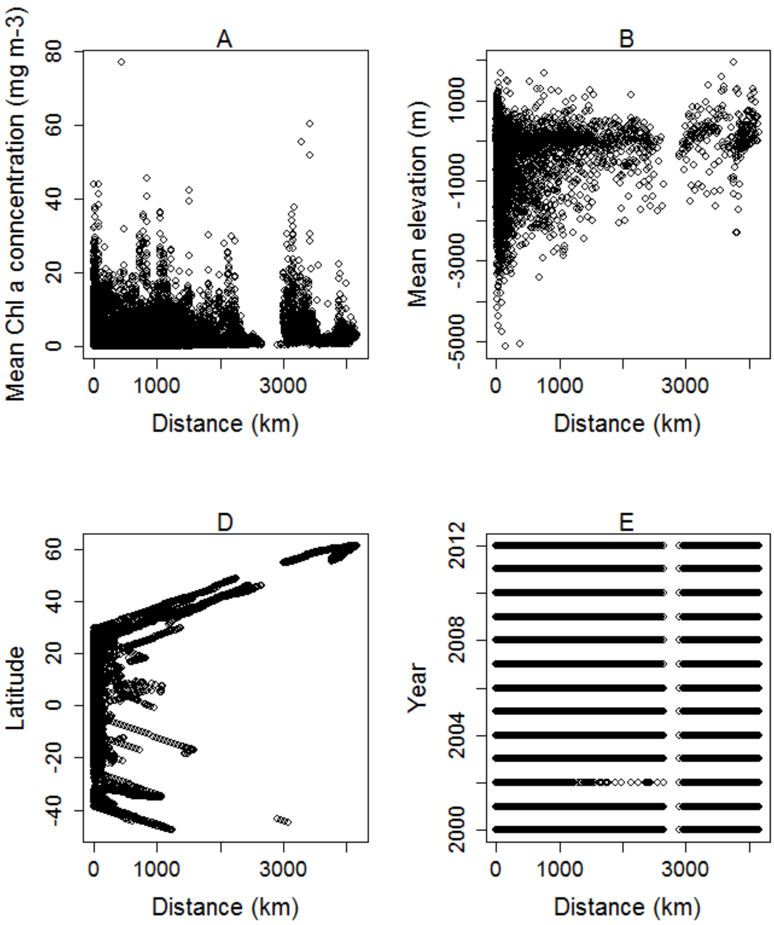


Figure 5-13. Catch occurrences at varying distances from the mangrove by measures of A) mean annual Chlorophyll a concentration, B) elevation, C) mean annual sea surface temperature (SST), D) latitude and E) year of observation including only those grid cells from mangrove-holding countries in which mangrove-associated fish catches were observed within the 2000-2012 period.

5.3.3 Control analysis

A two-sample Kolmogorov-Smirnov test indicated that mangrove-associated species catches and non-mangrove associated species catches are distributed differently (D=0.35, P <0.005%). Figure 5-14 demonstrates that mangrove-associated and non-mangrove associated catches are also distributed differently over distance from the nearest mangrove. Mangrove-associated species at shorter distances to the mangrove are highly skewed towards the mangrove whereas catches of non-mangrove species are near constant at short distances to the mangrove but begin to increase in catches (by tonnage) past 1,000 km, levelling off to similar levels of catch to those observed at short distances at approximately 3,000–4,000 km from the nearest mangrove. Larger catches of non-mangrove associates appear to persist at greater distances than mangrove associates, displaying relatively larger mean catches between 1,000–3,000 km from the mangrove (Fig. 4-14). Means of non-mangrove associates are not dissimilar from medians at the same distances displayed in Figure 5-14, suggesting that the means are a fair representation of the typical non-mangrove associate catch volumes at large distances from the mangrove. The distribution of catches within each 40 km distance category confirmed the distribution of larger catches at greater distances from the mangrove for non-mangrove species, with the opposite trend for mangrove species (see Appendix 7a and b).

Catches of non-mangrove and mangrove-associated species normalized to area of 1 for direct comparison are plotted against distance from the mangrove in Figure 5-15. Figure 5-15A demonstrates the prominence of mangrove associated catches at shorter distances to the mangrove, and conversely the persistence of non-mangrove catches at distances over which mangrove associated catches decline. Mangrove catches also exhibited a steeper decline away from the mangrove than non-mangrove species (Fig. 5-15B). Analysis of covariance (ANCOVA) confirmed that both distance from the mangrove, and mangrove association (yes or no) had a significant influence on catch volume ($p =< 0.001$), as did the interaction term (the influence of species mangrove association on distance from the mangrove at which they are caught) [$F(1,99) = 19.23$, $p = < 0.001$]. Residual QQ plots for this analysis, reiterating the skew of the data towards shorter distances from the mangrove, are reported in Appendix 5-8. The control analysis therefore suggests that while catches of non-mangrove species were higher at all locations, as to be expected given the small proportion of mangrove species in observations compared to non-mangrove associated species, there was a significant difference in the distribution of catches for mangrove-associated and non-mangrove associated species.

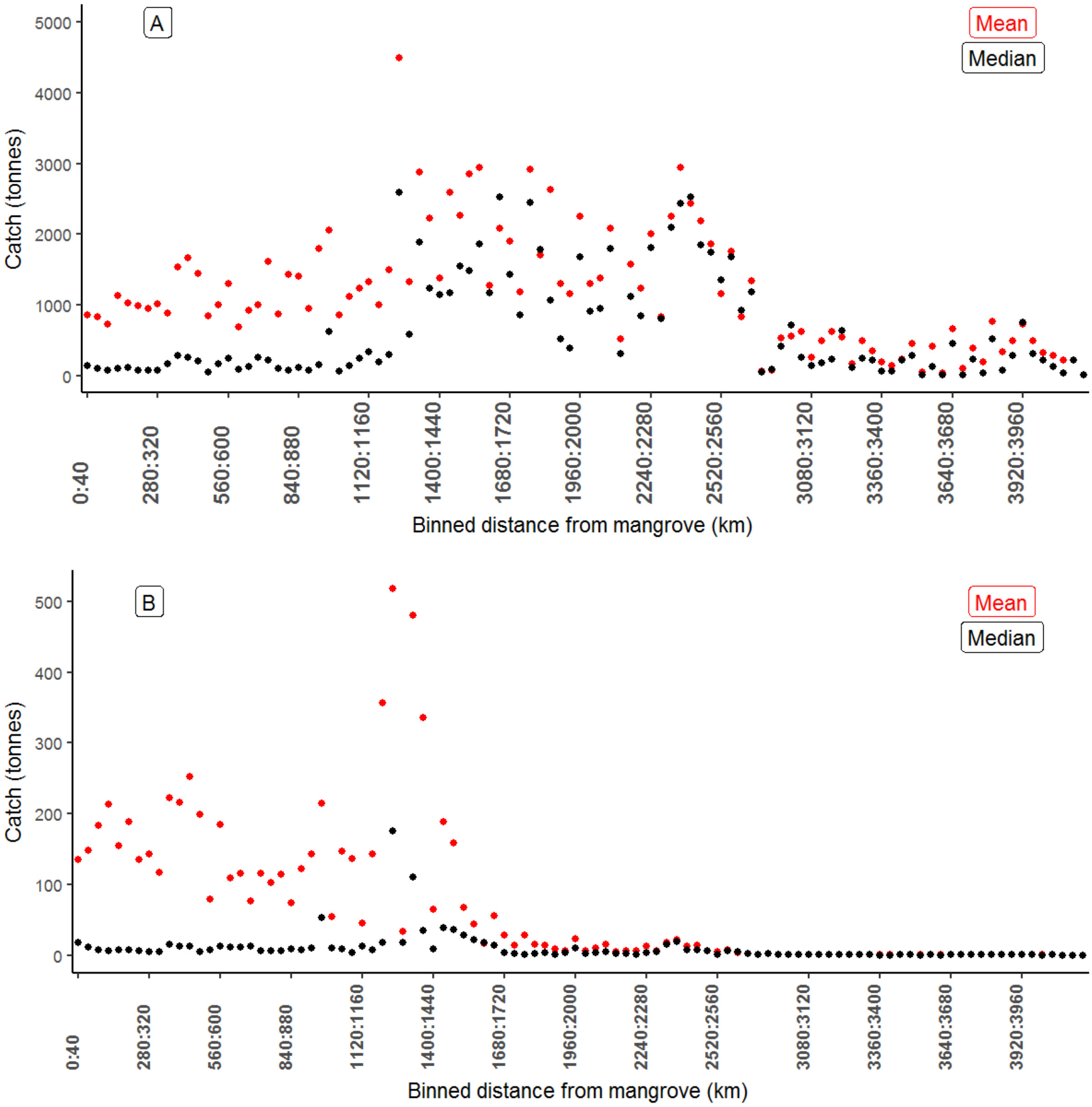


Figure 5-14. Mean and median catches at 40± 40 km distance categories from the nearest mangrove for A) non-mangrove species catches and B) mangrove-associated species catches, for the years 2000-2012.

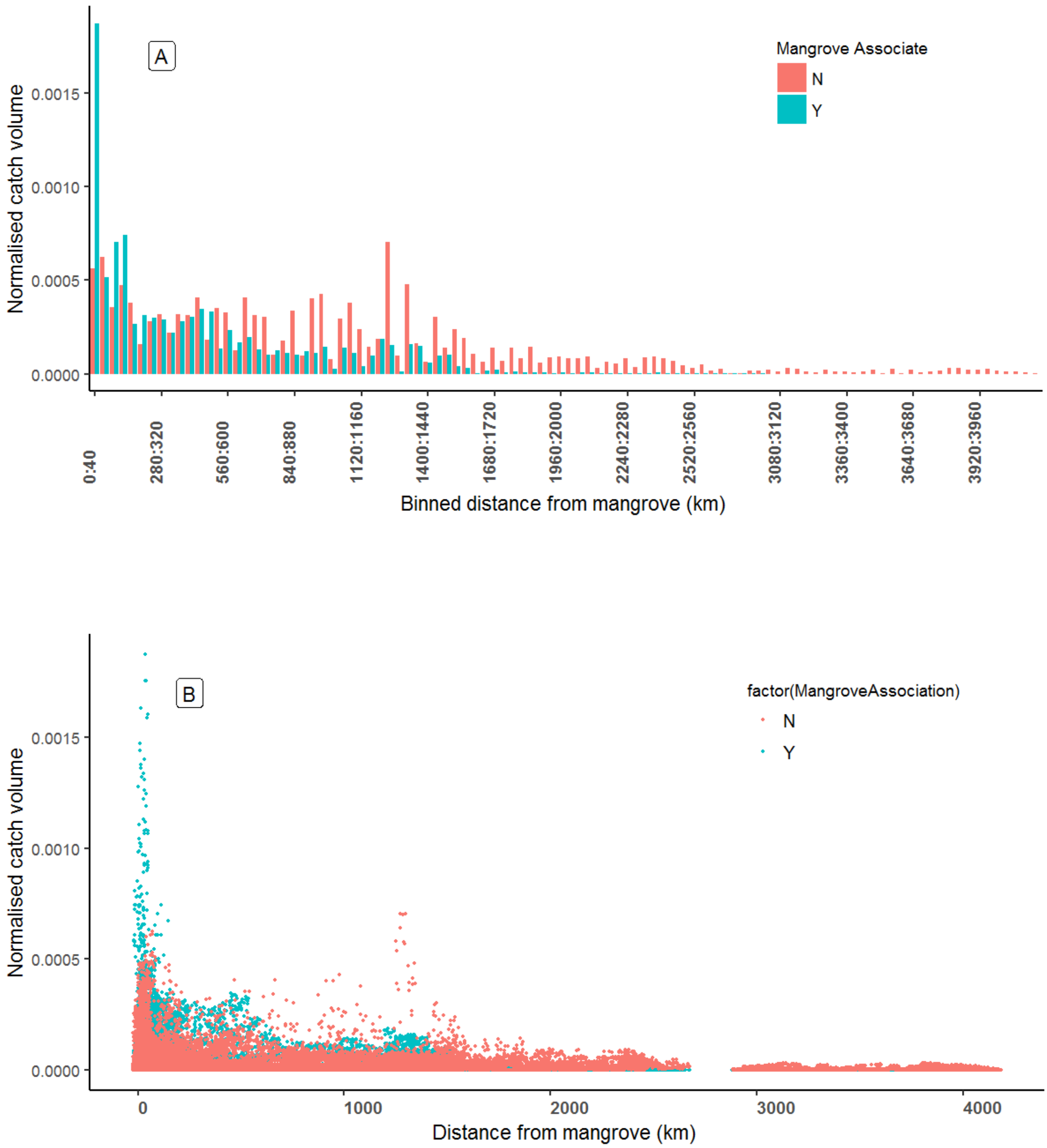


Figure 5-15. Total catches per grid cell of mangrove associated and non-mangrove associated species normalised to total area of 1 for each dataset to enable direct comparison of the relative distribution of catches over distance without the influence of difference in catch magnitude (non-mangrove associated catches being more represented within the dataset than mangrove associates). This is plotted as A) a bar graph showing the normalised total catch volume at each 40 ±40 km distance category and B) a scatter plot of per grid cell catch volume along continuous distance from the mangrove. Non-mangrove associated species occurrences (pink coloured points) are offset + 50 km on the x axis of Fig. B for visualisation purposes.

5.4 Discussion

5.4.1 Getting the scale right

The large proportion of mangrove-associated fish catches which occur outside of grid cells within which mangroves occur suggest that a half degree area (approximately 55 x 55 km, depending on latitude) is an inappropriate geographical scale at which to investigate the relationship between mangroves and fishing. As catches of mangrove-associated species were observed over a much larger distance range, from 0–4,200 km from the nearest mangrove, the grid cell only accounts for a very small subset of the spatial extent over which fishing associated with mangroves can take place. Measurements limited to this scale therefore underestimate the magnitude and geographical scale of the small scale fishing sector's interaction with mangrove forests. As such, the relationship between mangrove extent and mangrove-associated fish catches here, measured as mangrove area per grid cell, showed a negative trend.

Previous studies of mangrove value to fishing have used varied geographical scales to measure the effects of mangroves on fishing, but these measures have not looked at distances further than a half degree from the mangrove (Manson et al. 2005a, 2005b, Aburto-Oropeza et al. 2008, Carrasquilla-Henao et al. 2013). The relationship between mangrove extent and fishing, looked at from a global scale, may be wider ranging than previously thought. This is not to say that all studies should include a perimeter of 4,200 km from the mangrove in question. Without sufficient detail on species life history and migratory limitations, as well as oceanographic controls such as current circulation patterns, more evidence is needed to confirm that species caught so far outside of the range of mangroves are actually using or benefitting from the presence of mangrove.

This applies particularly to species caught at the upper limit of the range of distances from the nearest mangrove, which were observed as far as 61.25° latitude in the Northern Hemisphere, far beyond the latitudinal range of mangroves. Euchalon (*Thaleichthys pacificus)*, a species of smelt caught at furthest distance from the mangrove is an important target species on the Pacific Coast of North America, particularly amongst indigenous groups where euchalon is used for subsistence and as an important commodity when processed for oil (Mitchell and Donald 2001). This species is anadromous and is uses river tributaries in the NW Pacific Coast for spawning (Mitchell and Donald 2001). The large volume of euchalon catches observed are more likely the result of the locality of these river tributaries, along with high fishing pressure for this species in this region, than the result of a mangrove effect. Similarly, the dominance of largehead hairtail (*Trichiurus lepturus)*, within peaks of catch volumes at 1,960–2,200 km and 2,320–2,440 km from the mangrove may be more reflective of high fishing effort for the species in China and Japan (Kwok and Ni 1994, FAO 2019).

Furthermore, the distribution of largehead hairtail catches has also been linked to ocean dynamics, being associated with warm ocean currents in the East China Sea (Kim et al. 2005). This is consistent with increasing confidence intervals surrounding distance as a predictor of mangrove-associated catches with increasing distance from the mangrove, as suggested by GAM outputs. Catches at the upper end of the range of distances that mangrove associated species are caught may be better explained by socio-economic and oceanographic factors than by mangrove extent. Overall however, there was a clear trend in decreasing mangrove-associated species catch observations with increasing distance from the mangrove.

5.4.2 Trends in catch with mangrove extent and environment

Results highlighted that the area within 120 ± 40 km of a mangrove, with almost 65% of catches taking place within this threshold, is an important area for catches of mangrove-associated fish and invertebrate species. In particular, the first 40 km from a mangrove are popular fishing grounds for mangrove-associated species. Frequency of catches with increasing distance from the mangrove could be in part put down to varied fishing effort with increasing distance from the coast. However, comparison with the distribution in catches of non-mangrove associated species, which showed catches to persist at further distances than mangrove-associated catches, suggest an effect other than fishing effort alone. Trends in mean catches also varied, demonstrating that peak catch volumes of mangrove-associated species catches occur in closer proximity to mangroves than catches of non-mangrove associated species. For instance, after a threshold of 1,520 km, catches of mangrove-associated species remain low, where non-mangrove associated species catch volumes increase. Distance from the mangrove may therefore be a limiting factor determining the volume of mangrove-associated species, a control that does not exist for non-mangrove associated species.

The addition of further explanatory variables, Chl a, depth, SST and latitude, substantially improved the variance in mangrove-associated fish catches explained by the model compared to distance from the mangrove alone. An increase in catches with higher SST, and decrease in catches with increasing latitude, agrees with the argument that the “tropicalness” of the environment is important (Lee 2004). On this basis, it might be argued that catches at lower latitudes and higher SST represent simply the ecological niche of tropical fish and invertebrate species present, rather than a mangrove effect. Nevertheless, 86% of catches were incorporated within the general latitudinal range of mangrove forests. Catches tailed further towards the Northern hemisphere than the Southern hemisphere. However large catches in North America, Japan and China, outside of the latitudinal range of mangrove forests, as discussed earlier, were a big contributor to this trend. Catches at such latitudes were included due to the inclusion of all mangrove-holding countries, including those such as the USA and Japan that cover a large latitudinal range. Future work might set thresholds of catches that are included by latitude, rather than by country, to avoid this issue.

Catches were largest and most frequent between mean elevations of 0 to -100m. The area of shallow water (< 5 m) has been previously suggested as an important factor in mangrove-associated catches (Loneragan et al. 2005). Difficulty in obtaining shallow water estimates from Landsat imagery at the global scale meant this study could not measure the area of water <5 m explicitly (Daniell 2010, GEBCO 2014). However if this hypothesis holds, most frequent and largest catches would be expected to found within the lowest elevation category (0-100 m elevation, i.e. those grid cells overlapping land). However, results show that smaller and less frequent catches were found in this zone. The study conducted by Loneragan et al. (2005) however only focussed on catches of prawn species, none of which are included within the Sea Around Us database. A study of bay areas in the Curaçao (Netherlands Antilles) which included non-estuary mangrove areas, found small adult fish were less abundant in shallow water habitats such as mangroves (< 2 m) than at 10 m depth, and large adult fish were not found in the shallow water habitat at all, being restricted only to coral reef areas at water depths of 5-15 m (Nagelkerken et al. 2002). Larger adult fish at greater depths may explain the increase in catch volume (and greater fishing popularity in this area) observed from very shallow water to the 0 to -100m elevation category.

The optimum depth for catch of mangrove-associated fish observed may also reflect the depth limits of other coastal habitats, seagrasses and reef-building corals, which are typically limited to 90 and 70 m respectively due to light limitation (Duarte 1991, Scripps Institute of Oceanography 2019). Fish using mangroves as nursery areas are important recruits to coral reefs (Nagelkerken et al. 2002). Moreover, coastal habitats such as seagrass, coral reefs and mangroves, are connected through both ontogenetic and inshore-offshore migration of fish in what have been described as “seascape” nurseries (Nagelkerken et al. 2015). Prominence of mangrove-associated fish catches within waters of up to 100 m mean depth could reflect the use of key coastal habitats by fish species, and subsequently the target of these areas by fishers.

Varying trends were also observed between demersal, benthopelagic and pelagic fish. Catches of demersal fish declined most rapidly with increasing distance to the mangrove, while benthopelagic species persisted at further distances, perhaps signifying differences in species specific obligation to mangroves or other coastal habitats. Demersal catches included species of snappers, mojarras and barracudas, many species of which are known to use both mangroves, seagrasses and corals during their life history (Nagelkerken et al. 2002). Trends observed may therefore represent three different relationships between mangrove extent and fisheries catches over a spectrum of species dependence on mangrove habitat. Dominance of benthopelagic fish at further distances can also explain the gradual increase in mean catches up to approximately 1,400 km from the mangrove (while median catches remained consistent), representing infrequent but large catches of schooling species at volumes that logistically would not occur when targeting solitary demersal fish.

Conversely, trends in depth and distance from the mangrove (as mangroves occupy shallow waters) of catch locations could simply be representative of varying levels of fishing effort, driven by configuration of gear and boat size. Those with larger boats and more modern gear are restricted by depth in shallow water and by governance (having to fish at a set distance from the shore). At the upper depth range, fishing from larger boats is only restricted by exposure to bad weather and willingness to travel (time and cost of fuel). At the opposite end of the spectrum, smaller boats, using more traditional gears (such as traps, lines and small nets) are restricted by the depth of water through which it is safe to travel in a small boat, and the optimum depth in which to place, and retrieve, fishing gear. Assuming that larger boats and more modern gears catch more fish, larger or more frequent catches should be expected at greater depths. Mangrove-associated fish catches by depth may therefore follow a trend of within sector fishing magnitude. As small-scale fishing data includes only catches within IFA's (within 50 km of shore or 250 m depth, whichever comes first), some bias to the relationship with depth is likely to be inherent. Nonetheless, a trend in catches was observed even within this restricted depth range, suggesting a relationship between mangrove-associated catches and depth exists at least for small-scale fisheries. Inclusion of mangrove-associated catches from commercial fisheries catches would be necessary to explore the trend over large depth ranges, and indeed, over further distances from shore.

A decreasing trend in catches was also observed within grid cells from small to large mangrove extents, at odds with the positive correlation between mangrove area and fish catches presented in much of the existing literature (Pauly and Ingles 1986, Lee 2004, Manson et al. 2005a, 2005b, Aburto-Oropeza et al. 2008, Vázquez-González et al. 2015). This trend can be explained by a number of socio-economic factors surrounding the practical issues surrounding fishing. These factors include the appropriate environment for boat size and gear used. Wealth and size of fishing fleets (individual fishers versus large boats) and levels of reporting could also influence this trend.

Where mangrove extent is very large, up to 1,100 km^2 in some grid cells, there is little open water (space) available for fishing. Fishing where there are dense mangrove forests is therefore logistically limited to small scale activities. These include traditional activities, such as gathering by hand within the mangrove or using small boats and fishing equipment which can withstand complex mangrove root structure and shallow water depths within mangrove channels (Rasolofo 1997, Glaser 2003, Islam and Haque 2005, Mirera et al. 2013). In grid cells covered by large mangrove extent, small catch volumes by individual fishers can therefore explain smaller catch volumes in these areas. Such activities undertaken directly within the mangrove are usually conducted by individuals or small groups for family consumption or local sale (Glaser 2003, Mirera et al. 2013).

As traditional catches are often not included in formal markets (Ruitenbeek 1994, Glaser 2003, Mirera et al. 2013), they are also likely to be under-reported in national catch statistics. The negative trend in catches with increasing mangrove area could therefore also reflect levels of reporting from larger to smaller, less officially recognised fishing sectors. The very low number of species that occurred within catches of large mangrove areas, for example just one species being observed within mangrove areas larger than 850 km^2, also indicates the underreporting of catches. Given that reports of mangrove gathering by artisanal fishing communities, of fish and invertebrates such as crabs, bivalves and shrimp, are numerous and geographically widespread within the socio-ecological literature (Glaser 2003, Islam and Haque 2005, Ocampo 2006, Rondinelli and Barros 2010, Beitl 2011, Marschke 2012, Côrtes et al. 2014), higher species numbers, albeit at smaller volumes, would be expected within mangroves. However, frequent catches in grid cells where mangrove extent is smaller and subsequently there is more, and deeper, open water, may represent a better environment for a variety of fishing types and sectors and therefore also a higher diversity of target species.

Chlorophyll a concentration, used as a proxy measure for primary production, explained some of the variation in catch volumes. The Chl a concentration however fluctuated with increasing distance from the mangrove and therefore did not show any clear pattern which alone would explain the trend observed. Sea surface temperature of fishing locations overall decreased with increasing distance from the mangrove, also reflecting increasing latitude. Increased SST (indicating an environment suitable for enhanced biological production) along with Chl a concentration (indicating food availability) together have been used to forecast potential fishing zones (Gulati et al. 2010). These areas of high productivity in which fish accumulate for spawning or feeding (driving fishing effort to these areas) often occur around ocean dynamics such as coastal upwelling, fronts, eddies, rings, and meanders (Gulati et al. 2010). Much of the variation in mangrove-associated fish catches could therefore potentially be explained by further investigation of parameters related to ocean circulation systems.

There are also a number of local factors such as rainfall, salinity, tidal amplitude (organic matter availability) and mangrove setting that were not investigated but which could influence the volume of fish caught at varying locations. Rainfall has been negatively correlated to fish biomass, due to its influence on water salinity (Lee 2004, Castellanos-Galindo and Krumme 2013). Lowered salinity has also been linked to lower species diversity in mangrove creeks (Castellanos-Galindo and Krumme 2013). However, increased rainfall was linked positively to grouper culture productivity and negatively to green mussel culture productivity in the Peam Krasaop Fishing Community (Chapter 4). The type of mangrove forest, whether it be riverine, fringing or basin, may also influence its function as a habitat for fauna, its productivity and degree of nutrient outwelling (Ewel et al. 2019).

Geomorphic variation within mangroves of the same type may also influence fishing. Thus for example in New South Wales, Australia, higher catch rates, abundance and species diversity have been found in barrier mangrove estuaries than intermittently open estuaries (Saintilan 2004). This pattern has been attributed to the intermittent hydrodynamic closure of estuaries, creating less opportunity for recruitment and more opportunities for salinity fluctuations (Saintilan 2004). Given that environmental variables investigated explained 11% of variation in mangrove-associated species catches, some or all of these variables discussed may have influenced trends observed in mangrove-associated catch volumes, frequency and species diversity.

An additional factor to consider regarding the relationship between mangrove-associated catches with proximity to the mangrove is the ability of fish and invertebrate larvae or post-larvae to detect water-borne chemical signals from decomposing mangrove leaf litter, hypothesised to be used as a cue for the location of food or shelter (Huijbers et al. 2008, Leis et al. 2011, Natin and Lee 2018). However, this body of research is in early stages and the use of these chemical cues has been observed in the laboratory over just a few centimetres distance from mangrove leaves (Huijbers et al. 2008, Natin and Lee 2018). It is believed however that these chemical cues might be used over tens of kilometres to locate habitats (Leis et al. 2011). The advancement of this research might shed some light on the spatial relationship observed between mangroves and catches.

Investigation into the relationship between catches and the area of the nearest mangrove was inconclusive, despite a positive relationship between mangrove area and fish catches being widely reported at local scales (Manson et al. 2005b, Aburto-Oropeza et al. 2008, Sheaves et al. 2012, Carrasquilla-Henao et al. 2013, Vázquez-González et al. 2015, Carrasquilla-Henao and Juanes 2017). However, there were two limitations to the measurement of the nearest mangrove area that have likely contributed to an inconclusive result. Firstly, as mangrove area was measured per grid cell, it did not account for the full extent of large mangrove forests that overlap more than one grid cell. An example of this is the Sundarbans mangrove forest which covers an area of 10,000 km^2 across Bangladesh and India (Ghosh et al. 2015). Catches in the Bay of Bengal in close proximity to the Sundarbans mangrove forest were large in volume (as observed in Fig. 5-5). However the nearest mangrove area, recorded from the grid cells in closest proximity by straight line distance included only 450-500 km^2 of mangrove extent, therefore under-representing the influence that the whole mangrove extent has on catch volume. Furthermore, measures of mangrove extent were taken from the closest mangrove regardless of size, therefore measuring the effect of the closest mangrove (which could be very small), where a larger mangrove forest expanse could sit close by, and vice versa. To remedy this, measures of the "closest" mangrove could be conducted using a least cost pathway approach, which can be used to identify possible corridors in a landscape (Singleton et al. 2002, Hanke et al. 2014). However this would require assumptions to be made about the underlying mechanisms of mangrove-fish relationships, such as fish swimming capacity, habitat patch use and influence of circulation (Hanke et al. 2014) which are not yet known for these systems. Nonetheless, results here, despite not showing a clear pattern in the relationship, suggest that the area of the nearest mangrove has some influence on mangrove-associated fish catches that is worth investigating further.

Catches in grid cells containing large protected areas were unsurprisingly very low, as many of these areas are no take zones. However, a large proportion of grid cells in which mangrove-associated catches contained a small protected area extent (< 1 km^2). No information could be obtained regarding where the catches were made within the grid cell in relation to the protected area (i.e. they could have taken place within the protected area or up to approximately 40 km away) due to the scale of the fisheries data used. However, the prominence of catches in grid cells where protected area covered a small area of the cell might make some indication of "fishing the line", whereby fishers target the periphery of no take marine reserves to benefit from a spill-over effect (Kellner et al. 2007). There is not enough information here however to suggest that catches are the result of marine protected areas designated for the protected of mangrove habitat specifically. However, in the Sadani National Marine Park, Tanzania, increased artisanal fishing incomes were recorded following the instigation of a marine protected area, within a 5 km periphery of the protected mangrove area (McNally et al. 2011).

On the other hand, 45% of mangrove-associated catches took place in grid cells where no protected area was present. Most marine protected areas designated for mangrove protection are intended to protect the nursery function (or to conserve blue carbon stocks) (McNally et al. 2011, Miteva et al. 2015). According to Bull et al (2013), for MPA's to be effective they must not only incorporate critical habitats such as nursery and feeding grounds but also be inclusive of mobile species movements. While protecting critical nursery habitat is essential to sustaining the ecosystem service provided by mangroves, this could also be met with the sustainable harvesting of mobile species (McNally et al. 2011). Mangrove-associate species that make ontogenetic migrations outside of the mangrove are important recruits into adult fish stocks (Faunce and Serafy 2006, Kimirei et al. 2013, Hutchison et al. 2014). This study has provided some spatial information regarding the locations that mangrove-associated species can be found outside of the mangrove, via the location of catches. Knowledge of the spatial distribution of mangrove-associated species, and where they are harvested (indicating areas of pressure on resources), could help in incorporating mobile species into efforts to protect mangrove resources. The relationship between mangrove extent and fishing of mangrove-associate species presented here therefore raises questions about protected area implementation, more dynamic approaches to resource conservation and sustainable fisheries management.

5.4.3 Limitations of the analysis

Fish and invertebrate species use mangroves in different ways. Some species are permanent residents while others use mangroves during certain life stages or only occasionally (Faunce and Serafy 2006, Blaber 2007). Information on species-specific use of mangroves is lacking (Faunce and Serafy 2006) and therefore this study was unable to separate obligate mangrove species from weakly associated species. Varying levels of mangrove use by different species are likely to generate very different trends in the relationship between mangrove extent and fish catches. Differences in species links to mangrove were demonstrated solely by separating species by whether they use demersal, benthopelagic or pelagic environments and their schooling behaviour. Species separated by their level of dependence on mangroves during their life history would surely change the results obtained. However a quantitative overview of the possible range of interaction between mangrove and fishing has been presented here for the first time.

Lacking information on mangrove-associated species life history (specifically how far they might travel from the mangrove) also makes it difficult to definitively suggest at what distance from the mangrove species caught by a fishery are the product of some mangrove effect. GAM model outputs suggested that, after a threshold of 2,000 km, the distance from the mangrove that fish or invertebrates are caught becomes a less important factor in catch volume. However, the overall variance in catch explained by distance from the mangrove was very small, suggesting that there are a number of other factors that constitute mangrove-associated fishing grounds. Species distribution models, using species occurrence data together with environmental variables, can be used to identify the ecological niche of a species and thereby estimate species range in geographical space (Elith and Leathwick 2009). Identifying the ecological niche of mangrove-associated species through the use of species distribution models would allow any mangrove effect present to be separated from other variables influencing their distribution.

In addition, how far away from a mangrove a fish can be considered mangrove-associated could be explored through trajectory modelling. For example, Booker et al. (2008) modelled the migration trajectories of Atlantic salmon (*Salmo salar*) using SST and surface ocean circulation. Techniques such as this have also been used to estimate origins and destinations of reef fish larvae settling inshore (Limouzy-Paris et al. 1997). Mangrove fish movements from mangroves to coral reefs or seagrass meadows have been confirmed on small scales, using stable otolith signatures (Nagelkerken and Velde 2002, Nakamura et al. 2008, Kimirei et al. 2013). No research however has investigated further than this how and where mangrove-associated species travel after leaving the mangrove. Life history information together with information on ocean circulation would improve on the results presented here to clarify the relationship between mangrove and fish caught at varying distances from the mangrove.

This study was also limited by the scale of fisheries data available (the half degree cell). Despite having access to high resolution mangrove extent information (30 m), the relationship between mangrove extent and fish catches could not be investigated more accurately than to 40 km categories. As such, while results indicated that the first 40 km in proximity to a mangrove forest is the most important zone for mangrove-associated fishing, any trends that exist within that range could not be detected. There are also likely to be inaccuracies derived from the reconstruction of catch data. Source data used as the basis for reconstruction of catches are varied in quality, especially with regards to the accuracy of fishing grounds. Further research which uses geolocated fishing data at finer resolution would be useful in breaking down the trend in further detail. Currently, no freely available global fisheries dataset offers geolocated data on artisanal and subsistence fisheries at a finer spatial scale.

There are also limits to the computing capacity of studying the relationship between mangrove extent and fisheries catches at the global scale at the present time. Even using cloud computing, limits to computing power were reached using such large environmental datasets at high resolution, for example mangrove extent layers (available at 30m resolution) from the CGMFC-21 had to be aggregated to 900 m resolution for handling in Google Earth Engine. This was also the case for environmental variables extracted from the MODIS terra database which were available at 500 m resolution but had to be extracted at 1000 m resolution. Therefore, where mangrove research has driven high quality global information on mangrove forest extent which is greatly useful at regional scales (Hamilton and Casey 2016), it cannot yet be made use of to its full potential at such a wide scale analysis.

5.5 Conclusion

Trends in the relationship between mangrove-associated fisheries catches and mangrove extent explored at the global scale did not confirm the existing literature, presented at the regional scale, which has argued for a positive relationship between mangrove area and the volume of fish catch. Rather, a negative relationship between mangrove area and catch was quantitatively identified. This research has suggested that proximity to mangrove explains more of the variation in the volume of catches than mangrove area. However this study did support the hypothesis that those environmental parameters, particularly decreasing latitude and increasing sea surface temperature, together with Chl a concentration, which represent a productive tropical environment, have a positive influence on mangrove-associated catch volumes. However, catches of mangrove-associates were distributed differently to catches of non-mangrove associates, suggesting some influence or limitation on mangrove-associated fishing is imposed by the nature of mangrove ecosystems. The parameters investigated however only accounted for a small proportion of mangrove-associated catch variation, suggesting that there are further factors, such as oceanographic processes or socio-ecological aspects, contributing to the trends observed.

Mangrove-associated fish catches were observed over a much larger range than has typically been included in studies of mangrove-fishery linkages. Further evidence however is required to investigate the spatial limits to which a mangrove-associate species caught are truly mangrove-associated. To investigate this, detailed information on species life history, particularly migratory limits, teamed with local surface current and ocean basin current pathways, will be necessary to understand the possible origin of mangrove species caught at respective distances from the mangrove. Moreover local variation, including the distribution of other coastal habitats and their connectivity, the location of protected areas and other spatial governance boundaries as well as local geomorphology likely influence the relationship between mangrove extent and mangrove-associated catches from place to place.

The availability of freely accessible high resolution databases such as the CGMFC-21 and the use of cloud computing now makes the study of mangrove-fishery links at the global scale possible. However, finer scale study is still limited by computational capacity and fisheries data resolution. Research into this relationship at the global scale was not able to draw out local variation in mangrove-fishery linkages. Nonetheless, it has been possible to identify a relationship between small-scale fisheries catches and mangrove extent for the first time at the global scale. This study has also provided information on the spatial distribution of mangrove resource use which may prove useful for the design of management measures, such as protected areas, marine spatial planning and sustainable fisheries management.

6 - Conclusions

6.1 Mangrove-fishery relationships: not just a local phenomenon.

Most research on mangrove-fishery enhancement until now has demonstrated a relationship between mangroves and fisheries catches on a local or regional (national or smaller) scale. This thesis has demonstrated that a relationship between mangroves and fisheries catches can be observed on the global scale. Here distance to the mangrove appears the largest influence over fisheries catch, contrasting with much of the prior literature that has suggested mangrove area is most important. This contrast is somewhat unsurprising given the difference in scale between this and previous studies, which have not assessed the cumulative effect of mangrove area over multiple spatial units.

Prior to this study the relationship between mangrove extent and catches of penaeid prawn species is the only mangrove-fishery relationship that has been tested on a worldwide scale, even then being conducted through an aggregation of local studies. Furthermore, as highlighted in the analysis of the literature conducted in Chapter 3, a large proportion of quantitative research on the local and regional scale has focussed entirely on penaeid prawn yields despite known mangrove connections for more than 100 fish and invertebrate species. The literature on mangrove-fishery-community interactions is also not equally representative of mangrove ecosystems geographically, with most research being conducted in hot spots of mangrove research (for example Australia, Mexico and the Philippines). As such, the relationship thought to exist between mangrove extent and fisheries at the local and regional scale might not be representative of the relationship overall. This has been the first study of mangrove-fishery relationships that has been truly global in its reach and therefore there is little research on which to compare its results.

Nonetheless, the trends observed at the global scale in Chapter 5 did match some trends that were observed at the local scale in Chapters 3 and 4. An increase in the volume and frequency of catches with decreasing mangrove area is in keeping with the magnitude of catches observed in the Peam Krasaop Fishing Community (Chapter 4). This trend reflects the socio-economic structure of fishing in the PKFC whereby smallest scale (individual or family) fishing activity such as gathering and crab trapping within the mangrove and in small channels gives way to fishing by boat within the large channels using nets and lines. Finally, the largest scale fishing in the community (those that have the biggest boats) takes place offshore, outside of the Peam Krasaop mangrove area. A similar spatial socio-economic structure was also observed in Chapter 3, within the mangrove-fishing community in the Perancak Estuary, Bali where traditional fishing was conducted within the mangrove, small-scale fishing was conducted in the mangrove-estuary or in the coastal area and larger industrial fishing was conducted further offshore. As such the studies in chapters 3-5 promote the importance of the coastal areas in close proximity to mangroves as the locality from which mangrove-benefits are derived, in addition to inside the mangrove forest itself. This is an important consideration for marine spatial planning.

Both local and global scale results of the thesis also highlight the importance of small mangrove areas. As prior research has suggested that mangrove area is correlated to fisheries production, governments have prioritised the protection of large mangrove areas (Curnick et al. 2019). Results here suggesting that the proximity to mangrove area, rather than mangrove area itself, is an important driver of fisheries production suggest that this might not be the most efficient management strategy. Furthermore, small mangrove areas which have lesser overall value compared to larger mangroves can be vitally important areas for a particular community (Curnick et al. 2019). This was the case in the Perancak Estuary, Bali, where a mangrove area which covers just 1.25 km^2, forms an important role in the livelihoods of fishers from all sectors, from providing primary income and subsistence to back-up occupations. Moreover, measured quantitatively in the PKWS, 90% of fisheries production was made up of mangrove-associated species suggesting that the community are highly dependent on the mangrove. It should also be noted that the benefits that individual households obtained from the mangrove was wide ranging depending on the combination of activities each household participated in or had access to. Trade-off decisions over land use should therefore consider intra-community and inter-community benefits and dependence on mangrove resources as well as straightforward per hectare economic value as has been used in the past. These will also be important considerations for the fulfilment of the sustainable development goals, such as reducing poverty and achieving zero hunger.

The thesis has also demonstrated, at both local and global scales, that the relationship between mangroves and fisheries catches is non-linear. Ecosystem service provision by mangroves to fisheries is spatially non-linear, as suggested by the trend in fisheries catches with distance from the mangrove in Chapter 5, temporally non-linear, as revealed by the seasonality of mangrove-fishing conveyed in Chapters 3 and 4 and is variable by household based on socio-economic factors. This non-linearity in ecosystem service provision is important information for the effective implementation of ecosystem-based management as assumed linearity and temporal consistency of an ecosystem service can provide unrealistic expectations on resource provision (Koch et al. 2009).

Understanding this trend between mangroves and fisheries productivity at finer scales (< half degree) was limited by the current data and technology available. However new and emergent technologies are likely to improve our ability to detect this relationship in future. For example, global fishing data for small-scale fisheries does not currently exist at greater locational accuracy than the data used. However, the emergence of real-time vessel tracking through Automatic Identification Systems (AIS), a global positioning system that broadcasts the position of a vessel that can be picked up by satellites or ground stations, has revolutionized fisheries data collection and made that data publically available. As yet, this is only available for industrial vessels. However, Global Fishing Watch are currently piloting programmes that will make this data available for small-scale fishing fleets (Global Fishing Watch 2019). The emergence of this data would allow more accurate mapping of mangrove resource use and would likely uncover further trends in the spatial relationship between mangroves and fishing which is currently not possible to reach through global analysis. Spatial data of this accuracy is difficult to collect at the local scale as well as time consuming for fishers and researchers alike, thus global real-time tracking will be useful in improving the efficiency of mangrove-fishery research. Unfortunately, as the smallest scale fishing data (particularly the traditional fishing that takes place within mangroves) does not make it into official reporting of fisheries statistics and would not be picked up via vessel tracking (as it also does not always involve a boat), its inclusion in such initiatives is unlikely. The collection of the smallest scale mangrove-fishery data, as was collected and utilised in this thesis, will therefore continue to be important, notwithstanding these technological advances.

Progress is also being made with the accuracy of mangrove cover data available. The CGMFC-21 mangrove cover database was a useful tool for a global overview of trends in mangrove-fishery relationships. Nevertheless continuing inaccuracies at the local scale will still lead to misleading information on mangrove-fishery relationships. Notably, the mangroves of the Perancak Estuary (Chapter 3) are not included on the CGMFC-21 map. Additionally, maps currently available provide information on mangrove cover up to the year 2012. As mangrove cover, as well as many global environmental factors such as atmospheric and ocean temperature, sea level and ocean circulation have changed from 2012 to current (2019), the ecosystem service function and distribution of mangroves, and therefore the relationship between mangroves and fisheries, may have also changed during this period. The Global Mangrove Watch initiative, established in 2018, has generated a revised baseline map of mangrove extent for the year 2010. This initiative will soon release 7 epochs of mangrove cover between 1997-2017 and intends to generate area maps annually from 2018 onwards. These maps will be useful not only for demonstrating the dynamics of mangrove cover change (and potentially the relative, regionally varying importance of anthropogenic and/or natural drivers of change) but also in providing an improved underpinning for the analysis of mangrove fisheries interactions. This, together with real-time vessel tracking, will bring about an opportunity to measure how mangrove ecosystem service provision changes annually and monitor spatially how fishing effort changes in response.

A new technology that this thesis was able to use was the Google Earth Engine platform (Gorelick et al. 2017), to access and manipulate high resolution global satellite imagery on a large geographic scale. It has been argued that mangrove research so far has not taken advantage of the technology available, particularly information from earth observation satellites and use of cloud computing, to answer deeper questions at the global scale further than measuring mangrove area (Cárdenas et al. 2017). This has been attributed to a lack of programming knowledge within the field which therefore limits the spatial and temporal extent of mangrove studies conducted (Cárdenas et al. 2017). This study made use of global Landsat imagery for the period 2000-2012 to investigate a number of environmental factors and elucidate some patterns in the relationship between mangrove extent and fishing. Use of this data however was limited by current computing power; development of this platform will be needed for the use of remote sensing and satellite imagery to reach its full potential. This study however has demonstrated that global data is suitable for elucidating some trends in mangrove-fisheries and is therefore useful in informing the geographic scale at which to pitch future research.

6.2 Where do restored mangroves stand in the mangrove-fishery relationship?

Both case studies in Peam Krasaop (Chapter 4) and the Perancak Estuary (Chapter 3) represent areas that have been exposed to both mangrove degradation and restoration and now support mangrove-fishing communities. However, there is currently no evidence to demonstrate that restored mangroves actually contribute to ecosystem services received by the communities. In both cases, no monitoring of mangrove-fish landings had occurred prior to these studies so there is nothing but anecdotal evidence to suggest there has been any change in production from before mangrove destruction to after mangrove destruction, or following mangrove restoration. To further complicate matters, fishing effort has not been consistent throughout these changes to mangrove cover, as the industries that caused such changes (work in shrimp culture or charcoal production), created jobs that temporarily provided alternative employment to fishers. Perception of change by fishers due to changing livelihood circumstances probably does not represent ecosystem change. As such, as was reported by some fishers in both locations, there was perceived to more fish available for capture when the mangrove was being destroyed.

Gauging the scale of mangrove change was particularly difficult in Peam Krasaop Wildlife Sanctuary, despite its status as a Protected Area, as neither mangrove destruction nor restoration was spatially documented. While fishers suggested that 80% of the mangrove was lost, researchers working on the community structure of restored sites in the region estimate that just 10% of mangrove area in the PKWS was destroyed (R Mackenzie, pers. comm. 2019). As such, it could be the remaining 90% of unaltered mangrove is responsible for providing the benefits observed to the fishing community. Using an expert knowledge approach to estimate mangrove recovery time, Mukherjee et al. (2014) suggest that the ecological function of mangroves can be restored within 20 years of destruction for extractive processes. It is therefore possible that the full ecological function of the destroyed mangroves in the PKWS has been restored since their destruction in the 1980s and now (2017). However, in both case study locations, fishers were currently experiencing declines in catches. This could indicate that the ecological function provided by mangroves are currently compromised or deteriorating. The idea that the fishing communities in Peam Krasaop and in the Perancak Estuary are now beginning to feel the delayed after-effects of mangrove clearance should not be ruled out.

Lack of assessment of restoration success at the ecosystem level is a much wider issue (Bosire et al. 2008). For example, fish utilization of restored mangroves is rarely used as an indicator of restoration success (Lewis and Gilmore 2007). Subsequently, little evidence that restored mangroves function to provide nursery habitat or support fisheries enhancement exists. Conversely, it has been suggested that mangrove restoration efforts often fail to restore mangroves that are fit for purpose as fish nursery habitats (Lewis and Gilmore 2007). Lewis and Gilmore (2007) suggest that for restoration to be successful (i.e. providing adequate nursery habitat for fish and invertebrates) they must 1) mimic the plant cover of adjacent mangroves, 2) incorporate tidal hydrology that allows low tide refuge for mobile organisms and 3) establish a heterogeneous landscape which is similar to the local mangrove ecosystem. This is in contrast to the most common approach to mangrove restoration where seedlings are planted in a nursery and large numbers of potted mangroves are plotted, often on mud flats that have never hosted mangroves.

Nonetheless, some studies have shown that restored mangroves do host an abundance of some species, particularly crab species, at levels equal to or higher than adjacent natural mangroves (Macintosh et al. 2002, Bosire et al. 2004, Walton et al. 2007). Additionally, a study in Florida showed that fish biodiversity in older replanted mangroves was higher than recently replanted mangroves, and included some commercially important fish species, suggesting ecosystem function of replanted mangroves is restored over time (Barimo and Serafy 2003). However, different fish assemblage and community structure have been observed in restored mangroves compared to natural (unaltered) mangroves (Bosire et al. 2008, Peters et al. 2015). Restored mangroves therefore do not always provide the same ecosystem services to fishing communities as natural mangroves.

The UN decade on restoration (2021 – 2030), which will see UN nations scale up the restoration of degraded and destroyed ecosystems (UN Environment 2019), presents an opportunity for the restoration of mangrove ecosystems and the sustaining or enhancement of their role in supporting fisheries. A new map of global mangrove restoration potential has suggested that 60 trillion fish or invertebrates (individuals of 39 commercially important mangrove-associated species) could be added per year under the estimated restoration potential of 8,120 km^2 of mangrove cover (Worthington and Spalding 2019). According to the model, current global mangrove cover adds 1,000 trillion individual fish or invertebrates of commercial value. How this restoration potential translates into fisheries production is still unknown. Restoration that focuses on the production of suitable nursery habitat, uses fish and invertebrate abundance and biodiversity as a measure of restoration success, along with monitoring and reporting of subsequent changes (or the opposite) to fisheries production will be necessary in order to make the most of restoration efforts in the next decade.

6.3 The future of mangrove-fishery-community livelihoods under global environmental change

Chapter 2 concluded that there are a number of potential threats to mangrove-fishing-communities from global environmental change, from loss of mangrove habitat caused by sea level rise, to shifting distribution of fish and invertebrates through changing rainfall regimes and atmospheric temperature. Further, it concluded that the vulnerability of mangrove-fishing communities would be influenced by the level of dependence of individual communities on resources under threat. The mangrove-fishing communities in Bali and in Peam Krasaop, having a very high dependence on mangrove resources for income, as well reliance on regionally produced food, fit the descriptors of communities which are of the most vulnerable to climate change (Ludena and Yoon 2015). In Peam Krasaop in particular, there were a number of activities that were sensitive to annual fluctuations in water salinity and temperature, such as mariculture of green mussels and grouper species, as a result of local variation in rainfall and atmospheric temperature. These activities are therefore likely to be the most sensitive to variation in local climate as a result of future global environmental change. Climate change could thus force changes to the productivity and seasonality of these activities, amongst the most economically productive activities for the community.

However, while these communities can be deemed highly vulnerable through their potential exposure to climate change impacts, and their dependence on resources, they are also highly adaptive. Fishers at both case study sites were observed to switch between activities seasonally and annually in response to pressures on fisheries production, whether it be by changing gear, target or location of fishing. As such, one could assume that these communities have the potential to adapt similarly to climate change impacts. Future climate change could therefore see mangroves used in even more diverse ways.

Slowing population growth is often discussed with regards to adapting to climate change. Here, growth of households in Peam Krasaop Fishing Community, whilst increasing the overall number of mouths to feed, enables households to diversify into non-fishing occupations whilst continuing to meet subsistence needs. The conclusion easily jumped to in the face of fishery declines is that of population driven over-fishing. It is therefore important to consider that population growth in mangrove-fishing communities is not necessarily linearly correlated with fishing effort.

Furthermore, the adaptive capacity of mangrove-fishing communities to climate could be limited by additional direct human impacts on the ecosystem. The Peam Krasaop Wildlife Sanctuary, despite its status as a Protected Area, is a good example of this problem. While the pressures are high on the coastal ecosystem through the boom and bust fishing strategy employed by fishers, external pressures, for example illegal sand dredging, are likely causing changes to sediment availability, hydrology and consequently changes to the ecosystem as a whole. In the neighbouring village, Koh Sraloa, some popular fishing routes can no longer be used by the community because sand dredging has caused them to be too deep, and therefore too dangerous to be crossed in small boats (Koh Sraloa fishers, pers. comm. 2019). Moreover, increased mobility of sediments through dredging could have deleterious impacts on shellfish through sediment smothering (Mercaldo-Allen and Goldberg 2011). This would impact the community greatly as bivalves such as common mangrove clam are an important commercial and food product in the PKFC. Conversely, decreasing sediment supply could inhibit the ability of the mangrove to adapt to sea level rise through vertical sediment accretion. The Peam Krasaop Wildlife Sanctuary has already experienced coastal erosion of sand barriers which has caused concern for the long-term protection of the mangrove. Planning for adaptation to climate change for mangrove-fishing will need to consider more than just the pressures put on the system by fishers themselves but also those that are expected to exacerbate impacts.

Both case studies showed that young people are reluctant to be involved in fishing and are beginning to find new non-fishing occupations. Despite this, fishing for family subsistence needs continues even where fishing is no longer a primary occupation, suggesting that subsistence use of mangroves is still imbedded in the culture of mangrove-fisheries. Subsistence fishing is therefore likely to continue despite diversification and mangrove-fishing communities will continue to be dependent on mangrove resources for food security under future climate change. Climate change related fishery declines are expected to cause issues of reduction of protein, calories and micronutrients available which subsequently will impact upon human health (Golden et al. 2016). For example, modelling of the potential climate related declines in seafood harvest in the coastal First Nations in British Columbia has suggested that the intake of essential nutrients will be reduced by 31% under a “business as usual” climate change projection to 2050 relative to a 2000 baseline (Marushka et al. 2019). A decline of this magnitude could have devastating consequences for the mangrove-fishing-communities reliant on fishery resources as their main source of subsistence, particularly those who are isolated from other food sources, either geographically or by wealth. An assessment of the nutritional benefits mangrove-fishing communities receive from subsistence catches, particularly from the smallest scale catches that are circulated among communities and do not reach formal markets, would be useful in demonstrating that mangrove benefits are not purely economic.

Monitoring of such benefits will also be an important indicator of continued mangrove-ecosystem service provision, or otherwise, under future climate change.

6.4 Progress and future research directions

Through the process of defining mangrove-fisheries, this thesis has moved beyond simplified descriptions of mangrove-fishing. Further research following the framework developed in Chapter 3 in other mangrove regions will help to build a wider picture of what mangrove-fisheries currently encompass. This information will be important information going forward with efforts to sustain or restore ecosystem services on local scales through mangrove restoration. This better understanding of the many ways in which people use mangroves for fishing, and therefore benefit from their ecosystem services, should lessen ambiguity over who is involved in mangrove-fishing and by whom they should be managed. This definition is also a first step towards more thorough quantification of mangroves benefits to fishing. By including all activities, targets, seasons and locations in an approximation of mangrove-fishery benefits, Chapter 4 demonstrated that the community in Peam Krasaop is highly dependent on mangrove-associated catches.

The thesis was also able to demonstrate a relationship between mangroves and fishing at a global scale, suggesting that measurements of mangrove-fishery linkages thus far have perhaps been too narrow in their geographical reach. However, this study was not able to gauge the upper bound of the spatial relationship between mangroves and fishing; how far a fish caught from a mangrove can be assumed mangrove-associated is still an open question. Direct evidence for mangrove associated fish movements, which have been tracked through from stable isotope records, currently only exist for distances between 2-9 km from the mangrove (Morinière et al. 2003, Nakamura et al. 2008, Kimirei et al. 2013). Chapter 5 showed catches of mangrove-associated species to occur at much further distances from the mangrove. However, while all known mangrove-associate species continue to be assumed a product of mangroves present, no matter the location they were caught, the mangrove-fishery relationship will likely to continue to be contested.

Further research is therefore required to investigate the spatial limits to which a mangrove-associate species caught are truly mangrove-associated. This could be investigated through trajectory modelling. However, to understand the possible origin of mangrove species caught at respective distances from the mangrove much more detailed information on species life history, particularly migratory limits, is required. In particular, information is lacking at the individual species level on dependence on mangrove habitat. This is key information as mangrove obligates will have a much smaller spatial range than those that are weakly obligated. Furthermore, Generalised Additive Models, used to explore the relationships observed in Chapter 5, here explained just 11% of variation in mangrove-fishery catches, suggesting that there are further variables influencing the spatial distribution of mangrove-associated species catches. Research which investigates additional potential factors influencing the distribution of mangrove-associated fish, and the socio-economic factors influencing their catch, should therefore be addressed first.

Nonetheless, this thesis has provided baseline information which previously did not exist for mangrove-fisheries. The complex fishing strategies observed to be carried out by mangrove-fishing communities suggests that they are inherently adaptive. However, direct human impacts that continue to threaten mangrove area, such as oil palm production and sand dredging, are likely to exacerbate the pressures brought about by climate change. This thesis has come some way to promote the importance of mangrove for fishing community livelihoods, beyond simplified per hectare monetary values which are easily outcompeted by other land use options during land use decision making. However, quantification of the subsistence value is still necessary to demonstrate the importance of mangroves for food security. In the coming years, governments will undoubtedly step up their efforts to preserve and restore mangroves in order to meet commitments to the sustainable development goals (SDGs), as well as to contribute to the UN decade on restoration. More research will be needed which builds on the results presented here, both to understand how mangroves and fisheries are linked at both local and global scales, and to expand this knowledge towards understanding the potential of restored mangroves in supporting fisheries. Such studies will be necessary to guide, and make the most of, these governmental and international efforts.

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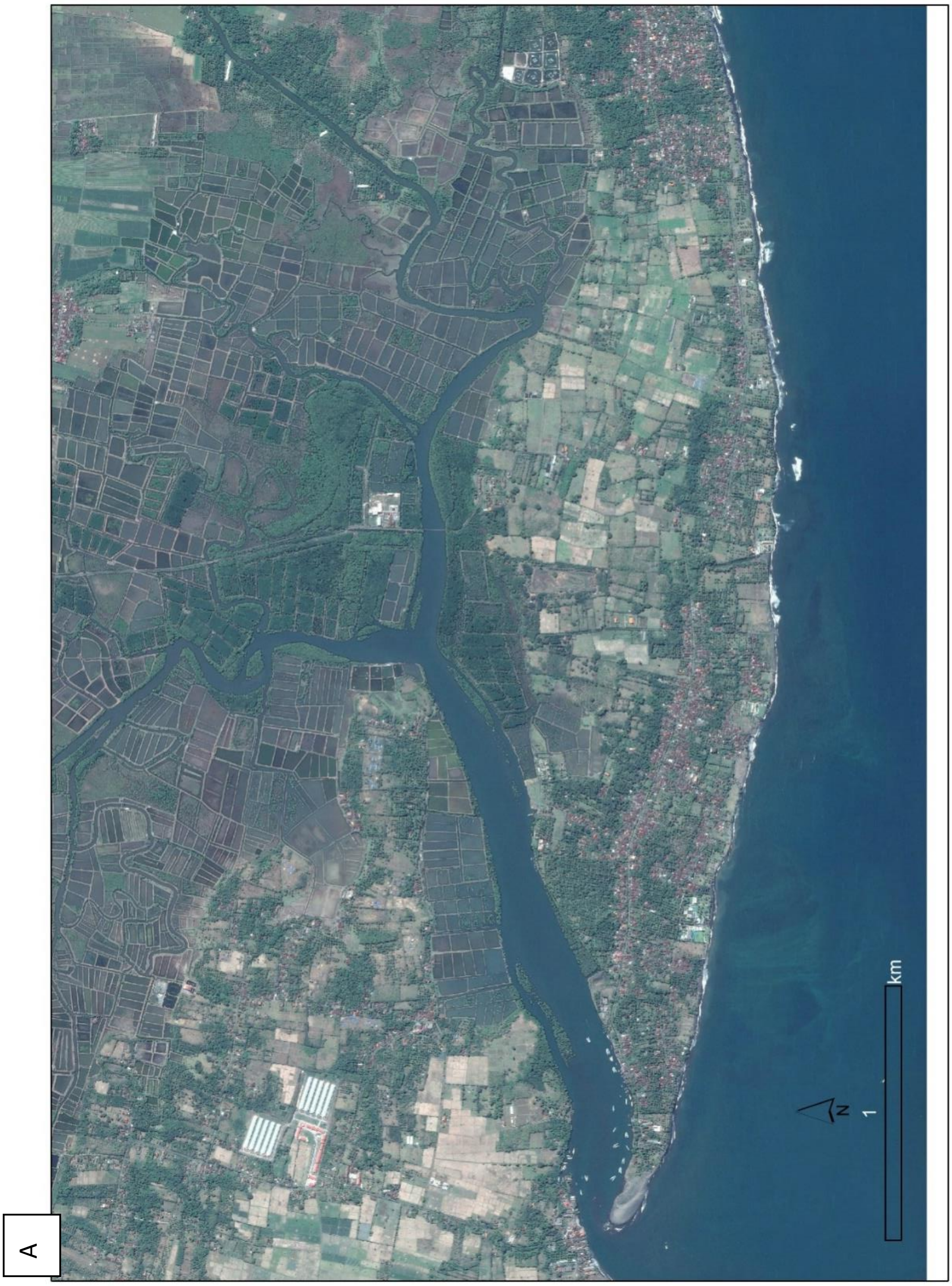
Appendices

Appendix 3-1. Interview schedule used for interviews with fishers in Bali (Chapter 3).

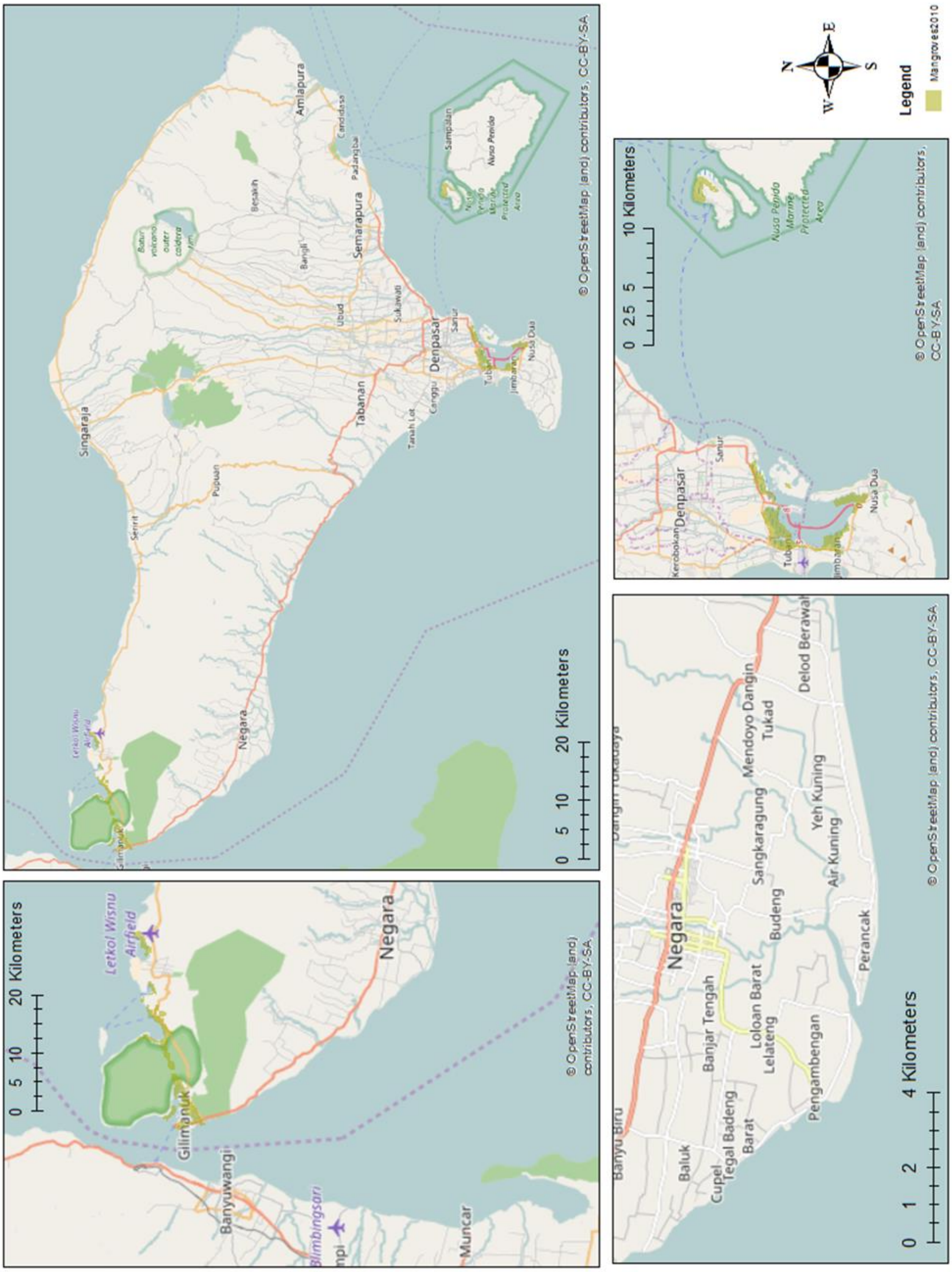
Respondent has confirmed that they give consent to be interviewed and for the discussion to be recorded and used in the research project described?	
Fishing sector	
Age	
Gender	
Family size	
How long have you been fishing?	
How did you start fishing? Who taught you to fish?	
Do you always fish alone/ who do you fish with?	
Are you family involved in fishing?	
How much time do you spend fishing? In the good season and the bad season?	
What is your household income from fishing? How much do you make from fishing?	
Do you go the market to sell the fish or do you keep most for yourself and your family to eat?	
How much of the fish you catch do you sell?	
How much of the fish you catch do you eat?	

Is your catch similar to the other fishers? What are the most profitable catches?	
Do you think a lot of your diet comes from fish/seafood in Bali? Do you also go out to eat out or buy other foods from the market?	
What kind of fishing gear do you use?	Other:
Hook and line Gill net Spear fishing Payang (pelagic Danish net) Bagan (lift net) Troll line Hand line Purse seine Cast net Beach seine Tuba Gathering by hand	
Where do you fish? And why do you fish there? (Economic, ecological or social reasons?)	
Which fish do you usually catch? How much?	
Lemuru (Bali sardinella) Cakalang (Skipjack tuna) Layang (Scad) Belanak (Mangrove mullets) Tongkol (Frigate tuna) Selar (Trevallies) Cumi-cumi (Common squids) Tembang (Fringescale) Layur (Hairtails) Tenggiri (Narrow-barred spanish mackerel) Kerapu (Grouper) Kakap (Snappers) Kembung (Short-body mackerel) Tuna (Tuna)	

Appendix 3-2. Maps used for participatory mapping with Balinese fishers (Chapter 3), including A) the Perancak Estuary and B) Wider Bali.



B



Annotated versions are available to view via the following link:

https://v2.luminpdf.com/viewer/5d2e286ab540b70019fb0848

Appendix 3-3. Fish guide used for catch identification with fishers, extracted from list of species caught in biodiversity surveys by (Polunin et al. 1983) in Bali Barat Nature Reserve, West Bali. Pictures were taken from FishBase. The guide is available through the google drive link below.

https://drive.google.com/file/d/10ase3IqIga35lAqKIzjCNt-4a5nJin0H/view?usp=sharing

Appendix 4-1. Interview transcript used for interviews in Peam Krasaop (Chapter 4) for households conducting a) fishing/gathering and b) culture activities. Note: Where households conduct both capture fishing and culture activities, a mixture of both interview questions were used to obtain appropriate information.

A) Fishers/gatherers

Interview No.	
Respondent has confirmed that they give consent to be interviewed and for the discussion to be recorded and used in the research project described?	
Age	
Gender	
Family size	
Religion	
What kind of fishing gear do you use?	Crab trap Crab net Fish net Gathering Other:
Where do you fish? And why do you fish there? (Economic, ecological or social reasons?) Use map from here	
What do you catch? Name How much (kg) Value	
How much money do you make from fishing? And the other family members?	
Are there any expenses for bait or fuel?	
What kind of habitat/ sediment is there? (Just sand/ rock/ seagrass/ coral reef/ mangrove)	
How deep do you fish and how far from shore?	
Do you go to different locations at different times of day? Why? (Targets, gear, commercial/subsistence etc.)	
Do you go to different locations at different times of the year? Why? (Targets, gear, commercial/subsistence etc.)	

Do you ever go to the mangrove? How often? How far from the mangrove?	
Where is the mangrove in the area? Are there any areas that used to be mangrove?	
What do you catch there?	
Do you harvest any other products from the mangrove? Mangrove crab for example or anything else?	
Do your family (the children and women) go to the mangrove? Do they collect anything?	
Are these kept for the family to eat or to sell at the market?	
What fishing gear do you use when you are fishing in the mangrove?	
How much do you catch from the mangrove?	
Do you know anything about which fish use the mangrove?	
Do you think that the mangrove is important? Do you make any money out of mangroves?	
Has there been any damage to the mangrove forest?	
Does mangrove damage affect you?	
Have there been any pressures on fishing in general?	
Do you do any other work other than fishing?	
Do your family have other jobs?	
Would you like your children to become a fisherman?	

B) Mariculture

Interview no.	
Respondent has confirmed that they give consent to be interviewed and for the discussion to be recorded and used in the research project described?	
How long have you been working in aquaculture?	
How did you start?	
Are the family involved?	
How many days per week do spend working (and for how long)?	Mon Tues Wed Thurs Fri Sat Sun
Is there a good season and a bad season?	
What do you produce? (Shrimp/mussels/fish?)	
How much of the yield do you sell?	
How much of the yield do you eat?	
Is your production similar to other farms in the village? What is the most profitable product?	
What is the net value of production/ how much money do you make working at the aquaculture farm? Product How much (kg) Value	
Have there been changes to the aquaculture production from the start until now? What caused them?	
Can you show me where the ponds are on the map? Map used? Y/N	
Are there mangroves in the area? Have they changed over time?	
Are there any damages to the mangrove forest?	
Does mangrove damage affect you?	
Are there any pressures in general on aquaculture?	
Do you collect any products from the mangrove? Wood, crabs, mussels etc.?	
How much of your diet comes from fish/seafood? Do you also go out to eat out or buy other foods from the market?	

Do you think that the mangrove is important?	
Do you make any money out of mangroves?	
Do you do any other work other than aquaculture?	
Do your family have other jobs?	
Would you like your children to work in aquaculture?	

Appendix 4-2. Maps annotated with fishing grounds and the fish key used for interviews with the Peam Krasaop Fishing Community, available with the following links:

Annotated maps:

https://drive.google.com/open?id=1KJ4tXRvMjAapffaH12gaP84F7Kld825X

Fish key:

https://drive.google.com/file/d/1YXON1F6ArEW69ekknQBF5JwDF81FdiTR/view?usp=sharing

Appendix 4-3. Table of original and adjusted household catch and gross income values according to number of possible fishing days assumed per month, in each season, for each target catch. This includes the original values used to calculate catch and income (the average number of days fishing per household per target, assuming fishing is everyday unless stated otherwise), the adjusted values based on expert opinion, regional patters, research observations and 2016 community fishing reports. Also included are the values of estimated possible fishing days per target from the 2016 community fishing report (note: not all species recorded in surveys were mentioned in the report).

	Average fishing days per month (Dry)			**Average fishing days per month (Rainy)**			**Average total catch per year**		**Average gross income per year**	
	Original	**Adjusted**	**2016**	**Original**	**Adjusted**	**2016**	**Original**	**Adjusted**	**Original**	**Adjusted**
Blue swimming crab	26.9	22.9	25.0	23.1	13.3	15.0	969.8	780.4	5430.6	4320.7
Common mangrove clam / mud clam	11.4	9.9		13.9	8.3		10355.0	7338.8	1524.1	1080.7
Dollfus octopus	22.8	22.8	23.0	NA	NA	0.0	895.2	895.2	2557.4	2557.4
Fourfinger threadfin	18.7	16.0		7.0	7.0		2207.1	2000.0	7095.7	6286.1
Green and giant tiger shrimp	30.5	25.0	25.0	7.0	7.0	15.0	373.0	310.7	544.8	453.8
Green mussel	NA	NA	15.0	NA	NA	0.0	5803.2	5803.2	1882.1	1882.1
Grouper	NA	NA		NA	NA		138.6	138.6	1000.0	1000.0
Longlegged crab	28.3	25.0		26.1	15.0		3958.5	2875.0	1454.7	1056.6
Mangrove oyster	2.8	2.8	14.0	2.8	2.8	15.0	103.2	103.2	NA	NA
Mangrove snail	4.0	4.0		5.5	5.5		488.3	488.3	127.5	127.5
Mantis shrimp	7.0	7.0	7.0	7.0	7.0	0.0	71.5	71.5	543.1	543.1
Mixed fish	26.0	21.9		24.2	13.9		523.5	481.1	888.4	766.1
Mixed molluscs	1.7	1.7		1.7	1.7		20.0	20.0	22.9	45.9
Mixed shrimp	24.7	20.7	25.0	13.6	9.9	15.0	547.4	467.3	3372.0	2898.2
Serrated mud crab	26.5	22.7	25.0	25.9	13.9	15.0	791.3	571.0	6193.0	4461.4
Spotted catfish	NA	NA		30.5	15.0		190.3	93.8	111.9	55.1
Striped sea catfish	28.3	25.0		29.0	15.0		707.2	675.0	668.2	661.5
Telescope creeper	3.0	3.0		3.0	3.0		3.6	3.6	NA	NA
Whitefish	30.5	25.0	15.0	NA	NA	0.0	3045.0	2500.0	3730.1	3062.5

Appendix 4-4. Assumptions made when calculating household catch volumes and gross incomes for the Peam Krasaop Fishing Community. “IP” codes refer to individual respondent identity codes.

- The local fish name “Trey ok” is taken to be *Arius maculatus* (spotted catfish). It was described to look like *Arius maculatus* in the species book but with grey on the back. This fits the descriptions/photographs of *Arius maculatus* found on FishBase.
- IP14: Catfish assumed striped sea catfish species as this one was specified by others in the New Peam Krasaop village using this local name.
- IP31: Catfish assumed striped sea catfish species as this one was specified by others in the New Peam Krasaop village using this local name.
- IP40: Some local fish names could not be translated and therefore were not identified, however their contribution towards total fish catch will be included. These were fish listed as “extras” and not the main catch of the respondent and are therefore included as mixed fish.
- IP14 – “Trey kobai” translates as buffalo fish but a reasonable match could not be found in fishbase, weight will be included within mixed fish.
- Green mussel culture harvest is included in the spreadsheet as yield (kg) per year, not as catch per day (kg) as all the other products.
- IP3: Catch calculated as 20kg total, made up of 4kg fish, 10kg Kdam Kmo and 6kg Kdam Ses as specified for both seasons. Catch not divided equally in this case as the proportions were specified.
- Where proportions are not specified, catch per species is divided equally.
- Crab size: If market price is not specified by the respondent, the medium sized price (described by several respondents and the middleperson) has been taken.
- Assume that if fishers are involved in green mussel culture, they are not conducting their usual fishing activities during that time (based on interview discussion).
- Where a range of weight (kg) is given for catch, the mid-point is always taken.
- Where not specified, assume price remains the same for a particular product in rainy and dry season.
- Where the family is not involved in aquaculture, and it is not stated otherwise, assume fishing is 12 months per year, unless other jobs are mentioned. Most fishermen specified that fishing was their only job in this case.

- IP4: 5 kg of oyster is enough for a family of 5 to eat, therefore assume about 1 kg per person is adequate. IP6 has a family of 4 and catch just for eating so have estimated 4 kg, IP5 have a family of 3 so assume 3 kg.
- IP7: Price for green mussels is between 10-15 baht so have used midpoint of 12.5 baht.
- The number of weeks per month is 4.35.
- Mixed bivalves includes all bivalves listed by respondent (see species list).
- IP10: Children's catch of snails and shells mixed as "mixed molluscs". Mud clam and telescope creeper separate as they are caught by the father. Assume 3 kg for family of 3 (him, his wife and grandchild he looks after) and approx. 0.1 kg of snails (would be approx. 100 snails as they are very small, more than enough for 1 meal).
- IP12: Only goes fishing 4 times per year, the main job is aquaculture and therefore fishing catch was not included as no information was given about gear or catch.
- IP13: Assume the children can catch the same amount as other children (1kg of clams/snails).
- IP13: Only caught 1 individual Kdam Kmo (rock crab), 1 rock crab weighs approx. 0.5kg. While this respondent usually catches more rock crab than this, they have a much higher proportion of long legged crab in that days catch and therefore this is an overestimate of the average for this species. Neither have been adjusted as their proportions are likely variable day by day so have taken today's catch as the measurement.
- IP14: Shrimp price: mid-point between "small" and "large" price.
- IP15: Catch split evenly between clam and snail, kg per product worked out using price and total catch value info. Total = 57 kg/2 = 28.7 kg of clam and 28.7 kg of snail.
- IP20: Mid-point of catch and size categories used for Kdam Kmo.
- IP20: As they stated that they "sometime catch nothing", a conservative estimate of 6 fishing days per week was used rather than 7 days.
- IP21: Shrimp 2-5kg but not regular so given a conservative estimate of 6 fishing days given @ 3.5kg.
- IP22: Assume average price of Kdam Ses is 30,000 riel per kg as described by other respondents.
- IP24: Using the most recent price (last year it was between 9-10 baht), therefore 9.5 baht per kg used.

- IP27: Kdam Ses catch volume was not specified so assume is the same as IP23, who also goes to put traps and collect clams in the meantime as they put in the same effort.
- IP35: Fishing is “a few days per week, sometimes takes a week off”. Assume 4 days per week, 3 weeks per month, except octopus fishing in November to May where schedule is specified.
- IP35: Clam gathering is by the grandmother in the household. Assume she goes 2 days per week as it is suggested that 2 days per week is enough catch to sell.
- IP35: Octopus fishing is every day for 2 weeks from November – May, assume that he leaves them for 2 weeks and then takes a break in between (same as net fishing in which he takes a week off). 75kg/14 days = 5.6kg, this was adjusted to fit with the kg per day calculated per fisher.
- IP2: 5$ between mixed fish/crab/gathering in the rainy season. No further information about proportions so have split the catch evenly by cost. $5/3 = $1.7 each for mixed fish, crab and clam. In dry season $12/13 total catch, within which $10 is Kdam Kmo, therefore leaves 2.5$ split between clam and fish.
- IP2: This respondent points out shrimp catch by neighbour (respondent IP1) but does not mention catching shrimp himself so these species have not been included in the catch of IP2, but have been for IP1.
- IP37: Price range suggests that the crab he gets is Kdam Kmo (fits that of other respondents and the middleperson. Also he puts the traps near the mangrove all year and doesn’t go to sea which suggests only rock crab fishing.
- IP38: Assume Kdam Kmo price is 30,000 riel per kg.
- IP38: Assume respondent continued fishing crab during green mussel season as he had no harvest.
- IP38: Clam price is 500 baht per kg (mainland price rather than island price) because he sells on the mainland.
- IP39: Work for other fishers not included in catch/direct income as to avoid duplication.
- IP40: Doesn’t always catch long-legged crab so have used a conservative 6 fishing days.
- IP40: Mixed fish is sold as bait fish and fish for eating so set price as mid-point between the two (5000 riel).
- IP28: 7 heads of mixed fish. This included striped catfish so have taken the weight for this species at length at maturity (14cm = 0.3kg) from FishBase. Also used for IP5.

- IP29: Price is in dry weight so have converted price to per kg wet weight which will be converted to dry shrimp for sale. Respondent catches approx. 17.5kg per month in the rainy season but sells 5kg per month. Price altered for whole shrimp is therefore 850 baht/17.5 = 48.57 baht per kg in wet weight = 1.46 $ per kg. This is based on fishing trips of 3.5 days, 2 weeks per month (7 days fishing per month in the rainy season).
- IP29: Shrimp catch combined as Green and Giant tiger shrimp as 2 specified species are caught together and whitefish combined for 3 species caught together.
- IP29: Seahorse not included in catch due to rarity and lack of information.
- IP29: Pong-pang total catch split evenly between mixed fish and crab (minus shrimp specified).
- IP29: Assume Kdam ses (swimming crab) is the species caught using Pong-pang gear.
- IP30: Gathering for mangrove snails, enough for eating assumed 1kg each.
- IP30: Conservative estimate of 6 fishing days as respondent "sometimes gets nothing".
- IP31: Split rainy and dry season catch between catfish and trey ok evenly (6000 riel/2= 3000 riel per species).
- IP31: Snails enough for 100 hooks (1 snail per hook) for 2/3 (2.5) days = 250 snails. Observed fishers mounting 1 snail per hook. Vannini et al. (2008) suggest this species = approximately 1g per individual.
- IP32: Whitefish catch volume not specified. Assume during this peak season can catch the same as others with similar gear, 100kg per trip for 1 month.
- IP32: 2-5 days fishing per trip taken as 3.5, catch adjusted to represent catch per day.
- IP32: Assume Kdam ses caught with Pong-pang.
- IP6: Use Kdam kmo price = 30,000 riel per kg.
- IP7: Rainy catch crab and fish split equally.
- IP7: Price of fish assumed 7000 riel per kg as the catch is made up of large fish. Other respondents say big fish is worth 6000-8000 riel per kg.
- Currency conversion: THB to US$ on 03/08/2017 (the mid-point of the interview period) = 0.03007.
- Currency conversion: KHR to US$ on 03/08/2017 = 0.00245.

- Seasonality: According to Theoun (2015), the rainy season is Mid-May to early October and dry season where winds and humidity are low is early November to mid-March. Also according to PMMR report which is specific to the PKWS, dry season is October to May. Therefore, the dry season will be referred to as 7 months between November to May and the rainy season as 5 months between June and October.
- Number of weeks per month on average = 4.35.
- Number of days per month on average = 30.42.
- Green mussel season will refer to 4 months between December and March. While some fishers may harvest until April, and put the poles in October, these 4 months are the most significant periods.
- During the green mussel season (4 months), those who harvest mussels are not conducting their usual fishing activities.
- Price of Kdam ses (swimming crab), use mid-point price of 30,000 riel per kg where not specified. Big = 50,000, Small = 30,000 and Smallest = 10,000 according to respondents and middleperson.
- IP5: Striped sea catfish = 400 riel per kg as in IP3.
- IP8: Assume mangrove gathering is 3 times per month as others who go "just when they want to eat". Respondent suggests they "sell the extras to neighbours" but this is not included in income measures as there is no additional information and extras would be minimal.
- Green mussel price: According to the green mussel middleman, the price is between 8-20 baht for per kg green mussels. A mid-point of 14 baht per kg is therefore used where not specified.
- IP9: Net income from green mussel given but no expense information given therefore this is likely an underestimate of total harvest for this respondent as catch volume was calculated from total harvest income.
- IP10: Telescope creeper and oyster harvest, assumed 7 times per month as others.
- IP10: Two crab species and shrimp catch divided equally.
- IP10: Shrimp price: taken from IP14, also not specified as dried shrimp so assumed full shrimp price.

- First green mussel harvest: If not harvested yet, assume the household were fishing during last years' green mussel season (i.e. do not discount 4 months) as last years' fishing would have continued through these months.
- Mud clam price: Where not specified, will use 500 riel per kg as specified by the mud clam middleperson in NPK.
- Telescope creeper price: 4700 per kg according to middlewoman in NPK.
- Incidental fish catch in nets = approx. 2kg, in traps approx. 1.5kg if the size of nets/ number of traps is similar to other fishers.
- Price of mixed fish = 5000 riel per kg (mixed fish including both bait fish and fish for eating).
- IP16: Assume mangrove gathering for clams is 3 times per month as others.
- IP16: Note other crab species included in "Kdam kmo" and "Kdam ses" catch as no info on catch proportions given, these are not target species rather incidental catch.
- IP16: "Sometimes get fish in dry season", not included due to lack of information.
- Shrimp price: According to IP14, Small = 25,000 riel per kg, Big = 37,000 riel per kg therefore mid-point of 31,000 riel per kg used where not specified elsewhere and not specified that shrimp is dried before sale.
- IP21: Kdam kmo catch volume based on IP16 as both get crab and fish with nets. Using a conservative 6 days per week as respondent says fishing is everyday but weather dependent.
- IP21: IP14 shrimp price used.
- IP32: IP14 shrimp price used.
- IP25: Only 3 months dry season catch accounted for as green mussel season takes up 5 months of this season.
- IP1: Shrimp catch volume taken from IP29 who also uses Pong-pang gear to catch shrimp.
- IP29: Used total of 100,000 baht per year for green mussel harvest.
- Whitefish price: None specified so mixed fish price used (5000 riel per kg).
- IP38: Plastic crab included in rock crab catch.
- IP38: Clam catch based on real observation of other boat landings as his catch is now "less than 200kg as in the past". Used observation of 105 kg, no other landings came close to 200kg per trip of mud clam.

- Price of long-legged crab for use as bait = 1500 riel per kg (according to IP13). Applied to IP40.
- IP28: Use catch volume + price rather than net profit estimate for green mussels.
- Trips that last > 1 day, the catch is divided between number of days to give catch and income per day for that trip. This does not apply to aquaculture activities.
- IP32: Grouper price is 7500 baht for the total catch not per kg.
- IP13: 6 fishing days per week in rainy season because fishing is "every day when the weather allows". This is applied to all rainy season catch by this respondent.
- IP36: "Some fish come into the traps but not often". No further information so not included.
- IP22: Gathering "if it's rainy". Assume based on others that they would go to the mangrove 3 times per month as no other information given. Only applied to dry season as they have other jobs during rainy season in factory work. Same applied to IP4.
- IP40: Respondent says there was no "benefit from harvest which cost $700", assume $700 worth of harvest as it did not say that there was no harvest.
- Kdam Kmo price: Medium sized Kdam Kmo according to middleperson (who confirms that all middlemen ask the same price) IS 30,000 riel per kg. This price will be used unless specified otherwise.
- Kdam ses: Mainly quoted as "kg of meat" however the exception is IP14 (wet season catch sold as whole crab).
- Kdam ses price: Price of meat in the dry season is 30,000 riel per kg according to most fishers. Price of medium sized whole crab in wet season is also 30,000 riel per kg.
- Kdam ses price (swimming crab) is measured as weight of meat as it is sold this way, everything else is total weight as caught.
- Kdam ses (Blue swimming crab): According to Wu et al. (2010), "Similar meat yields of about 32% were found for both female and male crabs". Therefore where it is stated that the swimming crab is sold by weight of meat or the kg sold per trip is quoted as weight of meat, the data will be adjusted to represent kg of whole crab caught. Therefore;

  Weight of whole crab catch = Meat weight given/ 0.32.

  Price of crab whole crab then adjusted to give price per kg of whole crab when sold by weight of meat;

Price of meat per kg* 0.32 = Price attained per kg of whole crab, sold as meat.

- Those respondents that specified that crab was sold as meat were: IP4 (dry season), IP11 (dry season), IP13 (dry season), IP17 (both seasons, in this case given in kg total weight and price in meat weight, but price needs to be adjusted to reflect that), IP21 (dry season).

- IP31. Wet catch volume given but dry price given, therefore the price gained for wet catch which is going to be dried is calculated using the wet to dry reduction calculated in IP14.

- IP32 Grouper catch unrealistically high considering family cannot afford green mussel culture and are using the same gear as IP28 (20 traps catching around the same number of "heads") which only amounts to $1000 sold per year. IP32 grouper income has therefore been adjusted to $1000 dollar.

Appendix 4-5. Information given regarding expenses associated with varying fishing activities derived from interviews with Peam Krasoap fishing households at New Peam Krasaop Village (NPK), Old Peam Krasaop Village (OPK) and Koh Kang Village (KK). No. interviews refers to the number of respondents who gave information on the expenses involved in a particular fishing activity. NA's refer to activities which are not carried out by this village. Expenses included are those related to bait, fuel, equipment and workers.

	NPK	No. interviews	Bait		Fuel	Equipment			Workers
Crab net		N = 5	None		2.46-8.2 US$ per trip	240m net (N=1), 150$			Boat workers: 10
Crab trap		N = 11	Collect through	0.5-0.7 US$ per trip	1.64-8.2 (rainy), up	200-700 traps @ 1.5			Mostly none
Fish net		N = 4	None		2.46-6.56 US$ per trip	No info			No info
Gathering by hand		N = 14	None		None	None or small tools			None
Shrimp net		N = 2	None		2.46-4.1 US$(rainy),	200m of net (N=1), 150$			No info
Aquaculture poles		N = 9	None		No info	700-1000 US$ pole	Plastic and rope to prepare poles (~1.23 $ per pole)	Poles replaced every 2-3 years	Divers (2 per boat) @
Shells for octopus		N =1	None		12.3 US$ per trip	0.6 US$ per shell, has 7000 shells, frequently lost			2 workers get 10% of the benefit each per trip
Pong-pang		NA							
Fish trap		NA							
Grouper aquaculture		NA							
Hook and line		NA							

		Workers			Equipment	Fuel	Bait	No. interviews	OPK		
		Workers paid 20% of catch			5x50 m net	No info	None	N = 1			
								NA			Crab meat processing: 1.2$ per kg.
		Worker paid 20% of				1.64		N = 1			
		None			None	None	None	N = 2			
							No info given	N = 1			
Harvesting 20 % of catch to workers or 9 US$ per day	Harvesting sometimes done themselves	Placing poles, 7.4$/day	Diving equipment is divers own	Plastic and role @ 1.2$ per pole	100-700 poles @ 1.2$ per pole	No info	None	N = 3		Labour and diving sometimes done without additional workers.	Labourers for cutting, transporting and setting poles, cost not described.
								NA			
		Pays 20% to one worker			No info	1.64	None	N =1			
		Pays 20% to one worker			20 traps	1.64	2.45 US$ per trip	N = 2			
		Pays 20% to one worker.			4 nets	1.64	3.7 US$ /net, 4x per week	N = 2			
		None			100 hooks on 100-150m line	30 min trip?	Collect own bait	N = 2			

	Workers		Equipment	Fuel		Bait	No. interviews		KK
							No info given	**Crab net**	
	None		100-160 traps @ 0.8 US$	1-9-2.85 US$ per trip	Bait also collected themselves	0.1-15 US$ per trip	N = 4	**Crab trap**	
							No info given	**Fish net**	
	None		None	None		None	N = 3	**Gathering by hand**	
							NA	**Shrimp net**	
Labour (cutting and diving) also done within families	Divers paid 15 US$ per trip	$700 set up for 2000 poles	200-2000 poles	No info		None	N = 4	**Aquaculture poles**	
							NA	**Shells for octopus**	
							No info	**Pong-pang**	
							NA	**Fish trap**	
							NA	**Grouper aquaculture**	
							NA	**Hook and line**	

Appendix 5-1. Mangrove-associated species included in analysis by common name, the general environment they inhabit in the water column (demersal, benthopelagic or pelagic) and their general behaviour (solitary, aggregating or schooling). Information on mangrove association of species and their environmental and behavioural characteristics was extracted from FishBase (Froese and Pauly 2017) and SeaLifeBase (Palomares and Pauly 2016).

Common Name	Scientific Name	Environment	Behaviour
Eulachon	*Thaleichthys pacificus*	Pelagic	Schooling
Flathead grey mullet	*Mugil cephalus*	Benthopelagic	Schooling
Largehead hairtail	*Trichiurus lepturus*	Benthopelagic	Schooling
Sheepshead	*Archosargus probatocephalus*	Demersal	Solitary
Summer flounder	*Paralichthys dentatus*	Demersal	Solitary
Crevalle jack	*Caranx hippos*	Pelagic	Schooling
Japanese seaperch	*Lateolabrax japonicus*	Pelagic	Schooling
Spotted weakfish	*Cynoscion nebulosus*	Demersal	Solitary
Atlantic spadefish	*Chaetodipterus faber*	Demersal	Schooling
Bull shark	*Carcharhinus leucas*	Benthopelagic	Solitary
Nurse shark	*Ginglymostoma cirratum*	Demersal	Solitary
Blacktip shark	*Carcharhinus limbatus*	Benthopelagic	Solitary
Tarpon	*Megalops atlanticus*	Benthopelagic	Schooling
Pigfish	*Orthopristis chrysoptera*	Demersal	Schooling
Blue swimming crab	*Portunus pelagicus*	Demersal	Solitary
Milkfish	*Chanos chanos*	Benthopelagic	Schooling
Grey snapper	*Lutjanus griseus*	Demersal	Aggregations
Mutton snapper	*Lutjanus analis*	Benthopelagic	Aggregations
Dorab wolf-herring	*Chirocentrus dorab*	Pelagic	Schooling
Goliath grouper	*Epinephelus itajara*	Demersal	Solitary
Great barracuda	*Sphyraena barracuda*	Pelagic	Aggregations
Broomtail grouper	*Mycteroperca xenarcha*	Demersal	Solitary
Silver croaker	*Bairdiella chrysoura*	Benthopelagic	Schooling
Barramundi	*Lates calcarifer*	Demersal	Solitary
Cobia	*Rachycentron canadum*	Pelagic	Schooling
Silver sillago	*Sillago sihama*	Demersal	Schooling
Jarbua terapon	*Terapon jarbua*	Demersal	Aggregations

Giant trevally	*Caranx ignobilis*	Pelagic	Schooling
Orange-spotted grouper	*Epinephelus coioides*	Demersal	Solitary
Pink ear emperor	*Lethrinus lentjan*	Demersal	Aggregations
Painted sweetlips	*Diagramma pictum*	Demersal	Solitary
Strongspine silver-biddy	*Gerres longirostris*	Benthopelagic	Aggregations
Johns snapper	*Lutjanus johnii*	Demersal	Solitary
Yellowtail scad	*Atule mate*	Pelagic	Schooling
Javelin grunter	*Pomadasys kaakan*	Demersal	Schooling
Spotted sicklefish	*Drepane punctata*	Demersal	Solitary
Spangled emperor	*Lethrinus nebulosus*	Demersal	Schooling
Greasy grouper	*Epinephelus tauvina*	Demersal	Solitary
Shorthead anchovy	*Encrasicholina heteroloba*	Pelagic	Schooling
Chacunda gizzard shad	*Anodontostoma chacunda*	Pelagic	Schooling
Bigeye trevally	*Caranx sexfasciatus*	Pelagic	Schooling
Blue-barred parrotfish	*Scarus ghobban*	Demersal	Solitary
Common silver-biddy	*Gerres oyena*	Demersal	Solitary
Thumbprint emperor	*Lethrinus harak*	Demersal	Schooling
Giant catfish	*Netuma thalassina*	Demersal	Solitary
Needlescaled queenfish	*Scomberoides tol*	Pelagic	Schooling
Doublespotted queenfish	*Scomberoides lysan*	Pelagic	Solitary
Ladyfish	*Elops saurus*	Benthopelagic	Schooling
Silver grunt	*Pomadasys argenteus*	Demersal	Solitary
Golden trevally	*Gnathanodon speciosus*	Benthopelagic	Schooling
Orangestriped emperor	*Lethrinus obsoletus*	Demersal	Solitary
Schoolmaster snapper	*Lutjanus apodus*	Demersal	Aggregations
Pickhandle barracuda	*Sphyraena jello*	Benthopelagic	Solitary
Common ponyfish	*Leiognathus equulus*	Demersal	Schooling
Fourfinger threadfin	*Eleutheronema tetradactylum*	Pelagic	Schooling
Malabar grouper	*Epinephelus malabaricus*	Demersal	Solitary
Mangrove red snapper	*Lutjanus argentimaculatus*	Demersal	Aggregations
Blacktip reef shark	*Carcharhinus melanopterus*	Demersal	Solitary
Feathered river-garfish	*Zenarchopterus dispar*	Benthopelagic	Schooling
Indo-Pacific tarpon	*Megalops cyprinoides*	Benthopelagic	Schooling
Hound needlefish	*Tylosurus crocodilus*	Pelagic	Solitary

Glasseye	*Heteropriacanthus cruentatus*	Benthopelagic	Aggregations
Squirrelfish	*Holocentrus adscensionis*	Demersal	Aggregations
Western Atlantic seabream	*Archosargus rhomboidalis*	Demersal	Solitary
Yellow fin mojarra	*Gerres cinereus*	Demersal	Aggregations
Caitipa mojarra	*Diapterus rhombeus*	Demersal	Solitary
Bonefish	*Albula vulpes*	Pelagic	Schooling
Longface emperor	*Lethrinus olivaceus*	Demersal	Schooling
Dash-and-dot goatfish	*Parupeneus barberinus*	Demersal	Solitary
Blacktail snapper	*Lutjanus fulvus*	Benthopelgic	Aggregations
Indian goatfish	*Parupeneus indicus*	Demersal	Solitary
Spotcheek emperor	*Lethrinus rubrioperculatus*	Demersal	Solitary
Toothpony	*Gazza minuta*	Demersal	Solitary
Spotted scat	*Scatophagus argus*	Demersal	Solitary
Yellowstriped goatfish	*Upeneus vittatus*	Demersal	Solitary
Ground croaker	*Bairdiella ronchus*	Demersal	Solitary
Dana swimming crab	*Callinectes danae*	Benthopelgic	Solitary
Striped eel catfish	*Plotosus lineatus*	Demersal	Solitary
Slender silverbiddy	*Gerres oblongus*	Demersal	Schooling
Devis anchovy	*Encrasicholina devisi*	Pelagic	Schooling
Indian anchovy	*Stolephorus indicus*	Pelagic	Schooling
Bluestripe herring	*Herklotsichthys quadrimaculatus*	Pelagic	Schooling
Silver moony	*Monodactylus argenteus*	Pelagic	Schooling
Harry hotlips	*Plectorhinchus gibbosus*	Demersal	Aggregations
Pacific yellowtail emperor	*Lethrinus atkinsoni*	Pelagic	Schooling
Russell's snapper	*Lutjanus russellii*	Demersal	Solitary
Blue-lined large-eye bream	*Gymnocranius grandoculis*	Demersal	Solitary
Squaretail mullet	*Ellochelon vaigiensis*	Demersal	Schooling
Goldenlined spinefoot	*Siganus lineatus*	Demersal	Schooling
Luderick	*Girella tricuspidata*	Benthopelagic	Schooling
Eastern Australian salmon	*Arripis trutta*	Pelagic	Schooling

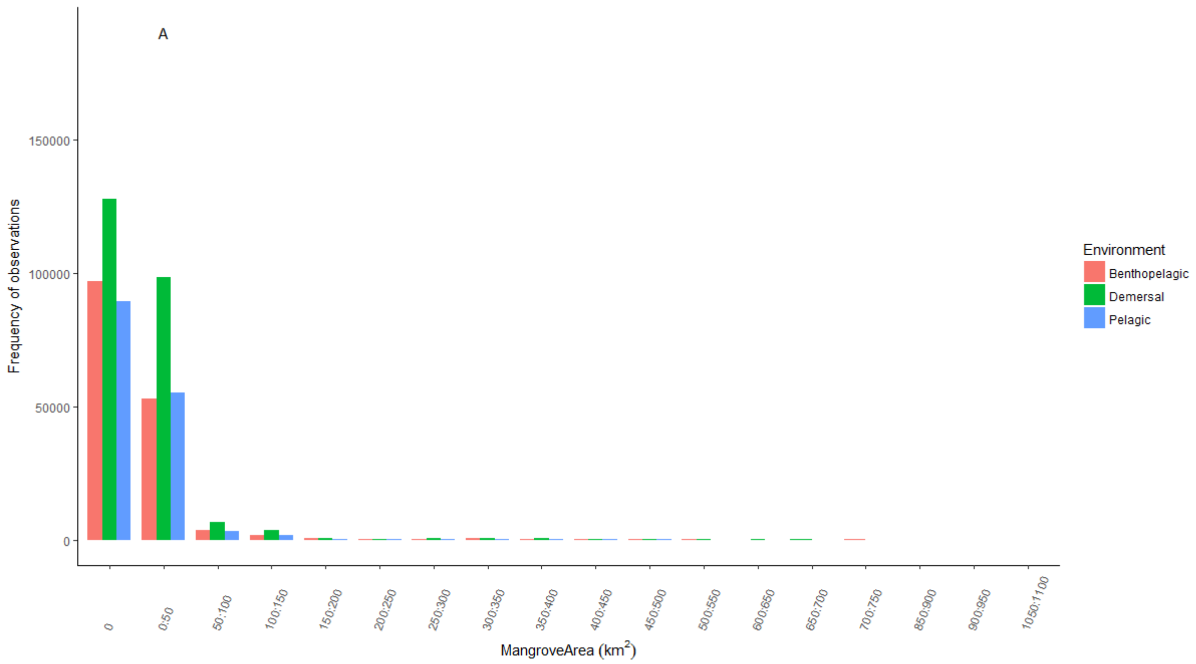
Appendix 5-2. Mangrove holding nations included in Chapter 6 analysis. A list of countries or nations containing mangrove was taken from the CGMFC-21 database (Hamilton and Casey 2016) and filtered by those nations that included mangrove-associated catch observations in the Sea Around Us database (Pauly and Zeller 2015) .

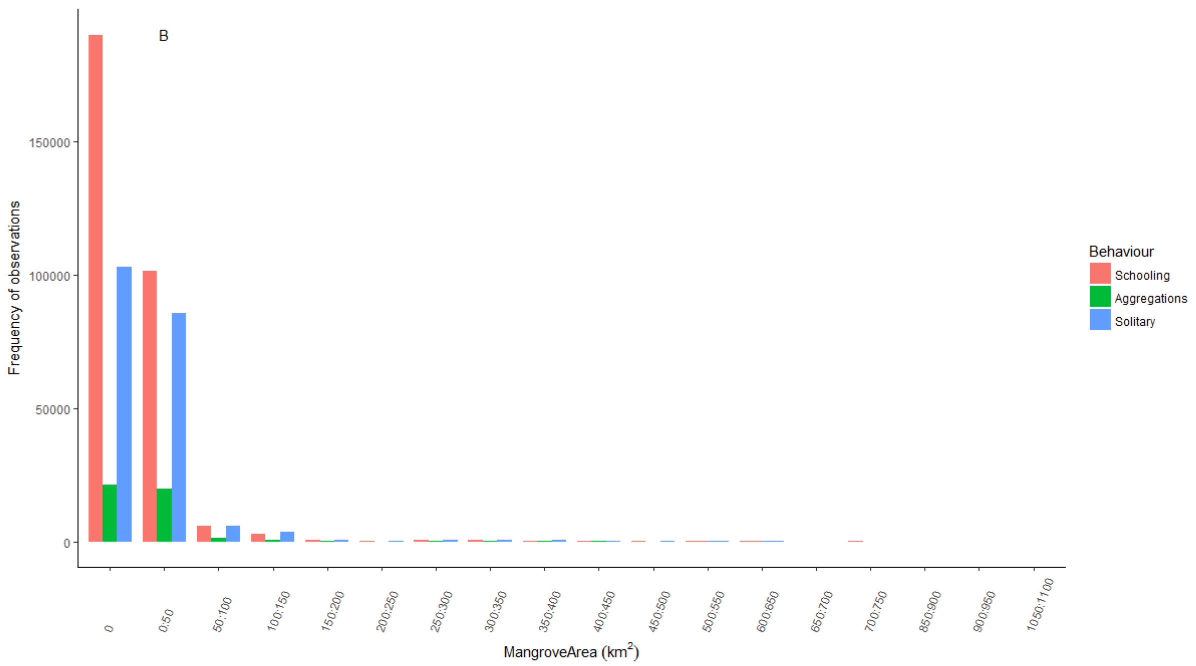
Country/Nation
USA
Japan
China
Mexico
Bermuda (UK)
Iran
Egypt
Saudi Arabia
Bahamas
Qatar
Oman
Taiwan
United Arab Emirates
Pakistan
India
Bangladesh
Hong Kong
Mauritania
Haiti
Dominican Republic
Philippines
Jamaica
British Virgin Isl. (UK)
Belize
St Martin
Eritrea
Honduras
Guadeloupe (France)

Senegal
Yemen
Venezuela
Nicaragua
Guatemala
Martinique (France)
Viet Nam
Saint Lucia
El Salvador
Gambia
Thailand
Saint Vincent & the Grenadines
Barbados
Colombia
Grenada
Djibouti
Bonaire (Netherlands)
Guinea-Bissau
Somalia
Cambodia
Trinidad & Tobago
Guinea
Sri Lanka
Micronesia
Panama
Sierra Leone
Guyana
Palau
Malaysia
Maldives
Liberia
Suriname
French Guiana
Togo

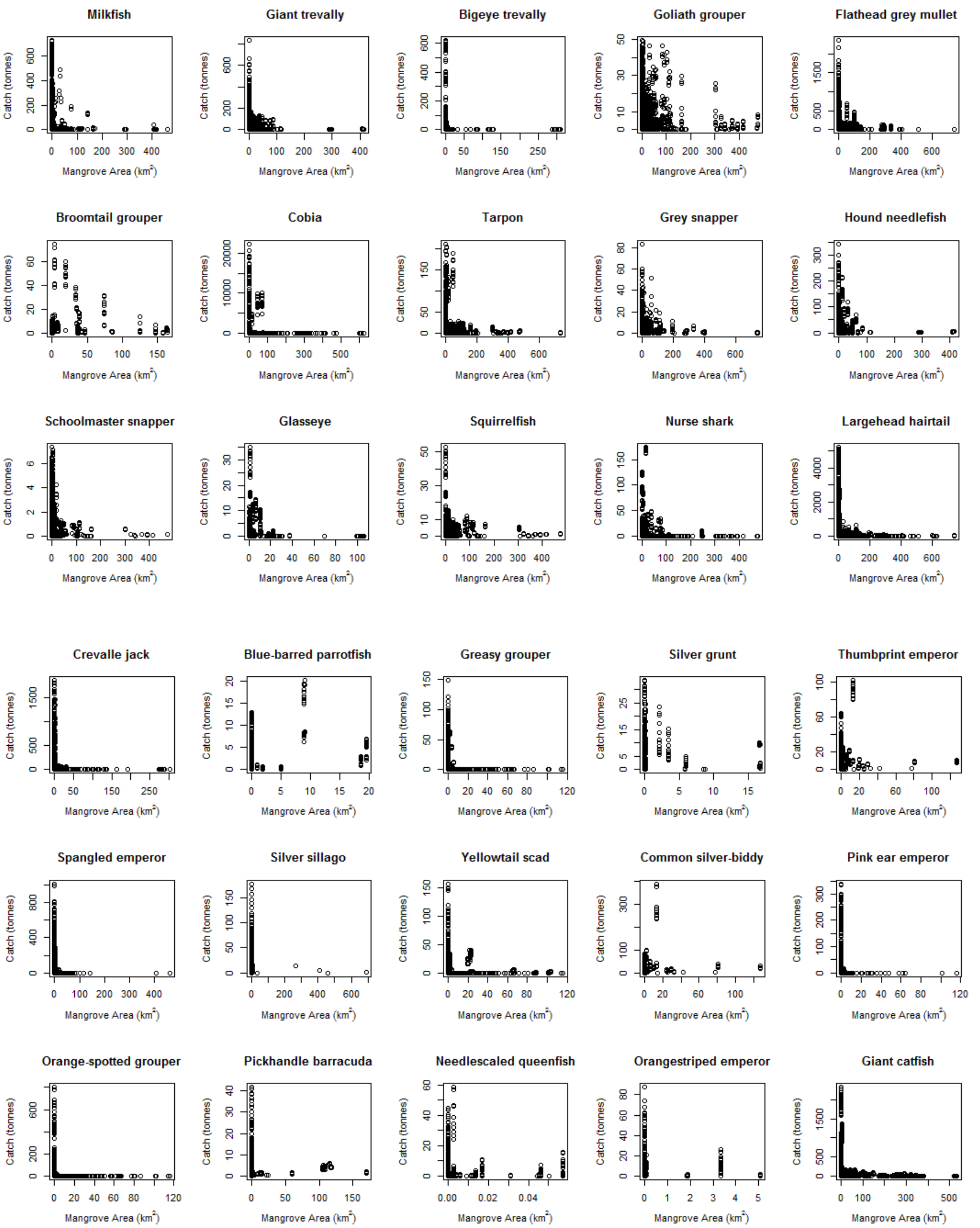
Ghana
Benin
Nigeria
Indonesia
Cote d'Ivoire
Brazil
Cameroon
Singapore
Gabon
Papua New Guinea
Peru
Congo, R. of
Tanzania
Angola
Solomon Isl.
Australia
Fiji
Mayotte (France)
Vanuatu
New Caledonia (France)
New Zealand

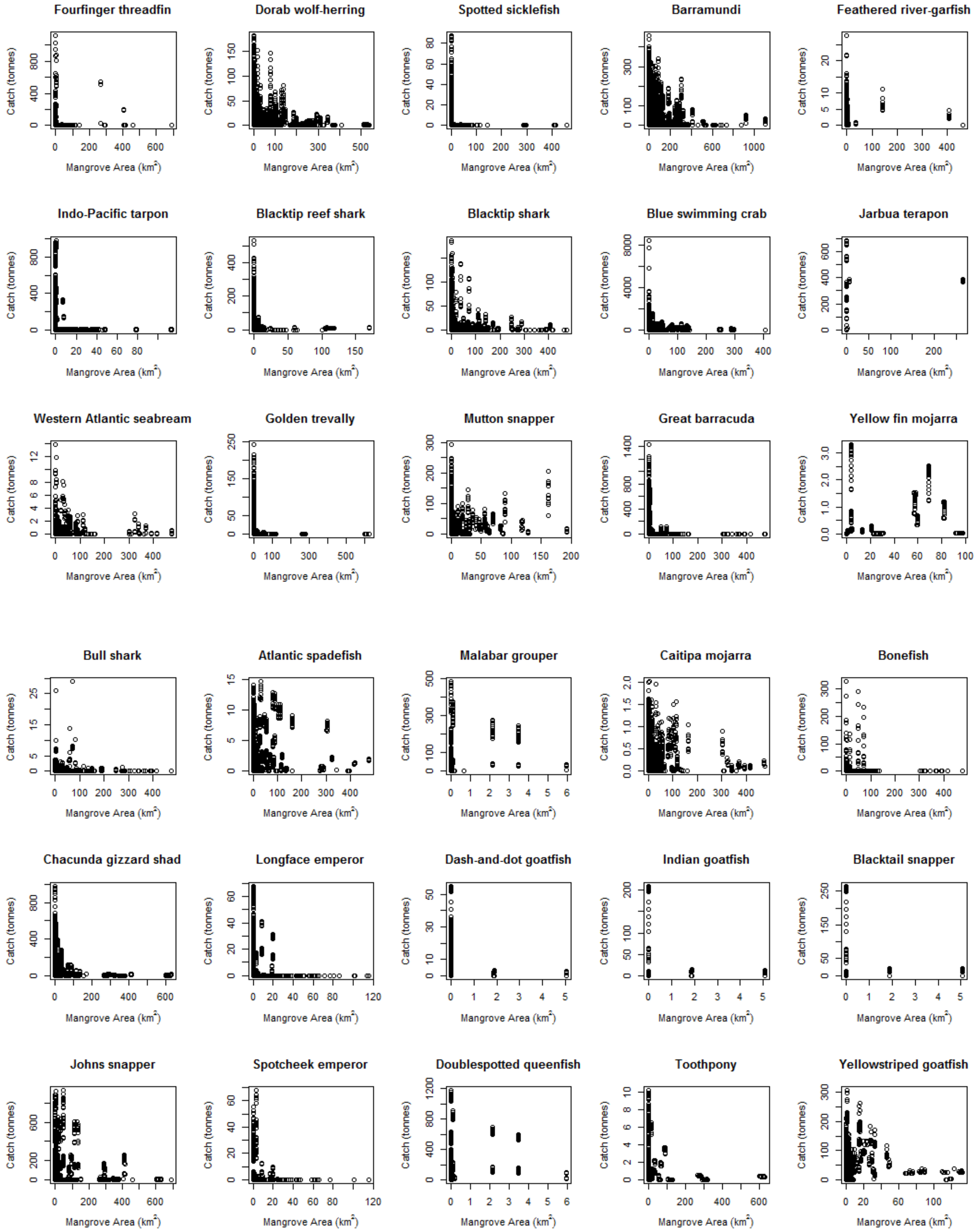
Appendix 5-3. Barplots showing the sum of mangrove-associated fish catches at categories of mangrove area within a 0.5x0.5° cell, divided by A) environment generally occupied within the water column and B) behaviour generally exhibited by the species. Catch data includes artisanal and subsistence catches of mangrove-associated fish and invertebrates from 2000-2012.

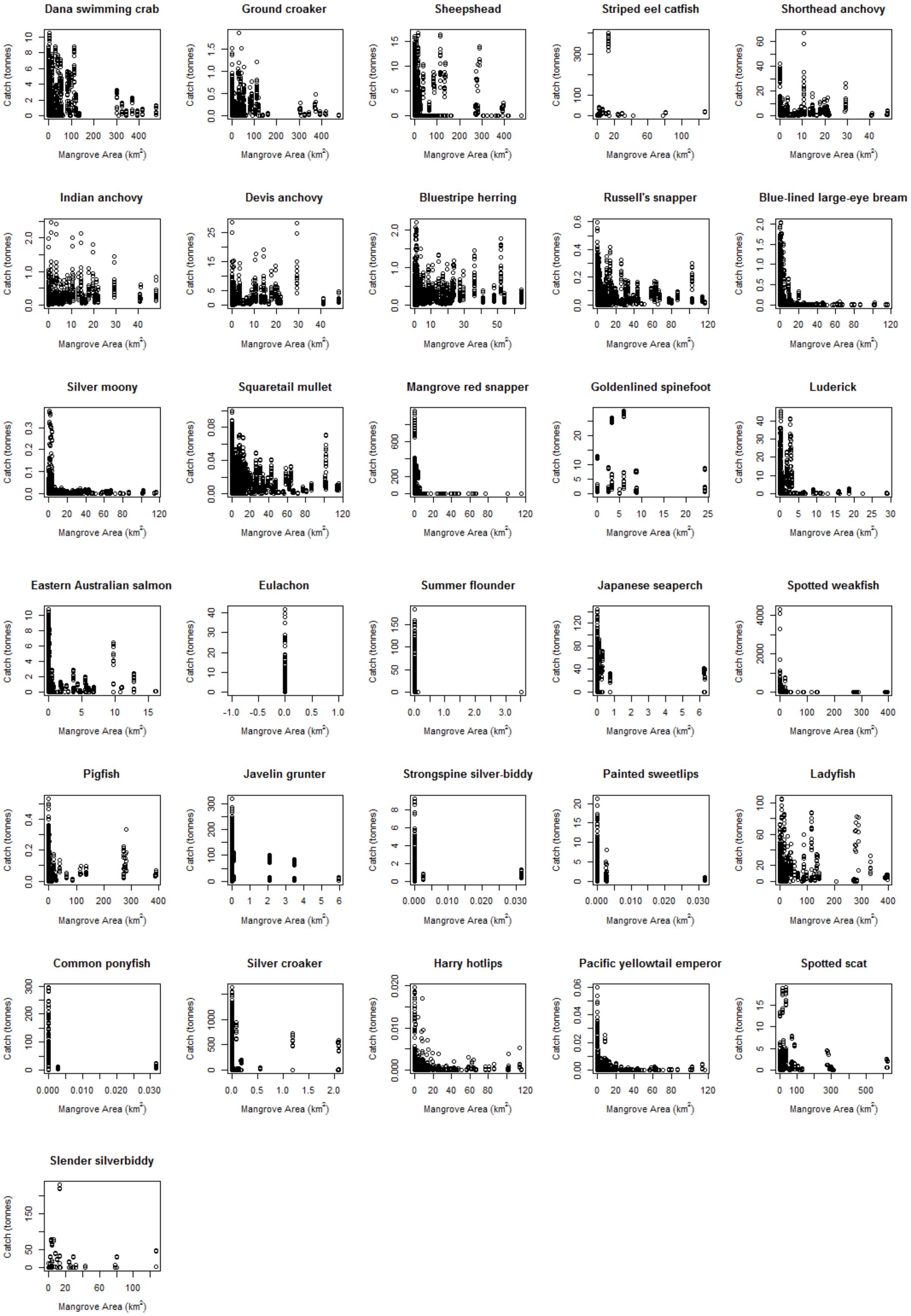




Appendix 5-4. Species level catch-mangrove area relationships.

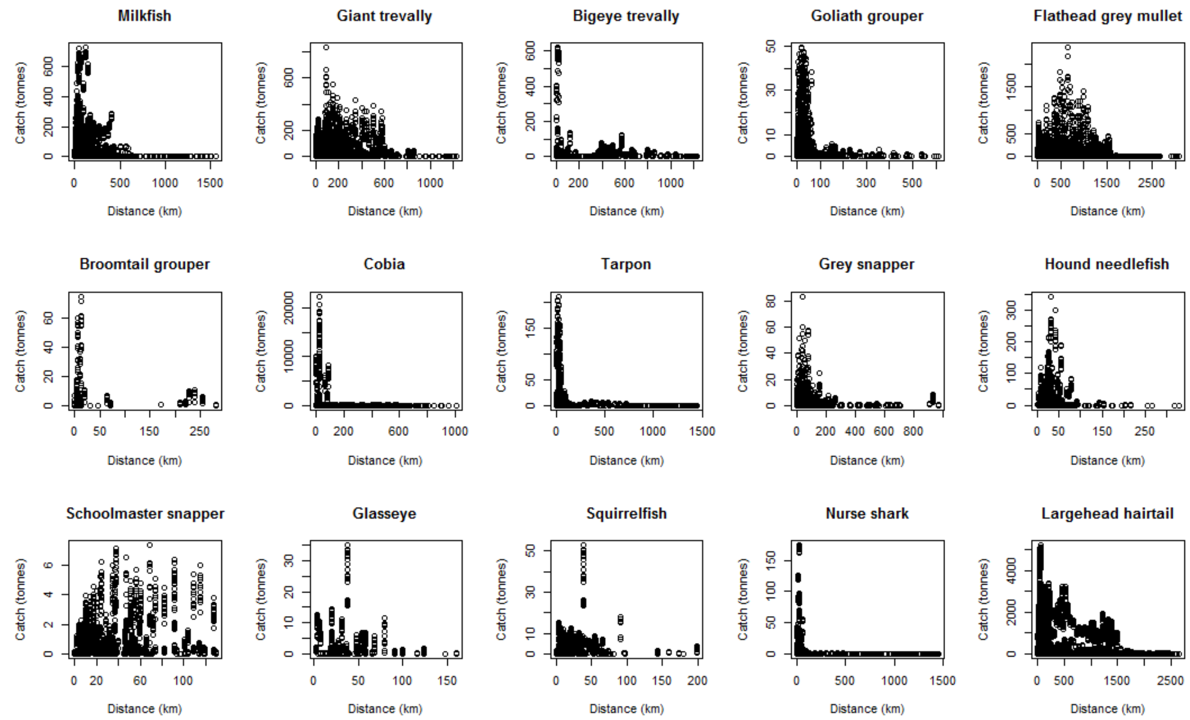


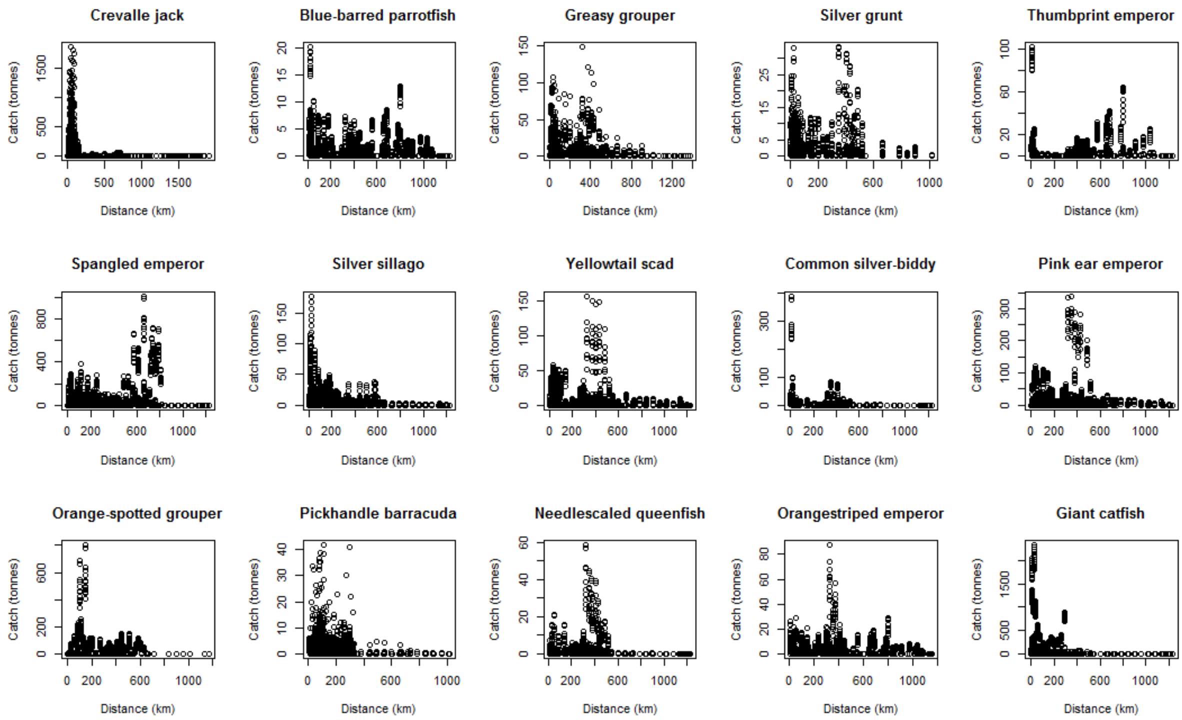

Fourfinger threadfin
Dorab wolf-herring
Spotted sicklefish
Barramundi
Feathered river-garfish
Indo-Pacific tarpon
Blacktip reef shark
Blacktip shark
Blue swimming crab
Jarbua terapon
Western Atlantic seabream
Golden trevally
Mutton snapper
Great barracuda
Yellow fin mojarra
Bull shark
Atlantic spadefish
Malabar grouper
Caitipa mojarra
Bonefish
Chacunda gizzard shad
Longface emperor
Dash-and-dot goatfish
Indian goatfish
Blacktail snapper
Johns snapper
Spotcheek emperor
Doublespotted queenfish
Toothpony
Yellowstriped goatfish
Catch (tonnes)
Mangrove Area (km^2)

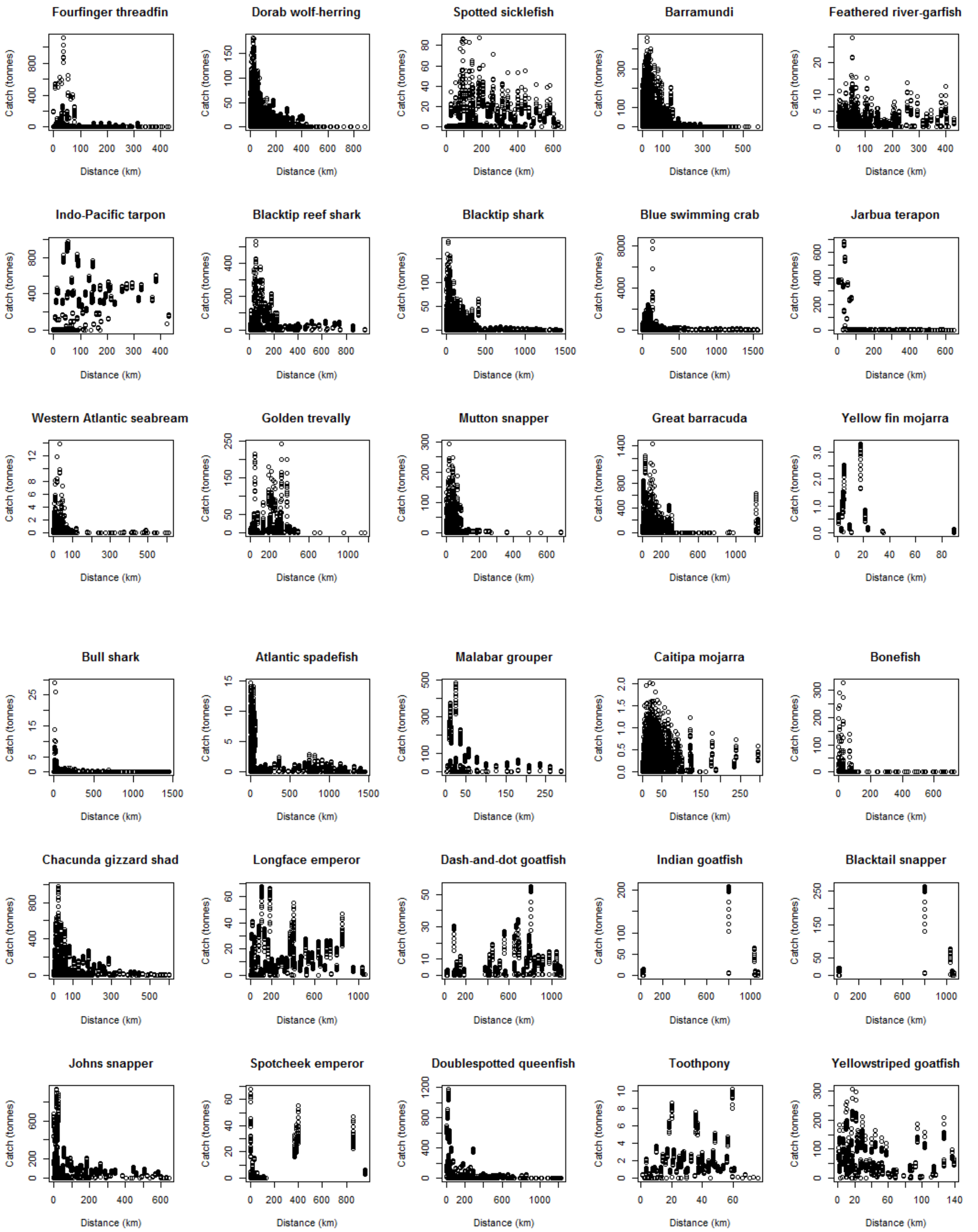


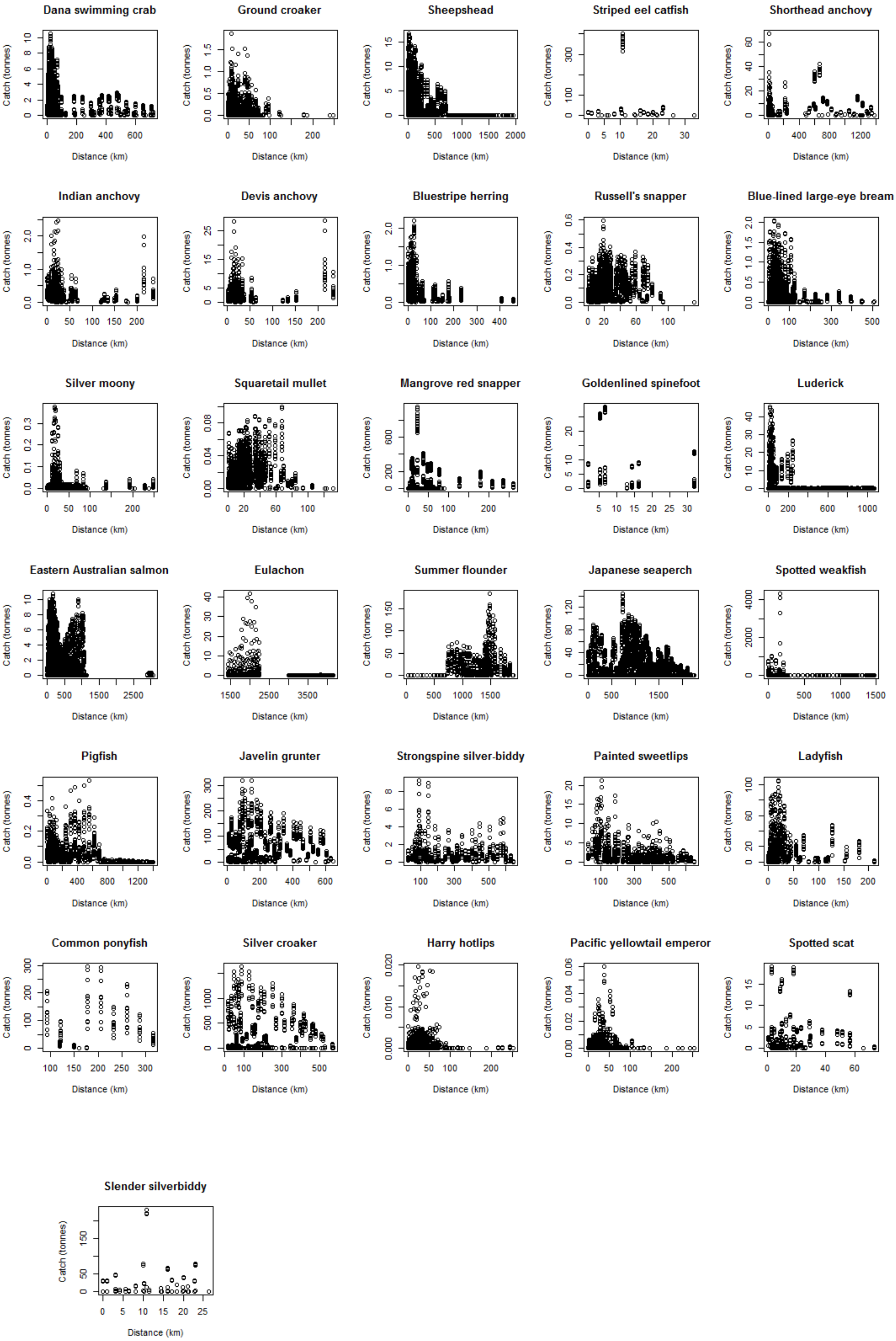
Dana swimming crab
Ground croaker
Sheepshead
Striped eel catfish
Shorthead anchovy
Indian anchovy
Devis anchovy
Bluestripe herring
Russell's snapper
Blue-lined large-eye bream
Silver moony
Squaretail mullet
Mangrove red snapper
Goldenlined spinefoot
Luderick
Eastern Australian salmon
Eulachon
Summer flounder
Japanese seaperch
Spotted weakfish
Pigfish
Javelin grunter
Strongspine silver-biddy
Painted sweetlips
Ladyfish
Common ponyfish
Silver croaker
Harry hotlips
Pacific yellowtail emperor
Spotted scat
Slender silverbiddy
Catch (tonnes)
Mangrove Area (km²)

Appendix 5-5. Species level catch-distance relationships.

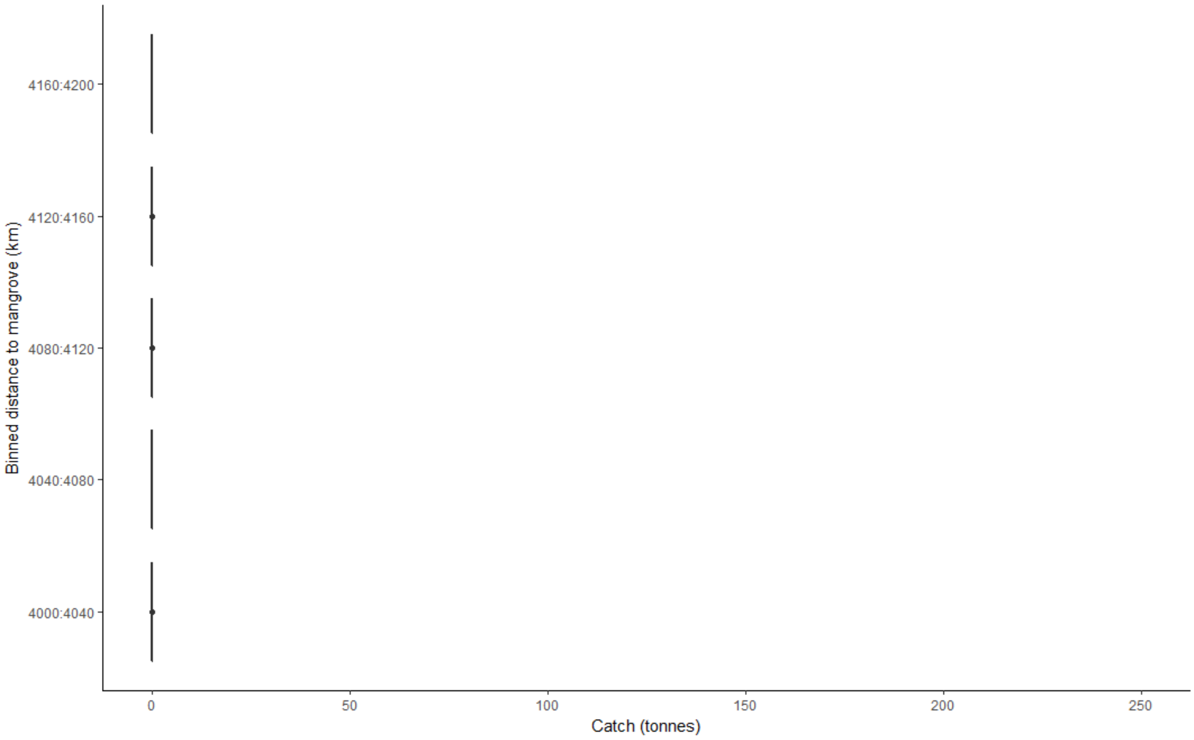


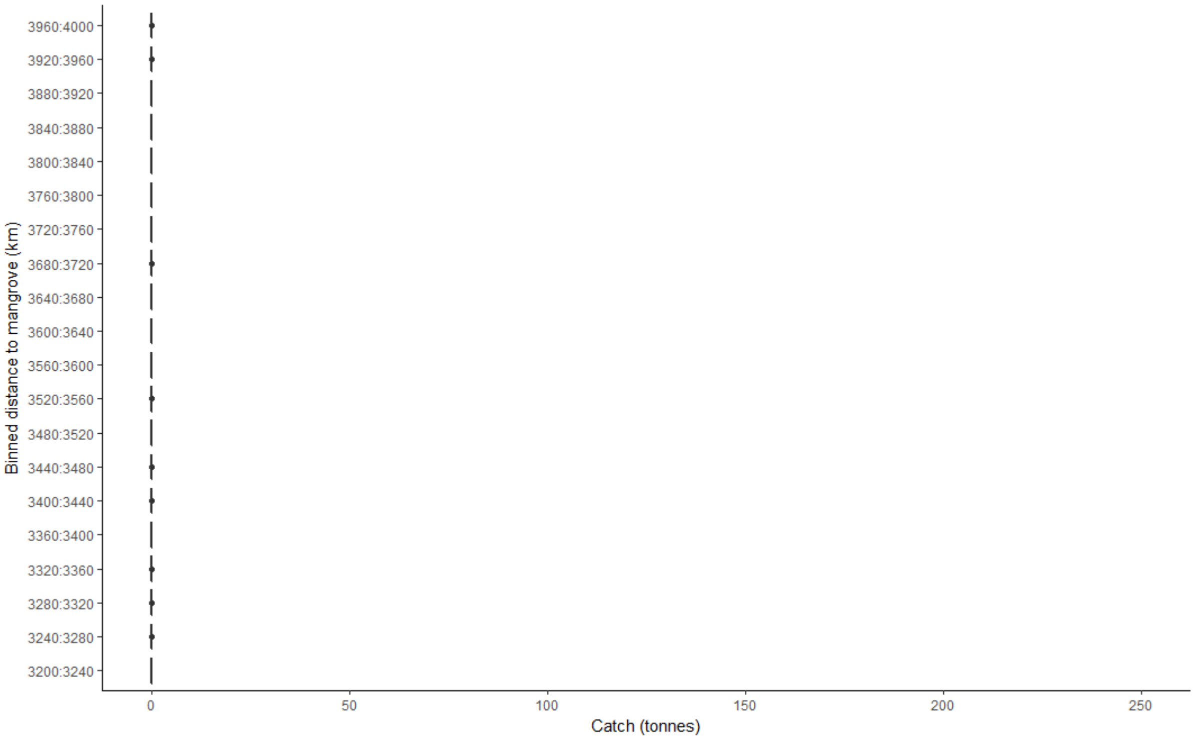


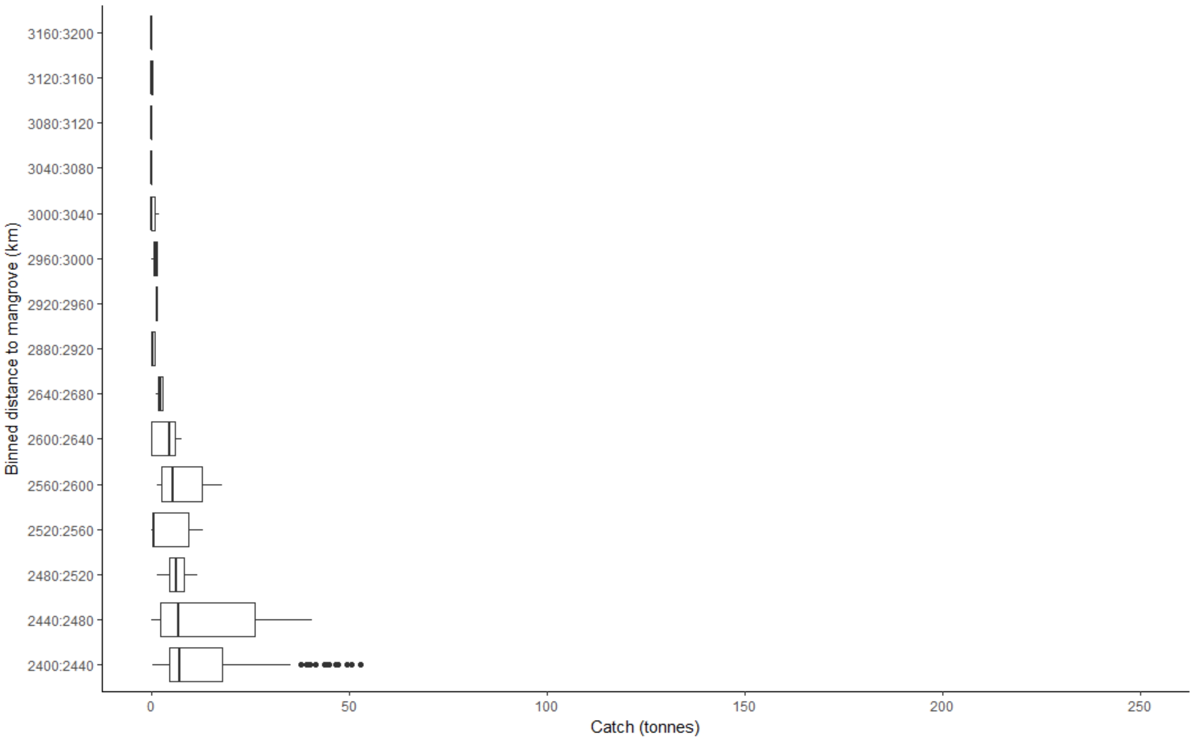

Fourfinger threadfin
Dorab wolf-herring
Spotted sicklefish
Barramundi
Feathered river-garfish
Indo-Pacific tarpon
Blacktip reef shark
Blacktip shark
Blue swimming crab
Jarbua terapon
Western Atlantic seabream
Golden trevally
Mutton snapper
Great barracuda
Yellow fin mojarra
Bull shark
Atlantic spadefish
Malabar grouper
Caitipa mojarra
Bonefish
Chacunda gizzard shad
Longface emperor
Dash-and-dot goatfish
Indian goatfish
Blacktail snapper
Johns snapper
Spotcheek emperor
Doublespotted queenfish
Toothpony
Yellowstriped goatfish
Catch (tonnes)
Distance (km)

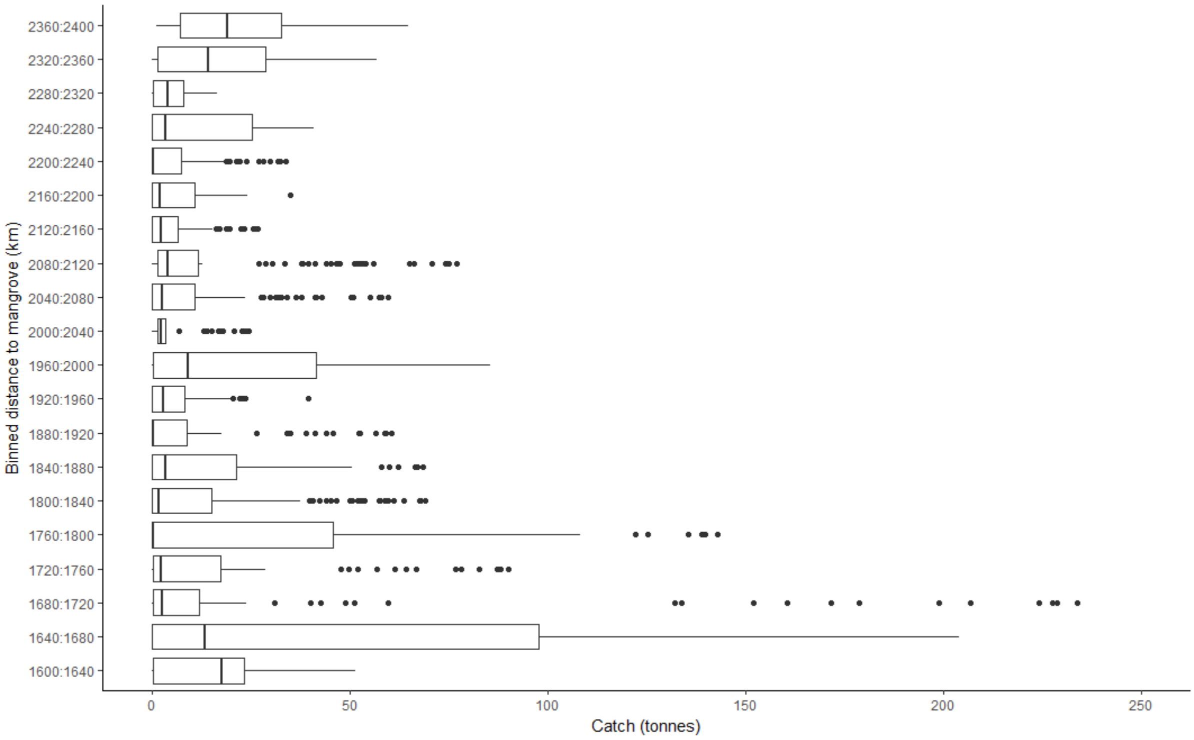

Dana swimming crab
Ground croaker
Sheepshead
Striped eel catfish
Shorthead anchovy
Indian anchovy
Devis anchovy
Bluestripe herring
Russell's snapper
Blue-lined large-eye bream
Silver moony
Squaretail mullet
Mangrove red snapper
Goldenlined spinefoot
Luderick
Eastern Australian salmon
Eulachon
Summer flounder
Japanese seaperch
Spotted weakfish
Pigfish
Javelin grunter
Strongspine silver-biddy
Painted sweetlips
Ladyfish
Common ponyfish
Silver croaker
Harry hotlips
Pacific yellowtail emperor
Spotted scat
Slender silverbiddy
Catch (tonnes)
Distance (km)

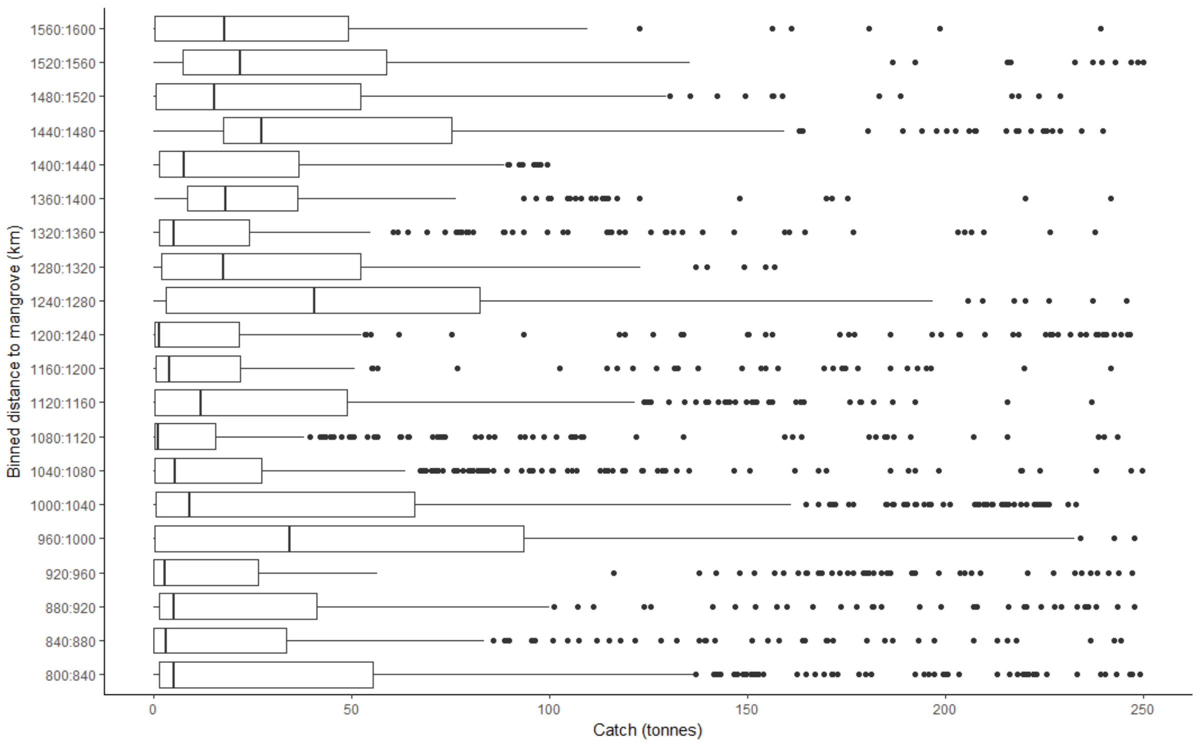
Appendix 5-6. Boxplots of mangrove associated fish catches within 40km binned distance categories representing distance to the nearest mangrove. Note that the x axis has been limited to 250 tonnes for visualisation purposes, therefore the final 2 plots (those showing 0-800km and 800-1600km plots) are missing 7333 and 1100 outlier points respectively that fall between 250-20,000 tonnes. The other plots are not missing any outlier values as the true maximum catch at those distances is < 250 tonnes. Catch data includes mangrove-associate fish and invertebrate species from the artisanal and subsistence fishing globally from 2000-2012. Distance measurements have a possible measurement error of ± 35 km.

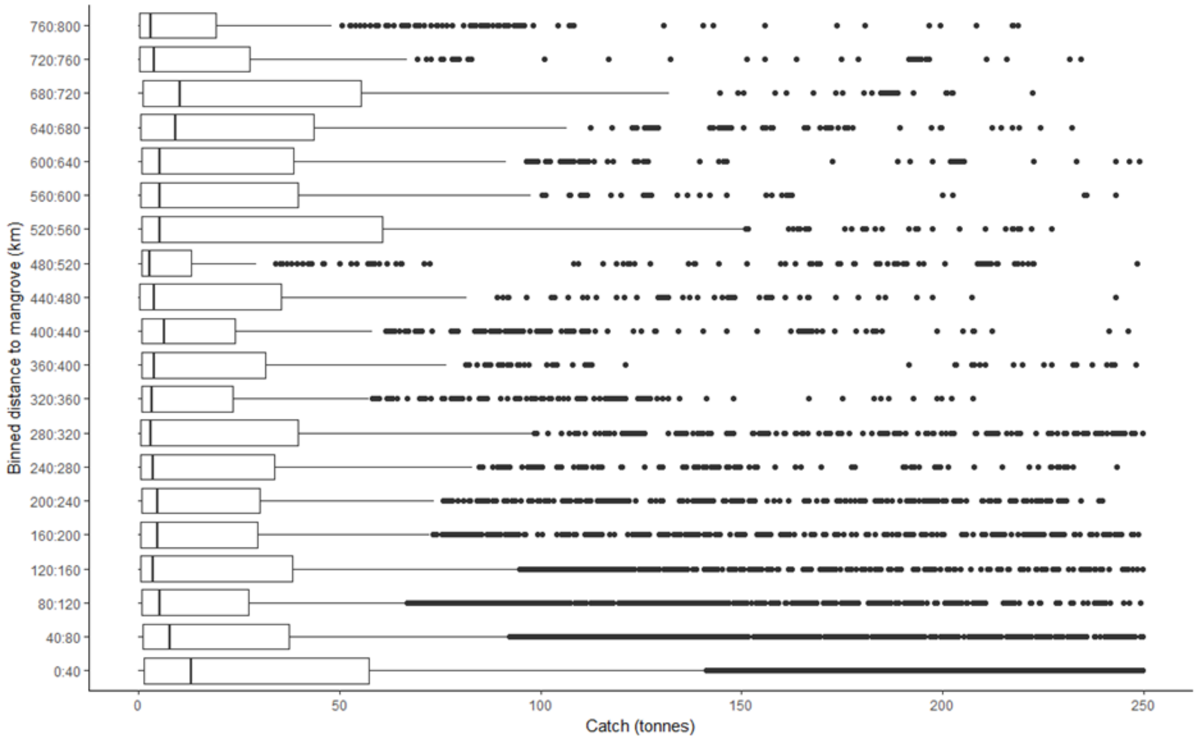



3960:4000
3920:3960
3880:3920
3840:3880
3800:3840
3760:3800
3720:3760
3680:3720
3640:3680
3600:3640
3560:3600
3520:3560
3480:3520
3440:3480
3400:3440
3360:3400
3320:3360
3280:3320
3240:3280
3200:3240
Binned distance to mangrove (km)
0
50
100
150
200
250
Catch (tonnes)


3160:3200
3120:3160
3080:3120
3040:3080
3000:3040
2960:3000
2920:2960
2880:2920
2640:2680
2600:2640
2560:2600
2520:2560
2480:2520
2440:2480
2400:2440
Binned distance to mangrove (km)
0
50
100
150
200
250
Catch (tonnes)


2360:2400
2320:2360
2280:2320
2240:2280
2200:2240
2160:2200
2120:2160
2080:2120
2040:2080
2000:2040
1960:2000
1920:1960
1880:1920
1840:1880
1800:1840
1760:1800
1720:1760
1680:1720
1640:1680
1600:1640
Binned distance to mangrove (km)
0
50
100
150
200
250
Catch (tonnes)

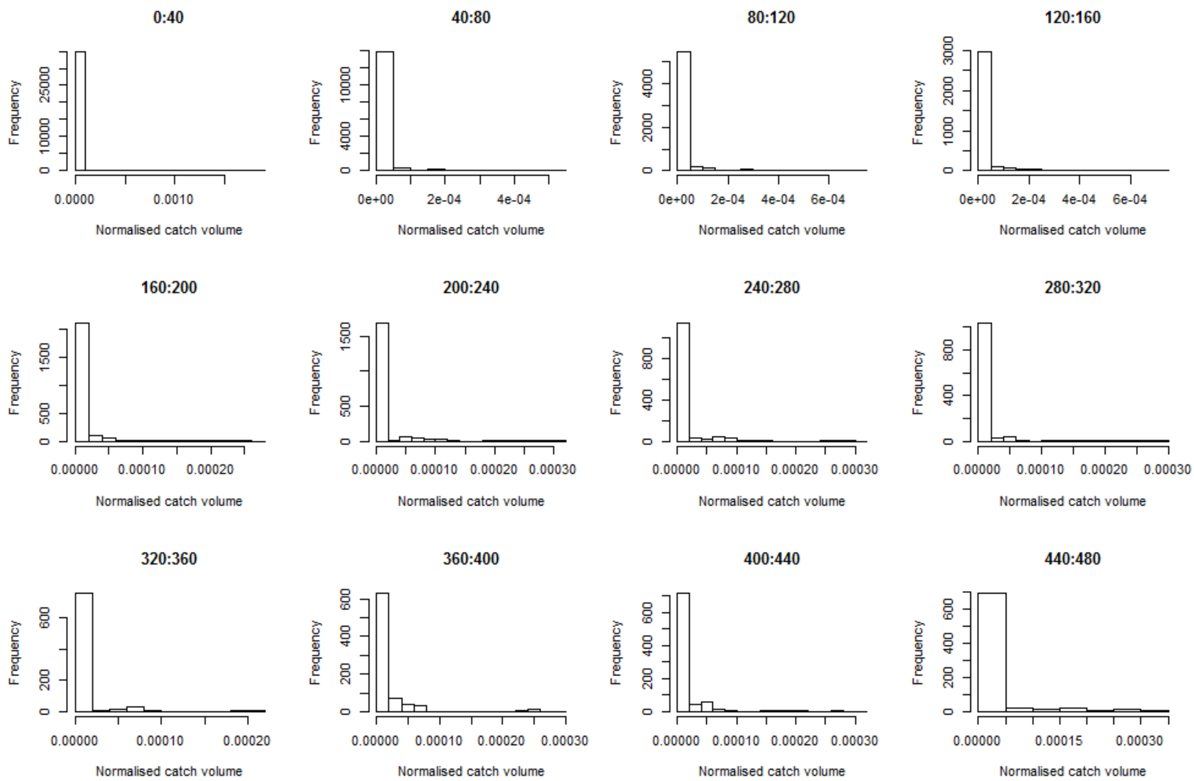

1560:1600
1520:1560
1480:1520
1440:1480
1400:1440
1360:1400
1320:1360
1280:1320
1240:1280
1200:1240
1160:1200
1120:1160
1080:1120
1040:1080
1000:1040
960:1000
920:960
880:920
840:880
800:840
Binned distance to mangrove (km)
0
50
100
150
200
250
Catch (tonnes)

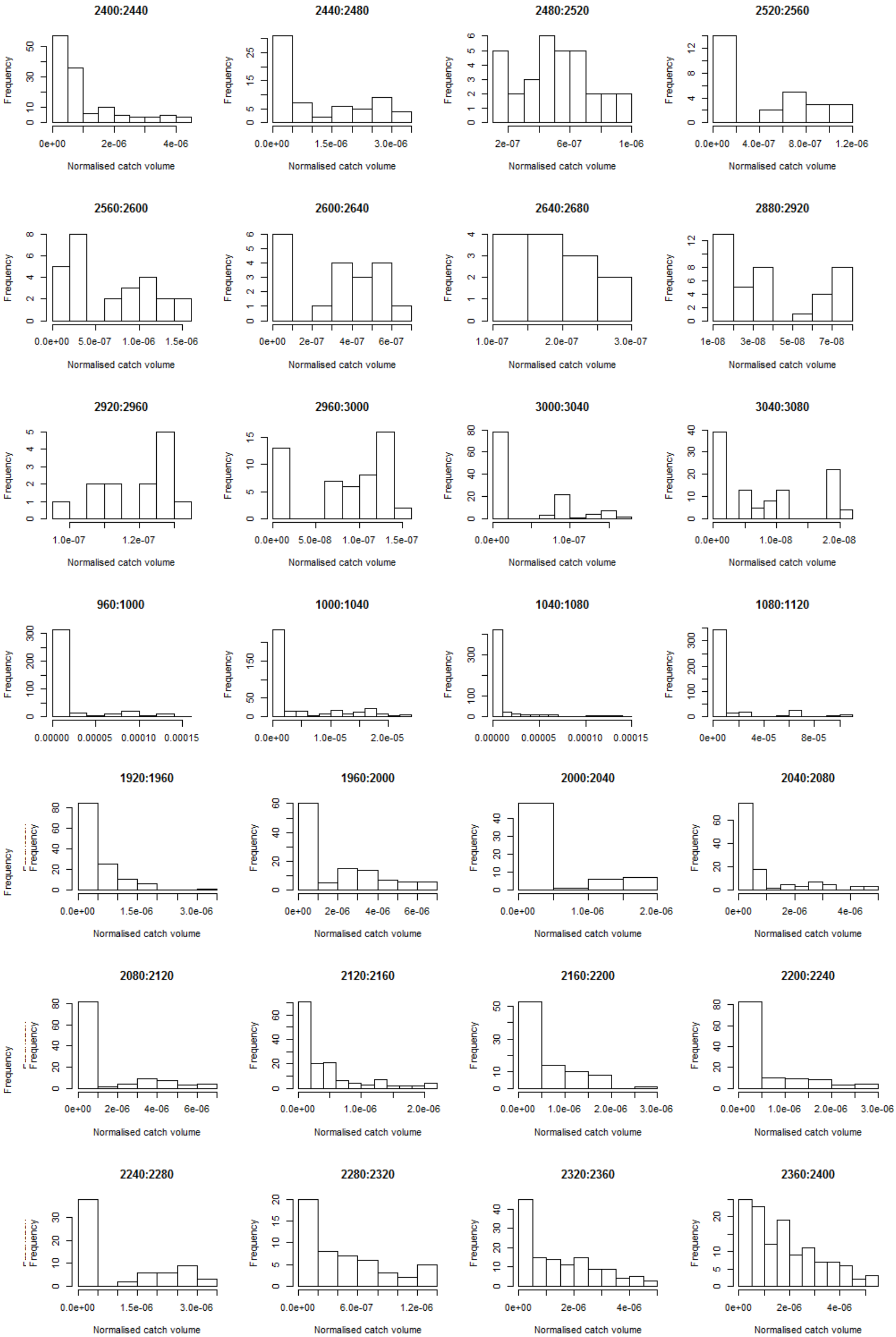


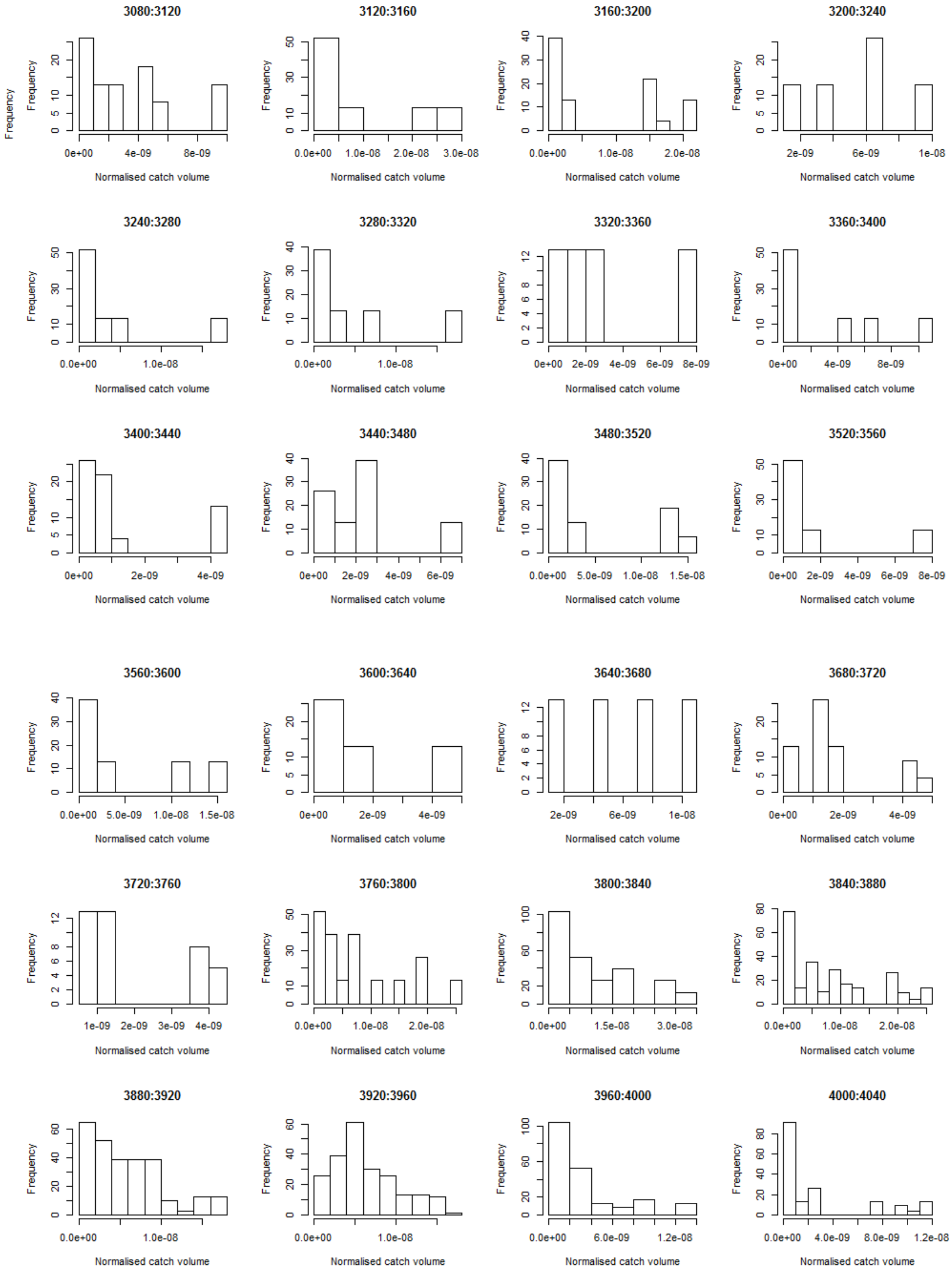
760:800
720:760
680:720
640:680
600:640
560:600
520:560
480:520
440:480
400:440
360:400
320:360
280:320
240:280
200:240
160:200
120:160
80:120
40:80
0:40
Binned distance to mangrove (km)
0
50
100
150
200
250
Catch (tonnes)

Appendix 5-7. Distribution of catches (normalised to area of 1), at 40 ± 39 km distance categories (distance from mangrove) for a) mangrove-associated fish only and b) non-mangrove species only.

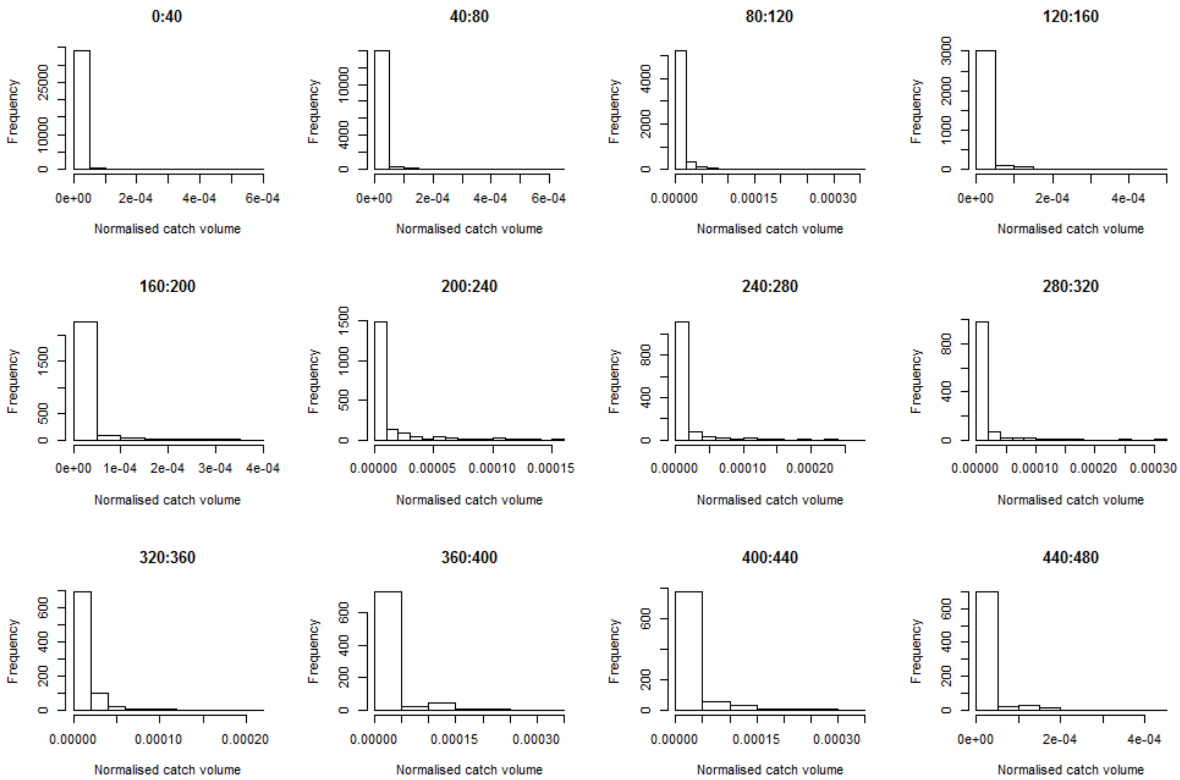
a) Mangrove-associated species

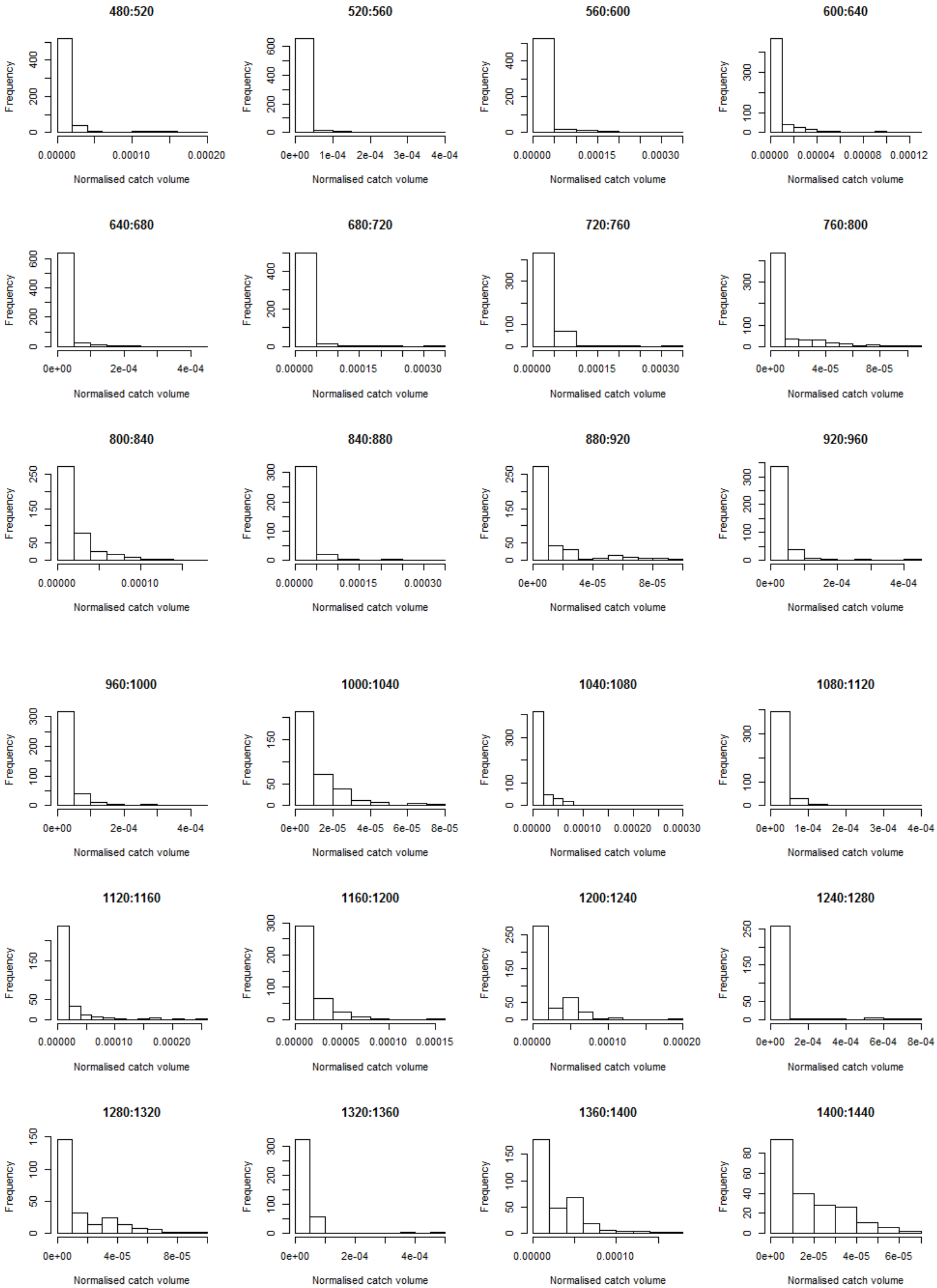


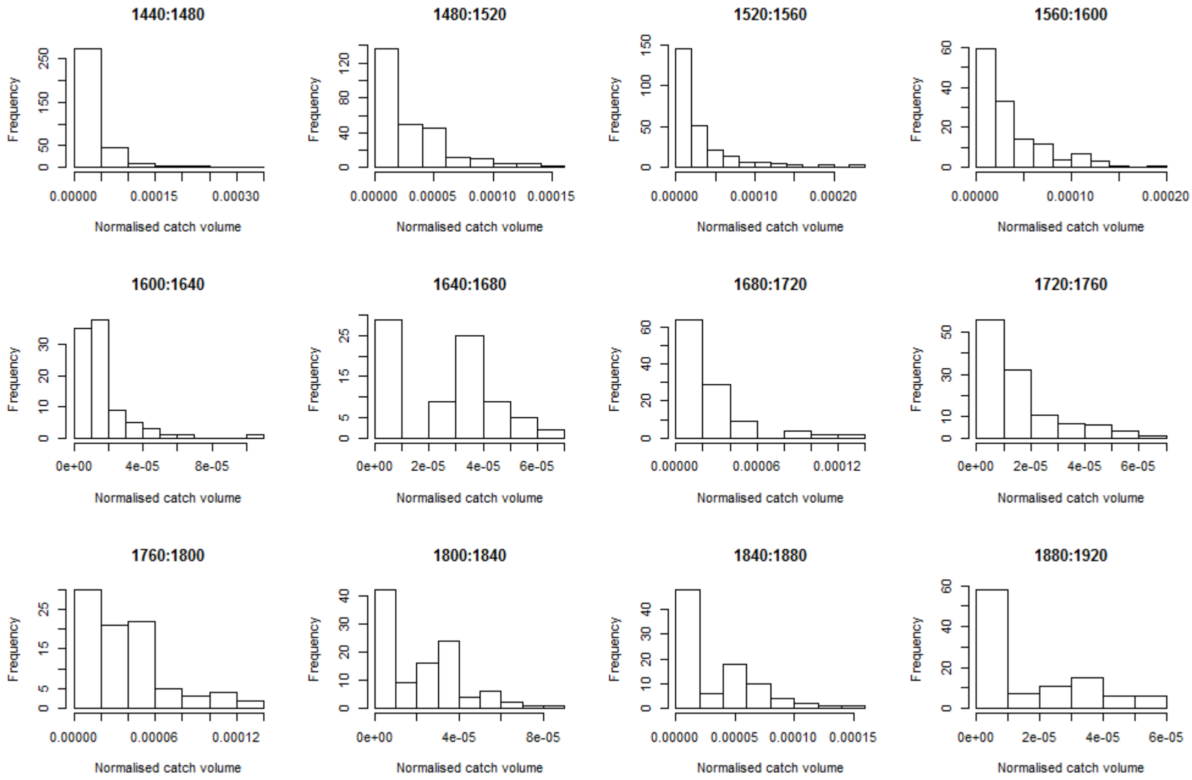

2400:2440
Frequency
Normalised catch volume
0e+00 2e-06 4e-06
2440:2480
Frequency
Normalised catch volume
0.0e+00 1.5e-06 3.0e-06
2480:2520
Frequency
Normalised catch volume
2e-07 6e-07 1e-06
2520:2560
Frequency
Normalised catch volume
0.0e+00 4.0e-07 8.0e-07 1.2e-06
2560:2600
Frequency
Normalised catch volume
0.0e+00 5.0e-07 1.0e-06 1.5e-06
2600:2640
Frequency
Normalised catch volume
0e+00 2e-07 4e-07 6e-07
2640:2680
Frequency
Normalised catch volume
1.0e-07 2.0e-07 3.0e-07
2880:2920
Frequency
Normalised catch volume
1e-08 3e-08 5e-08 7e-08
2920:2960
Frequency
Normalised catch volume
1.0e-07 1.2e-07
2960:3000
Frequency
Normalised catch volume
0.0e+00 5.0e-08 1.0e-07 1.5e-07
3000:3040
Frequency
Normalised catch volume
0.0e+00 1.0e-07
3040:3080
Frequency
Normalised catch volume
0.0e+00 1.0e-08 2.0e-08
960:1000
Frequency
0.00000 0.00005 0.00010 0.00015
1000:1040
Frequency
0.0e+00 1.0e-05 2.0e-05
1040:1080
Frequency
0.00000 0.00005 0.00010 0.00015
1080:1120
Frequency
0e+00 4e-05 8e-05
1920:1960
Frequency
Normalised catch volume
0.0e+00 1.5e-06 3.0e-06
1960:2000
Frequency
Normalised catch volume
0e+00 2e-06 4e-06 6e-06
2000:2040
Frequency
Normalised catch volume
0.0e+00 1.0e-06 2.0e-06
2040:2080
Frequency
Normalised catch volume
0e+00 2e-06 4e-06
2080:2120
Frequency
Normalised catch volume
0e+00 2e-06 4e-06 6e-06
2120:2160
Frequency
Normalised catch volume
0.0e+00 1.0e-06 2.0e-06
2160:2200
Frequency
Normalised catch volume
0.0e+00 1.0e-06 2.0e-06 3.0e-06
2200:2240
Frequency
Normalised catch volume
0.0e+00 1.0e-06 2.0e-06 3.0e-06
2240:2280
Frequency
Normalised catch volume
0.0e+00 1.5e-06 3.0e-06
2280:2320
Frequency
Normalised catch volume
0.0e+00 6.0e-07 1.2e-06
2320:2360
Frequency
Normalised catch volume
0e+00 2e-06 4e-06
2360:2400
Frequency
Normalised catch volume
0e+00 2e-06 4e-06

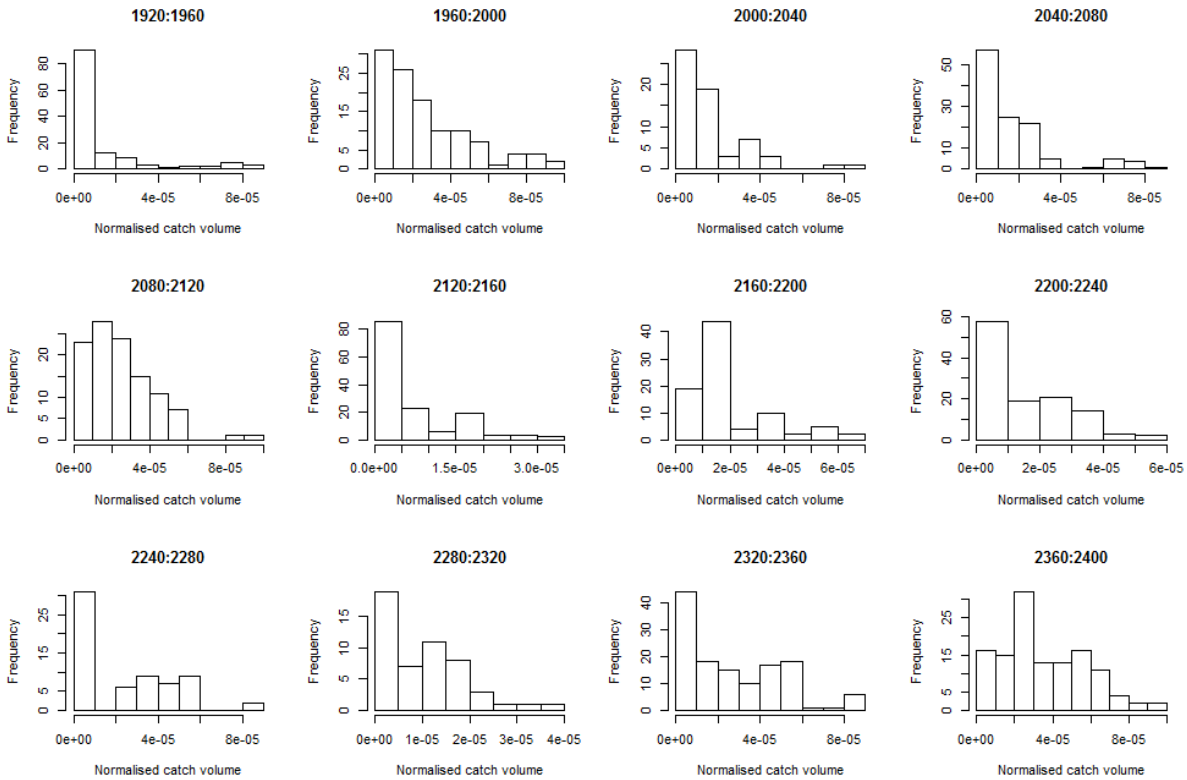

3080:3120
3120:3160
3160:3200
3200:3240
3240:3280
3280:3320
3320:3360
3360:3400
3400:3440
3440:3480
3480:3520
3520:3560
3560:3600
3600:3640
3640:3680
3680:3720
3720:3760
3760:3800
3800:3840
3840:3880
3880:3920
3920:3960
3960:4000
4000:4040
Frequency
Normalised catch volume

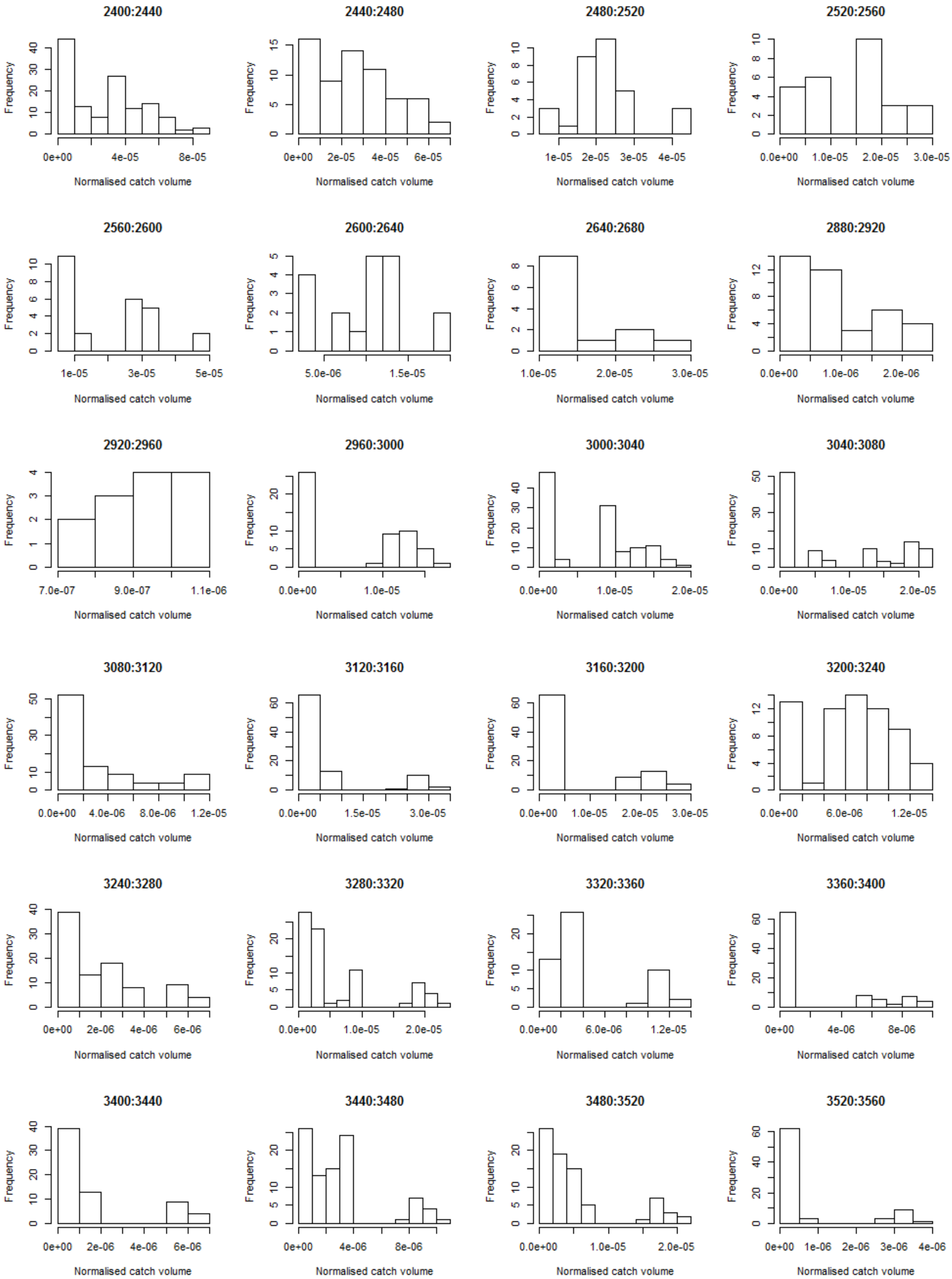
b) Non mangrove-associated species

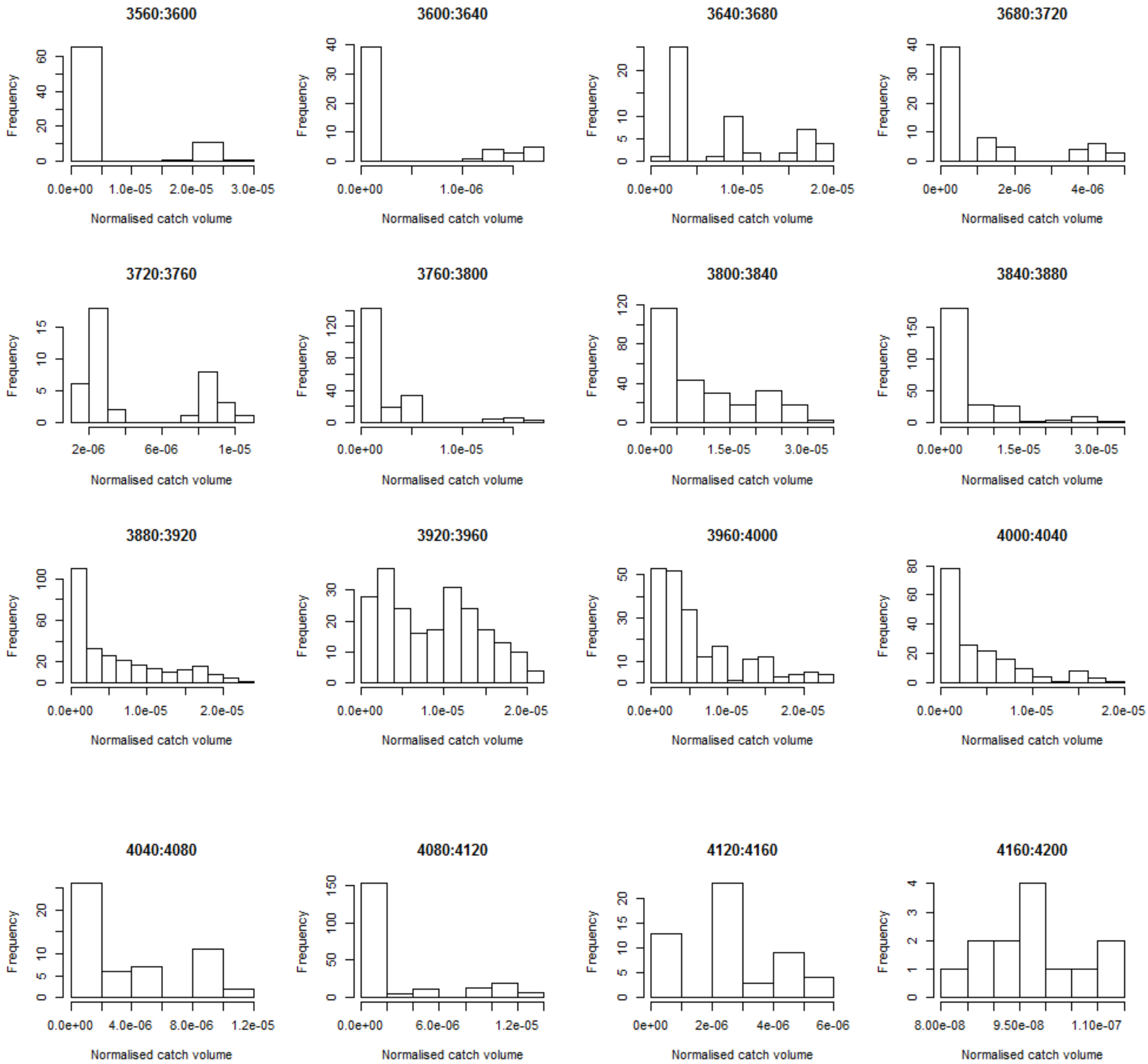



480:520
Frequency
0 200 400
0.00000 0.00010 0.00020
Normalised catch volume
520:560
Frequency
0 200 400 600
0e+00 1e-04 2e-04 3e-04 4e-04
Normalised catch volume
560:600
Frequency
0 200 400
0.00000 0.00015 0.00030
Normalised catch volume
600:640
Frequency
0 100 300
0.00000 0.00004 0.00008 0.00012
Normalised catch volume
640:680
Frequency
0 200 400 600
0e+00 2e-04 4e-04
Normalised catch volume
680:720
Frequency
0 200 400
0.00000 0.00015 0.00030
Normalised catch volume
720:760
Frequency
0 100 300
0.00000 0.00015 0.00030
Normalised catch volume
760:800
Frequency
0 100 300
0e+00 4e-05 8e-05
Normalised catch volume
800:840
Frequency
0 50 150 250
0.00000 0.00010
Normalised catch volume
840:880
Frequency
0 100 200 300
0.00000 0.00015 0.00030
Normalised catch volume
880:920
Frequency
0 50 150 250
0e+00 4e-05 8e-05
Normalised catch volume
920:960
Frequency
0 100 200 300
0e+00 2e-04 4e-04
Normalised catch volume
960:1000
Frequency
0 100 200 300
0e+00 2e-04 4e-04
Normalised catch volume
1000:1040
Frequency
50 150
0e+00 2e-05 4e-05 6e-05 8e-05
Normalised catch volume
1040:1080
Frequency
0 100 300
0.00000 0.00010 0.00020 0.00030
Normalised catch volume
1080:1120
Frequency
0 100 300
0e+00 1e-04 2e-04 3e-04 4e-04
Normalised catch volume
1120:1160
Frequency
0 50 150
0.00000 0.00010 0.00020
Normalised catch volume
1160:1200
Frequency
0 100 200 300
0.00000 0.00005 0.00010 0.00015
Normalised catch volume
1200:1240
Frequency
0 50 150 250
0.00000 0.00010 0.00020
Normalised catch volume
1240:1280
Frequency
0 50 150 250
0e+00 2e-04 4e-04 6e-04 8e-04
Normalised catch volume
1280:1320
Frequency
0 50 100 150
0e+00 4e-05 8e-05
Normalised catch volume
1320:1360
Frequency
0 100 200 300
0e+00 2e-04 4e-04
Normalised catch volume
1360:1400
Frequency
0 50 100 150
0.00000 0.00010
Normalised catch volume
1400:1440
Frequency
0 20 40 60 80
0e+00 2e-05 4e-05 6e-05
Normalised catch volume


1440:1480
1480:1520
1520:1560
1560:1600
1600:1640
1640:1680
1680:1720
1720:1760
1760:1800
1800:1840
1840:1880
1880:1920
Frequency
Normalised catch volume


1920:1960
1960:2000
2000:2040
2040:2080
2080:2120
2120:2160
2160:2200
2200:2240
2240:2280
2280:2320
2320:2360
2360:2400
Frequency
Normalised catch volume


2400:2440
2440:2480
2480:2520
2520:2560
2560:2600
2600:2640
2640:2680
2880:2920
2920:2960
2960:3000
3000:3040
3040:3080
3080:3120
3120:3160
3160:3200
3200:3240
3240:3280
3280:3320
3320:3360
3360:3400
3400:3440
3440:3480
3480:3520
3520:3560
Frequency
Normalised catch volume


3560:3600
3600:3640
3640:3680
3680:3720
3720:3760
3760:3800
3800:3840
3840:3880
3880:3920
3920:3960
3960:4000
4000:4040
4040:4080
4080:4120
4120:4160
4160:4200
Frequency
Normalised catch volume

Appendix 5-8. Residual plots of the analysis of covariance test between fish catch volume as the dependent variable and distance from the nearest mangrove and mangrove association, and the interaction between the two, as the independent variables.