Food from the Sulawesi Sea,

the need for integrated sea use planning

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Thesis

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.....to my parents

“I’m a slow walker, but I never walk back”

Abraham Lincoln, 1809 –1865

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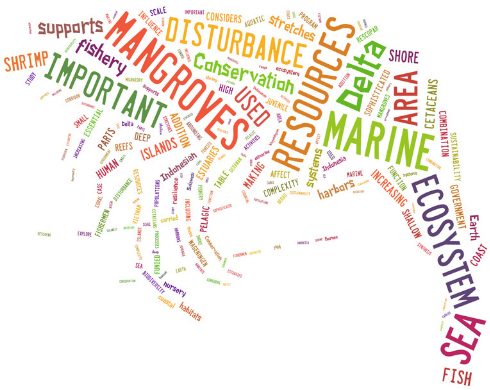
General Introduction



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Chapter 1

General Introduction

1.1 Project background

Fish and shrimp are important protein sources for humans. With the increasing human population and technological development, the global demand for fish and shrimp is also increasing. On the other hand, the natural supply of fish and shrimp is dwindling, which makes fishing more difficult. Fishing technology has been developed to enhance the catch per unit effort or increase the yield of aquaculture to meet the demand. Some of these 'modern' fisheries and aquaculture techniques are destructive to the environment or have other adverse effects on the fish and shrimp stock.

The fishing efforts have been used by scientists to identify important factors that influence the stability of fish and shrimp populations in nature. One of the key factors identified is an availability of sufficient adult animals that can reproduce. To ensure that enough juveniles can reach adulthood, the amount of animals caught should be in balance with its natural supply. It is also important that suitable habitat and sufficient food be available for juveniles. Mangroves offer a critical habitat for the juveniles of many commercial fish and shrimp species (Mumby et al. 2004, Mumby 2006), and my Ph.D. project focused on the importance of the mangrove habitat for sustainable fisheries.

1.2 Mangroves as nursery for fish and shrimp

Mangroves are defined as tidal forests, coastal woodlands or oceanic rainforests, which thrive in vast areas along shallow coastal areas, bays, estuaries, and deltas, with an abundant supply of fresh water from rivers (Kathiresan and Bingham 2001). Without a supply of fresh water, mangrove habitats cannot develop (Sukardjo 2004).

Related to the habitat in intertidal areas, the mangrove distribution, and vegetation types are closely associated with the salinity, soil type, tidal type and flooding frequency (Kusmana 1991). To be able to thrive in the intertidal area, mangrove vegetation should be tolerant to high salinity (Saenger et al. 1983). According to the FAO (1982), mangroves are trees and shrubs that grow below the highest tidal point. In more detail, Duke (1992); p.64 defined mangrove vegetation as: "a tree, shrub, palm or ground fern, generally exceeding one-half meter in height, and which normally grows above mean sea level in the intertidal zone in marine coastal environments or estuarine margins". When referring to the mangrove habitat, the term mangroves are commonly used, although it relates to the mangrove forest habitat, not to the individual trees. In general, mangrove vegetation can be categorized into true mangroves and associated mangroves. Wang et al. (2011) defined true mangroves as true halophytes and mangrove associates that are glycophytes with a certain salt tolerance. Globally, there are about 60 species of true mangroves (Saenger et al. 1983, Spalding et al. 2010). In Indonesia, where the study area of this research is located, all 60 species of mangroves have been recorded, 43 of which are true mangroves and the other 17 species are associated mangroves (Noor et al. 1999, Bengen 2003, Kusmana 2010).

Mangroves have a higher primary productivity than coastal terrestrial forests (Kusmana 1991, Sukardjo et al. 2013a). Lugo and Snedaker (1974) reported that the gross productivity of mangroves is higher than that of coral reefs and seagrass habitats. Due to this high productivity, mangrove habitats are highly important as feeding, spawning and nursery areas for fish and shrimp (Kusmana 1991, Primavera 2005a). Beck et al. (2001, p.635) define a nursery area as: “a habitat is a nursery for juveniles of a particular species if its contribution per unit area to the production of individuals that recruit to adult populations is greater, on average, than other habitats in which juveniles occur”. The mangrove habitat is an important nursery habitat for fish and shrimp, as illustrated by previous publications (Thayer et al. 1987, Morton 1990, Robertson and Duke 1990). Abundant of juveniles were found exclusively in mangrove habitats with much larger densities than those encountered in adjacent habitats, such as mudflats and seagrass beds (Laegdsgaard and Johnson 1995, Vance et al. 1996, Manson et al. 2003). A study conducted in the Bangalore Delta, Bangladesh, reported that 400 species used the mangrove habitat as the nursery ground, of which 20 were prawn species and 44 crab species (Gundermann et al. 1983, Lowe-McConnell and McConnell 1987). In addition, Mumby *et al*, (2004) described a strong positive relationship between the presence of adjacent mangroves and the abundance of reef fishes on coral reefs outside the intertidal area.

Fish use the mangrove habitat in various ways: some species are only occasional visitors, some only use it at certain life stages, whereas other species are only found in mangrove forests (Manson et al. 2005a). Some species use mangroves as a corridor to move between the low saline estuarine area to coral reefs (Mumby et al. 2004, Mumby 2006) and offshore waters (Ramírez-García et al. 1998). The relationship between mangroves and fish and shrimp is influenced by two main factors: a higher food availability in mangroves and increased possibilities to obtain shelter from predation (Nagelkerken and Van Der Velde 2002, Sheridan and Hays 2003, Manson et al. 2005a). The nursery, feeding, and protective roles are not mutually exclusive, but they interact in complex ways. For instance, a juvenile fish may simultaneously gain nursery advantages from a rich supply of food and the protection provided by the mangroves’ prop roots (Laegdsgaard and Johnson 2001). Hence, the complexity of mangrove root structures offers a place of refuge for juvenile marine animals. A more complex root structure reduces predator-prey encounters (Manson et al. 2005a). Further studies on the effect of disturbance on at different scale in mangroves habitat to the nursery function are hence necessary.

1.3 Structural complexity of mangrove

The mangrove habitat has at least three major structural descriptors: complexity, heterogeneity, and scale (McCoy and Bell 1991). The complex nature of a mangrove habitat refers to the amount of structure or variation attributable to the abundance of individual structural components. The heterogeneity in mangrove habitats represents the mangrove structures or variation attribute to the abundance of different structural components, and the scale in mangrove habitat emphasizes that the first two elements must be proportional with the dimensions of the trees or organisms being studied.

The variation in mangrove structure can be described by measurements of species composition, diversity, stem height, stem diameter, basal area, tree density, the age-class distributions and spatial distribution patterns of the species, and its roots and stems. The structural complexity in mangrove habitats is influenced by the mangroves' propagules, roots, trunks and branches (Cocheret de la Moriniere et al. 2004). The mangrove roots, especially those of *Rhizophora* sp. (red mangrove) is an important determinant for the complexity of the mangrove habitat structure (Beck 2000). Besides *Rhizophora* sp., *Bruguiera* sp. is also considered as a mangrove species that forms an important nursery ground for coastal fish (Vance et al. 1996) due to their roots and trunk system. These species are all found in the intertidal zone where their roots are periodically submerged. The submerged roots, trunks, and branches may attract rich epifaunal communities including fungi, macro-algae, bacteria, diatoms, and invertebrates (Kathiresan and Bingham 2001), which can serve as food for juvenile fish/shrimp.

Another important effect of the complexity mangrove roots structure is to reduce the water current speed from the rivers or streams so that robust and organic particles are deposited between the roots (Leh and Sasekumar 1991). Organic material in the sediment, detritus, and the associated microorganisms provide food for juveniles (Alongi 1991, Robertson et al. 1991). Some juvenile fish may themselves be piscivores targeting smaller fish that feed or shelter in these mangrove forests (Sheaves 2005, Sheaves et al. 2007). Also, the waters of the numerous canals and small creeks of the mangroves receive high levels of terrestrial runoff, which is rich in nutrients. These nutrients contribute to the larvae productivity, increasing the food base (Mazda et al. 1990, Ovalle et al. 1990, Chong et al. 1996, Wolanski et al. 2001).

The structural complexity of the mangroves' root system is also essential in providing shelter for juveniles against predation (Heck and Crowder 1991, Kathiresan and Bingham 2001, Cocheret de la Moriniere et al. 2004). This structural complexity can contribute to juvenile fish growth and survival in the estuarine area, providing food and minimizing the risk of predation (Laegdsgaard and Johnson 2001). Shallow waters with, e.g., mangrove prop roots can provide sanctuary habitats at a variety of scales (Thayer et al. 1987). The interactions between factors involved in the role of mangroves as a nursery habitat are illustrated in a conceptual diagram (Figure 1.1). The field experiments were setting up using artificial mangrove units (AMUs) to define the conditions when a different scale of complexity determines the abundance of a marine juvenile in the Delta to explain the interaction.

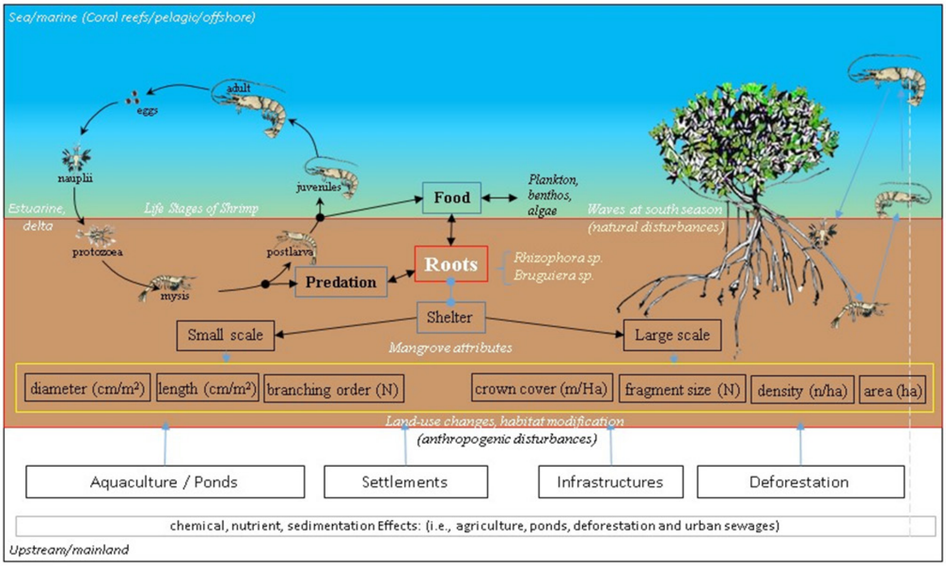


Figure 1.1. Conceptual diagram of interactions between juvenile fish and mangroves attributes

1.4 Disturbances to mangrove habitats

As described above, mangroves are highly important as a nursery area for fish and shrimp. Hence, changes or disturbances to the mangroves, even at the local scale may have an impact on the fisheries production, especially for species that are linked to the mangrove (Hatcher et al. 1989, Manson et al. 2005a). The disturbance is an integral component of mangrove forests dynamics, influencing forest structure, composition, and function (Pannier 1979, Hauff et al. 2006). Therefore, a comprehensive understanding of the disturbance regime is needed (Shearman 2010).

Changes from a healthy mangrove habitat to a degraded state have often been reported (Ellison and Farnsworth 1996, Hauff et al. 2006). Disturbances to mangroves can be categorized into two classes: (1) total or partial loss of mangrove habitat and (2) decrease of mangrove habitat quality.

A primary reason of mangrove habitat loss is the conversion of mangrove habitat for various purposes, such as settlements and aquaculture farming. As examples, in the Mahakam Delta in East Kalimantan, over 70% of the mangrove was converted to shrimp culture over the past 25 years (van Zwieten et al. 2006, Sidik 2008, Bosma et al. 2012). In the Ca Mau province in the Mekong Delta (Vietnam), over 20% of mangrove area was lost between 1978 and 1995 (de Graaf and Xuan 1998). Moreover, the global sea level rise is also damaging the mangroves closest to the sea, thereby reducing the total area covered by mangroves. Those changes may result in fragmentation of mangrove habitats at various scales. Some parts may be fragmented into several major pieces, while others may be fragmented into smaller areas, like small islands separated by shallow canals.

The second form of disturbance to mangrove habitat is the decrease in habitat quality. Hall et al. (1997), defines habitat quality as the ability of the environment to provide conditions that are appropriate for individual and population persistence. The habitat quality of mangroves depends, among other factors, on the composition of the vegetation that also determines the structural complexity of mangroves. The decline in habitat quality may occur because of anthropogenic disturbances. This disruption can be related to the use of fishing techniques that are damaging the habitat, such as poisoning or constructing large fish traps that close entire canals. The mangrove forests might also be affected by the construction of large fish ponds (Primavera 1997, Bao et al. 2013) or the effluents of these ponds that are dumped in the mangrove forests (Vaiphasa et al. 2007a). In addition, the habitat quality of mangroves can also be compromised by chemical pollution from rivers. Such disturbances may reduce the structural complexity of mangroves, either through the clearing of mangrove roots or the loss of particular mangrove species.

The importance of mangrove forests as nursery grounds for fishes was first documented by Heald and Odum (1970) who showed the dependence of commercial fisheries on the net production of *Rhizophora* sp. Lugo and Snedaker (1974) reported the dependence of sports fishing and commercial fisheries on mangroves in Florida. In subsequent research shown, not only the commercial fish and shrimp species use mangrove habitat as a nursery habitat (Blaber et al. 1989, Rönnbäck 1999, Edwards et al. 2001). Coral reefs fish also use that habitat (Nagelkerken et al. 2002, Nagelkerken and Van Der Velde 2002, Barbier 2003, 2007b). A healthy mangrove is, therefore, crucial for sustainable fishing activities in the surrounding area, as fish is the primary source of food and income in many communities living close to mangroves.

Local communities also use mangroves for various purposes, such as timber for construction materials, firewood and charcoal, food (i.e., honey, fish and shrimp), resin for boat maintenance, and medicines from mangrove fruits (Saenger et al. 1983, Kusmana 2002, Sukardjo 2004). Local communities also use mangroves as protection from winds and waves, for instance, settlement areas are generally located behind mangrove forests (Primavera 2005a). Local communities often have traditional knowledge that contributes to the protection of mangrove ecosystems (Walters et al. 2008). This knowledge is still being transferred from generation to generation, and has become an integral part of the local culture. Such knowledge often relates to resource management. For example, the methods used to exploit natural resources often take the function of the different factors in the ecosystem into account (Berkes 1999).

Although the increase of human populations increased the pressure on mangroves, the level of disturbance might be comparatively small compared to the conversion of mangroves into aquaculture farming area or called ponds (Primavera 1997, Bao et al. 2013). Ponds are usually built at a semi-intensive scale, such that vast areas of mangroves have to be cleared. The clearance of mangroves is harmful to the fish and shrimp populations, which in turn affects the livelihoods of local fishermen (Naylor et al. 2000). Therefore, further studies of disturbances on mangroves in different spatial scale on the Berau delta ecosystem are necessary.

1.5 The Derawan archipelago and small-scale fisheries

Cribb and Ford (2009) indicated that Indonesian waters are the richest fishing grounds. Indonesia is the world's fourth largest producer of fish after China, Peru and India. The Berau waters, also known as the Derawan archipelago, are the third richest area in Indonesia regarding tropical marine biodiversity after Raja Ampat and Wakatobi (Wiryawan et al. 2004, Hoeksema 2007, Green and Mous 2008). Located at the border of the Wallace line (Barber et al. 2000), the study area comprises estuarine areas, mangrove forests, a delta area, different formations of coral reefs (i.e., atolls, barrier, patch and fringing reefs), the large extent of seagrass meadows, and small islands. Cribb and Ford (2009) stated that fishing has traditionally provided incomes for millions of people in the coastal villages where fishing has been the most important source of employment in the marine sector. Statistics data from the Indonesian Ministry of Marine Affairs (ID_FishData 2009) reported that between 2003 and 2007 fish was the primary source of animal protein in Indonesia supplying 70% of the total protein consumption in the country, followed by meat and livestock products.

In the study area, most fishing activities are small-scale, multi-gear fisheries, targeting multiple species for both subsistence and commercial purposes (Johnson 2006). To sustain the fisheries of the Berau marine resources that are being extracted by small-scale fisheries, an investigation of the spatial allocation and the differences in fishing pressures over the different habitats urgently required.

This study was carried out in the Derawan Marine Conservation Area (DMCA), where I tried to answer the below-listed research questions.

1.6 Research question and aims

To be able to manage mangrove habitat and to optimize sustainable protein production of both coastal fisheries and shrimp farming in the mangrove ecosystem, there is a need to understand the impact of disturbances on the structural complexity of mangroves, which in turn may affect the productivity and catches of coastal fisheries. Therefore two important questions have to be answered:

(1) How do disturbances influence the structural complexity of mangroves?

(2) How is the decline in nursery function of mangrove habitat related to catches of nearby fishermen?

Before the impact of disturbances on mangrove habitat can be understood, four aspects that should be investigated in more detail:

1. the influence of human and natural disturbance factors on the structural complexity of mangrove forests,
2. the effect of mangrove roots on the abundance, biomass, and species richness of marine fish and shrimp
3. the relationships between the spatial configuration of the available nursery grounds and associated shrimp catches, and
4. the space allocation of small-scale fisheries activities over the different coastal habitats and the spatial differences in based on the distance to the fishing area.

The above factors have often been addressed separately in other studies in various locations. However, to obtain a thorough understanding of the interactions between these factors, an integrated investigation at the similar place is required. Based on the above explanation, the aim of this thesis is to obtain a thorough understanding of the role of mangrove structural complexity on marine communities that use mangroves as a nursery area, and to evaluate the effects of disturbances on the nursery function of mangroves and thereby on the catches and location of local fisheries.

1.7 Study area

The research was conducted in the Berau District (Figure 1.2), East Kalimantan Province, Indonesia (1^{o} 40' to 2^{o} 15'N; 117 ^{o} 30' to 118 ^{o} 40'E) from 2008 – 2010 in the mangrove delta. The climate of the study area is tropical with a dry season (July - November), wet season (December - March) and a transitional season (April – June). In the dry season, monthly rainfall ranges between 210 and 264 mm and mean temperature is 27.5^{o}C, while in the wet season, monthly rainfall ranges between 110 and 190 mm and the average temperature are 31^{o}C.

The study area was selected due to the presence of the delta with vast areas of mangrove forests. The mangroves in the southern part of the delta are still relatively undisturbed. On the other hand, the mangroves in the nort are already partially degraded, mostly by pond development. The presence of intact as well as disturbed mangrove forests in one location is an advantage for the analyses of the effect of disturbance on the function of the mangroves as a nursery, and thereby on the catches of local fishermen.

Another requirement for the study area was the presence of coastal fisheries. In Berau, a coastal fisheries for fish and shrimp has mainly taken off two decades ago and is still thriving. Therefore, the Berau Delta, estuarine and a marine area were considered a suitable study area for this research.

Since 2005, a Derawan Marine Conservation Area (DMCA) of 127,000 km^2, including the mangrove area, was declared by the government of the Berau District. The goal of the DMCA declaration was to conserve the marine biodiversity, especially reef fish, sea mammals and green turtles. The results of this research about the relation between mangroves and coastal fisheries are expected to be useful to the government in the planning of future management activities in the MCA.

1.8 Thesis structure

This thesis is composed of a general introduction (Chapter 1), four research chapters (Chapter 2, 3, 4 and 5) and a synthesis (Chapter 6).

In chapter 2, I describe the changes in the distribution of the mangrove habitats in the Berau Delta and an analysis of the structural complexity of mangrove at three areas with different levels of disturbance. In chapter 3, a field experiment was conducted to investigate the habitat requirements of juvenile shrimp and fish on the nursery grounds, which was studied using Artificial Mangrove Units (AMU's). Chapter 4 focuses on the impact of spatial context on catches of small-scale fisheries catches in the Berau Delta. Chapter 5 describes the distribution of small-scale fishing activities in the Berau Sea concerning different coastal habitats. Finally, in Chapter 6, I present a synthesis of the main findings. I integrate the obtained results into a wider perspective to analyze the importance of the determinants of the distribution of coastal fish and associated fisheries in mangrove forests. The scope of each chapter is illustrated in Figure 1.3.

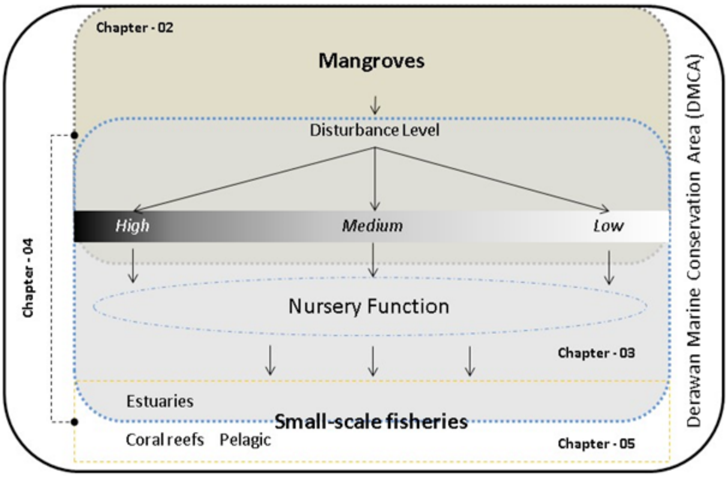


Figure 1.3. Diagram illustrating the structure of this thesis.

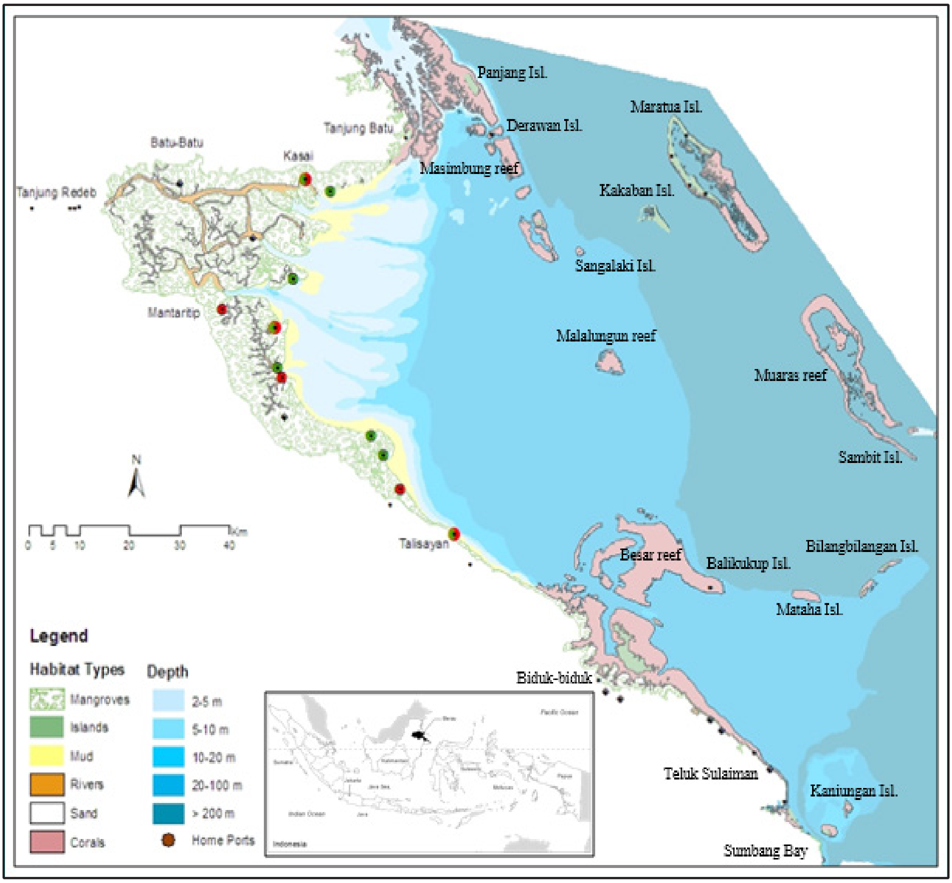


Figure 1.2. Map of the study area, Derawan Marine Conservation Area (DMCA).

Chapter 2

The influence of human disturbance on the structural complexity of mangrove forests in the Berau Delta, East Kalimantan

A.J. Siahainenia, W.F. de Boer, P.A.M. van Zwieten,
J.A.J. Verrethand H.H.T. Prins

Abstract

Mangroves forests in estuaries and deltas, known for their high biodiversity, are currently experiencing a rapid decline. There are two causes of this decline: natural (e.g., wave during tropical monsoon, insect, disease, and changes in sea level) and anthropogenic disturbances (e.g., wood harvesting and infrastructural developments). These disorders indirectly influence the function of mangrove forests as nursery grounds. We evaluated mangrove habitat loss and fragmentation over 18 years as a consequence of increasing human disturbances, and analyzed the relation between disturbance factors and several mangrove attributes, using remote sensing and field work in 120 randomly located plots. We expected to find a decrease in mangrove area over time; an increase in mangrove fragmentation, and a decline in the forests structural complexity with increasing human disturbance. Mangrove forests attributes, such as the number of seedlings, saplings, and trees, tree diameter, tree height, crown cover, root diameter and number of roots were measured. Two sets of data obtained from Landsat TM-5 images from 1991 and 2009 were analyzed to obtain estimated temporal changes in land cover. Classification accuracy was high, >80%. Results showed that over the past 18 years, the areas covered by ponds considerably increased during which the matters covered by mangrove trees (4.4% reduction) and especially mangrove palms (50%) decreased. Mangrove forest fragmentation increased over time. Correlation tests between mangroves attributes and disturbance factors showed that with decreasing distance to open water, sapling density increased, and root density, length, and diameter increased. Human settlements were located in areas with trees with a smaller diameter, which could have been caused by the removal of large trees, and higher seedlings densities characterized these regions. Human disturbance is responsible for a substantial decrease in the area covered by mangroves trees and mangrove palms.

Chapter 2

The influence of human disturbance on the structural complexity of mangrove forests in the Berau Delta, East Kalimantan

2.1 Introduction

Mangroves forest, characterized by high biodiversity and forming ecologically important ecosystems in estuaries and deltas, are currently experiencing a worldwide decline (Wilkie et al. 2003). There are 20 different families of mangrove plants over 30 genera, holding 80 different mangrove species, including mangrove species from the genera *Rhizophora*, *Xylocarpus*, *Bruguiera*, and *Avicennia*, and the nypa palm *Nypa fruticans* (Hutchings and Saenger 1987). In general, mangrove forests are structurally simple and distribute across the intertidal zone. Mangrove forests also vary in structural attributes such as species richness, canopy height, tree density and root complex system. The occurrence of species may differ across an estuary, apparently in response to differences in freshwater input.

The primary causes of the decline in mangrove forests are natural and anthropogenic disturbances. An example of natural disturbance is the continuous pounding of high coastal waves during tropical monsoon, which causes coastal erosion and increases the mortality of seedlings, sapling and adult trees of mangroves (Clarke 1995, Balke et al. 2013). Anthropogenic disturbances like urban development and aquaculture development have shown to cause significant loss of mangrove habitat (Ellison and Farnsworth 1996, Primavera 2000, 2005a, Holguin et al. 2006). In 1996, the price of shrimp increased in Indonesia, causing the rapid development of shrimp ponds, and urbanization of coastal areas, which increased the pressure on the marine resources along the coast (Sukardjo 2002, Primavera 2005a). Over time, a combination of timber harvesting, fuel-wood gathering (Chai 1982, Ainodion et al. 2002, Alongi 2008) and land clearing for human settlement have contributed to mangrove degradation. However, the transformation of mangroves into shrimp and fishponds is by far the largest cause of mangrove habitat modification in developing countries (Naylor et al. 2000, Sukardjo 2002, Primavera 2005a, b, Génio et al. 2008).

Mangrove habitats form an important nursery area for marine-estuarine fish species (Mumby et al. 2004, Blaber 2007). Mangrove attributes such as trees, trunks, leaves, and roots play a major role in providing food and shelter for juveniles (Primavera 1995, Manson et al. 2003, Mumby et al. 2004). These functions of mangroves are closely related to the root structure, such as root density and size. A more complex root structure, with, e.g., a higher root density, more twisted roots, larger roots sizes, or with a greater variation in sizes, offers more niches for the associated fauna than a simple structure. It was shown that juveniles of shrimp and fish preferred mangrove areas with complex root structures (Nagelkerken et al. 2008). Moreover, mangroves also provide food resources for juvenile fish and thereby have an important function in supporting coastal fisheries (Mumby et al. 2004, Génio et al. 2008).

Destruction or modification of mangrove habitats leads to habitat fragmentation (Strong and Bancroft 1994). Habitat fragmentation is defined as a process during which a large expanse of habitat is transformed into some smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original (Wilcox and Murphy 1985). Fragmentation is a major factor in the loss of connectivity between mangrove habitats, which could trigger an additional loss in the nursery area when juveniles cannot reach isolated mangrove patches.

The mangrove tree composition and root structure are also affected by anthropogenic activities. For example, people in Matang, Malaysia, collected trunks of *Rhizophora* spp. to produce active charcoal (Chai 1982). Selective harvesting changes the tree composition and the trees' size distribution (de Boer and Prins 2002). Tree harvesting and other human activities may also influence the root structure, because small roots are prone to be damaged, broken, and drift away so that the nursery function of mangroves becomes impaired.

So, there at least two different spatial scales at which habitat modification can take place: firstly by fragmentation at the extent of the entire estuary, when mangrove habitat patches become isolated, and the total area often decreases, negatively acting their nursery role (Mumby et al. 2004). The decline in mangrove area with increasing social pressure was described already a few decades ago (Chai 1982) but has since continued. Little is known about the effects of mangrove fragmentation on habitat quality. Secondly, habitat degradation can take place at a smaller spatial scale, as tree density, tree size, or root spatial complexity decrease. These processes reduce the habitat quality and thereby the nursery functions of mangroves (Syphard and Garcia 2001). So, there is an urgent need to study the relative importance of degradation at these two different spatial scales, to understand how changes in mangrove attributes might affect the functioning of coastal ecosystems.

Hence, this study has two objectives. The first is to evaluate changes in the distribution of mangrove habitat over the years, spatially and temporally, as a consequence of human disturbance in the Berau estuarine mangrove forest situated in East Kalimantan (Indonesia). The second is to analyze the relation between human disturbance and the mangrove forests structural complexity. We expected that more mangroves that are disturbed would be more fragmented, show a decline in tree density, diameter, and species richness, and have a simpler root structure compared to mangroves in undisturbed areas.

2.2 METHODS

2.2.1 Study site and species

Berau Delta is considered one of the largest healthy mangrove systems situated on the east coast of Kalimantan (1^o 40' to 2^o 15'N; 117^o 30' to 118^o 40'E). The delta is located at the western side of the Derawan Marine Conservation Area (DMCA). The total area of the DMCA is 12,800 km^2, less than 30% of which comprises estuarine habitats. The DMCA has the second highest marine diversity in Indonesia (Turak 2003, Hoyt 2012), is an important breeding location for green (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricate*), and is an important migration corridor for marine mammals. There are 21 coastal villages with a total human population of 16,000 inhabitants (BPS 2007) and the delta/estuarine covers a total area of 252,000ha about 28% of the larger MCA. Berau has a tropical climate with a monsoon season with average daily maximum temperatures up to 30^{o}C and an average monthly rainfall of ~1200 mm (BMG 2008).

The main mangrove species in the Berau Delta are *Rhizophora* spp., *Xylocarpus* spp., *Bruguiera* sp., *Sonneratia* spp., *Avicennia* spp., *Nypa fruticans, and Oncosperma* sp. (Bodegom et al. 1999, Bengen 2003). The villagers utilized these trees for fishing stakes, firewood, housing material, etc. In the delta, besides human settlements, there are brackish water fishponds. The number of these ponds has grown since 1998 (Bengen 2003).

2.2.2 Data collection and ground truthing

Differences in mangrove composition have been quantified by measuring species composition, tree density, tree height, tree diameter (Holdridge 1976) and canopy cover (Kathiresan and Bingham 2001). For this study, a hundred sampling points were chosen randomly based on a gridded map. At each sampling point, a 20×20m plot was set up from which information on tree characteristics. We recorded data (i.e., species, tree density, height, diameter at breast height (DBH), crown percentage cover and width, the number of seedlings and saplings) and root composition (i.e., root density, length, diameter and branching order) were recorded. Mangrove tree and root characteristics could only be measured in the plots that were located in mangrove forests, which were 64 plots of the above mentioned 100 plots. The remainder were situated in infrastructure area (e.g., coastal settlements), coastal forest and aquaculture ponds that could not be sampled the root structure. An additional 20 sampling points were located randomly in the rivers, canals, and sea, so in total, there were 120 sampling points of ground truthing data available (Table 2.1).

2.2.3 Tree characteristics

Within quadrat sampling plot with size 20x20 m, we identified mangrove species, count the tree density, measure tree height, tree diameter (DBH) and crown cover. Crown cover or canopy tree is defined as the proportion of a plot that is covered by the tree canopy stratum and is commonly expressed as a percentage where the maximum cover of any species is 100 percent (Anderson E. W 1986, Brocklehurst et al. 2007). The average percentage of canopy cover was visually estimated by three observers using the Estimated Foliage Cover method of Anderson E. W (1986). Tree height was measured with an electronic laser distance meter (Krisbow KW06-526). The average tree density at each plot was estimated for each diameter at breast height (DBH). Trees were defined as individuals with a tallness of >1.5m; saplings were <1.5m and seedlings were <0.5m (Kusmana 2005). The number of saplings and seedlings were counted over the entire 400m^2 plot. The geographical position of the central point of each plot was recorded using a hand-held GPS (Garmin GPS-Map 76CX).

2.2.4 Root structure

In each of the hundred 20×20m plots, randomly located over the area, five cubes (1×1×1 m) were set up to determine the root density of mangrove trees, with the aid of a collapsible tube structure made of PVC pipe. There are various unique structures of mangrove roots. The stilt or prop roots are found in *Rhizophora* sp., pneumatophores in *Bruguiera* sp., pencil-like roots in *Avicennia* sp*.,* and *Soneratia* sp., plank or buttresses in *Xylocarpus* sp., and rhizomes in *Nypa fruticans*. The species, number of roots, the total length and root diameter for each root were recorded in each quadrant where mangrove trees were present.

The branching pattern of the prop roots found in *Rhizophora apiculata* and *Rhizophora mucronata* was measured. A first branching order was recorded if the first root sprouted directly from the main tree trunk; when new roots branched off from the first root, it has been registeres as a second order, etc. Since *Nypa fruticans* (mangrove palm species) are anchored by rhizomes, root data was ignored for this species. The pencil root (pneumatophores of *Avicennia marina*) and knee roots (*Bruguiera* sp.) were counted within $5m^2$ plot. The root diameter at each plot was measured using calipers.

These root composition data were used to obtain the density and structural complexity of each sampling plot. We define the structural complexity of the area based on the root density, root length, root diameter and branching order. The structural complexity of mangrove roots is essentially a measure some different structural attributes in an area, related to the mangrove roots present, and based on the mean and the variation in root density, length, diameter, and branching order of these attributes. Structural characteristics related to the forest floor as local geomorphologies, litter and sediment quality, which can be attributed to the presence of mangrove tree species, were not taken into account.

2.2.5 Data processing and analysis

The GIS data sources used in this study were two sets of Landsat 5TM images, taken on 16 June 1991, and 4 August 2009, with geo-referenced point data representing the vegetation cover. The Landsat images (path 116, row 59) contained six spectral bands, but only combination of bands 4-5-3, with a spatial resolution of 30m, were used (Fung 1990). The remaining bands were considered too coarse to enable accurate detection and mapping of mangrove species. The selected bands were corrected for geometric distortions using, 120 ground control points (GCPs; Table 2.1). The GCPs were located evenly across the image at visible features on both the image and in the field, such as river Y-junction and road intersections. Each GCP had its field location measured using a GPS. After geometric rectification, the images was re-sampled to a Universal Transverse Mercator coordination system (WGS84 zone 50North) using the nearest interpolation technique. The cloud coverage of the used imageery was less than 10%.

The digital processing of the Landsat TM imagery in raster format was performed using ERDAS Imagine 9.3 and ER-Mapper 7.2 image processing system (ERDAS Atlanta, GA, USA). Software ARC-GIS 9.3 (The Environmental System Research Institute, USA) was used for digitization of different mangrove cover features and for making the final mangrove map.

Table 2.1. Distribution of the 120 sampling points over the different land use types. With coded names used for classification of the Landsat imagery data, plot numbers, and descriptions.

Land cover type	Code	Sampling points	Descriptions
Mangrove trees	MA	64	*Avicennia* sp, *Sonneratia* sp, *Rhizophora* sp, *Bruguiera* sp & *Xylocarpus* sp
Mangrove palms	PM	9	*Nypa fruticans & Oncosperma tigillarium*
Ponds	PD	8	Aquaculture farming (shrimp and fish)
Infrastructure	IF	9	Settlements, roads, industry and runway/airstrip
Coastal forest	CF	10	Secondary forest
Sea	SE	10	Additional ground control points (GCP) for sea, rivers, streams, canals and small creeks
Rivers	RV	10	
Total		**120**	

2.2.6 Classification procedures

After pre-processing and rectification of the imagery data, false color images of thematic bands 4-5-3 (R-G-B) were prepared for interpretation. The dataset of the hundred twenty sampling points was used as a training dataset. The training dataset was saved as vector polygons files and was divided into five land use type classes: mangrove trees, mangrove palms, coastal forest, infrastructure, and ponds. Two additional classes' sea and river, which were digitized on-screen to obtain digital values. The classification was added into the training dataset. The training dataset subsequently was used to classify the associated 120 regions in the Landsat images with the seven classes. These seven catagories were then utilized in the supervised classification (Mumby and Edwards 2002), resulting in fully classified Landsat images. For the classification of the vegetation types in the current study, I divided the mangrove forests in the Berau Delta into two classes:

a. Mangrove trees are dominated by a mixture of mangrove trees like *Rhizophora* spp., *Sonneratia* sp. and *Avicennia* sp.

b. Mangrove palms are dominated by *Nypa fruticans* and *Oncosperma tigillarium*.

Before proceeding to the supervised classification, a separability test was done to quantify the quality of the classification result.The accuracy of the seven land cover classes was calculated by a comparison between the field data (120 plots; table 2.1), and the detailed image was used to produce confusion matrices. The confusion matrices were generated using a maximum likelihood method, resulting the user accuracy, the producer accuracy, overall accuracy, including kappa statistics. A Digital Elevation Model (DEM) was used to quantify the differences in land use changes over different elevation classes.

2.2.7 Spatial metrics and change detection analysis

For further analysis, FRAGSTATS (McGarigal and Marks 1994) was used to quantify the landscape structure of the Berau Delta for each of the land use classes. FRAGSTATS calculates some spatial metrics for each patch and type coverage as well as for the entire landscape from 1991 – 2009. Some class-level metrics were computed for the land cover maps of the year 1991, and 2009. The metrics are the area (km), the number of patches (NP), mean patch size (MPS), coefficient of variation of patch sizes, perimeter, and as an index for patch shape complexity also the area weighted mean shape index (AWMSI) was calculated. We report here the changes in fragmentation of the five land cover classes: mangrove trees, mangrove palms, coastal forest, ponds, and infrastructure.

2.2.8 Statistical analysis

An ordination analysis was carried out in CANOCO (ter Braak 1996) on all vegetation variables to classify the vegetation in the plots with vegetation, to identify plots that had a similar vegetation structure, and to correlate the variation in each of the plant variables to change in natural and anthropogenic disturbances. Data was first tested with a Detrended Correspondent Analysis (DCA). The so-called length of gradients (<3) indicated that species followed a linear distribution (Kent and Coker 1992) and therefore a Principle Component Analysis (PCA) using PC-ORD ver.4.5 (ter Braak and Verdonschot 1995) was carried out. Results of the PCA were compared to the groups obtained from the supervised classification.

To assess the levels of disturbances to the mangroves, we were measured two parameters. First, the nearest distance to a water-body can be regarded as the distance to natural disturbances. The second, for anthropogenic interference the distances between the villages and the reference sampling plot.We took the differences in human population densities of each community village into account through a weighted the average calculation (Gauch 1982). The larger the distance, the smaller the expected disturbance effect. The distance to the nearest village weighted by human population size in the village was used to assess anthropogenic interference in a way that larger population in the villages had a higher disturbance, and hence a smaller weighted distance.

For a set of villages with different population sizes, the calculation of the Weighted Distance per plot is:

$$WD(P1) = \frac{(PV1 * DP1) + (PV2 * DP1) + (PV.....n = 21 * DP1)}{TP}$$

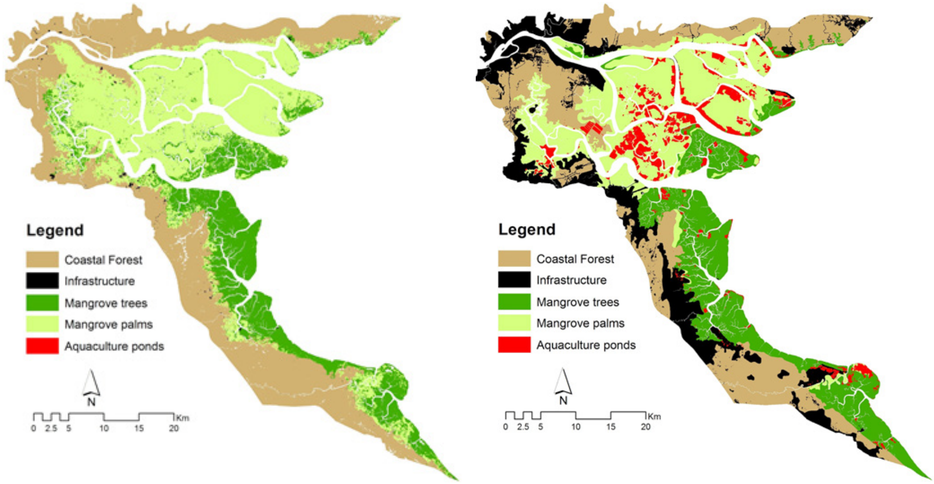
Note: WD (P1) = Weighted Distance Plot 1; PV1 = Population village 1; DP1 = Distance to plot 1 and TP = Total Population

Where weighted Distance (**WD**) per plot is the sum of total population of each village times the distance between the village, and divided by the total population of 21 villages. The smaller the WD, the larger the relative pressure of villages on a plot. Distances to disturbance sources were used as independent variables. The effects were tested concerning tree characteristics (tree density, height, and DBH), root structure (branching pattern, root density, length, and diameter) and species number, the percentage of estimated crown cover and top cover width, the number of saplings and seedlings. Individual tree data are available per plot, but not dependent on each other, and hence are pseudo-replicates. A more appropriate analysis is, therefore, the analysis of averages at plot levels such as carried out in the present study. The relationships between the dependent variables and the distances to disturbance was tested with a Spearman's rho test, as the correlation did not follow a linear relationship or the data was not normally distributed.

2.3 RESULTS

2.3.1 Land-use changes by Landsat 5-TM imagery

Two confusion matrices were calculated, one for each year (1991 and 2009; Table 2.2). The accuracy of the classification is relatively high, as the producer's accuracy value were 82% and the user accuracy values 80%. The overall accuracy and kappa statistics for both estimates were >70%.



Landsat-5 TM, Year 1991 Landsat-5 TM, Year 2009

Figure 2.1. Map of land cover types according to Landsat 5TM image classification from 1991 and 2009.

Mangrove palms were significantly reduced (50% reduction) between 1991 and 2009, compared to other land covers. The decrease of mangrove palm (Figure 2.1, Table 2.3) can be attributed to an increase in aquaculture pond areas with 10,346 ha (from 0.3 to 104 km^2) and an increase in areas with infrastructure with 30,578 ha (187%). The mangrove trees areas only slightly decreased by 4%.

The largest changes between 1991 and 2009, took place at 0-5 m above sea surface level where mangrove palm areas decreased by 50% and were replaced by ponds and villages. At the 6-25m elevation level, mangrove forests and coastal forest areas were converted to settlements. Above 35m, the forest cover remained stable.

Table 2.2. Confusion matrices for the classification produced by eight classes used to map the land use cover in the Berau Delta in 2009 (top part) and 1991 (bottom part). The main diagonal of the matrix shows the number of correctly allocated pixels.

a) Landsat imagery 5-TM, Band (4-5-3) 4 August 2009, cloud coverage <10%

Land cover type	MA	PM	PD	IF	CF	RV	SE	Total	Accuracy %	
									Producer's	*User's*
Mangrove trees (MA)	62	2	0	0	1	0	0	65	95	97
Mangrove palms (PM)	1	7	0	0	1	0	0	9	77	70
Ponds (PD)	0	0	7	1	0	1	1	10	70	88
Infrastructure (IF)	0	0	0	7	0	1	0	8	88	78
Coastal forest (CF)	1	1	0	0	7	0	0	9	78	78
River (RV)	0	0	1	0	0	9	0	10	90	82
Sea (SE)	0	0	0	1	0	0	8	9	89	89
Total	*64*	*10*	*8*	*9*	*9*	*11*	*9*	*120*		

Overall accuracy 89%, Kappa Statistic = 0.76

b) Landsat imagery 5-TM, Band (4-5-3) 16 June 1991, cloud coverage <30%

Land cover type	MA	PM	PD	IF	CF	RV	SE	Total	Accuracy %	
									Producer's	*User's*
Mangrove trees (MA)	60	2	3	0	0	0	0	65	92	95
Mangrove palms (PM)	1	7	1	0	2	0	0	11	64	64
Ponds (PD)	2	1	3	1	0	0	0	7	43	38
Infrastructure (IF)	0	0	0	7	0	0	0	7	100	88
Coastal forest (CF)	0	1	1	0	8	0	0	10	80	80
River (RV)	0	0	0	0	0	10	0	10	10	100
Sea (SE)	0	0	0	0	0	0	10	10	100	100
Total	*63*	*11*	*8*	*8*	*10*	*10*	*10*	*120*		

Overall accuracy 88% Kappa Statistic = 0.74

The existing land cover changes in the Berau Delta from the year 1991 and 2009 are listed in Table 2.3 (a) and the information on the conversion rates of land cover types in Table 2.3 (b). In the period between 1991 and 2009, the reduction in the area of mangrove forests was highest (22,600 ha), mainly due to the derease in mangrove palm areas, followed by coastal forests (7,500 ha) and rivers (26 ha; Table 2.3a). The increasing human population is probably the reason for the growing area with settlement (20,000 ha), while the increased demand for shrimp triggered the developments of aquaculture ponds area (10,000 ha).

Table 2.3. (a) Land cover types in the Berau Delta, analyzed using supervised classification of Landsat 5TM images from the year 1991 & 2009.

Land cover type	**1991 (ha)**	**2009 (ha)**	**Change**	
			1991 – 2009 (ha)	*Value (%)*
Mangrove trees (MA)	36,158	34,562	-1,596	-4
Mangrove palms (PM)	42,238	21,174	-21,064	-50
Ponds (PD)	32	10,378	10,346	32,331
Infrastructure (IF)	12,654	32,587	19,933	158
Coastal forest (CF)	38,582	30,989	-7,593	-20
River (RV)	16,981	16,955	-26	-0.2
Sea (SE)	105,293	105293	0	0
Total	251,938	251,938	-	-

A negative change indicates a decrease and positive change indicates an increase.

(b)Land-cover type changes in the Berau Delta from 1991 to 2009 and information on the conversion between land-cover types.

		Converted to (2009)						
Land cover types (1991)	**Total**	Mangrove trees	Mangrove palms	Ponds	Infra-struc-ture	Coastal forest	River	Sea
Mangrove trees (MA)	-1,596	**0**	0	82	1,514	0	0	0
Mangrove palms (PM)	-21,064	0	**0**		10,800	0	0	0
Ponds (PD)	10,346	-82	-10,238	**0**	0	0	-26	0
Infrastructure (IF)	19,933	-1,514	-10,800	0	**0**	-7,619	0	0
Coastal forest (CF)	-7,593	0	0	0	7,593	**0**	0	0
River (RV)	-26	0	0	0	26	0	**0**	0
Sea (SE)	0	0	0	0	0	0	0	**0**

Spatial metrics analysis

The changes in the spatial structure of the five land cover types were evaluated through the indices generated by FRAGSTAT. The number of forested patches decreased for the entire landscape by 155% from 11,985 to 4706 ha, whereas the mean patch size decreased from 10.5 to 27.1 ha and the coefficient of variation of patch size declined by 133% (Table 2.4).

Table 2.4. Statistics of landscape changes between (1991 and 2009) in the Berau Delta analyzed by FRAGSTATS.

Metric	**Year**		**Change**	
	1991	**2009**	**Value**	**(%)**
Area (ha)	127,740	127,740	0	0
Number of patches (NP)	11,985	4,706	-7,279	-155
Patch density (PD)	10.7	27.1	16.4	60
Mean patch size (MPS)	10.5	27.1	17	61
Patch size coefficient of varian (PSCoV)	2,213	958	-1,255	-133
Area weighted mean shape index (AWMSI)	6.4	4.9	-1.5	-31
Mean shape index (MSI)	1.4	1.6	0.2	9
Shannon Diversity Index (SDI)	1.1	1.5	0.4	27
Shannon Evenness Index (SEI)	0.8	0.9	0.1	11

A negative change indicates that the metric has decreased between 1991 and 2009: a positive change indicates an increase (see Appendix E.C for a details of this results)

The patch shape complexity was obtained from the Area-Weighted Mean Shape Index (AWMSI) showing decreased (1.5) from 6.4 to 4.9 in 2009 (Table 2.4), indicating that patch form became uniform than the situation in 1991. Shannon's diversity and evenness indices both reflect the relative distribution in the area among the five patch types, and showed that both diversity and evenness slightly increased, indicating that the difference in different patch types increased, but also that this distribution became more even.

2.3.3 Mangrove attributes and structure

In total 1,226 trees and 29 species were recorded within the 100 plots, of which 21 species were mangrove trees, and two species were mangrove palms. *Rhizophora* sp. and *Bruguiera* sp. were found as a dominant mangrove trees species with an average height and DBH of 9m and 4cm respectively. On average, 10 saplings and 13 seedlings were found in each 20x20 m plot. The average canopy (crown) cover was 36%.

Table 2.5. Spearman rank correlation tests results (N, rs, P). Relationship between various mangrove structural variables and distances to disturbances factors.

		Weighted distance to villages (anthropogenic disturbance)		*Minimum distance to the nearest water (natural disturbance)*	
Tree characteristics	**N**	rs	P	rs	P
Tree density (N/Ha)	64	-0.175	ns	-0.121	ns
Tree height (m)	64	0.217	ns	0.144	ns
Tree diameter (cm)	64	0.251*	0.05	-0.023	ns
Species number (N/Ha)	64	-0.149	ns	0.032	ns
Crown cover (M/Ha)	64	0.199	ns	-0.183	ns
Saplings density (N/Ha)	64	0.039	ns	-0.254*	0.04
Seedlings density (N/Ha)	64	-0.252*	0.04	-0.086	ns
Root structural complexity					
Root density (m²)	64	-0.183	ns	-0.251*	0.05
Root length (cm/m²)	64	-0.379**	0.002	-0.385**	0.002
Root diameter (cm/m²)	64	-0.190	ns	-0.337**	0.006
Branching order (N)	64	-0.179	ns	-0.207	ns

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

From the 100 sampling plots, 64 plots were located in mangrove forests with mangrove trees while others are sampling plots (36) were found in ponds, settlements, and coastal forests. In these 64 mangrove plots, tree characteristics (e.g., tree density, diameter, and other tree metrics) were not significantly related to the distance to the nearest water edge, except saplings density, which decreased with increasing distance to the water edge (Table 2.5). Root characteristics (e.g., root density, length, and diameter) also decreased with increasing distance from the water edge. Tree diameter significantly increased with increasing weighted distance to villages (i.e., with decreasing human disturbance). Seedling density and root length significantly decreased with increasing weighted distance to the villages.

2.3.4 Relationship between disturbances and mangrove attributes

The variation in characteristics and structure of the forest in the sampled plots was analyzed through a PCA. We calculated the related distances to both natural and anthropogenic disturbances. The result of the PCA (Figure 2.2) showed that natural disturbance (i.e. a lower distance to the nearest water) was negatively associated with forests, whereas human disturbance (a higher disturbance means a lower value on the anthropogenic disturbance arrow, representing the weighted distance to villages) was negatively associated with ponds. Most of the mangrove tree plots were clustered together, but some of these mangrove tree plots were similar to coastal forests, or ponds. Height, diameter, density, seedling, N species and crown cover were all negatively correlated with weighted distance from villages (i.e., all are less with increasing weighted distance); inversely these variables are uncorrelated with distance to the water bodies (arrows are orthogonal). Root branch, root length (RL), diameter root (DR) and density were uncorrelated with anthropogenic disturbance (i.e., the arrows were orthogonal) and they were negatively correlated with distance to the nearest water body. These attributes were associated with most mangrove forests plots and not with coastal forests, so natural disturbance was associated with an increase in root structural complexity. It is also evident that tree height and diameter were closely associated, as well as tree density and seedlings, and the root parameters were also tightly clustered. The distance to villages from each sampling plot was weighted with the human population size. Most mangrove areas and all aquaculture ponds are found under low anthropogenic disturbance, i.e., relatively far from villages, while coastal forests were associated with a relatively high human disturbance (low weighted distance).

The percentage variance explained by the first and second ordination axis was, respectively, 33 and 29 %. The average tree height, diameter, crown cover, and roots structure (density, length, and diameter) were only weakly correlated with the average distance from plots to the nearest water (natural disturbance). The distance from the villages to sampling plots (anthropogenic disturbance), but had larger values in mangrove plots, compared to coastal forests.

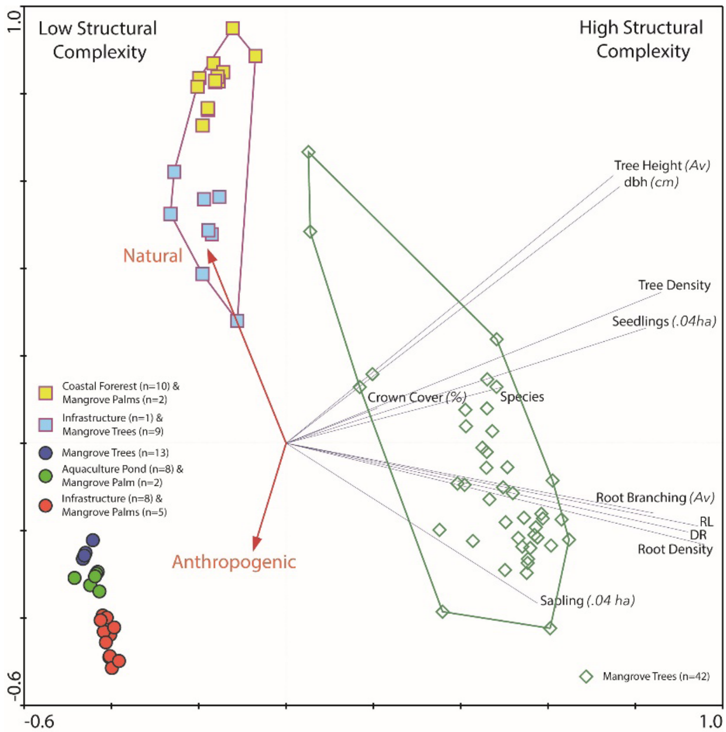


Figure 2.2. Ordination plot of mangrove vegetation variables (n=100) on the first two PCA axes. Environment variables: Anthropogenic = weighted distance from the village to plots; Natural = distance from nearest water edge to plots. Species variables consist of infrastructure, coastal forest, aquaculture ponds, mangrove palms, and mangroves. The detail of mangrove component (i.e., the number of mangrove species, seedling density, sapling density, tree density, crown cover, tree diameter (DBH), tree height, root density, mean root branching order, root length (RL) and root diameter (DR)). The shapes (e.g., circle, diamond and square box) indicate clusters of samples in three groups.

2.4 DISCUSSION

Explaining the habitat changes due to disturbances that occur in mangrove ecosystems is an important topic in mangrove ecology. However, there is little information on the impact of anthropogenic and natural disturbance factors on the structural complexity of mangroves, a critical mangrove attribute which influences the quality of the nursery function for juvenile shrimp and fish (Primavera 1995, Barbier 2003, Lee et al. 2014).

Land-cover changes in the Berau Delta

Mangrove forests are comprised of unique plant species that form the critical interface between terrestrial, estuarine, and near-shore marine ecosystems in tropical and subtropical regions (Robertson and Alongi 1992, Primavera 2005a, Polidoro et al. 2010). Land-cover types from 1991 to 2009 were classified into seven categories, which were based on the USGS standard land-use and land-cover categories. The seven categories had high levels of producer accuracy and user accuracy (>80%) for Landsat Data in 1991 and 2009. The 120 ground control points (Table 2.1) were correctly positioned, land cover types could be accurately classified, and hence the land-cover changes in this area could be analyzed with a high confidence level, yielding this high accuracy.

The total cover of mangrove forests declined by 54% within 18 years from 78,000 ha in the year 1991 to 56,000 ha in 2009 (Table 2.3). The decrease of mangrove palms (PM) was the most extensive, with an average rate of 102 ha per month since 1991. The primary cause of the decline in the mangrove palms area was a vast land conversion for settlement and aquaculture development. This type of habitat conversion is an important anthropogenic disturbance (Figure 2.1). Conversion of mangroves palms (*Nypa fruticans*) was more frequently reported than conversion of mangrove trees, probably due to three main reasons:

- The mangrove palm areas are located close to the settlements and easily to access and to the clearing. The mangrove palms are an open access resource, and a farmer can claim the area without permit and intervention of the forestry department.
- The type and density of the vegetation are also an indicator of the soil types and the elevation of the water table (Szilvassy 1984). A sandy clay to clayey loam is the best type of soil for pond construction, and these soil types are ideal areas for palm vegetation, as most of the mangrove trees are associated with more clayey substrates (FAO 1984).
- An extensive and high windbreak of thick vegetation (i.e., pristine mangrove trees) protects against prevailing winds and wave action (Szilvassy 1984). This situation is the main reason why local farmers protect the mangrove trees around their ponds or aquaculture farming.

We found that the mangrove trees were the third most disturbed habitat, but the decrease in cover was rather small at 4% (1,596 ha). The loss of mangrove forests and coastal forests in the north of the delta was more extensive than in the southern part. In the northern part, there were more settlements and ponds compared to the southern part. Coastal forests were only converted into infrastructures such as settlements and roads.

A loss of mangrove forests may affect the population sizes of mangrove palms and individual mangrove palm forest related species (Valiela et al. 2001, FAO 2003, Wilkie and Fortuna 2003, Polidoro et al. 2010). Furthermore, these changes may also influence the structure and complexity of the mangrove system (Lee 1999, Alongi 2008). In turn, the estuary biota communities especially juvenile fish and shrimp that are related to mangroves could also be affected (Primavera 1995, Blaber 2008).

Causes and impacts of land-cover change in the Berau Delta

There are probably two causes of anthropogenic disturbances in the Berau Delta: (1) free use and exploitation of mangrove forest trees and palms by the local community in the Delta. (2) Conversion of both mangrove palm and mangrove tree areas for various purposes (e.g., settlements, aquaculture activities, and industrial developments). The expansion of settlements and extensive infrastructural activities (e.g., coal harbor, coal wash activities, and urban settlements) are probably at the base of these anthropogenic disturbances in the Berau Delta. In early 1995, the local government of Berau promoted large economic businesses (i.e., coal mining in the upstream area of the Berau, shrimp factory, and a pulp and paper factory). Since then, the human population increased (BPS 1997), as more people immigrated from Java and Sulawesi to work in the industries as mentioned above.

The major land-cover change was from mangrove palms to ponds (Table 2.3b), These newly constructed ponds can disconnect the numerous small streams from the influence of seawater by the construction of dikes and stop banks (Hughes and Paramor 2004). This situation can affect juvenile fish and shrimp that may suffer from the indirect effects of river damming, such as interference with their local dispersal route during tidal periods. Dikes can reduce the amount of water reaching mangrove forests, blocking both the flow of fresh and saline waters and thereby changing the salinity level of water in the mangrove forests. If salinity becomes too high or too low, the survival of mangroves forest trees and palms can be reduced. Freshwater diversions can also lead to mangrove forests drying out, and increased erosion due to land deforestation can massively increase the amount of sediments in rivers. A rapid expansion of aquaculture ponds has been linked to increased deposits supply by rivers that can negatively affect the habitat quality for shrimps and juvenile fish (Laegdsgaard and Johnson 2001, Kon et al. 2009). This habitat modification may result in the loss of essential ecosystem services in the delta generated by mangroves, including the provision of the nursery habitat (Naylor et al. 2000). The varied habitat can trigger substantial economic effects, as mangrove forests can act as nurseries that provide food and shelter to juvenile fish and shrimp caught as adults in coastal and offshores fisheries.

We showed that patch size increased, and the number of pieces decreased over the study period. The fragmentation of mangroves into smaller patches (Table 2.4) was expected to increase its forest water interface, but we found opposite trends in the field. Our study showed that the water area decreased and became smaller (Table 2.3a), probably due to river damming and construction of pond dikes (Figure 2.3). This damming may influence access to juvenile marine species such as shrimp and fish, which use mangroves as a shelter against predators and hence their abundance (Primavera 1997). A decrease some forest patches might reduce the potential nursery area and its services, and therefore make juvenile shrimp and fish more prone to predation. However, the mean patch size increased, maybe because of the decrease in channel area, which might generate negative effects for juvenile marine organisms. In addition, the patches with infrastructure were increases, as small settlements were joined into larger pieces that connected several smaller settlements (Figure 2.1). So the net effect of these changes in fragmentation is hard to predict and deserve further studies.

Figure 2.3. An example of a land covers change that occurred in the Berau Delta, from previous mangrove forest to an aquaculture pond. Small creeks became disconnected from their main canal. The red line indicates the dikes and the yellow lines the riverbanks.

Changes in mangrove distribution and structural complexity

Mangrove forests can vary in structural attributes such as species richness, canopy height, tree density and root complexity. Disturbances can modify the mangrove habitat zonation and affect mangroves attributes, potentially negatively affecting the quality of the habitat for juvenile shrimps and fish. This study showed that anthorpogenic and natural disturbances were both negative and positive related with some of the size, and density attributes of mangrove trees roots. Tree diameter was positively related to a weighted distance to human settlements (Table 2.5), so trees had a smaller mean diameter at breast height (DBHs) close to human settlements. Hence, our study probably showed the preference of people to construct their house in areas where mangrove trees were smaller, while the larger trees have been used for construction purposes, leaving smaller trees close to settlements. Root length was bigger while seedling density higher with thinner size was recorded close to settlements. These might be caused by the larger availability of light, due to the removal of larger trees (Ellison and Farnsworth 1993, Sousa et al. 2003). The analysis was not able to pick up the effect of human disturbance over time on changes in, e.g., tree densities. The PCA-analysis showed that the root structure variables were plotted orthogonal to the anthropogenic disturbance factor (Figure 2.2), indicating that, if root structure is essential for the nursery habitat, these root structural variables are relatively little affected by human disturbance, because they were uncorrelated to anthropogenic disturbance. The PCA findings agree with the correlation test results, as the human disturbance was not strongly associated with the decrease in mangrove root structural complexity.

In the Delta, mangrove forests with single-species zonation pattern were found in zones parallel to the coastline and riverbanks (unpublished data). The coastal edge area was occupied by species like *Avicennia* and *Sonneratia*. *Rhizophora* was found along river and creeks, while *Bruguiera*, *Ceriops*, and *Xylocarpus* were found more land inwards, at a higher elevation. Further, landward where sandy and loamy substrates are present, species like *Nypa fruticans* and *Oncosperma tigillarium* were dominant.

Inland areas have a lower level of natural disturbances, which is associated with a lower complexity of the root system. Changes in these regions are probably relatively more influenced by changes in salinity, soil type, weak tidal currents (Kathiresan and Rajendran 2005), and stability of the bottom substrate. Supriyadi and Wouthuyzen (2005) found that the average height of mangrove trees at the coastline in Kotania Bay was lower than landwards. In our study, we did not detect such a correlation.

The mangrove areas further away from the coastline were dissected by small creeks. Muddy particles may form a thicker layer in areas with fewer waves and weaker tidal currents, and these areas are more suitable for mangrove seed establishment, seed survival, and growth of mangroves (Alongi 2002). Trees from the genera *Rhizophora, Bruguiera, Ceriops, and Xylocarpus* can be 30-35 m tall with dynamic and complex roots structure. These pristine mangrove trees are characterized by more complex and larger root sizes and a higher seedling and tree density and are usually regarded as more mature mangrove trees that are important nursery and feeding ground for juvenile shrimp and fish (Singh et al. 1994).

The coastline area is influenced by continuous waves, which reduce the thickness of the muddy substrate and are responsible for piling up sands along this mangrove fringe. Shallow mud and sandy substrates do not offer safe anchorage for prop roots of *Rhizophora* species (Gill and Tomlinson 1977), but *Avicennia* trees thrive under this condition, which probably partly explains the higher root complexity in the coastal area (Table 2.5). Avicennia pneumatophores reduce water currents and trap propagules, which might explain the larger sampling densities in this field as illustrated by both the correlation results and the PCA. The high sapling density in these coastal areas can result in competition for space and nutrients, which can negatively affect their growth (Alongi 2002). The root became more involved closer to the open water, which supports the statement of Brown and Lugo (1982) that root structural complexity is correlated with natural disturbance. However, this relation was not harmful as hypothesized, but surprisingly; root systems that are more complex were found closer to the coast. We expect that the role of *Avicennia* trees, a pioneer species with numerous pneumatophores, is partly responsible for this unexpected finding. These relatively more complex root structures can represent high-quality nursery grounds for marine organisms (Nagelkerken et al. 2008). We found that natural disturbance patterns were present in the Berau Delta and affected the root structural complexity of mangrove.

In conclusion, this study described the changes in mangrove forests cover from 1991 to 2009 in the Berau Delta. In total 22,660 ha of mangroves forest, was converted over 18 years. Landsat TM Images with a 30m pixel resolution combined with ground truth data from 100 plots and additional 20 plots data on rivers and sea have provided an overview of land cover changes in the Berau Delta with overall accuracy almost 90% and kappa accuracy above 70%. The area covered by mangrove palms showed the largest decrease over time (21,064 ha). Coastal forests were found at a significant distance from the water edge, with small natural disturbance, whereas the mangrove trees, closer to the water edge under great physical disturbance had a higher root structural complexity. However, current rates of mangrove cover changes in the Berau Delta are significant, with an average of 102 ha per month. Therefore, without proper management and strong regulation from the local government, we predict that over 10 years if these rates of change and their causes remain the same, the mangrove ecosystem in the Berau Delta might be strongly negative affected, with negative impacts on the nursery function of the mangrove forest.

Chapter 3

Influence of mangrove roots system on marine fish and crustacean communities, an experimental approach

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Abstract

Mangroves in coastal and estuarine areas offer an important nursery habitat for fish and shrimp by providing shelter against predation among other functions. Anthropogenic disturbances can affect this critical ecological function of mangroves by changing the mangrove root density and patch size. Artificial Mangrove Units (AMU) were built at three locations with different levels of disturbance. The effects of root density, as represented by the number of sticks in the AMU, and the effects of patch size, as represented by the scale of the AMU, on the abundance and species richness of juvenile fish and shrimp were investigated. Shrimp were most abundant at the least disturbed site, though no causation could be inferred. Both the abundance and the diversity of both shrimp and fish species were increased with AMU size and stick density. In conclusion, anthropogenic disturbances in mangroves, as indexed by differences in root density, patch size, and other indirect effects can decrease the abundance of shrimp, fish, and other species.

Chpater 3

Influence of mangrove roots system on marine fish and crustacean communities, an experimental approach

3.1 Introduction

Mangroves have an important nursery function for marine fish and crustaceans (Wilkie et al. 2003, Dorenbosch et al. 2004a, Mumby et al. 2004). Mumby (2006) showed a strong relationship between the abundance of coral reef fish and the size of nearby mangrove forest, and they attributed the increase in reef fish abundance to increased juvenile fish survival in the mangrove forest. The decline of mangrove forests in general results from a decrease in forest size, basal area, tree density, a change in the tree age-class distribution, species composition and distribution, and a reduction in the root density (Barbier and Cox 2003). These factors have been linked to ecological changes including the loss of the nursery function of mangroves, with concomitant large economic impacts (Odum and Heald 1972, Barbier and Cox 2003).

Mangroves forest attracts juvenile fish and other organisms (Nagelkerken and Van Der Velde 2002, Sheridan and Hays 2003, Manson et al. 2005b) through two potential mechanisms. First, mangroves have a very high primary productivity (Bunt et al. 1979) and thus provide ample food to vertebrate and invertebrate communities (Chong et al. 1990, Lee 2004, Lugendo et al. 2006). Submerged structures formed by the stem and the roots of mangrove trees may increase food availability due to the large surface area that mangrove trunks and roots provide as a substrate for algae to grow on (Kathiresan and Bingham 2001). These algae are in turn eaten by fish and gastropods (Bouillon et al. 2002). Moreover, the mangrove roots reduce the current speed, thereby enhancing sediment particle deposition (Leh and Sasekumar 1991), including leaf litter that is produced by the mangrove trees (Jennerjahn and Ittekkot 2002). Accelerated decomposition of mangrove litter, facilitated by the shade provided by the mangrove trees, provides nutrients and act as a food base for mangrove dwelling organisms (Macnae 1969).

Second, mangroves can provide shelter, thus decrease the predation pressure of juvenile fish and invertebrates. The shelter function of mangroves can be in the form of sediment formation (Meager et al. 2005, Lugendo et al. 2006), which provide a loose substrate for shrimp to hide from predators (Manson et al. 2005b). Sedimentation can increase with a higher density of root structures, which lowers the water current (Manson et al. 2005b). It was shown that the presence of root structures in mangroves reduced the predation rate of juvenile fish and shrimp (Shulman 1985, Thayer et al. 1987, Parrish 1989, Dorenbosch et al. 2004b). A higher fish species diversity and fish abundance was found with increased root heterogeneity and root density (Luckhurst and Luckhurst 1978). Related to the shelter function of mangroves, Robertson and Blaber (1992) reported that a larger patch area of mangroves provides greater protection for fish and shrimp against predators than a smaller area.

Heterogeneity of root size, mangrove patch size, and density of roots in a mangrove habitat are attributes that can be summarized as the structural complexity of mangroves (Cocheret de la Moriniere et al. 2004). The relation between the structural complexity of mangroves and the attractiveness of mangroves as a shelter for juvenile fish has been previously investigated by catching fish and shrimp in mangroves with different structural complexity (Ikejima et al. 2006). The results, however, were not satisfactory because it could not be confirmed that the species caught used mangrove roots as shelter (Wang et al. 2009). Hence, artificial mangrove units (AMUs) were designed to mimic the structural complexity of mangrove roots. Therefore, the role of structural complexity in the nursery function of mangroves is more accurately to assess (Nagelkerken and Van Der Velde 2002, Cocheret de la Moriniere et al. 2004, Nagelkerken et al. 2010). The results of previous studies suggested that the root structural complexity, together with shade provided by the underlying structures and trees, reduced the predation of juvenile fish in clear estuarine waters. These studies further showed that young fish appeared to be attracted to a higher root density (Cocheret de la Moriniere et al. 2004, Nagelkerken et al. 2010).

Different aspects of mangrove's structural complexity and its ecological function as a nursery for estuarine communities have been investigated. These elements include food availability, shelter, and shade. However, the effect of different levels of disturbances of mangroves stands, and the cascading consequences of these disturbances on the estuarine community has rarely been addressed. Hence, there is a need to investigate the effect of mangrove disturbances, because anthropogenic factors can affect the density and structure of mangrove forests, which may in turn cause negative ecological or economic impacts (Barbier and Cox 2003). In Southeast Asia, for instance, the construction of fish ponds is one of the largest sources of disturbance (Sukardjo 2004). Other disturbances include the construction of roads, human settlements, or industries. Anthropogenic factors have been linked to increased forest fragmentation, habitat loss for organisms, and decreased the density of large trees (Collingham and Huntley 2000, Golden and Crist 2000). We, therefore, expect a reduction in the quality of the mangrove nursery habitat under increased human disturbance.

The aim of this experiment is to quantify the influence of the mangrove root structural complexity on the coastal marine fish and crustacean community using artificial mangrove units (AMUs). The AMU platform was designed as an open trap with different trap sizes, and with the various densities of sticks (i.e., roots), simulating the variables that influence the structural complexity of mangrove habitats. The experiment was performed at three locations with different levels of anthropogenic disturbance. It was expected that higher abundance and diversity of fish and shrimp would be found in larger traps, in traps with greater density of sticks, and under the lowest level of anthropogenic disturbance.

3.2 Data collection

3.2.1 Site description

The study was carried out in the Berau Delta, East Kalimantan, a delta with a total area of 2850 km^2, extending 113 km from North to South and 35 km from the river mouth to the mainland. The vegetation along the river and coast is dominated by *Rhizophora* sp (Siahainenia et al., in Chapter 2). The average tidal amplitude in the area was 1.7 ±0.7m (SD; neap tide 0.7 ±0.3m and spring tide 3.0 ±0.4m) and the average depth at the three research sites was 2.2 ±0.2m, increasing to 3.8±0.2m at high tide and with lowest values 0.2±0.3m at low tide. Average underwater visibility was 110±32 NTU during the pilot study, as measured by a Horiba W-23XD Water Quality Meter. Tidal amplitude was measured continuously during the research period through a tide gauge installed in Pegat village, at the center of the study area.

Three locations have different anthropogenic disturbances were selected. (a) Gunung Padai area, where the mangroves were least disturbed. (b) Lungsuran Naga area, where 20% of the mangroves have been converted to fish ponds as calculated from Landsat images from 1991 and 2009 (unpublished data), and (c) Batumbuk area, where more than 50% of the mangroves have been converted to aquaculture ponds. Research sites (Figure 3.1) were selected based on the geomorphology of the coastline, to ensure morphological similarity between research areas.

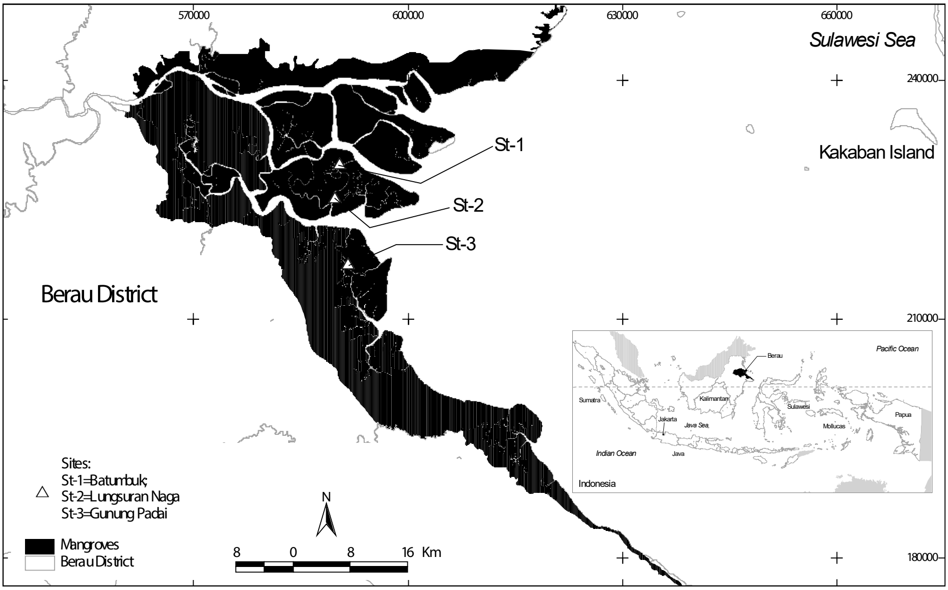

Figure 3.1. Map of study area.

3.2.2 Field methods and sampling design

3.2.2.1 *Experimental design*

Within each of the three research sites selected, six artificial mangrove unit platforms (AMU) were built. Three sizes of platforms were used 1x1m, 2x2m, and 4x4m. Wooden poles (sticks) (150cm long, with a diameter 2.9cm, of *Shorea* sp.) were attached to the platform at different stick densities (Table 3.1). The design of the platforms is presented in Figure 3.2.

Table 3.1. Distribution of Artificial Mangrove Unit (AMU) platforms in the three locations, with their respective sizes (m^2), stick density (n/m^2), and level of disturbance.

Location	Platform	Size (m^2)	Density (n/m^2)	Disturbance
Batumbuk	1	4	13	High
Batumbuk	2	4	20	High
Batumbuk	3	4	6	High
Batumbuk	4	1	6	High
Batumbuk	5	16	6	High
Batumbuk	6	4	6	High
Lungsuran Naga	1	4	13	Intermediate
Lungsuran Naga	2	4	20	Intermediate
Lungsuran Naga	3	4	6	Intermediate
Lungsuran Naga	4	1	6	Intermediate
Lungsuran Naga	5	16	6	Intermediate
Lungsuran Naga	6	4	6	Intermediate
Gunung Padai	1	4	13	Low
Gunung Padai	2	4	20	Low
Gunung Padai	3	4	6	Low
Gunung Padai	4	1	6	Low
Gunung Padai	5	16	6	Low
Gunung Padai	6	4	6	Low

3.2.2.2 *Sample collection and identification*

Samples were taken during daytime (8:00 – 16:00) for 60 days from December 2009 – February 2010. On each day, six platforms in one site were sampled. The AMU platforms were tested using a net drop method (Pihl and Rosenberg 1982), and a lift-net. The lift-net was set up at the bottom, on the platform, with nylon ropes connected to the platform for sampling (Figure 3.2). When taking a sample, the four-drop nets on each side were released using a quick release mechanism, enclosing the platform and preventing animals from escaping from the platform. The wooden sticks were then removed, after which the lift-net was lifted together with the drop nets to extract all animals from the plot. The entire catch was preserved in 5% formaldehyde and 25% ethanol for further analysis.

Individuals larger than 14mm were identified to species-level and counted, measured, and weighed. Individuals smaller than 14mm in length were pooled based on species considered and sub-sampled. The number of individual species in a sub-sample were counted and the total number present estimated by using a weight factor. Unknown species were given a unique code and were preserved for identification at Indonesia Science Institute of Oceanography (P2O-LIPI) Jakarta.

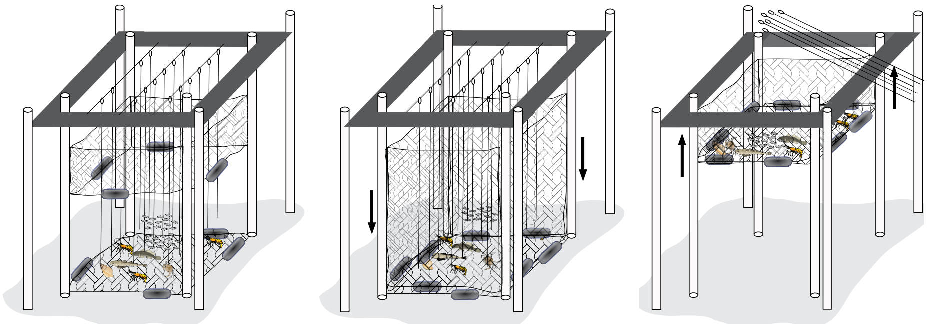

Figure 3.2. Schematic diagram of a AMUs platform in: (a) its normal position (drop-net hanging, lift-net setup at the bottom, (b) the sampling position (drop-net released with quick release mechanism and fish/shrimp trapped, (c) and the position during the sample collection (drop-net and lift-net was lifted together with fish/shrimp.

3.2.2.3 *Statistical Analysis*

Statistical analysis was carried out by using a Generalized Linear Model (GENMOD). We used maximum likelihood calculations, to test the effect of stick density, platform size, and site on each of the dependent variables (number of fish, the number of shrimp, and the number of species). Due to the data consist of fish and shrimp numbers; we are using a negative binomial distribution in SAS Software (SAS 9.2).

To correct for confounding variable, also the month, tidal range (Range, the maximum difference between low and high water at that day), and the Time After High Tide (THAT) at the moment of sampling were included as predictor variables in the model. We expected to find a hump-shaped relationship between THAT, and the number of individuals and species, with the highest number of low water, so that we also included its squared term (THAT2) in the analysis as to account for these non-linear tidal effects. The GENMOD was carried out using a backward selection of predictor variables, maintaining only the significant terms in the final model. The abundance of shrimp and fish in the research sites was also analyzed using a negative binomial distribution. We used a Poisson distribution for the analysis of differences in species richness as the data consisted of counts of species.

3.3 **Results**

3.3.1 The abundance of shrimp

The final model of the Pearson Chi-Square value indicated a good model fit for the shrimp density analysis (N=360, DF=350, value=380.9 and value/df=1.08). The final model, retaining only significant factors, showed that the abundance of shrimp increased with platform size (χ^2 = 49.6, df = 2, P = <0.0001; Figure 3.3a), and stick density (χ^2 = 15.7, df = 2, P = 0.0006; Figure 3.3b). Largest shrimp catches were reported from February (χ^2 = 25.1, df = 2, P = <0.0001; Figure 3.3c). There was a significantly lower shrimp abundance in high and intermediate disturbed sites compared to the level disturbance location (χ^2 = 14.9, df = 2, P = 0.0006; Figure 3.2d; Table 3.3). With increasing difference between high and bottom water during sampling (i.e., tidal range) the shrimp abundance increased (χ^2 = 5.2, df = 1, P = 0.02).

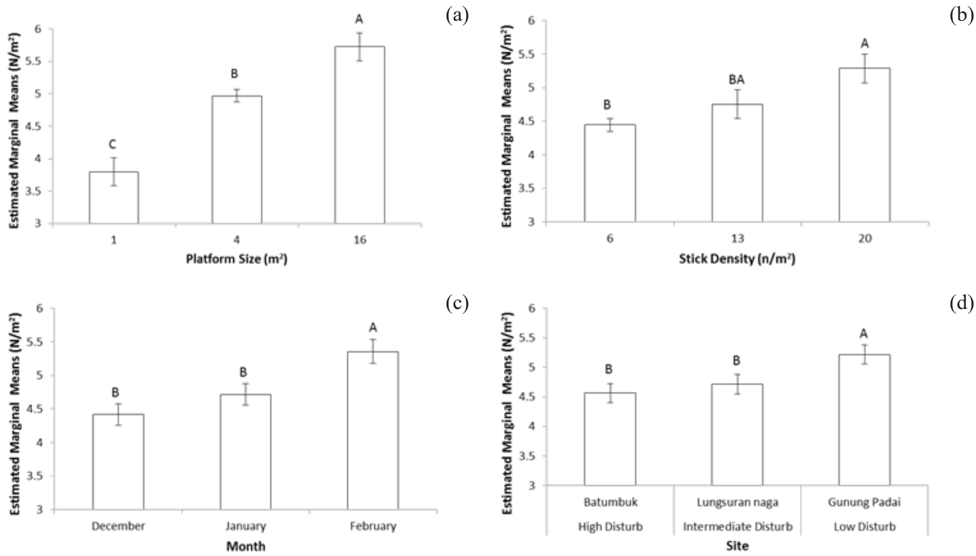

Figure 3.3. The abundance of shrimp as plotted against (a) platform size, (b) stick density, (c) month of sample collection, and (d) disturbance level. The y-axes show estimated marginal means, N/m² (Wald 95% confidence intervals, N = 360).

3.3.2 The abundance of fish

The Pearson Chi-Square value indicated a good model fit for the fish density analysis in the final model (N=360, DF=353, value=311.4 and value/df=0.9). The abundance of fish significantly increased by platform size (final model; χ^2 = 86.0, df = 2, P = <0.0001; Figure 3.4a), and stick density (χ^2 = 55.9, df = 2, P = <0.0001; Figure 3.4b), but the location had no effect on fish catches. Largest fish catches were reported from January (χ^2 = 11.5, df = 2, P = 0.003; Figure 3.4c).

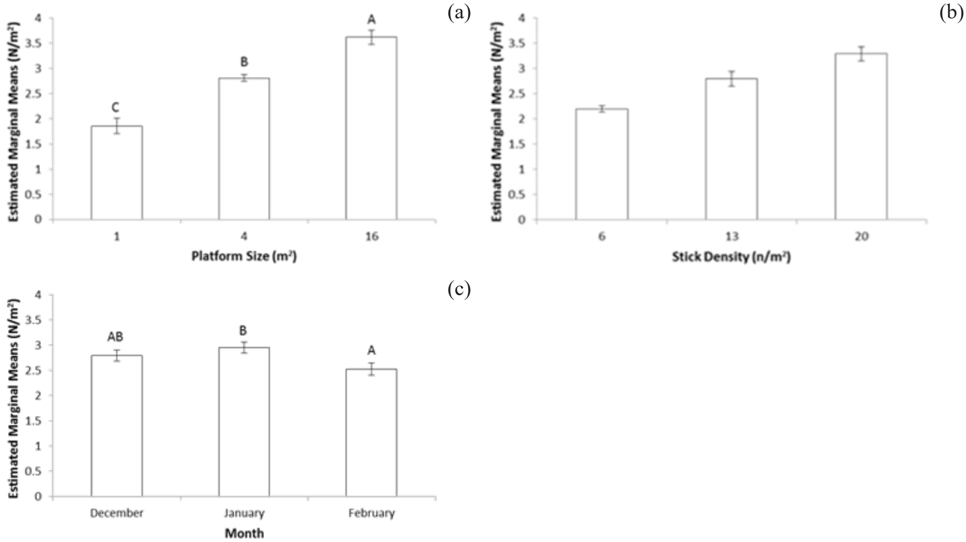

Figure 3.4. The abundance of fish as plotted against: (a) platform size, (b) stick density, and (c) month of sample collection. The y-axes show estimated marginal means, N/m² (Wald 95% confidence intervals, N = 360).

3.3.3 The number of species

The Pearson Chi-Square value indicated a good model fit for the latter analysis (N=360, DF=353, value=345.4 and value/df=0.9). The number of species significantly increased with platform size (final model; $\chi^2 = 36.4$, df = 2, P = <0.0001; Figure 3.5a), and stick density ($\chi^2 = 31.6$, df = 2, P = <0.0001; Figure 3.5b), but no effect of location could be detected. A larger number of species were reported in February ($\chi^2 = 7.8$, df = 2, $P = 0.02$; Figure 3.5c).

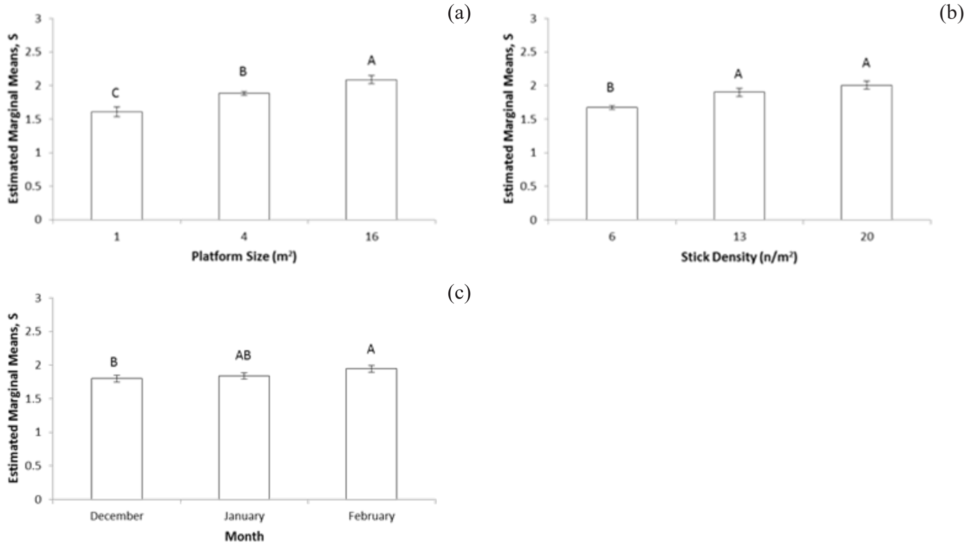

Figure 3.5. Number of species on (a) platform size, (b) stick density, and (c) month of sample collection. The y-axes show estimated marginal means of the number of species, S (Wald 95% confidence intervals, N = 360).

Table 3.2. Scientific names of species caught in AMUs during the experiment by location, indicated are number of samples in which at least one specimen was encountered, median, maximum and minimum number from total sampling (N=360 AMU samples)

Species	Site - 01 (High)				Site - 02 (Medium)				Site - 03 (Low)			
	N	*Med*	*Max*	*Min*	*N*	*Med*	*Max*	*Min*	*N*	*Med*	*Max*	*Min*
Ambassis urotaenia (Bleeker 1852)	1	22	22	22	2	19.5	21	18	-	-	-	-
A. marianus (Günther, 1880	1	20	20	20	-	-	-	-	-	-	-	-
Arius maculatus (Thunberg, 1792)	1	10	10	10	2	6.5	10	3	1	22	22	22
Caranx papuensis (Alleyne & Macleay 1877)	1	4	4	4	3	4	7	2	-	-	-	-
Channa striata (Bloch, 1793)	39	2	10	0	38	3	18	1	40	2	22	1
Chanos chanos (Forsskal, 1775)	1	20	20	20	1	17	17	17	1	10	10	10
Dermogenys sumatrana (Bleeker, 1854)	19	2	9	1	18	2.5	8	1	18	2	12	1
Doryichthys martensii (Peter, 1868)	-	-	-	-	1	1	1	1	-	-	-	-
Eleutheronema tetradactylum (Shaw, 1804)	4	7.5	20	3	3	9	9	4	5	12	30	3
Epinephelus coioides (Hamilton, 1822)	1	6	6	6	1	2	2	2	2	7	12	2
Glossogobius giuris (Hamilton, 1822)	16	6	22	1	12	4.5	21	1	17	8	40	1
Lepidopus caudatus (Euphrasen, 1788)	-	-	-	-	1	3	3	3	-	-	-	-
Lutjanus fulvus (Forster, 1801)	2	10	18	2	2	3	5	1	1	16	16	16
L. argentimaculatus (Forsskal, 1775)	14	2.5	7	1	19	4	20	1	20	2.5	14	1
Pampus argenteus (Euphrasen, 1788)	4	7	12	3	2	4.5	7	2	6	5.5	10	3
Parapriacanthus ransonneti (Steindachner, 1870)	-	-	-	-	1	5	5	5	-	-	-	-
Rastrelliger kanagurta (Cuvier, 1816)	3	6	10	3	4	4.5	10	3	1	8	8	8
Rhyacichthys aspro (Kuhl & van Hasselt, 1823)	18	2	12	1	15	2	10	1	19	3	12	1
Scatophagus argus (Linnaeus, 1766)	25	10	22	2	27	8	30	1	28	7.5	28	2
Siganus canaliculatus (Park, 1979)	7	4	20	1	5	8	10	2	13	6	12	1
Stolepholus indicus (van Hasselt, 1823)	51	10	32	1	40	10	32	1	43	7	41	1
S. waitei (Jordan & Seale 1926)	-	-	-	-	1	7	7	7	-	-	-	-
Syngnathoides biaculeatus (Bloch, 1785)	27	4	32	1	25	6	32	1	27	4	20	1
Taxotes jaculatrix (Pallas, 1767)	18	6	21	1	18	2	11	1	19	3	16	1

Table 3.2. Continued……

Species	Site - 01 (High)				Site - 02 (Medium)				Site - 03 (Low)			
	N	*Med*	*Max*	*Min*	*N*	*Med*	*Max*	*Min*	*N*	*Med*	*Max*	*Min*
Tetraodon sabahensis (Dekkers, 1975)	26	6.5	28	2	28	5	18	1	30	6.5	26	1
Trichiurus lepturus (Linnaeus 1758)	-	-	-	-	2	5	8	2	-	-	-	-
Alpheus estuariensis (Christoffersen, 1984)	3	1	2	1	2	2	3	1	6	2	3	1
Metapenaeus ensis (de Haan, 1850)	38	12	74	1	40	8.5	62	1	42	12	56	1
M. endeavouri (Schmitt, 1926)	-	-	-	-	2	8.5	9	8	-	-	-	-
M. brevicormis (Milne-Edwards, 1837)	67	6	159	1	69	4	82	1	71	6	142	1
Panaeus indicus (Milne-Edwards, 1837)	110	10	159	1	126	9	95	1	125	9	185	1
P. latisulcatus (Kishinouye 1896)	56	11.5	142	1	70	12	109	1	69	12	264	1
P. merguiensis (de Man, 1888)	12	25.5	101	6	14	22	112	10	20	19.5	215	1
Penaeus spp. (Mysis)	72	57.5	1058	5	70	61	769	3	92	90	792	3
Parapenaeopsis sculptilis (Heller, 1862)	10	8.5	26	2	9	7	38	1	9	7	29	1
Trachypenaeus granulosus (Haswell, 1879)	11	26	62	15	10	25	58	16	8	54	80	21
Octopus	-	-	-	-	-	-	-	-	1	2	2	2
Squid	-	-	-	-	1	3	3	3	1	7	7	7
Estuarine sea stars	9	2	8	1	14	1.5	8	1	20	2.5	12	1
Crabs	91	2	18	0	92	2.5	11	0	79	4	17	0
Bivalve	52	4	12	1	51	4	12	1	54	4	22	1
Fish parasite	-	-	-	-	-	-	-	-	1	2	2	2
Gastropod	7	3	7	1	4	5.5	15	2	4	8	10	6

3.4 Discussion

We conducted our experiment with sticks to represent roots within the natural mangrove environment. With increased number of wooden poles, representing a component of the mangrove root structural complexity, the abundance of shrimp and fish, as well as the number of species increased (Table 3.2). Our finding is consistent with our expectation and previous studies (Cocheret de la Moriniere et al. 2004).

Furthermore, the effects of stick density indicated that mangroves provide shelter for various marine organisms. It was also shown that the presence and the ferequency of sticks, which provided a sophisticated submerged structure, positively influenced the species diversity in the experimental area. The submerged sticks could function as barriers, which can hinder the movement of water and promote sedimentation of small particles. Juvenile shrimp use sediment particles as a cover to escape from their predators. The presence of the sticks and associated sediment accumulation can increase the structural complexity, providing favorable habitat for, e.g., cockles, and also facilitating the growth of, e.g., echinostome parasites, which in a different situation would not be able to grow in the area (Thomas and Poulin 1998).

Mangrove pneumatophores provide structures that can be used by juvenile shrimp as a refuge from predation. However, the availability of these structures alone is not always sufficient to protect shrimp from predators, especially at low pneumatophore density (Primavera 1997). The quality of the shelter is determined by the complexity and density of the structure. With an increase in structural complexity as represented by the stick density, predation risk may decrease. This decrease could also be correlated with a reduction of visual contacts between prey and predators (Macia et al. 2003). It has for instance been shown that in areas with a high density of prop-roots, predation on post-larvae shrimp and juvenile shrimp decreased significantly (Robertson and Duke 1987, Thayer et al. 1987).

The platform size had a larger relative effect than the effect of wooden pole density (Figure. 3.2). A larger platform size resulted in increased abundance of shrimp and fish, as well as in the number of species, which is similar to the results reported previously (Cocheret de la Moriniere et al. 2004). Platform size was used here as a proxy for the scale of a mangrove patch for juvenile shrimp and fish. It is assumed that the larger the size of the platform, the nore significant its role as a shelter against predators. A larger area with high density of sticks is also expected to promote lower and scattered light conditions, thereby reducing the contrast and providing shade. Hence, the chance of prey being detected by predators may decrease, enhancing the survival rate of juvenile shrimp and fish.

Disturbances to mangroves can influence the root structural complexity directly through, for example, utilization of wood from mangroves with complex root structures (i.e., *Rhizophora sp*, *Bruguiera* sp.), or indirectly, through the land clearing of the area covered by *Nypa fruticans*. Mangrove species are distributed in zones (Macnae and Kalk 1962), where *Avicennia* sp. Dominated the coastline, the riverine area is dominated by *Rhizophora* sp., and landward areas with higher altitudes are dominated by Nypa palms (Chong et al. 1990). This zonation was also seen in Berau Delta. The clearing of Nypa palms may change the soil type in the riverbanks from mud to sand. This alteration makes the riverbanks less habitable by mangroves with complex root structure, which may further negatively affect shrimp abundance.

Unlike the shrimp abundance, the fish abundance and the number of fish species were not influenced by the different locations of the AMUs. The fish abundant might be due to certain differences in site characteristics, which were not included in the initial criteria for site selection. It was observed that the bottom substrate in Gunung Padai was less coarse compared to the substrate in Batumbuk and Lungsuran Naga. It is known that some *Penaeid* species prefer soft substrate to bury themselves during the day to avoid predation (Vance and Staples 1992, Primavera 1998). Another possibility is that shrimp are more sensitive than fish to minor changes in their environment which may have caused by directly or indirectly human disturbances, such as from insecticide pollution from activities at ponds (Krieger 2001). However, to study the influence of disturbance caused by the different loations, a larger experiment is required that includes repetition of interference levels, as the current set-up is not suitable to properly test this.

In February, the abundance of shrimp and the number of species increased, while the abundance of fish decreased (unpublished data). This reason of increasing abundance of shrimp could be related to annual variability in the abundance of shrimp larvae, as confirmed by local fishermen who indicate that juvenile shrimp reach their highest densities around February.

In conclusion, the size of a mangrove area and the densities of the mangrove roots, as simulated in our AMU-experiment, increased the density of shrimp and fish, probably by providing shelter against predators due to the sticks which obstruct predators and reduce visibility (Cocheret de la Moriniere et al. 2004). The anthropogenic disturbance was negatively correlated with the shrimp abundance, but not with the fish abundance and species diversity. Anthropogenic disturbances in mangrove areas that alter the structural complexity of the root zone of these forestz (e.g., by cutting, trampling or otherwise damaging mangroves trees, saplings or roots) may result in the loss of shelter, which is an important habitat quality parameter for juveniles fish and shrimp. This study provides more information about the importance of mangrove structural complexity for juvenile shrimp and fish.

Chapter 4

Impact of spatial context on catches of small-scale fisheries in the Berau Delta, Indonesia

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Abstract

Most shrimp species select different parts of coastal and estuarine habitats, like mangroves, shallow sandy waters, and rivers with tidal variation, at particular stages of their life cycle. The aim of this study was to investigate whether the spatial context affected the catch-per-unit-effort (CpUE) of shrimp catches by local fishermen using three different fishing gears (minitrawls, trammelnets, and gillnets). These three gears were deployed at various depths in the estuary. Factors such as the distance of the fishing location to the coastal habitats and the exrtent of the fishing locations were analyzed for their effects on CpUE. The survey catch data was obtained from 638 respondents in 2006. We expected that catch-rates would be positively associated with the extent of mangrove forests and would decrease with increasing distance from mangrove forest. Statistical analysis showed that the magnitude of the land cover classes (coastal habitats) affected CpUE over distances ranging from 1-32 km. The relationships between shrimp catches and the distance to estuarine habitats were often negative for minitrawls, trammelnets and gillnets, meaning that with increasing distance from the estuarine habitat types, CpUE decreased. Trammelnets CpUE was positively correlated to the extent of the estuarine waters. The results highlight the importance of the spatial configuration of the estuary on shrimp catches and the spatial scale at which this habitat affects shrimp catches.

CHAPTER 4

Impact of spatial context on catches of small-scale fisheries in the Berau Delta, Indonesia

4.1 Introduction

Shrimp is one of the leading commodities from fisheries and aquaculture activities in Asia, including Indonesia (Hall 2004, Tran et al. 2013). The global consumption of shrimp increased the market demand for this product (Newton et al. 2014), increasing the value of shrimp sold at local, national and global markets. Hence, fishermen have an incentive to increase their wild shrimp catches by increasing their fishing effort, using a variety of fishing gears. However, these catches also depend on the abundance of adult shrimp stock, and shrimp sizes (Sheaves et al. 2013, Baker et al. 2014*)*. The distribution of shrimp is affected by a range of environmental factors and spatial attributes that affect the growth and survival rates of juvenile shrimp in different habitats (Primavera 2005a, Barbier 2007a, Chong 2007). For instance, natural mangrove habitats provide shelter around mangrove roots. This mangroves area also support food resources such as leaf litter for juvenile shrimp and fish (Laegdsgaard and Johnson 2001, Verweij et al. 2006, Blaber 2007, Lentner and Ellis 2014), and therefore co-determines the distribution of adult shrimp stock in coastal areas and with that the allocation of fishery activities.

Besides wild catches, shrimp are often grown in aquaculture farms to meet the increasing market demand. Shrimp farmers often convert mangrove forests into shrimp farms, negatively affecting the total area of mangroves, and globally 11% of the mangrove area has already been transformed for shrimp aquaculture (Valiela et al. 2001, Alongi 2002, Bengen 2003, Primavera 2005a, Sidik 2008). Also in the Berau Delta, Indonesia, a reduction in the mangroves forest area has been reported (Siahainenia et al., in prep: Chapter 2). However, both shrimp aquaculture production and wild catches are indirectly supported by mangrove habitats, as they serve as nursery areas for shrimp (Martosubroto and Naamin 1977, Primavera 1995, Jenness 2005, Blaber 2007).

Tropical mangrove forests are one of the most productive coastal ecosystems and function as a nursery ground for many marine species (Sukardjo et al. 2013a, Alongi 2014). The food availability in mangrove forests partly drives the productivity of shrimp species (Primavera 1996). The impairment of mangrove habitats may, therefore, result in a decreased function of mangroves as a natural supplier of shrimp to the surrounding estuarine and coastal ecosystems (Primavera 1995, Rönnbäck 1999, Manson et al. 2005a). Some shrimp species, such as the white shrimp (*Panaeus indicus*), will be profoundly affected as they almost exclusively use mangrove habitats during their juvenile stages (Rönnbäck et al. 2002, Vance et al. 2002, Kenyon et al. 2004, Loneragan et al. 2005). Other shrimp and fish species may use mangroves to hide from predators, and to forage during some life stages, but they are not entirely dependent on mangroves. A weak functioning of mangrove forests may lead to decreased survival rates of shrimp, hence to lowered stock sizes comparable to what was found in coral reef fish communities that also used mangroves during part of their lifecycle (Mumby et al. 2004).

Beck et al. (2001) on page 635 defined a nursery as "…. if its contribution per unit area to the production of individuals that recruit to adult populations is greater, on average, than production from other habitats in which juveniles occur". Many studies have been carried out to understand the relationships between the presence and sizes of mangroves forest, and nearby shrimp catches (Beck et al. 2001, Manson et al. 2005b, Hill and Weissburg 2013). A study about shrimp catches concerning the mangrove extent in Malaysia (Loneragan et al. 2005) showed that shrimp catches were negatively affected by damage to mangroves. Besides, the contribution of other estuarine habitats are also important (Laegdsgaard and Johnson 2001, Barbier 2003, Hajisamae et al. 2006, Hajisamae and Yeesin 2014), These also support shrimp populations, influencing the overall supply of wild shrimp stock, which is essential for the continuity and sustainability of the fishery activities of local communities. Manson et al. (2005a) showed that the positive influence of mangrove forests on fisheries catches depended on a range of spatial factors and attributes, including the distances between fishing locations and mangrove forests. In their study, however, information on fishing locations, catch rates, and species composition was limited to low resolution spatial and temporal aggregations. Moreover, to analyze impacts of mangrove cover and change concerning shrimp distribution, variables like the extent of mangrove forest should be measured at the appropriate scale. Most research focused on localized variables without taking the spatial context into account. Studies of a combination of variables at different spatial scales are required to capture better the spatial configuration of the landscape surrounding a fisheries location, and to better understand the relationships between catch rates and environmental variables.

The aims of this paper are, therefore, to study the relationship between shrimp catch rates of three different gears (minitrawls, trammelnets, and gillnets) with the spatial configuration of nearby mangrove forests and other marine habitat types (distance, area). The three types of fishery gears target shrimp in different parts of the estuary in the Berau Delta. We hypothesized that shrimp catch rates are positively associated with the extent of mangrove forests and shallow estuarine areas and negatively related to the distance to the mangrove forest.

4.2 **Methods**

4.2.1. Study area

The Berau Delta and its estuarine area have a coastal length of 110 km. Based on a map with a resolution of 1:1000 meter (DISHIDROS Map Np.78). Berau River dissects the estuarine area has 15 channels and 220 creeks and has a total coast length of 2500 km. There are 77 larger and smaller islands scattered in the delta with an entire coastline of 1400 km. The mangrove forests have more than 30 mangrove tree species and cover a total area of 600 km^2 (Wiryawan et al. 2004). In 2006 more than 15% of the mangrove area (especially mangrove palms areas) in the Delta appeared to be converted to aquaculture ponds with a total area of 104 km^2.

The Berau Delta is home to about 10,400 people, distributed over 10 coastal villages (BPS 2009). About 15% of the population, 1600 people are fishermen who use different fishing gears and target a range of species. The fishing grounds of these fishermen (Table 4.1) are mainly located in the shallow estuarine waters, less than 30m deep, and below four nautical miles from the coastline. The size composition of the shrimp catches influenced by the mesh size of the net, the fishing techniques, the fishing gear, and the time, location and duration of the fishing activities. A range of these gears targets five shrimp species – *Penaeus merguensis*, *P. indicus*, *P. monodon*, *P. semisulcatus* and *Oratosquilla nepa*. In this study, we focus on three gears: gillnets, trammelnets, and minitrawls.

Gillnets and trammelnets are passive devices (Liang et al. 2013). In Indonesia, gillnets with large mesh sizes (35-70 mm) are applied using drifting techniques, following the movement of the tides. Trammelnets comprise three different mesh sizes (outer net 79-100 mm; inner net 35-50 mm) and are set anchored to the bottom. Minitrawls, small otter-board trawls, are active fishing gear (Cochrane and Garcia 2009). The nets have a small mesh size (<20 mm) and are towed by a motorized boat with a speed of around 3-5 $km.hr^{-1}$ (Boopendranath 2013). (See Appendix A for a full description of these gears).

4.2.2 Data sampling and environmental variables

In this study, we use two datasets. The first dataset comprises estuarine fisheries data collected as a part of a resource use monitoring program in 2006. The second dataset consists of multiple environmental variables, such as the extent of mangroves forests, riverine area and the distribution of several depth classes of shallow estuarine areas (i.e., 0-5 m, 5-10 m, 10-20 m and >20 m; Table 4.2).

4.2.2.1 *Fisheries data*

634 fish data records, containing shrimp catches, were collected from fishermen fishing in the estuarine area adjacent to the Berau Delta. In total 599 records were from the three gears selected for this study. The data were collected using a roving creel surveys method (see Appendix C). During 2006 once every two weeks an investigation was held, resulting in a total of 30 study trips each with a 3-day duration. For a detailed description of the survey method and the data collected see Siahainenia et al., Chapter 5 in this thesis. A standardized catch per unit effort (CpUE) was estimated by applying a general linear model (GLM). The variable data consist of a year, month, fishing duration (i.e., the number of hours the boat had been fishing prior to the survey encounter), and location of the fishing vessels as fixed factors, using a lognormal error structure (chapter 5).

CpUE is usually calculated for a particular period, and corrections were made, accounting for the difference in the total number of hours fished (i.e. fishing duration), by calculating the size of positive catches at a full fishing day per gear type (this thesis chapter 5). CpUE was defined as catch per standard trip per gear type, corrected for differences in an effort (fishing duration).

Positive catches were standardized to a regular fishing trip by regressing the 10log-transformed positive catch over the 10log-transformed reported number of hours catch. The estimated slopes of the regressions equations were used to estimate the standardized catch rate (kg.trip^{-1}) by gear type:

$$CpUE_i^s = CpUI_i \cdot \left(\frac{H_s}{H_i} \right)^{\beta}$$

Where:

$CpUE_i^s$ = the standardized (s) total catch rate for the i-the fishing trip (kg.hr.trip^{-1}),

$CpUI_i$ = the observed total catch rate of the i-the fishing trip,

H_S = the mean value for the standard fishing duration

H_i = the actual observed fishing hours (fishing duration) of i-the fishing trip.

β = the estimated slope parameter, estimated from the linear regression

We extracted CpUE data for the three different fishing gears (i.e., gillnets, trammelnets, and minitrawls), and tested for a correlation between the CpUE data and the distance and the extent of each of the land cover classes using different buffer distances. At H_s, the probability of catch for the three gears was about 98% (see Chapter 5) and hence no correction was made for reported zero catches. Fishermen that had no catch at encounter were excluded from the analysis.

4.2.2.2 *Land cover data*

The land cover data of the Berau Delta were derived from Landsat 5TM imagery from 2006 with total cloud cover less than 10%. We classified the Landsat imagery in seven classes (i.e., coastal forest, settlement, and mangrove forests, aquaculture ponds, and rivers/channels, shallow estuarine water over several water depth levels, pelagic area, and coral reefs). For this research, we combined mangrove trees and mangrove palms into one habitat type named mangrove forests, as many mangrove palm areas have been replaced by ponds (chapter 2), and we did not expect to find a large difference between the effects of mangrove palms and mangrove trees on shrimp CpUE.

For this Landsat imagery classification, we used the Land Use/Land Cover (LULC) method, combined with 100 random data points of field ground truthing, and a base map from the National Geospatial Information Agency, the Badan Informasi Geospasial (BIG). The information about the depth of shallow estuarine waters and pelagic area were obtained from bathymetry map no.18, produced by the National Hydrology and Oceanography Agency (DISHIDROS). This bathymetry map consists of depth information and contour lines of the estuarine and pelagic area. These bottom data points were validated with 250 randomized depth data points obtained from an echo sounder (Garmin Map76). We then separated the estuarine area in three depth classes (i.e., <2 m, 2-5 m, and 5-20 m). The pelagic area was defined as areas >20 m in depth. The calculations of the total area of the different land cover classes were carried out using the mapping program ArcGIS (v.10.2).

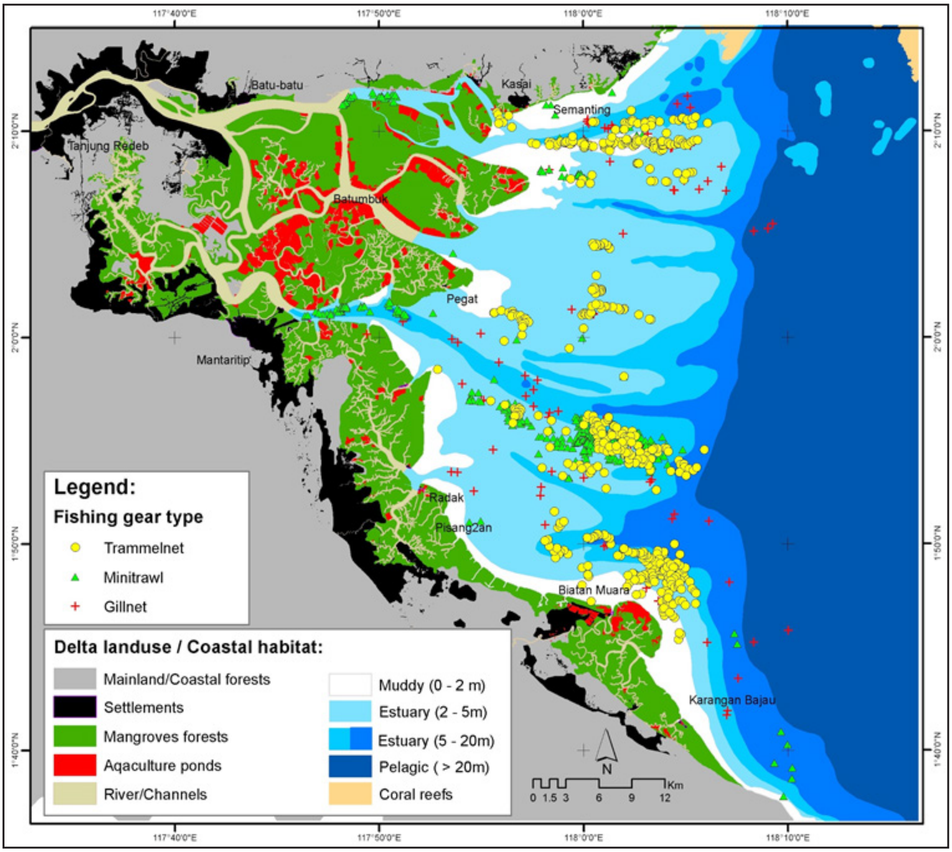


Figure 4.1. The distribution of three dominant fishing gears (minitrawls, trammelnets, and gillnets) operating in the Berau Delta as encountered during the roving creel surveys in 2006.

4.2.3 Spatial measurement

We used two types of measurements to test for the relationship between the catches at a precise location and landuse cover classes. (a) The nearest distance, for which we measured the distances between the site of each fishing boat in the Berau Delta to the nearest habitat using the nearest-dist function in ArcGIS (Jenness 2002); and (b) The buffer area: we measured the extent of each of the land cover classes using different buffer distances. Within a circle, a location the size of the habitat areas were calculated in circles with various radii, from 0.5, 1, 2, 4, 8, 16, 32, 64, to 128 km.

4.2.4 Data analysis

We tested for a correlation between the CpUE data and the distance and the extent of each of the land cover classes using different buffer distances. Around each CpUE data point, buffer distances with increasing radii (i.e., 0.5, 1, 2, 4, 8, 16, 32, 64, 128 km) were made. We used the intercept function in ArcGIS to calculate the proportion of habitat in each buffer area for each of the CpUE data points. We assumed that there would be an optimum fit at intermediate distances, as the extent of a particular land cover class in a circle of, e.g., 0.5 or 128 km around the catch location was not expected to yield the highest explanatory power for catch sizes at a certain location. Using regression analysis, for each of the three gear types and each of the land cover classes, we first calculated which spatial extent yielded the highest r^2 in the regression with CpUE. The degree with the highest predictive power was subsequently used in the multiple regression models (see below). The spatial data was calculated using ArcGIS (v10.2) and the regression analyses were done in SAS (v9.3).

Next, a multiple regression was applied to test for the correlation between environmental variables and the wild shrimp catch rates. A separate regression was done for each gear type. A backward elimination selection was used to test whether variation in catch rates was related to the distances to the different habitat types (mangrove habitat, aquaculture ponds, river, and shallow estuarine water in several depth classes, pelagic area, and coral reefs), and the different extents of these habitat types. A full model was first constructed followed by a backward elimination procedure to build the best model with only significant covariates. The full model for each of the three fishing gears used for both the nearest distance and the selected buffer distances per habitat type was:

$$
\begin{aligned}
CpUE_{std} = {} & a + b.CF_{bd} + c.SE_{bd} + d.MF_{bd} + e.AP_{bd} + f.Rvr_{bd} + g.Est02m_{bd} \\
& + h.Est25m_{bd} + i.Est20m_{bd} + j.Pel_{bd} + k.CR_{bd} + l.CF_{nd} + m.SE_{nd} \\
& + n.MF_{nd} + o.AP_{nd} + p.Rvr_{nd} + q.Est02m_{nd} + r.Est25m_{nd} + s.Est520m_{nd} \\
& + t.Pel_{nd} + u.CR_{nd} + error
\end{aligned}
$$

Where:
- $CpUE_{std}$ = standardized catch rate shrimp, by gear, excluding all other species
- CF = coastal forest area (km^2)
- SE = settlements area (km^2)
- MF = mangrove forest area (km^2)
- AP = aquaculture ponds area (km^2)
- Rvr = river/channel area (km^2)
- Est_{02m} = estuarine area at 0 – 2 meter deep (km^2)
- Est_{25m} = estuarine area at 2 – 5 meter deep (km^2)
- Est_{520m} = estuarine area at 5 – 20 meter deep (km^2)
- Pel = pelagic area >20 meter deep (km^2)
- CR = coral reefs area (km^2)
- bd/nd = measurement of buffer density (bd) / nearest density (nd)

4.3 Results

4.3.1 Fisheries activities in the estuarine near the Berau Delta

Of the types of gears type used in the Berau estuarine, trammelnets were observed most frequently (40%; average=5; SD=2.9; Table 4.1), followed by minitrawls (20%; average=5; SD=2.6), gillnets (19%; average=4; SD=2.8), Danish push nets (11%; average=51; SD=18.6), and estuarine traps (8%). Barrier nets were rarely used (2%).

Minitrawl had a larger shrimp catch rate (Table 4.1) compared to trammelnets and gillnets. Only large shrimp sizes become entangled in the broader net sizes of trammelnets and gillnets, whereas the minitrawl shrimp catches consisted of smaller shrimp sizes (unpublished data). While shrimp is a target for minitrawls (average catch 7.9 kg.trip^{-1}; SE 0.6 and trammelnet (average catch 4.4 kg.trip^{-1}; SE 0.2), they were bycatch for gillnets (average catch 1.4 kg.trip^{-1}; SE 0.4) that mainly target Pomfret and sea bass respectively (Table 4.1).

Table 4.1. The total number of records for each fishing gear registered in the Berau Delta area in 2006 and range of observed (i.e., not corrected for differences in trip duration) catches per fishing gear. Mean observed catch rates (kg.trip^{-1}), sample size (N), standard error (SE) and standard deviation (SD) for catches of shrimp and other fish species for minitrawls, trammelnets, and gillnets.

Fishing gear	N	%	Catch rates (kg.trip^{-1})		Shrimp		Others	
			Range	Ave (SD)	Mean	SD	Mean	SD
Trammelnets	337	45	1 – 26	5 (2.9)	4.4	3.5	1.9	10.5
Minitrawls	189	26	6 – 27	5 (2.6)	7.9	9.1	1.2	5.9
Gillnets	73	10	1 – 17	4 (2.8)	1.4	3.4	23.8	33.8
Total	***740***	***100***						

4.3.2 Land cover classes in the Berau Delta

The Berau Delta is covered with coastal forests (41%; Table 4.2), followed by the estuarine area (26%), pelagic area (18%), mangroves forests (11%), and rivers/channels (2%). The settlement and coral reef habitats each cover <1%. The estuarine habitat with the largest cover was in the 2-5 m estuarine water class (13%), followed by 5–20 m (10%), and the smallest cover for the <2 m class (3%).

Table 4.2. Depths (m) and extent (km^2, %) of land cover classes in the Berau Delta.

Land cover class	Depth (m)	Area cover *(km^2)*	Land cover (%)	Coverage area	Fishing area (%)
Coastal forests	-	2318	41	Lands (53%)	-
Mangroves forests	-	613	11	3027 km^2	-
Aquaculture ponds	-	85	1		-
Settlements	-	11	<1		-
Rivers/channels	0 – 17	129	2	Waters (47%)	5
Estuarine	2 – 5	713	13	2647 km^2	27
Estuarine	0 – 2	193	3		7
Estuarine	5 – 20	592	10		22
Pelagic	>20	1007	18		38
Coral reefs	0 – 25	13	<1		<1
Total	**-**	***5674***	***100***		

4.3.3 Nearest distance from fishing spot to the land cover classes.

Fishing boats were mostly recorded fisheries in the estuarine area but their distance to the nearest habitat differed slightly for the different fishing types. The 189 minitrawls (Table 4.3) had the nearest distance of on average 0.3 km to the 2-5 m depth class of the estuarine area. The closest distance to mangrove forests was on average 9 km, and the nearest distance for coral reefs was 36 km. Trammelnets (n=337; 45%) were located at an average distance of 0.8 km from the 5-20 m depth of estuarine area, and the distance to mangrove forest was 7 km, whereas the longest distance was from coral reefs, with the average distance of 35 km. There were 73 gillnet fishermen (48%), with a mean distance of 0.6 km from the estuarine land cover class (2-5 m and 5-20 m depth) and an average distance of 8 km to mangroves. Minitrawls and trammelnets were found mostly in the estuarine areas with the depth between 2-20m, while gillnets were located at the edge of 2-20 m, deep estuarine waters, close to the pelagic area.

In total, there were 599 fishing boats in the estuarine area (98%), followed by <1% of the fishermen fishing in the pelagic area and only <2% of fishermen were fishing in river/channels. The shallow estuarine area (depth 2-5 m), was the favorite habitat where all three fishing gears operated. Minitrawls, trammelnets, and gillnets were mostly found in the estuarine area with a depth of 5–20 m.

4.3.4 Buffer distance analysis

The buffer distances with the highest explanatory power differed over the land cover classes and the fishing gear (Table 4.4), varying between 2-64 km. Vast distances to the coastal forest, settlements, ponds, pelagic areas, and coral reefs (≥16 km) best explained the variation in CpUE. Distances to the shallow estuarine water in the 2-5 m and 5-20 m classes were relatively smaller compared to other classes.

Gillnets fishing gears with large CpUE were more closely associated with the extent of nearby shallow estuarine waters (so relatively small buffer size of 4 km), whereas trammelnet CpUE was better explained by deeper estuarine habitats (2-5 m, 5-20 m) in the buffer around the location of only 1-2 km. Minitrawls CpUE as best illustrated with the extent of mangrove forest and rivers in a buffer of 8 km, but the impact of the magnitude of the shallow estuarine area (0-2 m) was best captured in a large buffer (32 km).

Table 4.3. The mean nearest distance between the fishing locations and each of the land cover classes (km) of three fishing gears in the Berau Delta (n = number of fishing boats; Min = the nearest distance to the land cover class; SD = standard deviation).

Land cover class	Minitrawls (km)				Trammelnets (km)				Gillnets (km)				N	%
	n	*%*	*Min*	*mean (SD)*	n	*%*	*Min*	*mean (SD)*	*n*	*%*	*Min*	*mean (SD)*		
Coastal forests	-	-	0.3	11.2 (5.7)	-	-	0.8	9.9 (5.6)	-	-	0.6	10.7 (5.1)	-	-
Settlements	-	-	0.4	11.4 (4.4)	-	-	1.7	10.1 (4.5)	-	-	2.4	11.4 (4.1)	-	-
Mangrove forest	-	-	0.1	9.0 (5.9)	-	-	0.1	7.4 (4.7)	-	-	0	8.2 (4.0)	-	-
Aquaculture ponds	-	-	0.2	9.5 (5.6)	-	-	0.2	8.4 (4.8)	-	-	0.1	9.2 (4.1)	-	-
Rivers/canals	10	5.3	0	10.3 (6.0)	-	-	0.2	8.9 (4.8)	3	4.1	0.2	9.5 (4.3)	13	2.2
Estuarine 0 – 2m	1	0.5	0	8.6 (3.9)	41	12.2	0	4.6 (4.6)	1	1.4	0	5.2 (3.8)	43	7.2
Estuarine 2 – 5m	100	52.9	0	0.3 (0.6)	154	45.7	0	0.4 (0.7)	33	45.2	0	0.6 (1.2)	287	47.9
Estuarine 5 – 20m	78	41.3	0	2.2 (4.8)	142	42.1	0	0.8 (1.2)	35	47.9	0	0.6 (1.0)	255	42.6
Pelagic >20m	-	-	1	16.4 (12.1)	-	-	0.6	9.9 (4.9)	1	1.4	0	11.3 (6.9)	1	0.2
Coral reefs	-	-	10.4	36.4 (5.9)	-	-	5.7	34.7 (15.7)	-	-	4.6	26.9 (14.8)	-	-
Total	***189***	***100***			***337***	***100***			***73***	***100***			***599***	***100***

4

Table 4.4. Buffer distance (km) that yielded the highest predictive power for each of the land cover classes for three fishing gears (i.e., trammelnets, gillnets, minitrawls) in the Berau Delta. Obtained from comparing the r^2 values from regression analysis with land cover class and catch per unit effort (CpUE), using different buffer sizes.

Land cover class	Minitrawls km (r^2); N=189	Trammelnets km (r^2); N=337	Gillnets km (r^2); N=73
Coastal forests	32 (0.02)**	-	64 (0.03)*
Settlements	16 (0.03)**	-	-
Mangrove forest	8 (0.02)**	4 (0.01)*	16 (0.07)**
Aquaculture ponds	8 (0.02)**	4 (0.02)**	16 (0.09)**
Rivers/canals	8 (0.02)*	8 (0.01)*	16 (0.07)**
Estuarine 0–2m	32 (0.01)*	8 (0.01)*	4 (0.03)*
Estuarine 2–5m	-	1 (0.01)*	-
Estuarine 5–20m	32 (0.01)*	2 (0.01)*	32 (0.06)**
Pelagic >20m	32 (0.01)**	-	32 (0.09)**
Coral reefs	-	-	-

p values: *** = <0.0001, ** = 0.05, and * = 0.1.

4.3.5 The model for spatial context on CpUE of small-scale fisheries

As expected, minitrawl and trammelnet catches had a highly significant positive relationship with the extent (BD) of the shallow (2-5m) estuarine area, where the abundance of shrimp is located (Table 4.5), but the shrimp CpUE of trammelnet was also positively associated with the distance to mangrove forests. Gillnets were not strongly significantly linked to these habitats, probably because their target catch is large sized shrimp which are mostly located in deeper waters between the estuarine and pelagic area. Trammelnets shrimp CpUE was strongly correlated with mangrove habitats, pelagic and coral reefs, probably due to their target catch: fishes and large sized shrimp. Gillnets shrimp CpUE had a strong negatively correlation with the extent of coral reefs (Table 4.5) indicating that with increasing length of nearby coral reefs, shrimp catches decreased.

Table 4.5. Overview of multiple regression models, explaining differences in CPUE of three fishing gears in the Berau estuarine delta by differences the extent of nearby land cover class (BD see table 4.4 for used buffer sizes) and the nearest distance (ND) to each of land cover classes; estimated standard error (SE), significant p-value (p), r^2 and Mallows's Cp index.

Model	Minitrawls (r^2=0.1; C_p =3.2)			Trammelnets (r^2=0.1; C_p =4.4)			Gillnets (r^2=0.2; C_p =1.4)		
	Estimate	*SE*	*p*	*estimate*	*SE*	*p*	*estimate*	*SE*	*p*
Intercept	13.5	3.5	<0.0001	-1.7	1.6	0.3	12.3	6.1	0.04
BD_Estuarine 5-20m				2.0	0.7	0.008			
BD_Estuarine 0-2m				16.7	3.6	<0.0001			
BD_Rivers	-0.1	0.1	0.02						
ND_Mangroves	-1.2	0.3	0.0004						
ND_Estuarine 0-2m	0.4	0.2	0.02						
ND_Estuarine 2-5m	-56.6	17.8	0.002	-43	18.6	0.02	-125.9	53.9	0.02
ND_River				35.0	10.0	0.0006			

Note: BD=buffer distance, ND=nearest distance

4

4.4 Discussion

In the present study, we used two types of measurement (i.e., nearest distance to a land cover class and area or extent of a particular land cover class) to characterize the spatial configuration around the location of a fishing boat. These measurements were used to explain the relationships between shrimp catches at a precise location and the spatial context over various spatial scales. Little is known about the relative influence of spatial contextual environmental factors on the distribution and catches of local estuarine fisheries. Our analysis was carried out separately for three gear types (e.g., minitrawls, trammelnets, and gillnets).

Shrimp movements and fishing gear types in the Berau estuary

The mangrove forests support the wild shrimp population and thereby sustain coastal shrimp fisheries (Laegdsgaard and Johnson 1995, Vance et al. 1996, Barbier 2003, Lee 2004, Loneragan et al. 2005, Barbier et al. 2011). The abundance of a wild shrimp population depends on three factors. (1) The available stock, (2) Fishing pressure, and (3) Continuous supply of young adult shrimp that disperse from their nursery grounds to ofshores (Vance et al. 1990, Vance et al. 1996, Primavera 1998, Laegdsgaard and Johnson 2001, Lee et al. 2014). Mumby (2006) analyzed the connectivity between mangroves and coral reefs for particular reef fishes in the Caribbean through shallow canals. Many studies on the estuarine area indicated that the availability of suitable shelter space and food, contribute to a productive shrimp population (Laegdsgaard and Johnson 2001, Lewis et al. 2003, Loneragan et al. 2005). As shrimp become young adult, they leave the nursery area and move offshore on the outgoing tide. White shrimp move from the shallow estuary creeks into coastal rivers when their size is about 10-12 cm (Muncy et al. 1984). They size extent continue to grow as they move into the depth level of estuaries and thr edge river mouths, where they gather just before turning into the pelagic area and offshore (Muncy et al. 1984). Most shrimp probably leave the mangrove creeks during ebb tides, and this may be more pronounced at night to avoid predation. These edge between estuaries and pelagic areas, termed staging areas by some biologists, serve to accumulate shrimp just before their dispersal into the ocean (Muncy et al. 1984, Sasekumar et al. 1992, Sukardjo 2004, Satyanarayana et al. 2010). Therefore, the dispersal pattern of shrimp starts from their nursery grounds in mangroves, to shallow estuarine water (2-20 m) to their offshore reproductive areas in pelagic waters (>20 m depth).

In the study area, fishing activities in the estuaries depend on the season (Hutabarat and Evans 1985). The local fishermen in the area are knowledgeable the impact of seasonal factors (Gunawan 2012). They use multi-gears depending on their knowledge and skills (Monintja and Yusfiandayani 2001, Nikijuluw 2002, Pomeroy et al. 2014), and select their fishing areas per trip. We recorded three main fishing gears (i.e., minitrawl, trammelnets, and gillnets) in the area, which was all mainly reported from the estuarine waters. Minitrawls operated mostly in the shallow area between 2-5 m depth (Table 4.3) near the main channels in the south of the delta. Trammelnet were also found scattered over the estuarine areas that were 2-20m deep. There were four different groups of trammelnet fishing boats, and three groups were fishing at the river mouth of the main channel, and one group was distributed in the shallow waters in front of Pegat village (Figure 4.1). Trammelnet fishermen sometimes drift away from the channels due to high winds from June to October (Gunawan 2012). The gillnet gears were also located in the deeper river areas or the river mouth toward the pelagic area but also selected mainly the 2-20m deep estuarine areas. Some gillnets were found closer to the reef area in the north part of Semanting village and the south of Karangan Bajau village.

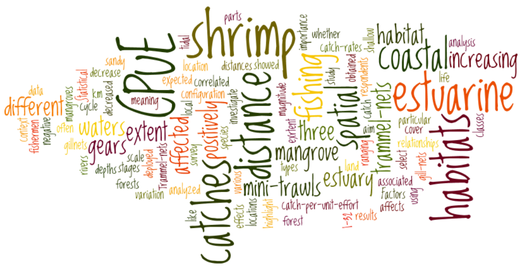
Each of the three gears targeted a particular part of the shrimp population at specific locations in the estuary, e.g., the minitrawls targeted small shrimp, the trammelnets, and gillnets targeted medium to larger adult shrimp (unpublished data). However, it may be a reliable measure of the relative stock size (i.e., comparable over time), as these fishers do the same thing in the same area with the same set of gears over a longer period. Their catches that are highly variable over time, their efforts could be comparable to "random" sampling and hence averaged over all fishers a relative measure of the stock size (i.e., CpUE = q . β). From fishermen, perspective these habitats probably offer the largest shrimp catches for their used gear, to various other production goals (e.g., safety, distance to homeport, limitations to operational flexibility due to equipment, boat, and propulsion characteristics, etc.).

The scaling of the spatial context of the fishing location

Our analyses on the CpUE of minitrawls, trammelnets, and gillnets suggest that distances to rivers, mangroves and estuarine areas are important factors in a spatial pattern that partly explain the change in shrimp CpUE. The size of these different land cover classes also explains part of the variation in shrimp CpUE (Table 4.5). The highest catch rates for minitrawls were recorded closer to estuarine habitats (2-5 m). This shrimp CpUE has probably also to do with seasonal and logistical constraints, such as the distance to homeports. For trammelnets highest catch rates were also reported closer to estuarine waters that were 2-5 m depth, and their CpUE increased further away from rivers. For gillnets, there was no significant correlation between CpUE and mangrove extent or distance to mangroves. This different CpUE can be explained by the fact that trammelnets tend to target fish and crustaceans, but gillnets do not specifically target shrimp. Furthermore, gillnets are therefore also not reported over the entire estuarine area, and their locations are therefore biased towards regions with a high probability of catching fish, such as sea bass near coral reefs. Thus, gillnet locations are not be driven by the spatial variation in the available shrimp stock.

The extent of the estuarine habitats was positively correlated with trammelnet CpUE of shrimp as well. This extent of habitat suggests that the spatial configuration of especially the estuarine area plays a significant role in supporting the shrimp catches through trammelnets. One point of concern is that these relationship are all partly confounded, e.g., closer to rivers or mangroves, means further away from coral reefs or deep estuarine waters. In such a correlative field studies, these effects cannot be separated, and more controlled and systematic sampling will be required to separate all these effects. The catch rates of minitrawls showed a negative correlation with distance to mangroves, maybe because mangrove habitats supply sub-adult shrimp to the estuarine area through rivers and channels, so the closer one fishes with minitrawls next to mangrove forests, the higher the shrimp catches. However, less than 10% of the minitrawls were found close to rivers and mangroves, which are surprising, given the fact that CpUE was higher there (see also Chapter 5). Possible causes are: (1) sampling bias during the creel survey, as the survey boat could only enter waters 1.5 m depth, so not close to the mangrove fringe forest. So, the 10% of the minitrawls observed near rivers, and mangroves could be an underestimation. (2) Minitrawl fishermen may avoid very shallow areas as these are also areas with lots of leaves and soft sediments which hampers trawling, creating difficulties when pulling an otter-board through the soft sediment. Therefore, there are trade-offs in site selection.

This study investigated whether mangrove cover and distance to mangroves and other land cover types in the estuarine delta had a relationship with the abundance of shrimp catches within the Berau estuary. Our results support the link between gear-specific shrimp catch rates and the spatial configuration around their fishing location, although the explanatory power of these analyses was relatively small. Our studies showed that spatial context at an appropriate scale and distance to certain habitat classes could be used to predict the shrimp CpUE partly. We found, as expected that minitrawls catch rates were negatively correlated with the distance to mangrove forests. Trammelnet catch rates increased with increasing extent of nearby shallow estuarine waters, illustrating the importance of spatial configuration of an estuary on catch-rates of small-scale fisheries.


CPUE
shrimp
distance
catches
habitats
estuarine
coastal
spatial
fishing
habitat
increasing
different
mini-trawls
trammel-nets
mangrove
estuary
three
extent
gears
affected
positively
waters

Chapter 5

Effort allocation and total catches of small-scale multi-gear fisheries in the Derawan Marine Conservation Area (DMCA), East Kalimantan, Indonesia

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H.H.T. Prins and J.A.J. Verreth

Abstract

Conservation of marine habitats and economically important fish species is the primary target of many marine protected areas (MPAs). In Indonesia, the MPAs are not closed for fisheries and therefore are also attractive to fishermen that do not live in the area and who sometimes travel long distances from their homeport to fish in the MPA. The aim of this study was to describe the fishing effort allocation and to estimate the total catches of the small-scale fisheries by residency and by gear type over three marine protected habitats in the Derawan Marine Conservation Area at Berau, East Kalimantan, Indonesia. Between February 2005 and August 2009, we sampled the fisheries activities using a roving creel survey technique. Most resident fishermen were habitat specialists, fishing close to their homeports with gear-types that were closely linked to the three habitat types. Non-resident fishermen used the same methods and focussed on the same habitat types. Resident fishermen had a slightly higher average total catch (5600 $t.year^{-1}$) over five years compared to non-residents (4900 $t.year^{-1}$). The maximum fishing pressure was recorded in the coral reefs (average catch 4600 $t.year^{-1}$ or 20 $kg.ha^{-1}.year^{-1}$), which was greater than in the estuarine (3100 $t.year^{-1}$ or 17 $kg.ha^{-1}.year^{-1}$) and pelagic area (2800 $t.year^{-1}$ or 4 $kg.ha^{-1}.year^{-1}$). The highest trip density, 55% of the total, was located in the estuarine habitat, of which 61% was from non-resident fishermen. The total number of trips in the coral reefs habitat amounted to 38% of the total, this time with the highest effort by resident fishermen (60%). The lowest trip density was found in the pelagic habitat (7% of all trips), of which resident fishermen made 55 %. The highest trip density, 55% of the total, was located in the estuarine habitat, of which 61% was from non-resident fishermen. I concluded that the CpUE in the Derawan Marine Conservation Area is low compared to other areas.

CHAPTER 5

Effort allocation and total catches of small-scale multi-gear fisheries in the Derawan Marine Conservation Area (DMCA), East Kalimantan, Indonesia

5.1 Introduction

Marine coastal areas comprising of coral reefs, seagrass meadows, mangroves, and estuarine areas are characterized by a high marine biodiversity and are important for fisheries, marine tourism, and other environmental services (Stephens 2008, Gonzalez and Jentoft 2010, Shearman 2010). Marine Protected Areas (MPAs) are a form of coastal management that aims at conserving marine biodiversity. In particular, in Indonesia, (Ferse et al. 2010, Foale et al. 2013) MPAs also seek to benefit coastal communities, as small-scale sustainable fishing is often allowed as a means to maintain food security (Roberts et al. 2001, Gell and Roberts 2003, Mascia et al. 2010). While fishing is an important economic activity of coastal communities that depend on marine resources in tropical countries (Piou et al. 2007, Kincaid and Rose 2014, Kincaid et al. 2014), the evaluation of the effectiveness of MPAs for those communities is difficult. As fishing can affect the conditions of marine habitats and the availability of marine resources (Lentini et al. 2013), there are often many unsubstantiated conjectures about the impact and sustainability of these small-scale fisheries (Béné 2009, Lentini et al. 2013). MPAs are often a mosaic of different habitats and marine fish communities that have different vulnerabilities to fishing pressure, and the spatial and temporal patterns in the fishery pressure are necessary to assess impacts and sustainability goals. For example, coral reef communities are more vulnerable to fishing pressure than estuarine and pelagic communities (Dalzell 1996, Floeter et al. 2006, Bonaldo and Bellwood 2008, Blaber 2013). As coral reef ecosystems are complex, dynamic and sensitive systems (Bellwood et al. 2004, Hoegh-Guldberg et al. 2007). Relatively small changes in one component of this ecosystem can affect the structure, composition, and resilience of other elements within these reef communities (Rosenberg and Loya 2013). Hence, an expanding human population may affect marine communities in many ways through the associated increasing fishing pressure of different fishing techniques, but also through other impacts such as through destructive fishing (e.g., explosives and fishing with poison), gleaning activities and anchoring by fishing boats.

Therefore, the estimation of the total fishing pressure, including their spatiotemporal patterns should be the basis for the formulation of an MPA management plan, but these are often not well documented. A mismatch between conservation and food security goals can result in poorly formulated MPA management plans. In Indonesia, appropriate conservation tools that can assist in weighing preservation and food safety goals are hard to find, let alone implement, due to a lack of information on fishing patterns and pressure of small-scale coastal fisheries. As the available information on fish and shrimp catches are only available in aggregated form, collected from fish landing stations or fish collectors with limited spatial resolution. So, the questions concerning where these fishermen are fishing, how many fishing boats operate in a particular area, what the spatial heterogeneity in fishery pressure is, and where these fishermen come from cannot be answered.

Small-scale fishing activities in MPAs in Indonesia show a high diversity in gear types, target species and habitat (Piou et al. 2007, Rocklin et al. 2009). Gear type and fishing location are determined by the availability of the target species and the type and quality of habitat where fishermen fish, but also by operational constraints given the limited means for investment these fishermen have (Daw et al. 2012, Cohen and Alexander 2013, Kolding et al. 2015). Hence, fishermen tend to fish close to their landing sites and homeports, while they adapt their fishing methods to the specific habitats that they can reach.{Blaber, 2012 #3185} Nevertheless, marine protected areas are also attractive to fishermen who do not live close to these MPAs, and it is an open question whether the regulations to keep MPAs open to small-scale fishermen also should include access by non-resident fishers. In Indonesia, fishermen are known to travel far (Visser and Adhuri 2007, Pramod et al. 2008, Kusumawati 2014). For example, Bajo fishermen from South Sulawesi and Madura (East Java) are known to fish far outside their home fishing grounds, visiting other parts of Indonesia, including MPAs. Regular fisheries monitoring systems in Indonesia often do not capture the pressures exerted by these fishermen, as they may land their catches outside the area monitored. This monitoring system makes an assessment of the actual pressure exerted on MPAs difficult, and complicates the evaluation of the consequences and sustainability of the implementation of MPA management plans (Field et al. 2006).

In this chapter, we aim to describe and analyse the spatial patterns of small-scale fishing effort and to calculate the total fishing pressure in the different marine habitats (i.e., coral reefs, a mangrove-lined estuary, and a pelagic area) in the Derawan Marine Conservation Area (DMCA), Indonesia. We also calculate the total catches per year from both resident and non-resident fishermen, studying the differences in gear type, fishing location, and catch sizes between resident and non-resident fishermen. The ultimate goal is to assess the fisheries productivity of small-scale fishing in different marine habitats within the conservation area.

5.2 **Methods**

5.2.1 Study area

The Marine Conservation Area of the Derawan archipelago (DMCA) is located in the Berau District of East Kalimantan province in Indonesia. The DMCA has a total area of 12,800 km^2 with 30 small islands. The mainland's coastline is 650 km. The marine area holds three different habitat types. (1) A deltaic area, consist of turbid water estuary consisting of shallow mudflats and sandbars, and intertidal areas with islands covered with mangroves interspersed with brackish rivers (1800 km^2). (2) Coral reefs formation around the small islands, located at the outer edge of the conservation area (2300 km^2). (3) A pelagic area, cover between the Delta and the coral reef islands (8100 km^2). These habitats provide marine resources (e.g., for food, income), and coastal protection for around

45,500 inhabitants from 8900 households, who are distributed over seven villages on the islands and 24 villages on the mainland (Figure 5.1).

5.2.2 Roving creel surveys

Catch and effort data were obtained from in-situ interviews with the fishermen through a roving creel survey (Pollock et al. 1997), a sampling technique developed to gather data to estimate total fishing activities and harvest by interviewing fishermen. In roving creel surveys, fishermen to be interviewed on a given day are intercepted with a certain probability of a catch, which is related to the length of a completed fishing trip (Pollock et al. 1997). The interviews took place from a research boat, a 9 m speedboat with two 145 hp outboard engines, during monitoring trips that each took three days to complete. The surveys started in the north of the DMCA from the mouth of the Lungsuran Naga River, the southernmost tributary of the Berau River and followed the shallow estuarine coast towards the coral islands in the South. The return trip to the North followed the coral islands in the pelagic zone of the depth waters towards Derawan Island and back to the Kasai River, the main artery of the Berau River connecting to Tanjung Redeb, the largest city of the Berau District. A total of 54 three-day roving creel surveys, 174 days, were conducted between February 2005 and December 2009 (Figure 1). The mean distance per day traveled by the speedboat was around 190 km, totaling about 580 km for each 3-day trip. The actual track taken was recorded for each survey between 8 am to 6 pm (10 hours). From the starting point, the team hopped from boat to boat visible within a distance of 1km on either side of the survey speedboat; the range was checked using a digital range-meter and the position confirmed by GPS. The actual transect area surveyed per 3-day trip was 1,180 km^2 (N=54; SD ±129 km^2) which is equal to 8% of the total DMCA.

The data collected were: date and time of the interview; name of captain; name and identity of the boat; location (latitude, longitude and habitat); type of boat (fishing, transport); activity at moment of encounter; number of crew; homeport; gear-type; estimated catch by category in weight of fish (kg); total number of hours that the crew had been fishing prior to the moment of encounter. We distinguished local fishermen from the mainland (residents) and fishermen from outside the region (non-residents) by recording their homeport and place of origin. The positions of the fishing boats have been registered with a Garmin GPSMAP 75CX.

In total, 20 different fishing gears were distinguished (FAO, 2004; Appendix A). Fishing activities carried out along the coast with a maximum distance of less than three nautical miles (about 5 km) from the mainland are categorized as small-scale fisheries, and regulated under the national act (no.9/1985 and no.45/2009). This fisheries law includes licenses for fishing fleets and type of fishing gears to avoid competition between small-scale and industrial fisheries. However, during the roving creel surveys from the start untill the end of 2005, we recorded in total 21 different large otter-board trawlers that violated these rules and fished without a legal permit.

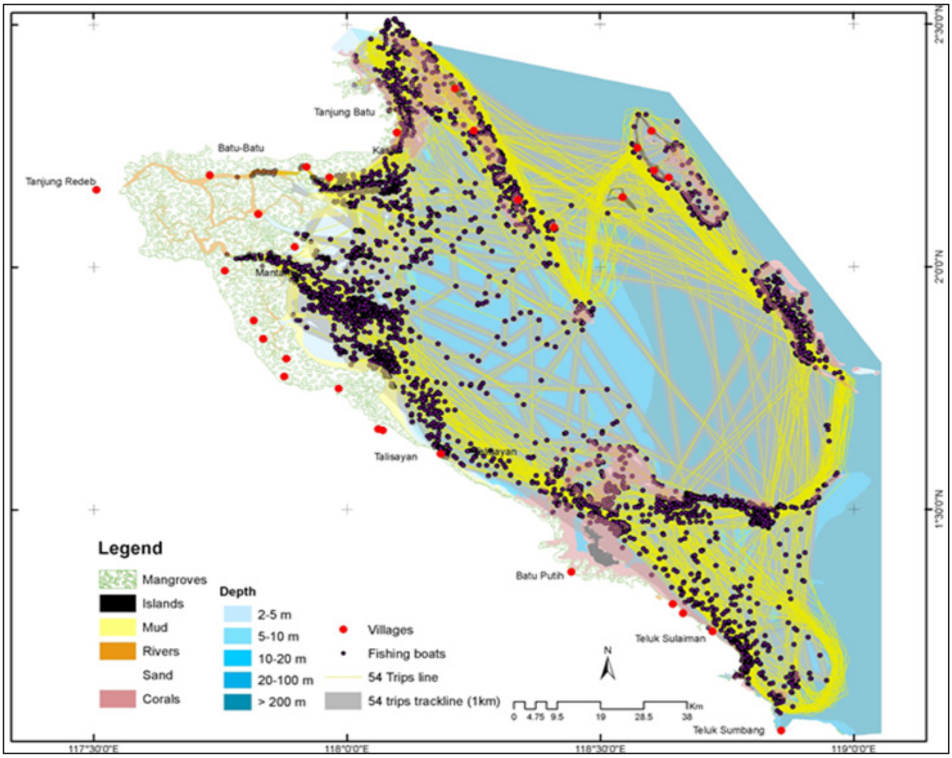

Figure 5.1. Map of the Berau Sea and Derawan archipelago in the East Kalimantan Province, Indonesia. The area includes 24 coastal villages (red dots), islands, coral reefs, an estuarine-delta and a pelagic area. Thick hatched and yellow lines: the 54 trip tracks (2 km distance) and trip lines. Black dots (small): the distribution of fishing boats encountered.

Catches were categorised in 12 species (groups) of fish, three crustacean groups (lobster, crabs, and shrimp), and seven others (*Trochus* spp., giant clam, squid, octopus, sea cucumber, black coral, and turtles). A full list of species encountered and the categorisation used can be found in Appendix B.

5.2.3 Supporting data

Historical data of total fishing effort of the resident fisheries from 1980-2009 were obtained from the Berau statistical agency reports (BPS 2010). These reports showed that there was no change in some fishing boats from 2003 to 2009. Working hours of fisherman were calculate using, the average total number of days fished per year, the number of working hours per trip (i.e., trip duration) and the type of fishing gears used was recorded through focused group discussions. In total, we carried out 120 focus group discussions (FGD) from 15 selected villages along the mainland coast and the islands. These FGD interviews have been conducted between 2008 and 2009, and for each community, 5 to 10 meetings were held, for a minimum of four and a maximum of 10 fishermen. The data from the focus group discussions were cross-checked against the reported data from the fisheries agency.

During 2008-2009, logbooks were kept by 15 resident fishermen from 5 fishing villages (Mantaritip, Pegat, Batumbuk, Pisang-pisangan and Radak). The fishermen mainly used four types of fishing gears, namely: barrier nets (3), minitrawls (5), trammelnets (5) and gillnets (2). Each day, the fishermen recorded their fishing activities and catches by species. For the current chapter, these data were used to estimate the seasonal movement pattern (average and standard deviation of the total number of days fished per year) of these gear types.

5.2.4 Data processing and analysis

The total catch per year in the DMCA was calculated in our study entailed two main steps: First, we quantified the spatial distribution of fishing effort by gear type by estimating the densities of fishing boats and gear types. Next, we quantified the total catch rates per trip by gear type.

5.2.4.1 Establishing densities of fishermen by gear and habitat

The density of fishermen by gear and habitat was calculated based on the number of encounters with these fishermen, the surface area of the survey trip tracks and the extent of the three habitat types.

Transect surface area

The surface area transect of the 54 trips (Figure 5.1) was calculated as follows: to obtain each strip's trajectory (trip line). We recorded the GPS positions of each fishing boat encountered starting with the first boat that we met on day-1 until the last boat on day-3 up to the end point of the survey. Then, we created a buffer of one km both to the left and to the right of the trip line. One km buffer was selected based on the minimum visibility at the time the survey was done. When more than one boat was observed within the visible range, all boats were visited, and the average position of the boats was taken as transect point. When the trip line was on the border between two habitats, the left and right buffer areas were each assigned to one of the two habitats.

Delineation of the three marine habitat types in DMCA

Three types of habitat were distinguished in the study site. (a) A deltaic estuary with shallow waters (< 20 meters), (b) coral reefs, delimited by the occurrence of corals to a depth of 50 meters, and (c) a pelagic habitat, starting from 50m depth into the deep sea (max 600 m). The spatial extent of the three areas was determined from bathymetry map no.18, produced by the National Hydrology and Oceanography Agency (DISHIDROS). This bathymetry map consist of depth information and contour lines of the estuarine and coral reef area (Figure 1.2).

Density of fishing boats by gear type per habitat

The use of direct counts to investigate distribution, abundance, and density of the fishery boats poses a challenge especially if fishermen do not have some form of an automated identification system. A feasible and practical alternative is to use sampling to investigate a representative portion of the fishing vessels per survey trip. We used a sampling technique, in which all fishing boats within a known fraction of the total area under investigation (i.e., transect area) were counted. The overall encountered number of the fishery boats data was then converted to an estimate of the total number of fishing boats by gear type by habitat using the formula:

$$D_{fb} = \sum C_{fb} * \frac{H_a}{S_a} \qquad \text{...} (1)$$

Where:

- D_{fb} = estimated number of fishing boats.day^{-1} on the water by gear type and habitat
- C_{fb} = counted number of fishing boat by gear type in the transect area.trip^{-1} per habitat.
- H_a = total area of each habitat (km^2)
- s_a = transect surface area by habitat (km^2)

The estimated total number of boats by gear type during a creel survey was cross-checked with the total number of boats by gear type reported through frame surveys and the licensing database, both under the responsibility of the Berau Fisheries Agency. The frame survey was carried out by the staff of the Berau Fisheries Agency through a census-based approach of fishing boats for each local coastal village. For non-resident fishermen, their boats were counted when they visited the mainland to refuel for water and gasoline. The total number of fishing boats and the fishing gear used are reported on an annual basis in this frame survey. In all calculations except one, the number of boats by gear type estimated to be at sea did not exceed the total number of boats by gear type counted in the frame surveys. The one exception was floating liftnets as these were encountered in only one area in the southernmost portion of the DMCA; hence, it made no sense to calculate their densities over the total estuarine habitat. All other gears were distributed over their gear specific total habitat areas.

The overall effort of the non-resident fishermen was calculated from the total number of boats encountered during the monitoring survey. Hence, the crosscheck could not be carried out for these boats, only for the resident fishermen, and therefore the estimate for non-resident fishermen is more uncertain than that of the resident fishermen. The density estimates lead to a total number of boats by gear type: these effort data were cross-checked with the total number of boats reported by the Berau Fisheries Agency.

5.2.4.2 Establishing a standardized catch rate

Catch per unit effort (CpUE, kg.trip^{-1}) was used to be able to make valid comparisons across the entire small-scale fisheries. To establish an unbiased CpUE, we carefully examined the 4654 survey records; 49 data points were incomplete and were excluded from the database. 22% of the interviews were with non-resident fishermen (1009 of 4605) and were analyzed separately. From the remaining resident fishermen (78% of the total), 38%

of the boats spent more than 24h fishing. These were excluded from the CpUE analysis because the reported catches most likely were not associated with the location and date of an encounter. The final database of resident fishermen consisted of 2219 records.

During the creel survey, fishing duration of the remaining fishermen varied between 0 and 24 hours. Corrections were made when calculated CpUE, accounting for the difference in the total number of hours fished, by calculating the probability of a catch and the size of positive catches for a full fishing day per gear type. CpUE was defined as catch per standard trip duration, with the duration of a fishing trip varying between gear types (Table 5.1). To calculate the probability of a catch at the time encounter, we used a binary response for zero catches and estimated the likelihood of a real capture, by applying a binary logistic regression:

$$\log\left(\frac{p_{ij}}{p_{ij}-1}\right) = a + b\log\left(H_i\right) + \in_{ij} \quad \text{..........}(2)$$

Where:

p = the probability of catch (0, 1) at the encounter, and

H_i = the actual number of hours fished at an encounter.

Subsequently, the probability of a catch, Pc ($trip^{-1}$), at a standard trip duration was calculated. Positive catches were standardized to a regular fishing trip by regressing the ^{10}log-transformed positive catch over the ^{10}log-transformed reported number of fishing hours. The slopes of the regressions by gear type were used to estimate standardized catch rate (kg per standardized trip) as follows:

5

$$CpUE_i^s = CpUE_i \cdot \left(\frac{H_s}{H_i}\right)^{\beta} \quad \text{..........}(3)$$

Where:

$CpUE_i^s$ = the standardized (s) total catch rate for the *i*-th fishing trip ($kg.trip^{-1}$),

$CpUE_i$ = the observed total catch rate of the *i*-th fishing trip,

H_s = the mean value for the standard trip duration in hours (Table 5.1)

H_i = the actual observed fishing hours (fishing duration) of *i*-th fishing trip.

b = the estimated slope parameter estimate from the linear regression.

The total catch of resident fishers was calculated by assuming that the average boat density calculated through the roving creel survey is a good predictor of the mean density during the year. Using the average standardized CpUE (equation 3) per survey, and their 95% confidence limits, we then calculated the total catch of the resident fishermen as:

$$T_{Ci} = \sum_{j=1}^{p} CpUE_{ij}^{sa} * T_{ij}^{t} * P_{cij} \quad \text{...}(4)$$

Where:

T_{Ci} = the total catch in year$_{i,}$ over all gear types (j=1…. p)

$\sum_{j=1}^{p} CpUE_{ij}^{sa}$ = the average (or the upper and lower 95% CL) indicated as minimum (min) and maximum (max) in the result of standardised catch over all creel surveys in a year per unit effort in year$_{i,}$ and gear type $j_{,}$

T_{ij}^{t} = the total number of trips per year$_{i,}$ and by gear type $j_{,}$ calculated as the density of boats.day^{-1} averaged over the creel survey trips multiplied by the total days in a year: * 365.

P_{cij} = probability of catch for year$_{i,}$ and gear type $j_{,}$

Due to the low sample size, trawls, purse seine, and floating liftnets were excluded from the detailed CpUE analysis; furthermore, floating liftnets were only encountered in the southernmost portion of the DMCA, associated with only one village. We calculated the total catch of these gears by using secondary data reported from the Berau Fisheries Agency (Dinas Kelautan & Perikanan Berau). The catch of these three gears was estimated from the total effort and the total reported catch per year in Tanjung Batu, Teluk Semanting and Balikukup villages (DKP 2010).

Two fishing gears (static liftnets finding small pelagic and tidal barrier nets, locally known as "togo") were not covered in the monitoring program as these fishing gears operated at night or early morning, outside the time of the monitoring survey. Static liftnet and barrier net were counted on two occasions in 2005 and 2007, and their GPS positions recorded. Catch per day was estimated through the average catch per day per gear type. Data on the total number of gears and catch per day per gear for Danish seines, tidal barrier nets, and static liftnets were gathered from interviews and focus group discussions. We used the average total number of working days per year, per boat and gear combination as reported in the logbooks (unpublished data) as activity pattern. To estimate the total catch per year for these three gear types, we multiplied the total effort, catch per day and activity pattern.

The total catch of non-resident fishermen was calculated by assuming that the average boat density calculated through the roving creel survey was a good predictor of the mean density during the year. A second assumption was that the estimated probabilities of catch and standardised positive catch rates by boat and gear combination are the same as those for the resident fishermen. Calculations then proceeded following the procedure described in equation (4). This assumption was needed as non-resident fishers did not make day trips to the shore to unload their catch, but stayed in the area for extended periods. Hence, their reported catches most likely were not associated with the location and date of encounter except for catches obtained at the day of the meeting.

The total catch of the DMCA is a summation of these four categories of estimated catches. Furthermore, we also calculated the total catch taken from each of the three different marine habitats (estuarine, coral reefs and pelagic). We carried out a GLM to test for differences in mean catch sizes over the years and between fishing techniques, habitat types, and origin of the fishermen. The analysis and results are presented in Appendix F.

5.2.4.3 Spatial allocation of small-scale fishermen and species analysis

To understand the spatial effort allocation of small-scale fishermen, we analyzed the relationship between total catch rates (kg.trip^{-1}), catch rates by species category (kg.trip^{-1}) and the distance from the different marine habitats and the distance to the homeport (km) for resident fishermen. A Canonical Correspondence Analysis (CCA) was used to analyze the species composition between different gear types with the distance to the different habitats. CCA was used as the responses were unimodal and we intended to investigate the relationships between species composition of catches and the "environmental variables" i.e., the distance to the different habitats. Habitat was initially grouped into five categories: 'sandbar', 'river', 'mangrove', 'pelagic sea' and 'coral', and distances were calculated from the position at encounter during the creel survey and the nearest distance of a habitat category. In a subsequent analysis, we combined the categories of 'sandbar', 'river' and 'mangrove' into 'estuarine area'. The significance of the effect of each variable was tested using a Monte Carlo permutation test ($P<0.001$; 1000 random permutations). The null hypothesis tested was that the samples were randomly linked to the environmental variables (ter Braak and Verdonschot 1995). Based on the CCA analysis, the association of gear types with habitats could be determined.

The geometric mean, maximum, minimum and standard deviations of distances from homeport by gear type were calculated from log-transformed distances between a position at encounter during the creel survey and the homeport mentioned by the fishermen.

Survey track analysis and effort densities were calculated using ArcGIS v9.3 from ESRI. All statistical analyses were carried out in SAS/STAT® v8, using the GLM procedure, except for the Canonical Correspondence Analysis that was done in CANOCO v4.5 (ter Braak and Šmilauer 2002).

5.3 **Results**

5.3.1 Fisheries activities in the DMCA

Table 5.1 gives an overview of the total gears encountered for residents and non-residents over all surveys based on the creel surveys (2005-2009), unadjusted for day trips. 22% of all gears (from the total records with Pc>0), mostly set in the top layer of the water column, were used in all three-habitat areas: gillnets, towed handlines, longlines and purse seines. The remainder of the gears were habitat specific. These were bottom-set handlines and coral traps in the coral reef area (12.8%); floating liftnets in the pelagic area (0.6%); and trammelnets (23%), minitrawls and trawl (15%), estuarine traps and trawls (1.5%) in the estuarine area. Other gear types (9%) such as cast-netting, gleaning and spear gun fishing. However, cyanide and blast fishing represented <2% (45 of 2594) of total records of resident fishermen (Table 5.1), while static liftnet (11%), Danish push net and barrier net (3.4%) were also recorded.

Resident and non-residents focus on different parts of the fish communities and habitats as implied by their gear use and spatial distribution. Resident fishermen focused on the coral reef. They mostly use towed and bottom handlines (28% of the fishing gear encountered in this area), gillnets (8%), and coral traps (2%). They were also recorded in the estuarine areas with trammel nets, mini trawls and trawls (30%), and estuarine traps (2%). In the pelagic area, they used other gear types: longlines and purse seine and floating liftnet (10%), and other gears (19%). Residents only operated cyanide and blast fishing (>1%; 45 of 3596) gears encountered.

Non-resident fishermen focused on coral reefs and pelagic area, used gillnets (29%) and purse seines (17%). Handlines were also frequently used by this group (14%), but coral traps (<4%) and other gears (23%) were relatively less frequently observed. The non-resident fishermen in the pelagic area used longlines (2%) and floating liftnet (6%). In the estuarine area, non-resident fishermen were rarely observed with trammelnets, estuarine trap, mini trawl and trawls (<6% fishing gears). Non-residents used more general purpose gillnets in all three habitats, with a particular focus on the coral-reef and pelagic areas, while resident fishermen seemed more specialized in the estuarine area. This conclusion is strengthened when taking into account the gears that were not covered by the surveys: Danish nets and barrier nets (3.4%), static liftnets (11%) and trawls (1.2%). These three gears, which were rarely recorded in the estuarine area because they were operated at night, hiding from the patrols and were all managed by resident fishermen.

The resident fishermen that used gillnets (n=279) and coral traps (n=58) worked on average for many hours (mean trip duration: 24h; H_s in the equation 3). Whereas, the fishermen that used other fishing gears (i.e., handline towing, handline bottom, purse seine, and others) spent on average around 12h fishing. The fishing gears with the shortest working hours were trammelnets and minitrawls, with on average 10h per trip.

A gear type employed in more than one habitat targeting different species were gillnets (Table 5.4 & 5.5). Gillnets were used in the estuarine, pelagic and coral reef habitats depending on their target species and season. Coral reef gillnets targeted wrasses while, during the east monsoon, when young tuna from species *Katsuwonus pelamis* or skipjack tuna appear in the area, these nets were set in the pelagic area (unpublished data). Both resident and non-resident fishermen were a pecialist in a particular fishing gear, fishing with only one type of fishing gear in their boat. The non-resident fishermen focused on particular species with a high economic value, i.e., red snapper and groupers and pomfrets.

Barrier nets, though they represent only 0.1% of the gears, are highly visible due to the large structures set-up in river mouths. They make use of the tides in the delta and have relatively large catches with a high diversity of small species. Fishermen use this type of gear to target shrimp but have a highly diverse bycatch of fish species. The Berau Fishery Agency also reported higher catches for certain pelagic gears (i.e., static liftnet or "bagan"), which were operated in the northern, shallow, part of the conservation area only with a depth range between 25-50 m. The areas where these static liftnets were deployed were close to the delta, where tidal currents are dominant. The area occupied by the static-liftnets shifted southwards and expanded from close to the shore in 2002 to more pelagic areas in front of the river mouth in 2009 (Figure 5.3).

Table 5.1. The frequency of fishing gears of resident and non-resident fishermen encountered in the study area during the 54 monitoring surveys conducted between February 2005 and December 2009. The total number of records of resident fishermen with day trips used in the analysis to calculate CpUE (see methods for explanation). The mean and standard deviation (SD) of trip duration per standard trip and catch probability (Pc) over a standard trip. The CpUE is adjusted for number of hours fished and represents the range in positive catch rates (un-adjusted for Pc). Static liftnet, Danish net and Barrier net were not encountered in the surveys. CpUE for these nets were based on logbook and FGD data.

Fishing gears	**Nr. gear resident fishermen**	**Nr. gear non-resident**	**Gear Total** *(N)*	**Total records Resident with Pc>0**	**%**	**Mean trip duration** *(hr.trip^{-1})*	**SD** *(hr.trip^{-1})*	**Catch probability** *(Pc)*	**Range CpUE** *(kg.trip^{-1})*	**Habitat fished (gear position in water column)**
Handline towing	439	57	496	277	11	12	2.7	0.96	2 – 7	Coral reef/Pelagic
Handline bottom	579	82	661	320	12	12	2.3	0.93	1 – 7	Coral reef
Gillnets	279	289	568	173	7	24	7.4	0.96	1 – 17	Coral reef/Pelagic/Estuarine
Coral trap	58	36	94	13	<1	24	10.1	0.99	30 - 105	Coral reef
Others	728	236	964	275	11	12	2.5	0.94	1 – 80	Coral reef/Estuarine
Longlines	105	22	127	67	3	12	2.5	0.99	8 – 12	Pelagic/Estuarine (pelagic)
Purse seine	97	174	271	57	2	-	-	-	35 – 157	Pelagic/Estuarine (pelagic)
Floating liftnets	164	57	221	15	<1	-	-	-	108 – 160	Pelagic (pelagic)
Static liftnets	-	-	-	287	11	-	-	-	64 – 186	Pelagic (pelagic)
Trammelnets	659	30	689	597	23	10	2.1	0.99	1- 26	Estuarine (demersal)
Estuarine trap	53	6	59	40	2	-	-	-	4 – 18	Estuarine (demersal)
Minitrawls	391	1	392	353	14	10	2.3	0.99	6 - 27	Estuarine (demersal)
Trawls	44	19	63	32	1	-	-	-	22 - 230	Estuarine (demersal)
Danish nets	-	-	-	74	3	-	-	-	21 - 47	Estuarine (demersal)
Barrier nets	-	-	-	14	<1	-	-	-	100 - 212	Estuarine (demersal)
Total	**3,596**	**1,009**	**4,605**	**2,594**	**100**	**-**	**-**	**-**	**-**	**-**

5

Purse seining was frequently reported from pelagic areas near Maratua and Kakaban Island (Figure 5.3). Purse seine and static liftnet fishermen often operated at night and used light to attract small pelagic fish.

5.3.2 Fishing effort allocation

In 2009 in total 2285 fishing boats were counted in the DMCA, operated by 3747 fishermen (Table 5.2; (BPS 2010). With a total surface area of 12,800 km^2, this amounts to an average density over the whole conservation area of 0.2 fishing boats.km^{-2}.

Table 5.2. Total number of resident fishermen and fishing boats by coastal village in the DMCA in 2007-2009. The number of boats and fishermen did not change between 2007 to 2009 (BPS 2010).

Coastal villages	Location	Fishermen	Fishing boats
Pulau derawan	Island/Coral reefs	507	159
Tanjung batu	Mainland/Coral reefs	438	147
Bohesilian	Island/Coral reefs	356	125
Kasai	Mainland/Estuarine	221	127
Payung payung	Island/Coral reefs	158	38
Balikukup	Island/Coral reefs	157	184
Teluk harapan	Island/Coral reefs	150	40
Biduk biduk	Mainland/Coral reefs	149	73
Teluk alulu	Island/Coral reefs	145	33
Radak/buyung buyung	Mainland/Estuarine	142	125
Teluk semanting	Mainland/Estuarine	136	111
Pilanjau/mantaritip	Mainland/Estuarine	125	134
Pisang pisangan	Mainland/Estuarine	121	160
Talisayan	Mainland/Coral reefs	120	198
Karang bajau	Mainland/Estuarine	101	51
Teluk sulaiman	Mainland/Coral reefs	98	49
Tabalar muara	Mainland/Estuarine	97	97
Tanjung perepat	Mainland/Coral reefs	85	33
Biatan muara	Mainland/Estuarine	80	44
Batu putih	Mainland/Coral reefs	59	75
Pantai harapan	Mainland/Coral reefs	45	23
Giring giring	Mainland/Estuarine	43	20
Pegat/batumbuk	Delta/Estuarine	90	93
Tubaan	Mainland/Estuarine	40	52
Teluk sumbang	Mainland/Coral reefs	40	27
Merancang ilir	Mainland/Estuarine	32	43
Batu batu	Mainland/Estuarine	12	24
TOTAL		**3,747**	**2,285**

Between 1980 and 2001 number of the fishery boats increased from 257 to 1328 (Figure 5.2). The increase had the number of jumps: between 1981 and 1982, effort increased threefold; a second sudden increase was reported between 1983 and 1984. The very steady growth between 1984 and 2002 probably represent the low quality of the recording system for fisheries data in the Berau District by the Fisheries Agency, where in each year numbers increased with a certain percentage. Since 2002, the data collection improved and since 2005 the number of boats stabilized to around 2285 boats. The rapid increase in many fishing boats between years 2000 to 2005 is due to the increase in many minitrawls and trammelnets used by fishermen in the estuarine area. They were targeting shrimp, because of an increase in the global market demand for wild shrimp (Delgado et al. 2003, Glantz 2005, Gillet 2008, Diana 2009).

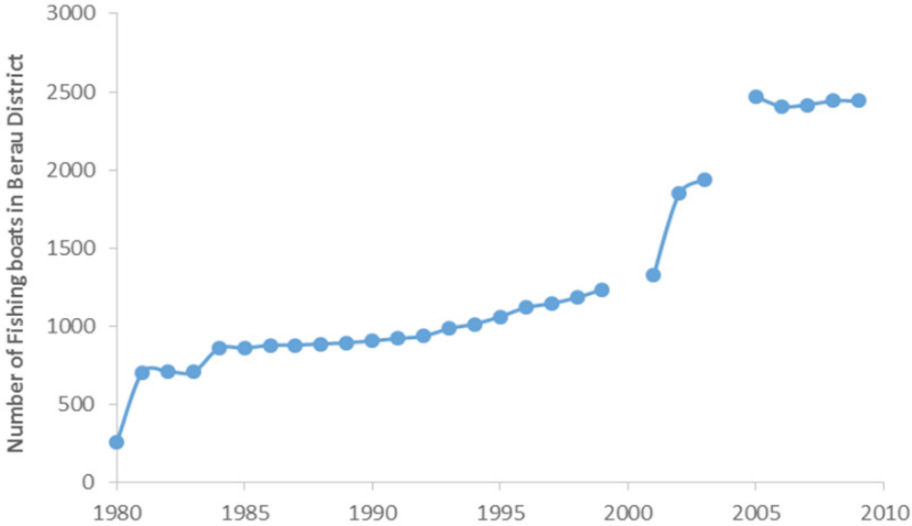

Figure 5.2. The number of fishing boat for resident fishermen only in the Berau District from 1980-2009. No data were available for 2002 and 2004. Source: Berau Statistic Agency, 2010 (BPS 2010); see text for further explanation.

5.3.3 Effort allocation in the DMCA

The distribution of fishermen over the various habitats clearly shows that resident fishermen did not travel far from their homeports (Figure 5.3; Table 3.3). The average distance from their homeports of resident fishermen was 29 km (N=3596; SD=25km). The distance traveled of the resident fishermen varied with fishing gear and habitat. Fishermen were fishing nearby their villages need to use a gear type that is suitable for the dominant habitat type there. For instance, fishermen using trammelnets or minitrawls were located in and near the estuarine area in for example villages as Radak and Talisayan.

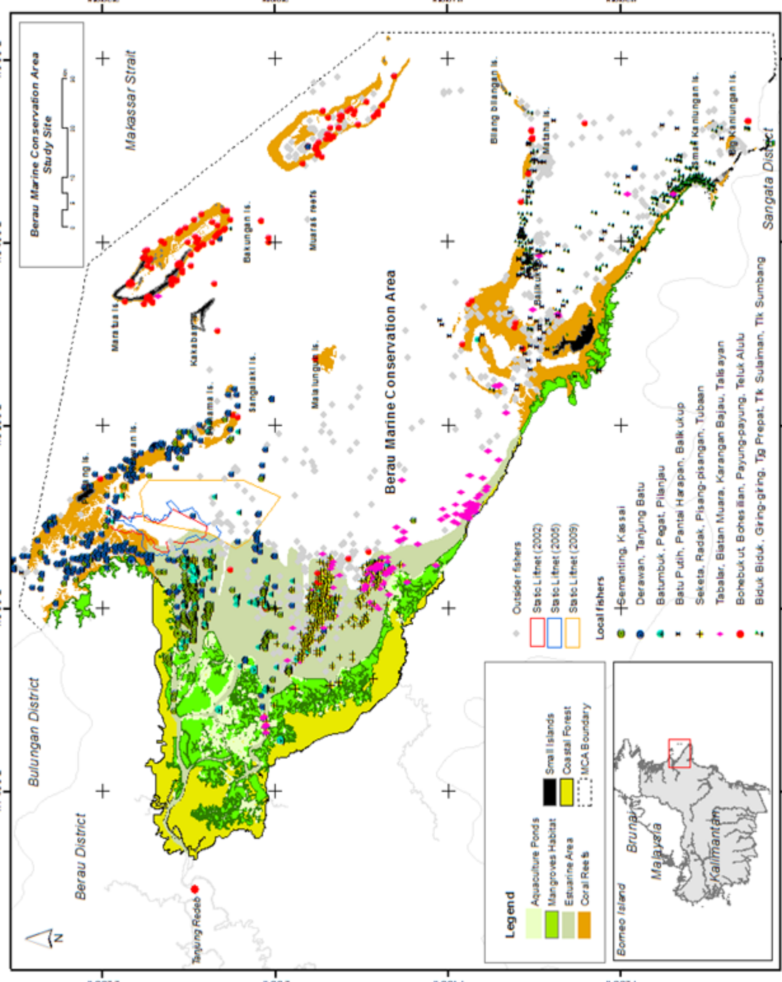

Figure 5.3. Effort allocation map, with all encounters from the creel surveys from 2002, 2005 & 2009. Distribution of resident (coloured dots) and non-resident (grey dots) fishermen. Different colours indicate homeport of resident fishermen. Area with static fishing gears (Bagan) are indicated as coloured polygons. The area fished by Bagan shifted between estuarine and near coral reefs from north to south. Between these periods, the number of static fishing gears increased from 154 to 317.

Table 5.3. The mean distance between fishing ground in the DMCA and homeport of the fishermen over various fishing gears and habitat. N = number of fishing boats from creel survey data, min/max=nearest/farthest distance from origin homeport, SD = standard deviation.

Habitats	Fishing gears	Resident (Km)				Non-resident (Km)			
		N	*Min*	*Max*	*Mean (SD)*	*N*	*Min*	*Max*	*Mean (SD)*
Coral reef	Handline towing	500	0.6	179.5	33 (26)	55	82.9	1106	269 (204)
	Handline bottom	603	0.7	204.1	23 (22)	82	90.9	1149	284 (271)
	Gillnet	139	0.7	143.9	19 (15)	219	147.8	1089	254 (87)
	Coral trap	60	2.1	91.6	41 (26)	36	130.3	1082	441 (265)
	Others	211	0.3	126.8	26 (22)	16	165.3	1149	289 (201)
Pelagic	Gillnet	37	6.9	160.8	52 (52)	35	147.1	1438	420 (88)
	Longline	108	2.3	55.2	22 (13)	22	125.6	1156	745 (442)
	Purse seine	96	1.8	119.7	31 (22)	175	153.2	2297	281 (233)
	Floating liftnet	169	5.2	165.1	47 (37)	58	184.9	477.7	431 (89)
	Others	36	3.5	161.6	58 (41)	49	90.7	2297	357 (285)
Estuary	Trammelnet	663	0.44	125.3	19 (15)	31	184.6	1133	761 (417)
	Estuarine trap	53	0.8	74.8	23 (15)	6	926.9	1158	1118 (93)
	Minitrawl	395	1.3	112.2	22 (15)	1	1148	1148	NA
	Gillnet	127	2.9	190.5	47 (37)	33	154.1	1293	456 (420)
	Trawl	44	14.6	105.1	46 (27)	19	143.2	866.4	303 (252)
	Others	355	1.66	165.8	40 (27)	172	131.3	2109	713 (467)

Non-resident fishermen presented 21.9% of the total number of encounters during the surveys. These fishermen often had traveled long distances from their origin to the DMCA (Figure 5.4). The majority of encounters of non-residents (829) were fishermen from neighboring areas in East Kalimantan, ranging from Tarakan and Nunukan to the North and Balikpapan to the south of the DMCA. The remaining fishermen came from Madura (129), followed by fishermen from South Sulawesi (82), Southeast Sulawesi (32) and Lombok Island (Nusa Tenggara Barat-NTB province) (12). The latter was a group of highly specialized fishers producing “terasi” (shrimp paste). An additional 11 encounters were with fishermen from Sumatra, Central Java, Bali, North-Sulawesi, and the Moluccas. We observed two illegal fishing boats from China using large mesh size for shark fisheries in the area.

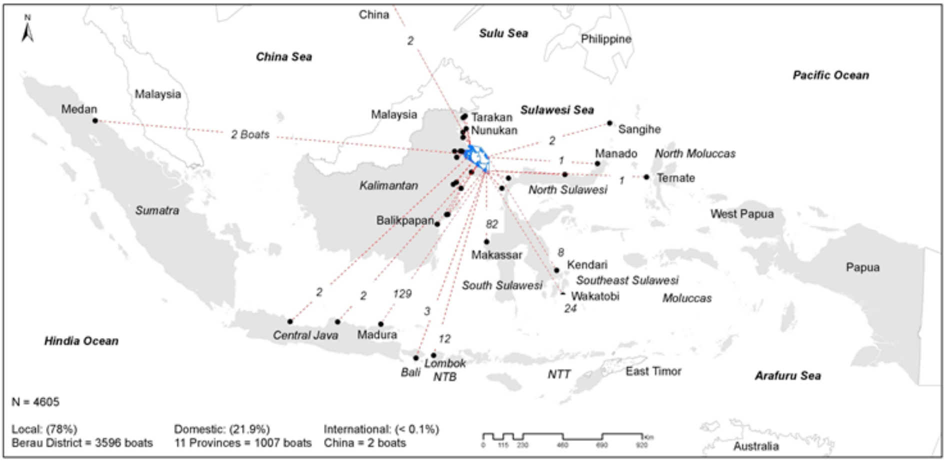

Figure 5.4. Map showing the original homeport of the outsider fishermen who were fishing in the DMCA (blue polygon), and the straight red line illustrates the distance between homeport and the DMCA. Numbers are the number of boats encountered in the roving creel survey between 2005 and 2009 per homeport.

5.3.4 Catch composition concerning effort distribution by habitat

Catch composition for resident fishermen was also related to gear type and homeport (Figure 5.5). Shrimp were mainly found in and near the estuarine area, while reef fish, crustaceans, and holothurians (sea cucumbers) were more abundant on and around reef zones. The first axis of the CCA (explaining 64.3% of the total variation in species data) distinguished the more open sea catches (pelagic and coral reefs). Where handline, coral traps and other gear (gleaning, castnet, speargun, and destructive methods as diving with cyanide and blast fishing, all typical coral reef methods) were used, from the shallow areas (sandbars, rivers, and mangroves as a part of the estuarine area). For minitrawls and trammelnets were more frequently used. The second axis (explaining 26.0% of the total variation in species data) did not have a clear association with any of the explanatory variables, though species associated with non-specialized gears such as nets (top part of the CCA, with species groups such as jackfish, anchovy, and pomfret). These seem to be contrasted with more specialized gears such as handlines (bottom part CCA, with species groups: wrasses, snappers, and sharks). Trammelnets and minitrawls were closely associated with shallow estuarine species as pomfrets, shrimp, catfish and small pelagic. Handline was closely associated with typical coral species as wrasses, groupers, and snappers. Gillnets were found in all habitats, and not specifically related to any of the species.

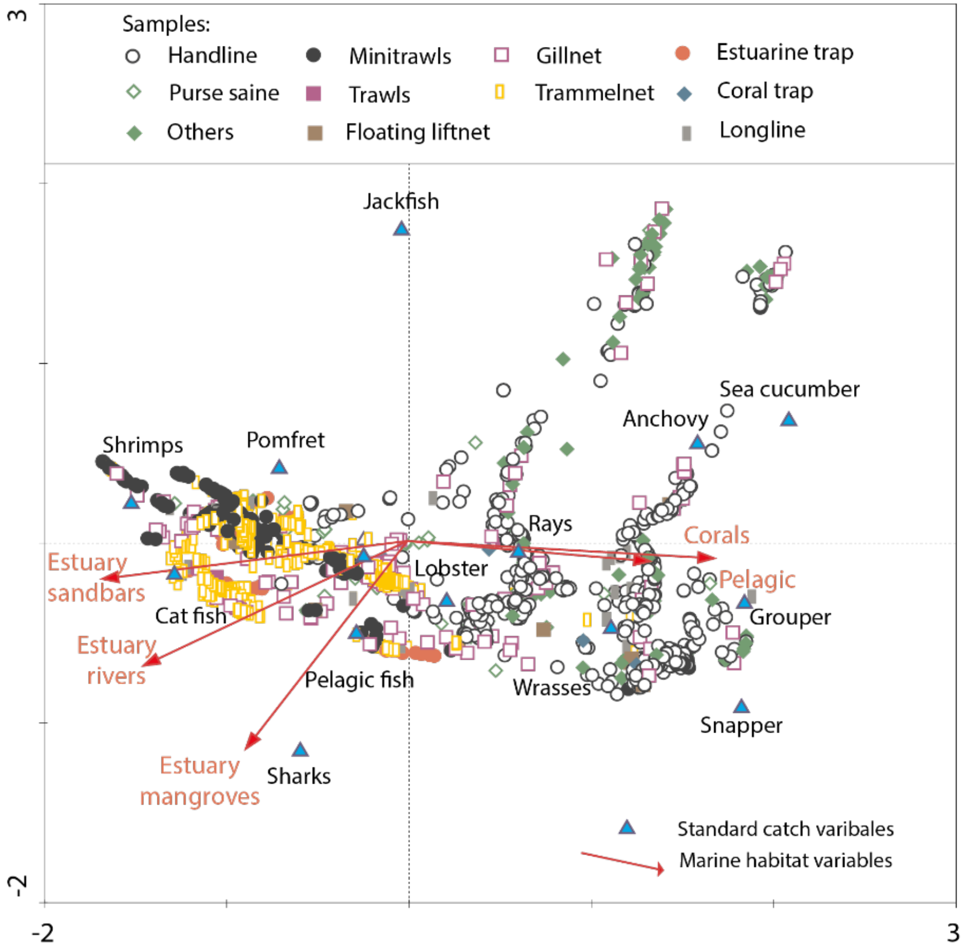

Figure 5.5. Multivariate ordination of catch species composition per gear type in the DMCA to distances to all habitats, as obtained through a CCA ordination. The red line indicates differences in distances to marine habitat, and the triangles indicate the species, and circles the catches of different gear types.

5.3.5 Catch rates

The probability of a catch (Pc) increased with the number of hours fished at the moment of encounter during the creel survey (Figure 5.6) with strong differences between fishing gears. Pc reached almost one within 3-6 hours in estuarine traps, minitrawls and trammelnets. The longlines, bottom and towed handlines took between 8-12 hours before reaching Pc=1 (Table 5.4). Gillnets reached Pc=1 only after 24 hours fishing. Coral traps usually are set overnight and then lifted, and the high variability around the Pc is probably due to a mix-up of encounters with fishermen who were just setting their traps, and fishermen who were just lifting their traps.

All active fishing gears (minitrawls, handline) had high Pc's within the first-hour fishing. Gillnets and trammelnets are often also used actively as driftnets, set and hauled within a few hours, and therefore also had a relatively high Pc after the first few hours of fishing. Gillnets were used in all habitats and different modes of employment exist, from many short sets to longer, 12-24 hour stationary sets.

We calculated the catch-rates as kg per trip using the regression of log catches against log trip duration to estimate catch size of a positive catch (at Pc=1). The number of hours fished during a trip until Pc reach one differed among gear types (vertical lines in Figure 5.6). All fishing gears had slopes (b) lower than unity (Table 5.3), meaning that catch rates showed diminishing returns over the number of hours fished, with an exception for floating liftnets. The purse seine regressions were not significant (Table 5.4), probably due to the low number of data, and we, therefore, used the mean catch rates as the best predictor to calculated total catch sizes.

Table 5.4. Results of the regression equations, with gear type, habitat, and the slope of the regression of reported catches (10logCatch (kg.trip^{-1})) on reported hours fished (10log (hrs. fished) (hr)) used to calculate the standardized daily catch size per trip (CpUE-s (kg. trip^{-1})), together with p-values.

Fishing gears	Habitat	N	Slope	p
Others	Coral reef	304	0.74	<0.001
Floating liftnet	Pelagic	153	0.72	<0.001
Coral trap	Coral reef	45	1.22	<0.001
Gillnet	Coral reef/Pelagic/Estuarine	265	0.74	<0.001
Trammelnet	Estuarine	629	0.46	<0.001
Estuarine trap	Estuarine	543	0.67	<0.01
Handline towing	Coral reef	369	0.66	<0.001
Handline bottom	Coral reef	447	0.71	<0.001
Minitrawl	Estuarine	481	0.53	<0.001
Purse seine	Pelagic	15	0.54	n.s.
Trawl	Estuarine	36	0.81	<0.01
Longline	Pelagic/Estuarine	70	0.6	<0.001
Total		**2857**		

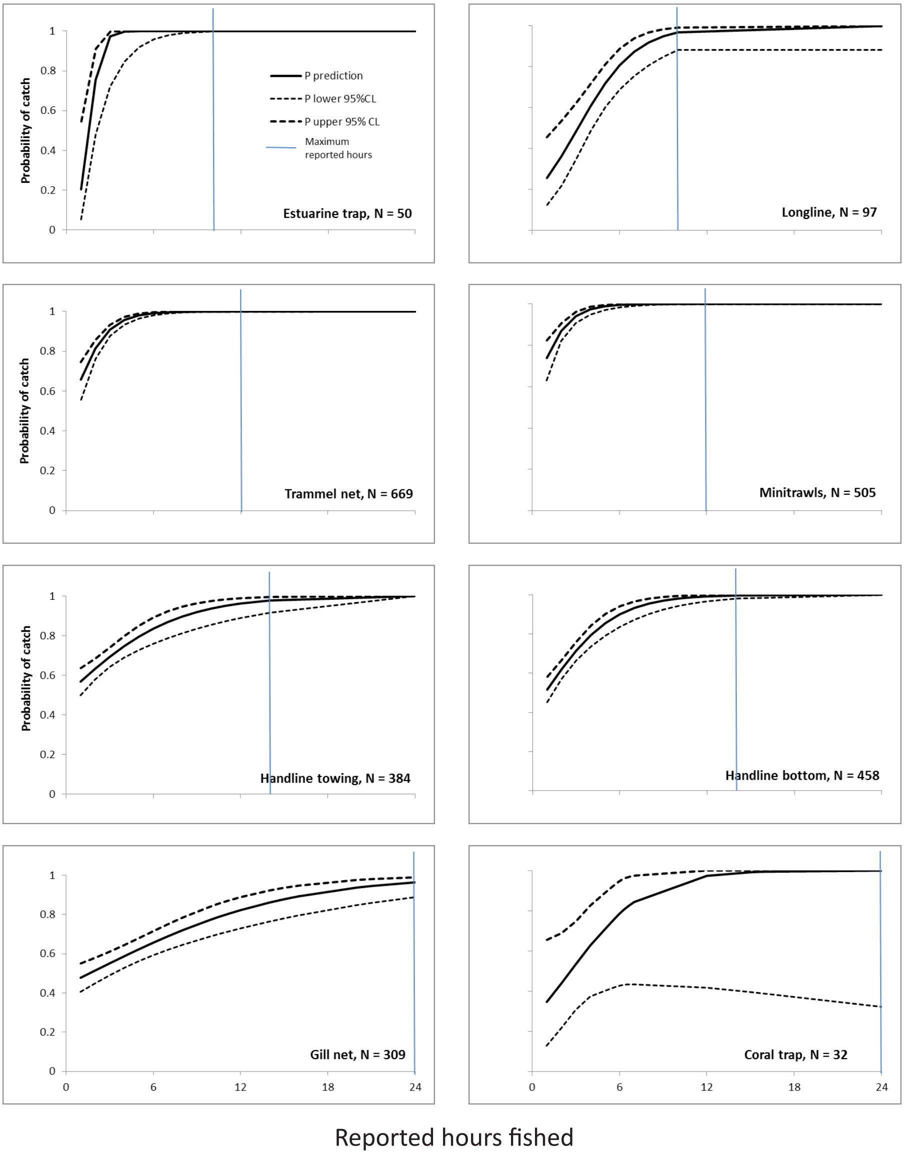

Figure 5.6. Increases in catch probability (± 95% CL) over the number of hours fished (x-axis) for eight fishing gears (handline towing, handline bottom, trammelnets, minirawls, estuarine trap, longline, gillnet, coral fish trap). Blue line represents a standard duration of a fishing trip with a particular gear. N=Sample size of the number of catches that were available to calculate the catch probability – fishing hours relationship.

5.3.6 Total effort and catch by gear type and habitat

Based on the previous analyses we estimated the total catches from the Derawan Marine Conservation Area and calculated the catches by habitat and by the residency of fishermen. An estimate of the fisheries productivity (kg.ha^{-1}.year^{-1}) by habitat type was calculated by dividing the total catches per habitat type by the total area of each of the three most important habitat types. First, we present the estimates of the total catches for all gears from the surveys of resident and non-resident fishermen. Second, we add the catch estimates from those gears that were not encountered during the study to obtain a total estimate of the total catch size from the entire DMCA.

Total catch for all gears of resident fishermen encountered during the survey amounted to 5550 ton (min: 4000 ton; max: 7900 ton). 43% of these catches were from coral reef habitats. The highest catches were from coral traps followed by bottom handlines (Table 5.5). In the estuarine area (24%), most of the catches were from estuarine traps followed by minitrawls. Pelagic fisheries accounted for 33 % of all catches, mostly taken by static and floating liftnets (23%).

For non-resident fishermen, adjusted catch rates per trip and probabilities of a catch were assumed to be the same for resident and non-resident fishermen. With this assumption, total catches for this group amounted to 4900 ton (min: 3900 ton; max: 9750 ton). Catches in coral reefs also accounted for 43%, similar to resident fishermen and were dominated by coral traps that were responsible for 22% of the total (Table 5.6). In addition, the relative distribution of catches in the pelagic area (20%) and estuarine areas (36%) were comparable to those of resident fishermen. In the estuarine area, the highest catches were from estuarine traps (13%) followed by trammelnets (12%). Floating liftnets catches (13%) dominated the pelagic catches.

Catch estimates of five fishing gears that could not be incorporated in the standard survey were obtained as follows. Of these, the floating liftnet or "bagan" was only recorded in the south of the study area near Balikukup Island. The estimation method was based on counting individual floating liftnets and their distribution within the habitat. A similar counting method was applied for trawl fishing. Static liftnets were mainly recorded near Derawan Island in the shallow pelagic area with a depth of 20-40 m. There were 317 units in total (Table 5.5), which operated only 24 days per month. The total catch was 186 $kg.month^{-1}$ (min-max: 65-368 $kg.month^{-1}$). Barrier nets were located in the river mouths. In total 13 units were recorded that operated 18 days per month. The total catch was 214 $kg.day^{-1}$ (min-max: 112-339 $kg.month^{-1}$). Danish seines were located at the estuarine area near the Delta. We recorded 108 sets in total, which operated 14 days per month. The average total catch was 48 $kg.day^{-1}$ (min-max: 21-78 $kg.month^{-1}$). The total annual catch of these five fishing gears was estimated 1560 $t.year^{-1}$ (min-max: 1200 – 2400 $t.year^{-1}$).

On average, a total catch of 10,460 $t.year^{-1}$(Table 5.7) was extracted by small-scale fisheries in the DMCA from 2005 to 2009 (min-max: 7850-17640 $t.year^{-1}$), of which resident fishermen on average took slightly more (53%) than non-resident fishermen (47%). Most of the catches were obtained from coral reefs (4560 $t.year^{-1}$ or 1.9 $t.km^{-2}.year^{-1}$), followed by the estuarine area (3100 $t.year^{-1}$ or 1.7 $t.km^{-2}.year^{-1}$), and the lowest catch originated from the pelagic area (2770 $t.year^{-1}$ or 0.3 $t.km^{-2}.year^{-1}$).

*Table 5.5. Estimated total catch per fishing gear of resident fishermen in three main habitats based on trip densities, number of trips per year, catch probability and CpUE per trip (see text for explanation). Purse seines and floating liftnets were excluded from the detailed CpUE analysis (see text for explanation). Σ fishing gears = number of fishing gears; (Pe) = Probability of encounter trip per fishing boat; Pcatch = Probability of catch; (SD: CL) = standard deviations:95% of confidence limit; $t.yr^{-1}$ = ton per year. * = estimated number of static liftnet "bagan", barrier net "togo" and Danish nets (see text for explanation). Total boat density per day excludes these numbers.*

Habitat	Fishing gear	∑ Fishing gear	Trip density $trip.day^{-1}$ (Pe)	Total trip. $year^{-1}$	Trip density trip. $year^{-1}$	P_{catch}	CpUE ($kg.trip^{-1}$) (SD: CL)	Total ($t.year^{-1}$)	%
Coral reefs	Hand line towing	634	134 (0.2)	48,910	77	0.96	6.5 (2.2: ±0.6)	305	5
	Hand line bottom	623	178 (0.3)	64,970	104	0.99	7.3 (2.0: ±0.6)	470	8
	Gillnet	414	86 (0.2)	31,390	76	0.96	16.6 (2.3: ±3.5)	500	9
	Coral trap	109	37 (0.3	13,505	124	0.99	58.4 (4.0: ±36.4)	781	14
	Others	817	154 (0.2)	56,094	69	0.95	7 (2.2: ±0.7)	373	7
Pelagic	Longline	111	55 (0.5)	19,932	180	0.98	10.2 (2.0: ±1.7)	199	4
	Gillnet	49	10 (0.2)	3,555	73	0.96	15.9 (2.2: ±7.4)	54	1
	Purse seine	78	-	-	-	-	-	260	5
	Floating liftnet	35	-	-	-	-	-	562	10
	Static liftnet	317*	-	-	-	-	-	708	13
Estuarine	Trammelnet	587	192 (0.3)	70,118	119	0.99	3.6 (2.3: ±0.3)	250	4
	Estuarine trap	244	135 (0.6)	49,275	202	0.99	5.8 (2.3: ±1.6)	283	5
	Minitrawl	212	121 (0.6)	44,165	208	0.99	6.1 (2.3: ±0.5)	267	5
	Gillnet	522	111 (0.2)	40,501	78	0.99	11.5 (2.3: ±2.1)	447	8
	Barrier net	14*	-	-	-	-	-	33	1
	Danish net	108*	-	-	-	-	-	62	1
Total			**1,079**	**442,415**				**5,553**	**100**

Table 5.6. Estimated total catch per fishing gear of non-resident fishermen in three main habitats based on trip densities, number of trips per year (see text for explanation). Floating liftnet and trawl were excluded from the detailed CpUE analysis (see text for explanation). Σ Fishing gears = number of fishing gears; (Pe) = Probability of encounter trip per fishing boat; and Total obtain catch t.yr^{-1} = ton per year

Habitat	**Fishing gear**	**Σ Fishing gears**	**Trip density. day^{-1} (Pe)**	**Total trip density trip.year^{-1}**	**Trip density. year^{-1}**	**Total (t.year^{-1})**	**%**
Coral reefs	Handline towing	217	84 (0.06)	30,660	141	191	4
	Handline bottom	138	63 (0.07)	22,995	167	166	3
	Coral trap	93	52 (0.21)	18,980	204	1,097	22
	Gillnet	89	59 (0.02)	21,535	243	343	7
	Others	460	137 (0.06)	50,005	109	333	7
Pelagic	Gillnet	96	64 (0.09)	23,472	245	358	7
	Floating liftnet	-	-	-	-	656	13
Estuarine	Trammelnet	717	466 (0.25)	170,090	237	606	12
	Estuarine trap	467	298 (0.38)	108,770	233	625	13
	Gillnet	170	112 (0.13)	40,880	240	451	9
	Trawl	-	-	-	-	79	2
Total catch *(t.year^{-1})*			1,335	**487.387**		**4,906**	**100**

Table 5.7. Total catch for twelve different fishing gears within three different habitat from resident and non-resident fishermen.

Fishing gear	Catch by habitats *($t.year^{-1}$)*						Total *($t.year^{-1}$)*	%
	Coral reefs		*Estuarine*		*Pelagic*			
	R [*)]	*NR*	*R*	*NR*	*R*	*N*		
Floating liftnet	-	-	-	-	561.9	655.6	1,218	12
Longline	-	-	-	-	199.2	-	199	2
Purse seine	-	-	-	-	259.4	-	259	2
Handline towing	305.2	191.3	-	-	-	-	497	5
Handline bottom	469.5	166.2	-	-	-	-	636	6
Coral trap	780.8	1097.3	-	-	-	-	1,878	18
Others	373.0	332.5	-	-	-	-	706	7
Static liftnet	-	-	-	-	707.9	-	708	7
Gillnet	500.2	343.2	447.1	451.3	54.3	358.3	2,154	20
Trammelnet	-	-	249.9	606.2	-	-	856	8
Estuarine trap	-	-	282.9	624.6	-	-	908	9
Trawl	-	-	-	79.3	-	-	79	1
Minitrawl	-	-	266.7	-	-	-	267	3
Barrier net	-	-	33.4	-	-	-	33	<1
Danish net	-	-	61.9	-	-	-	62	1
Total *($t.year^{-1}$)*	**2,429**	**2,131**	**1,342**	**1,761**	**1,783**	**1,014**	**10,459**	
Total by habitat	**4,559**		**3,103**		**2,797**			
%	**44**		**30**		**27**			**100**

[*)] *R* = resident fishermen; *NR* = non-resident fishermen

5.3.7 Effort density and total fishing pressure

The effort allocation was calculated for each fishing gear while taking their distribution over the different habitats into account, the average density of the fishery boats per habitat, and the total area of each habitat (Table 5.5 and 5.6). The total number of vessels estimated per day for the resident fishermen was 1,079 boats, which was less than the reported 2285 total fishing boats as obtained from statistical data (BPS 2010) distributed over the 27 villages (Table 5.2). So, 53% of the boats were operational each day, indicating that on average fishermen were fishing around 193 days per year.

We estimated that a total almost 9.3×10^5 fishing trips were carried out per year in the DMCA (Table 5.8), representing 76.2 fishing trips.km^{-2} .$year^{-1}$ (0.8 fishing trips.ha^{-1}.$year^{-1}$). In the coral reef area, with a total area of 2300 km^2; the estimated total was 3.7×10^5 fishing trips, (1.6 fishing trips.ha^{-1}.$year^{-1}$). For the estuarine area, 1790 km^2, the estimated total number of fishing trips was 5.3×10^5 (3.0 fishing trips.ha^{-1}.$year^{-1}$; Table 5.8). Non-resident fishermen made 52% of these total number of the fishery trips: though they only represent 22% of the encounters in the surveys, this means that their activity pattern was much higher. While that of resident fishermen was on average 119 boats.year^{-1}, non-residents spend almost double the amount of time at sea: 202 boats.year^{-1} (Table 5.5 and 5.6).

The highest trip density, 55% of the total, was located in the estuarine habitat, of which 61% was from non-resident fishermen (Table 5.8). The total number of trips in the coral reefs habitat amounted to 38% of the total, this time with the highest effort by resident fishermen (60%). The lowest trip density was found in the pelagic habitat (7% of all trips), 55% of which were made by resident fishermen.

Of the total catch in the DMCA, 44% was extracted from the coral reef (Table 5.9), 53% (2400 t.year^{-1}) of which was taken by resident fishermen. In the estuarine habitat, the highest catch was obtained by non-residents (57% or 1800 t.year^{-1}). The total catches from the pelagic habitat were lower (27% of total), and resident fishermen took most (63% or 1800 t.year^{-1}). In general, the total catch in the DMCA was slightly higher for resident fishermen (53%) than for non-residents (47%).

Regarding catch per unit area per year, the highest fishing productivity in the DMCA was obtained from the coral reef habitat (20 kg.ha^{-1}.yr^{-1}; Table 5.9), followed by the estuarine habitat (17 kg.ha^{-1}.yr^{-1}), and the lowest productivity was obtained from the pelagic area (3 kg.ha^{-1}.yr^{-1}). Overall, total fishery extraction in the DMCA amounted to 0.9 t.km^{-2}.yr^{-1} or 9 kg.ha^{-1}.yr^{-1}.

Table 5.8. The average total number of fishing trip density from resident and non-resident fishermen annually in three marine habitats in the DMCA, with the total trip density per year, the habitat size and the annual trip density.

Marine habitat	Resident *(trip.year^{-1})*	%	Non-resident *(trip.year^{-1})*	%	Total Trip *(year^{-1})*	%	Habitat size *(ha)*	Trip.area^{-1} *(trip.ha^{-1}.yr^{-1})*
Coral reefs	214,869	60	144,175	40	359,044	38	229,483	1.6
Estuarine	204,059	39	323,755	61	527,814	55	178,982	3.0
Pelagic	37,357	55	31,137	46	68,494	7	811,506	0.1
Total effort	**456,285**	**48**	**499,067**	**52**	**955,352**	**100**	**1,219,970**	**0.8**

Table 5.9. Estimated total catches and fishing pressure in three different habitats in the DMCA from resident and non-resident fishermen.

Marine habitat	Resident *(t.year^{-1})*	%	Non-resident *(t.year^{-1})*	%	Total *(t.year^{-1})*	%	Habitat size *(ha)*	Catch.area^{-1} *(kg.ha^{-1}.yr^{-1})*
Coral reefs	2,429	53	2,131	47	4,559	44	229,483	20
Estuarine	1,342	43	1,761	57	3,103	30	178,982	17
Pelagic	1,783	63	1.014	36	2,797	27	811,506	3
Total catch	***5,554***	***53***	***4,906***	***47***	***10,459***	***100***	***1,219,970***	***9***

Statistical differences in CpUE over the years and between fishing technique, habitat, and origin of the fishermen are presented in Appendix F.

5.4 Discussion

Knowledge of the spatial patterns of the fishing boats and their catches are a prerequisite to understanding the differences in fishery pressures as a first step in the evaluation of the sustainability of the fishing activities in marine protected areas. The present study was designed to determine the spatial patterns of small-scale fisheries activities in the Derawan Marine Conservation Area, with a particular focus on the catch per habitat, distinguishing the gear type used by resident and non-resident fishermen. We used a roving creel survey technique to estimate the effort density and the fishing pressure on small-scale fisheries. The roving creel survey in this study did not have a fixed track, but had a rough orientation; deviation of these records was made, depending on the number of encounters with boats, the time required for the questionnaires, and the constraints of arriving at the evening port before dark. Survey tracks could be reconstructed as GPS positions were recorded. The maximum detection distance between the survey midline and the fishing boat of 1 km we used has also been suggested in other studies (Anderson et al. 1993). We also refer to the creel survey on Lake Michigan (Fabrizio et al. 1990). This creel survey can estimate densities of fishing boats over different habitats that differ in size. Combining these creel-survey track data with the mean CpUE per gear type per habitat, estimates can be made about the total catches per habitat per year. The distributions of all encounters with boats (Figure 5.3) shows that this method gives a subsample of the total number of fishermen present at the time of the survey. These survey tracks thus show a directional random walk with the assumption that the densities obtained from the actual track taken are representative of the total mass over the habitats (Kleiven et al. 2011). Post-hoc stratification by habitat was necessary as gears were associated with distinct habitats (Figure 5.5). The total catch and fishing pressure was calculated from the density of fishing boats and their activity pattern, distributed over the three different marine habitats (i.e., coral reefs, estuarine and pelagic habitats), and an estimate of the catch per trip. Although the estimates of the total catches and the spatial distribution of small-scale fisheries for both resident and non-resident fishermen are specific for this study, the methods used are potentially useful for other coastal areas.

Distances between fishing location and homeport for local fishermen matter, as people tend to fish only during the day, and often take short fishing trips (Charles 2001, FAO 2004). The non-resident fishermen came mostly from neighboring districts like Tarakan, Nunukan or Bulungan, from the northern part of East Kalimantan (Figure 5.4). They appear to use more general purpose gears as gillnets and trammelnets, and are at the same time more specialized as they focus on one fish species target (e.g., using 10-12 cm meshed gillnets targeting silver pomfret) and have a higher activity pattern then resident fishermen.

Fishing pressure on different marine habitats in the DMCA

All habitats in the DMCA were fished, with an equal proportion of gears targeting the surface (29 % of all gears) and bottom (71%) in the study area. However, the catch-per-unit-effort in each of the three habitat types was not equal, with highest catches reported

5

from the coral reefs habitat, while estuarine and pelagic habitats had slightly lower catches (Table 5.9).

Total catches were dominated by catches from small-scale fishermen activities in the estuarine-mangroves habitat and the coral reefs. These were relatively higher than those from the pelagic area, probably due to an increased productivity relative ease of access, and a greater spatial diversity within these habitats (Marten & Polovina 1982; Blaber, 2013). The fishing activities from small-scale fisheries in the DMCA had a relatively small average total catch per $ha^{-1}.year^{-1}$ for all three habitats (estuarine, coral reefs and pelagic area) compared to other studies (Blaber, 2013). The Berau catches were estimated at 3 and 20 $kg.ha^{-1}.year^{-1}$ for the three habitats, which is rather similar to catches that were reported for the Semarang estuary, Central Java and Bintuni Bay, Papua (Firdaus, 2010; Iskandar, 2010; Rumakat, 2013) with an average total catch between 7-22 $kg.ha^{-1}.year^{-1}$. However, compared to other locations (e.g., Carpentaria Bay, Australia with catch rates of 125-171 $kg.ha^{-1}$ (Blaber et al. 1990) the catch-rates in the DMCA were small.

The average total catches and effort density were highest in the coral reefs and estuarine habitats compared to the pelagic habitat, as fishermen tend to fish in or close to areas that have a greater abundance of fish, a pattern that is also supported by the findings of Polovina (1984). These coral reef and estuarine habitats are also more accessible than the pelagic habitat. Other studies also showed that total catches in estuarine habitats were higher than those from pelagic habitats, such as reported in the study of Loneragan et al. (2005) about shrimp catches in waters around the Malaysian Peninsula, and Meager et al. (2003) for catches in pelagic and estuaries waters in Australia. Our findings support the general expectation that coral reefs and estuarine habitats have a higher fishery productivity than pelagic areas. Under this situation, these habitats will continue to attract a larger number of fishermen.

The average total catch in coral reefs (20 $kg.ha^{-1}.year^{-1}$) and estuarine habitats (17 $kg.ha^{-1}.year^{-1}$) was larger than in the pelagic habitat (3 $kg.ha^{-1}.year^{-1}$), probably because of two causes. The first is that fishermen targeted fish with a high value on the local and regional market (e.g., groupers and red snappers). Those fish species are mostly found around coral reefs, which are highly productive fishing grounds (Valiela et al. 2001, Mumby 2006). The second cause is a biological explanation, as the estuarine water benefit from the nutrient input from the mainland through rivers, and is highly productive areas for phytoplankton and zooplankton hold mangroves and seagrass, and therefore suitable areas for small herbivorous fish, also attracting large fish. The nutrient input is the primary factor behind the high productivity of estuarine fisheries. Pelagic areas have much lower nutrient input, and economic value of the specific resources seem to drive these patterns. However, fishermen can only choose relatively remote but productive fishing grounds (e.g., coral reefs) if they have enough gasoline, enough time, and the appropriate fishing gears. Fishermen fishing close to their homeports make smaller investments and return with on average higher catches.

The CpUE of most fishing gears was less than 20-30 $kg.trip^{-1}$, typical for most small-scale fisheries with little investment in the fishing gears. Catches of barrier nets were higher

(100 – 212 kg.trip^{-1}) followed by floating nets, static nets, purse seines and coral traps (Table 5.1). Trawling is considered an industrial fishing activity operated from larger boats with 600 hp engines for dragging, and their catches were much higher than from other gears (400 - 2500 kn.trip^{-1}). Trawls are in fact forbidden to operate in the DMCA, but due to a lack of surveillance, illegal operations continued until the end of 2005, when because of protests by small-scale estuarine fishermen local government put a halt on trawling.

Alcala (1988) reported that an increase in fishing pressure could have a significant impact on decreases in the abundance of small fish. Therefore, high fishing pressures can result in declining stocks of commercially important fish species. Fishing can have extensive primary and secondary impacts on coastal ecosystems, such as the removal of non-target species, or the removal of a vast number of top-predators resulting in an increase in fish biomass lower in the food web (Blaber et al. 2000). However, now the fishing pressure in the DMCA is relatively small regarding the total catch per unit area (9 kg.ha^{-1}). These compared to other estuarine areas (i.e., Mahakam delta: 35 kg.ha^{-1}; Genisa (2006)) implying that fishing pressure from an overall extraction point of view does not seem to be problematic. However, explicit references points for fisheries in marine protected areas in Indonesia are lacking, and additional research would be required to compare stock biomass, stock productivity, and catches from fisheries particularly in the species level, where the primary data essential per age classes based on length. In other words, a proper stock assessment is still required to draw firm conclusions about the fisheries' sustainability (Roberts et al. 2005), although the data reported here suggested that fishing pressure was relatively small.

Spatial distribution of fishing trips by both resident and non-resident fishermen were not equal in the three marine habitats in the DMCA. In total, the highest percentage of fishing trips (55%) was reported from the estuarine habitat, followed by coral reefs habitat (38%) and the lowest rate was found in the pelagic habitat (7%; Table 5.8). Total catches from non-resident fishermen were almost equal to the catches of resident fishermen, but in the estuarine area, the catches of non-residents were relatively larger. An important question is whether there is any problem related to the appearance of non-resident fishermen for resident fishers? The non-resident fishermen brought innovation, fishing efficiency and modernization of small-scale fisheries by increasing the use of motorized boats, which allowed to move further offshore and even further from their original home port (FAO-481 by Béné et al. (2007)). The non-resident fishermen are experienced fishermen, targeting economic high-value fish, especially coral reef fish, often with an export-oriented production (Pet-Soede and Erdmann 1998). While the increased number of fishing trips from non-resident fishermen could affect the conditions of the marine habitats and the availability of marine resources (Lentini et al. 2013), and the total pressure in the Berau was almost doubled by their activities, the total fishing pressure was still comparatively small. Resident fishermen can also adopt these fishing efficiencies quickly and increase their fishing pressure in the DMCA, which all can all lead to a larger fishing pressure, with potential adverse effect on the fisheries' long-term sustainability and the habitat quality. The absence of non-resident fishermen (e.g., through new regulation) will reduce the total number of fishing trips per year in the DMCA, lowering the fishing pressure in the area and lessen the impact on marine communities, but would require an enormous monitoring effort. The changes in the marine ecosystem as a consequence of these lower fishing pressure, especially in the structure, composition, and resilience of these marine communities are probably relatively small at the catch rates reported here (Sala et al. 2012, Rombouts et al. 2013).

In conclusion, we investigated the spatial distribution of small-scale fishermen and estimate fishing allocation over different habitats within the DMCA. We found that the highest effort density was recorded from the coral reefs, and lower catches were found both in the estuarine and pelagic habitats. Resident fishermen mainly selected the coral reefs and the pelagic area, while non-resident fishermen selected the estuarine and the pelagic area.


fishermen
habitat
total
t.year-1
kg.ha-1.year-1
Conservation
fisheries
estuarine
resident
non-resident
marine
highest
protected
density
fishing
pelagic
MPAs
Indonesia
Marine
coral
trip
trips
average
compared
habitats
area
Area
located
types
fish
effort
catch
areas
reefs
three
Derawan
Berau
East
Kalimantan
August
February
CPUE
MPA

Chapter 6

General discussion and conclusions


MANGROVES
MARINE
RESOURCES
IMPORTANT
DISTURBANCE
ECOSYSTEM
SEA
Delta
AREA
BIODIVERSITY
POPULATIONS
CORAL
BERAU
Sulawesi
Conservation
fishery
SHRIMP
ABOUNDING
FORESTS
SYNTHESIS
ACTIVITIES
supports
stretches
harbors
USED
EXPLORE
CORRIDOR
ESTUARINE
FISH
INCREASING
ISLANDS
Barhea
PARTS
ADDITION

Chapter 6

General discussion and conclusions

6.1 Introduction

In this thesis, I explore disturbance processes in the Berau Delta, an estuarine ecosystem on the shore of the Sulawesi Sea. This sea stretches between the islands of Borneo and Sulawesi. It still is an important migratory corridor for Cetaceans and harbors some of the most important biodiversity coral systems on Earth. In addition, an ever-increasing human population is making use of the marine resources from this sea. Along parts of its coast, mangrove ecosystems are abounding or used to abound. The Indonesian Government considers not only mangroves but also shallow estuaries, coral reefs, pelagic and deep-sea areas in the Derawan Marine Conservation Area as an important marine ecosystem that supports a high biodiversity of marine resources. This combination of sophisticated marine habitats supports fisheries activities (Table 6.1). Disturbances to these mangroves can affect the complexity of the mangrove forests and thereby influence the nursery function of mangroves forests for juvenile shrimp and fish. These shrimp and fish resources are essential for the sustainability of fishery activities of small-scale fishermen in the delta. As part of the Wageningen funded RESCOPAR program on the resilience of coastal populations and aquatic resources in Indonesia and Vietnam, this case study was carried out in the Berau Delta, including the Derawan Marine Conservation Area.

I examined the disturbances on mangrove extent and fragmentation from 1991-2009, focusing on land cover changes that can also affect the size and the structural complexity of mangrove trees and roots. Undisturbed mangrove forests have roots with a high structural complexity, influenced by the presence of pneumatophores and prop roots (Chapter 2).

Deforestation of mangrove forests negatively affects the habitat structure (Ley et al. 1999, Meager et al. 2005) and the biodiversity of the mangrove habitat (Primavera 1995, 1998, Primavera et al. 2007). That can reduce the abundance of the associated fauna (Blaber and Milton 1990, Nagelkerken et al. 2000, Nagelkerken et al. 2008). The potential to trigger cascading effects to higher trophic levels happens, which ultimately can affect also the productivity of fisheries in the Sulawesi Sea. The results of this study show that the anthropogenic disturbance in the Berau Delta can affect the roots structural complexity of mangroves. Closer to settlements, root structure, became unexpectedly, more complicated, thereby increasing the mangrove nursery function (Chapter 2). Covarying patterns probably cause this: people select healthy mangrove forest patches for sheltering their settlements, relatively well protected, and are characterized by a complex root structure.

I investigated how the impact of differences in root structural complexity on marine resources, by constructing artificial mangrove units (AMUs), mimicking the effects of root structure through changing the number of sticks, and modify the size of these AMUs. The results of these AMUs experiments provided a deeper understanding of the mangrove's nursery function for juvenile shrimp and fish. The mangroves patches that were larger and had a more complex root structure had more juveniles and more species, while the small mangroves patches and the patches with a less complex root structure had fewer juveniles and more rare species (chapter 3).

In general, the estuarine area forms a transition zone between the rivers and marine environments. It is under the influence of tides, waves, and the influx of saline water, and under riverine influences, such as flows of nutrient-rich river waters, which transport fine sediment that is rich in minerals. This mixing of fresh and salt water creates a transition zone with high levels of nutrients in the shallow water column, making estuaries highly productive. My analysis of the spatial context of the habitats in the proximity of the fishing location illustrates the influence of the estuarine habitats (e.g., size and distance to the different habitats) on the length size of the shrimp and fish catches of small-scale fisheries. The survey results from the fishery catches of three different fishing gears (i.e., mini trawl, trammel net and gill net) showed that distances to and extent of nearby estuarine habitats influenced the catch sizes of shrimp and fish (Chapter 4).

The final chapter of my study is about the spatial distribution of small-scale fisheries in the Derawan Marine Conservation Area. I showed how the small-scale fishing boats were distributed over the three different marine fishing habitats (mangrove-estuarine, coral reef, and pelagic areas). I could estimate fishing pressure from the total number of fishing trips in the different three habitats, and their catches (Chapter 5; Table 6.1). The catches per unit effort (CpUE) differed over the fishing habitats, under the influence of differences in the fishery pressure and differences in productivities of these habitats. I standardized the catch data of twelve types of fishing gear and used a standardized CpUE for further analysis. My results showed that the coral reef area had the highest fishing pressure, with the largest number of fishing trips per year in this area, followed by the estuarine habitat. I found the lowest fishing pressure in the pelagic areas.

Two hypotheses are at the basis of my study, the predator refuge theory, and feeding hypothesis (Robertson and Duke 1987, Primavera 1997, Kathiresan and Bingham 2001, Laegdsgaard and Johnson 2001, Barbier 2003, Lee 2004). The mangrove forests provide both food and shelter under an influence of the root structural complexity, which is the basis of both hypotheses. These two general theories explain why in general mangroves are so attractive to juvenile and small fish. Through the experiment, I found a higher abundance of young fish in the undisturbed mangrove with an intricate root system compared to the disturbed mangrove area. However, the differences in juvenile fish abundance and young species distribution concerning anthropogenic disturbances in estuarine areas are not documented well.

Therefore, this study was initiated to quantify the effect of mangrove disturbance on marine juveniles and link the catches of small-scale fisheries to the presence of nearby habitats. The objectives of this thesis were to (1) increase our knowledge about how human disturbance affects the structural complexity of mangroves, and (2) to evaluate the relationships between nursery habitat (mangroves and other estuarine habitats) and catches of nearby fishermen within the Marine Conservation Area. The objectives, captured by four research questions, were:

1. What is the effect of disturbance factors on the structural complexity of mangroves in the Berau Delta?
2. What the influence of mangrove roots on the abundance, biomass, and species richness of marine juvenile shrimp and fish?
3. Is there any relationship between the spatial configurations of the surrounding habitats on shrimp catches?
4. What is the spatial allocation of small-scale fisheries activities over the different coastal habitats and what are the spatial differences in catches of these fishing activities?

In this last sub-chapter, I discuss how the results from the various research chapters in this thesis relate to each other and what new perspectives they bring concerning the mangrove delta and estuarine nursery effects. I will also integrate the obtained results in the context of existing mangrove conditions.

6.2 The focus of the thesis

In my thesis, I focused on the interactions between marine juvenile fish and shrimp and their nursery environment in the mangrove forests. These mangrove forests support the fish productivity in the Derawan Marine Conservation Area. The study on mangroves focused on the mangroves forest patch size, on forest fragmentation and mangrove root complexity under the influence of two large disturbance factors, i.e., anthropogenic and natural disturbances.

The second subject is related to the spatial distribution of small-scale fishery activities in the Derawan Marine Conservation Area. This fishing activity supports the livelihood of small-scale fishermen, not only for local fishermen (resident) but also for non-resident fishermen who came from other provinces or even countries which are sometimes located thousands of kilometers from the study area.

Table 6.1. A summary of habitat and small-scale fisheries characteristics within the Derawan Marine Conservation Area (DMCA).

		Mangroves/Estuarine	Coral reefs	Pelagic	Notes	Methods
Derawan Marine Conservation Area (DMCA)	Habitat	1800	2300	8100	Area (Km^2)	BIG, 2007
		26	470	?	Species (N)	Bengen, 2003
		Mangroves: Roots, seedlings, saplings	Corals: Table, branching, brain, staghorn	-	Structure	Field survey
		High, medium	High, medium	Medium, low	Disturbance level	Field survey, Landsat Imagery 1991-2009
		Nursery	Nursery	Productivity	Function	Primavera et al, 2005; Lee et al, 2014
		Juvenile (fish/shrimp)	Sub-adult / Adult	Adult	Life stages	Field survey & experiments
	Small-scale fisheries	Resident	Non-resident		Categories	Creel survey
		21 local villages	2 Countries, 11 Provinces		Origin	Creel survey
		12	12		Fishing gears	Creel survey
		455	402		Catches (kg. km^2,trip^{-1})	Creel survey
		37	41		Fishing trip (N. trip.km^2.year^{-1})	Creel survey
		(3 – 135)	(63 – 250)		Average Distance (km)	Creel survey

At the end of this synthesis, the core themes of this thesis (impact of disturbance, fish-mangrove interactions, the spatial aspects of small-scale fisheries locations, and the productivity of these fisheries within the Derawan Marine Conservation Area) will be integrated, and new directions for research will be presented.

6.2.1 The fish-mangrove interaction, the structural complexity, and the nursery function

Mangrove forests are home to many wildlife species. The increasing human population in the delta where the mangrove forests occur has led to an increase in disturbance to this ecosystem. Human disturbances in mangrove forests might be dominant factors driving a transition in land use types, such as coastal developments for settlements, aquaculture ponds, roads, and industrial areas, triggering coastal erosion and mangrove conversion (Bengen 2003, Sukardjo et al. 2014). In chapter 2, I focused on the anthropogenic disturbances in the mangrove ecosystem. The decrease in the extent and quality of mangrove forests in the world has been well documented (FAO 2004, Spalding et al. 2010, Giri et al. 2011, Sukardjo et al. 2014). However, as discussed in the general introduction, the function of mangroves as a nursery area for juvenile marine species is not entirely understood, and we do not know how human disturbance affects the relationships between nursery grounds and juvenile fish.

The nursery function of structurally complex coastal habitats is useful for growing marine organisms (Edgar and Shaw 1995, Able 1999, Edgar et al. 2000, Nagelkerken et al. 2001, Nagelkerken et al. 2002, Manson et al. 2005b, Dahlgren et al. 2006, Nagelkerken et al. 2012, Lee et al. 2014, Nagelkerken et al. 2015). These services depend on the habitat size, root structural complexity as one of mangrove attributes, and standardized coverage per unit area. If the mangrove habitats are disturbed then the extent, root structural complexity, mangrove cover and the number of species will decrease. These changes have also been documented in previous studies (Blasco et al. 1996, Valiela et al. 2001, FAO 2004, Blaber et al. 2010, Spalding et al. 2010, Sukardjo et al. 2013b). To obtain a clearer picture of the effects of disturbance on the mangrove attributes, I studied mangrove roots, seedlings, saplings, and size of mangrove trees. I measured tree densities and root structural complexity concerning human disturbance and natural sources of disturbance such as coastal erosion through wave action (Chapter 2). Mangrove forests in the Berau Delta were dominated by *Rhizophora* sp. and *Nypa fruticans*. The estimated area of mangrove forests that was lost reached 30%, from 78,000 ha originally (1991) to 56,000 ha (2009) mainly due to infrastructure and aquaculture ponds from Nypa palm areas (Chapter 2; Table 2.3b). Three reasons have been given for the selection of mangrove palm conversion: i) farmers do not need permits for the conversion, ii) the soil type of mangrove palms is more suitable for pond construction than that of other mangrove trees, iii) mangrove trees protect the aquaculture ponds against wind and wave erosion. This disturbance affects the spatial configuration of the mangrove habitat and led to fragmentation of the nursery habitats. Moreover, in chapter 2, I also showed that mangrove root length and sapling density increased closer to villages in the Delta, while the trees diameter decreased. The trees diameter decline could have been caused by the removal of large trees by local communities, e.g., for construction material, leaving smaller trees closer to settlements, and opening the forest. The remaining gaps near villages' increases the availability of sunlight in the area, facilitating germination and seedling growth, partly explaining the high abundance of sapling density and larger root lengths there.

To quantify the changes in mangrove cover and its extent, I used remote sensing techniques. There are various techniques to quantify spatial changes at the scale of an entire delta. The question remains whether commonly applied methods, such as remote sensing (Field et al. 1998, Valiela et al. 2001, Lucas et al. 2007, Vaiphasa et al. 2007b, Mcleod et al. 2011, Fauzi et al. 2014), are suitable for quantifying anthropogenic disturbances in mangroves forests, especially when root structural complexity is essential. Moreover, mangroves extent and tree structure might not only influence the productivity of fisheries but also be related to species diversity in the area. Currently, the field of LiDAR offers news prospects to quantify tree structure (Naidoo et al. 2012, Wulder et al. 2012) in inaccessible places such as mangrove forests, although its application to mangrove structural complexity is still not fully exploited (Kamal et al. 2015).

Interestingly, changes in mangrove habitats might not only influence the marine community but also in the long term, the livelihood of local communities who depend indirectly on the marine resources (Chong 2007, Lee et al. 2014). The disappearance of a single mangrove species, such as the pioneer species *Rhizophora* sp. in and alongside cannals due to aquaculture pond construction, might negatively affect the quality of the habitat, because this species has a unique and extensive root structure. The complex root system attracts a wide variety and vast abundance of juvenile fish and shrimp during high tides, offering food and shelter (Primavera 1995, Laegdsgaard and Johnson 2001, Cocheret de la Moriniere et al. 2004, Tong et al. 2004). A lower mortality during the juvenile stages is therefore expected, due to a lower natural predation pressure (because of the higher shelter possibility and larger food availability in the nursery area). The nursery habitat is therefore expected to increase the abundance of young sub-adult fish and shrimp, and hence sustain the fishing, activities, supporting the future livelihood of local communities.

Comparing the four deltas in East Kalimantan Province, the degree of anthropogenic disturbance on the mangroves in the Berau Delta is probably smaller than in three other Deltas. Regarding extent habitats and species distributions as documented in various publications for the Mahakam Delta (Zuhair 1998, Dutrieux 2001, Suaib 2004, Sidik 2008, Nursigit et al. 2013, Fauzi et al. 2014), Bulungan-Nunukan Delta (Prasetyo 2010, Ilman et al. 2011) and Pasir Delta (MacKinnon et al. 1997, Sukardjo 2009).

The underlying mechanisms of anthropogenic disturbance on mangroves habitat for marine juveniles

Mangrove in the delta and estuaries hold different levels of structural complexity (Rönnbäck et al. 1999, Rönnbäck et al. 2002). Different zones within a mangrove ecosystem have different mangrove species that influence the complex nature of the root structure (Robertson and Duke 1987, Robertson and Alongi 1992, Laegdsgaard and Johnson 2001). So, human disturbance in mangroves can affect not only the species diversity, the densities of trees, but also the complexity of the root structure. Although other studies showed that more disturbed mangrove forests have a decreased root structural complexity (Ellison and Farnsworth 1993, Twilley et al. 1999). Other studies found that disturbance in mangrove forests can positively affect the densities of tree sapling of *Rhizophora* sp. due to increased light availability in canopy gaps and reduced propagule availability in these deficiencies (Sherman et al. 2000, Sousa et al. 2003).

The mangrove forest in the Berau Delta has a surface area of 56,000 ha and contains more than 20 mangrove tree species. Mangrove forests develop under the influence of a wide variety of factors, such as the diurnal tidal system, the freshwater flow from rivers (i.e., the Segah and Kelay River), and sedimentation of organic and inorganic particles. The root structure plays a significant role in this deposition, reducing the water current speed and trapping small detritus particles. The availability of nutrients is higher under mangrove trees (Ellison and Farnsworth 1993, Primavera 2005a, Reef et al. 2014). A more complex root structure provides more suitable shelter places to avoid predators. Predation has a substantial impact on the habitat choice of fish and shrimp (Kneib 1987, Ljungberg et al. 2013, Ory et al. 2014). All these elements play a role in influencing habitat quality for small fish and shrimp. The impacts of anthropogenic factors on mangroves can affect the abundance of fish and shrimp in the estuarine area. I studied the effects of anthropogenic disturbance at two different spatial scales:

a) Small scale: Anthropogenic effects can change the roots' structural complexity and thereby influence the nursery function of these roots as a feeding habitat and as a shelter for marine organisms to avoid predation.
b) Large scale: Changes in mangroves forest in the delta under anthropogenic disturbance can affect the nursery services, decreasing the CpUE of nearby coastal fisheries and hence the income of these fishermen.

For the small scale analysis of anthropogenic disturbance that occur in mangrove forest, I used the AMU experiment (chapter 3). I found that a larger cover of mangrove (simulated by a large size of the AMU platform) supports a higher abundance of juvenile shrimp and fish, while a smaller cover of mangrove (small AMU size, 1x1m) supports less shrimp and fish. This field experiment shows the ability of the size of mangrove cover (size of AMU platform) to affect the presence and abundance of fish and shrimp, and we expect that also other benthic organisms will show similar trends. Shelter, the availability of food, and the absence of pollutants are probably three important factors in the AMU experiment that can control the presence and abundance of the marine juvenile in the estuarine area, and their species richness (Nagelkerken et al. 2010, Nagelkerken et al. 2012). However, we were unable to test for the differences in effect size of these three factors in our experiment and our correlative studies. The AMU experiment showed that a large mangrove area with a denser root system attracted more juveniles and had a higher species diversity than smaller areas, or areas with less structure (Chapter 3). The number of fish caught and the fish and shrimp species distribution were correlated to the density of mangrove roots and the size of the mangrove patches. I also found that the level of disturbance and the distance to the mangrove areas also affected the abundance of juvenile marine fish species. The higher disturbed area, the lower the abundance of marine community. Juvenile white shrimp (Chapter 3, and unpublished data) dominated the shrimp caught in the AMU's. Hence, the extent of mangrove patches and the density of the mangrove root system can be used as indicators for the abundance and species richness of marine communities. Unfortunately, neither the field observations nor the experimental studies reported in this thesis enabled me to disentangle the relative role of mangroves as a food source or as a shelter for predation. Disentangling this dual role of mangroves would be a treasured topic for future research. In the next section, I will explain the shrimp-estuarine connectivity at the large scale.

6.2.2 Shrimp-estuarine connectivity, the spatial integration of shrimp fishing

Mangroves are connected to both land and marine environment through fresh water flows via rivers, tidal regimes and movement of marine fish and other organisms. Mangroves supply nutrients (Kristensen et al. 2008) and shelter for marine juveniles (Nagelkerken et al. 2008), but also act as a natural barrier and trap sediments from the land (Woodroffe 2016). The connectivity between mangroves, estuarine and marine environments (Aburto-Oropeza et al. 2008) is influenced by various interactions between a multi-variable. The variables such as hydrology regimes, climatic variations, tidal period, coastal landscape, structural complexity of marine habitat, accessibility of fauna (e.g., fish, shrimp, crabs, monkey's, birds etc.), including the proportion of mangrove forests. All these interactions influence the exchange across boundaries (Nagelkerken et al. 2008). Connectivity not only contributes to the services placed on mangroves, but also influences their vulnerability to disturbances (e.g., natural and anthropogenic; (Alongi 2008)).

The role of mangroves in supporting fisheries has been studied previously (Nagelkerken and Faunce 2008). We have a general understanding of the relationships between mangrove habitats and nearby coastal fisheries through tidal connectivity, but the factors that determine the variability of catches in the estuarine areas are involved and likely non-linear (Koch et al. 2009). Especially shrimp depend on a range of factors that include the species within its habitat and their feeding preferences, site characteristics, and the presence of predators (Aburto-Oropeza et al. 2008, Nagelkerken and Faunce 2008). Although mangroves may function as nurseries for many species of marine juveniles (Laegdsgaard and Johnson 2001, Nagelkerken and Faunce 2008, Lee et al. 2014), little is known about the Spatio-temporal dynamics of fish and shrimp populations while migrating between mangrove and offshore habitat through the shallow estuarine area.

The anthropogenic disturbances affected not only the structural complexity of the root systems in mangrove forests but also decreased the extent of the mangrove forest, potentially reducing the number of mangrove species. A decline in mangrove forest extent will reduce the total available shelter area and, on the long term, might negatively affect the populations of juveniles. In Chapter 4, I showed that the catch per unit effort (CpUE) was correlated with the size of nearby coastal habitats. This relation means that the distances from a fishing location to several estuarine habitats influenced the shrimp catch sizes of these fishermen. The used land cover habitats in this analysis were mangroves (including Nypa palms), riverine, infrastructure, aquaculture ponds, coral reefs, pelagic areas, and coastal forests. The catches also related not only to the sizes of nearby habitats but also to the distances towards the different land cover habitats. Hence, anthropogenic disturbance effects are found at multiple scales, at the lower root level scale, but also at a higher spatial scale, at the extent, distance, and configuration of the estuarine habitat types, influencing the CpUE of the fishermen.

In conclusion, the size of the estuarine habitat was correlated with the catch of medium-large sized shrimp with trammelnet, while the nearest distance to the mangrove habitat was correlated with the catches of smaller shrimp sizes with minitrawl.

6.2.3 Fisheries in the Derawan archipelago, food from the Sulawesi Sea

Already more than 30 years, foreign commercial fishing vessels (from Malaysia, the Philippines, Thailand, Vietnam, China, and Japan) come to Indonesian waters to fish. The commercial fishing activities mostly operated in the border area between Malaysia and the Philippines (e.g., northern area of Sumatra at the Strait of Malacca, West and East Kalimantan and North Sulawesi) and Australia (i.e., Papua and Maluku). The high pressure from foreign fishing vessels probably also affects catches from local fishermen who used the only traditional small fishing boat (Huntington et al. 2015, Petrossian 2015). Many small-scale fishermen in Indonesia tend to travel long distances from their homeport to the Berau Sea for fishing, (Chapter 5). Since the year 2000, this area has restricted access for the commercial fishery vessels larger than 30GT.

For almost six months per year during the wet season, the flat sea surface in the Derawan Marine Conservation Area is a good place for the reproduction of various species of fish and shrimp (Turak 2003, Gunawan 2012, Kusumawati 2014). This area is a semi-closed marine system protected by an atoll reef (e.g., Maratua Island and Muaras reef) as the border to the Sulawesi Sea. The annual upwelling events from the Sulawesi Sea during the dry season make this marine area fertile and the basis for the fish and shrimp fisheries.

Migrants from South Sulawesi dominate the fishing villages along the Kalimantan coastline. The majority is from the Bajo tribe (Foale et al. 2013, Ananta et al. 2015). Culturally, the Bajo people are hardworking and reliable fishermen. The Bajo people mostly have on average a low education and low income and are relatively poor communities. Coastal areas along the East Kalimantan shoreline are characterized by societal problems including poverty, over-population, weak economy, overfishing and urban pollution (e.g., plastic garbage and household waste) (Booij et al. 2012). These societal problems often contribute to uncontrolled and unsustainable urban development along the coastal area. The high fishing effort to support the increasing needs of the fast growing population might threaten the coastal ecosystems (Foale et al. 2013). The traditional fishing is driven by various small-scale, low-technology, low-capital, fishing practices undertaken by individual fishing households as opposed to commercial companies (Allison and Ellis 2001, Berkes et al. 2001, FAO 2002). In my study, I distinguished two groups of fishermen: the non-resident fishermen (Chapter 5), mostly fishing around the coral reefs and in the pelagic area, and the resident fishermen who fished near their settlements and in the estuarine area or the coral reefs near the small islands. In my study, the non-resident fishermen came from 11 provinces (e.g., North Sulawesi, South Sulawesi, Southeast Sulawesi, Central Sulawesi, North Maluku, East Java, Central Java, Southeast West Nusa, South Kalimantan, North Sumatra, Nusa Tenggara Barat, and Bali; Figure 5.4). They were traveled long distances to fish in this area. The resident fishermen are part of the coastal population with an estimated 45,000 people that make a living from fishing in the Berau water territory (BPS 2009). Most of these local fishermen have small-scale fisheries operations with a single boat of 2-8 m. Small-scale fisheries or traditional fishing in this study area are poor-scale fisheries with on average a little income.

To examine the relationships between marine resources and fisheries catches, I quantified the spatial and temporal distribution of fishing boat, and estimated the CpUE, by using standardized working hours per trip for twelve different fishing gears (Chapter 5). The effort from resident fishers was slightly lower than that of non-resident fishermen, considering the limited time that non-resident fishermen have. The largest catches were recorded on coral reefs and in the estuarine habitats and the fishing pressure in these two habitats was higher than in the pelagic habitat (Chapter 5).

If the fishing pressure in a habitat is too high in the estuarine area, it can result in a decline of juvenile commercially fish stocks (Tuya et al. 2006). Moreover, it can also have negative consequences for the biodiversity, such as i) the removal of non-target species as bycatch (e.g., flatfish, small swimming crabs, juvenile sharks, and other predators). There are also marine mammals, sea turtles and seabirds entangled in nets and long-lines as bycatch (Brito 2012). ii) physical damage to the bottom substrate in the shallow estuarine habitat by using bottom trawl fishing techniques (Domènech et al. 2014). The last consequence is (iii) changes in the abundance, diversity, and community structure of benthic invertebrates, triggering changes at higher trophic levels (Pinnegar et al. 2000, Casini et al. 2009). From my study, I conclude that fishing pressure was relatively small, but I cannot quantify the relationships between CpUE and fish stock size. Further research is required to determine stock sizes per fish species, but the first step in this analysis was achieved: the quantification and spatial distribution of fishing efforts over the entire Delta. The impacts of the fisheries activities, in relation the used fishing gear, and associated fishing pressures can however, affect both the marine community composition, and ecologically important species. The ecosystem approach (Heenan et al. 2015, Skern-Mauritzen et al. 2015) might offer a solution to understand these relationships and incorporate them into management's plans to preserve critical coastal habitats, and reduce disturbance from human activities and formulate sustainable fishing pressure levels.

6.3 Mangrove merit management: the resilience and persistence of juvenile marine species

From the discussion in Chapter 5, we conclude that fishing pressure was low. These estuarine systems are also quite resilient to anthropogenic disturbance (Alongi 2008, Pearson et al. 2015, Villanueva 2015). Are juvenile species also resilient against the current anthropogenic interference? We, therefore, re-calculated our data from the AMUs (Chapter 3) and carried out a simple analysis. We defined sensitivity as the capacity of a species to tolerate disturbance. Boesch (1974) set persistence and resilience of marine species in AMUs. Persistence refers to constancy over time, regardless of environmental perturbation.

Table 6.2. The distribution of abundance (n/m²) of marine species in the different artificial mangrove units (AMUs) and a relative estimate of their sensitivity to disturbance

Species	High Stick density		Low Stick density		Sensitivity to disturbance	Total	%
	Large AMU	*Small AMU*	*Large AMU*	*Small AMU*			
Crabs	53	33	42	36	Resilient	164	44
Penaeus semisulcatus (de Haan, 1850)	46	44	38	34	Resilient	162	43
Penaeus spp. *(Mysis)*	4	7	4	1	Vulnerable	16	4
Metapenaeus brevicormis (Milne-Edwards, 1837)	2	2	2	1	Stable	7	2
Seastars	3	2	1	0	Stable	6	2
Stolepholus indicus (van Hasselt, 1823)	2	1	1	1	Stable	5	1
Oratosquilla nepa (Latreille, 1828)	2	1	1	1	Stable	5	1
Scatophagus argus (Linnaeus, 1766)	2	1	0	0	-	3	1
Penaeus latisulcatus (Kishinouye 1896)	1	1	1	0	Stable	3	1
Penaeus merguiensis (de Man, 1888)	1	1	0	0	-	2	<1
Penaeus monodon (Fabricius, 1798)	1	0	1	0	Vulnerable	2	<1
Overall	**117**	**93**	**91**	**74**	**Stable**	**375**	**100**

Resilience means the ability to recover from disturbance to some persistence state. We hypothesized that all juvenile species have a mechanism to deal with the interference level in mangroves forests. In the field experiment of artificial mangrove units (AMUs) in Chapter 3, 125 fish species were sampled in three replicated sites at different conditions of the mangrove forest (i.e., high, medium and low disturbance level). 64% of the tested species were herbivorous and 36% carnivorous. This result corroborates with the findings of Pauly and Ingles (1986) who also found that two-thirds of the fish community in mangroves were herbivorous.

To analyze the effect of the mangroves disturbance levels in the presence and absence of shrimp and fish species, I reordered the data of chapter 3. The species samples were arranged based on the sticks density (e.g., high and low) and size of the AMU (Table 6.2).

The result shows that two species categories (e.g., crabs and *Penaeus semisulcatus*) were more resilient than the other species (groups). Five species were rather stable, and two species were vulnerable to anthropogenic disturbance in these AMUs. The conclusion is that the anthropogenic disruption of the mangrove forest can affect the abundance of certain estuarine juvenile organisms, in particular for the mysis stages of *Penaeus* spp, and *Penaeus monodon.* However, further research is required to test these relationships at the species level.

6.4 Recommendations

In this thesis, I analyzed the impact of mangrove disturbance in the Berau Delta on coastal fisheries, especially concerningto the abundance of shrimp and juvenile fish. This study was conducted in the context of the establishment of the Derawan marine conservation reserve and to develop guidelines for the improvement of the small-scale fisheries in Berau District, East Kalimantan, Indonesia.

In the following paragraphs, I present some recommendations to achieve an efficient and sustainable management of this mangrove-estuarine ecosystem. Based on the findings in chapter 2, I made three options of recommending:

1) Maintain the remaining dense mangrove forest (including Nypa palm areas) through strictly regulatory marine policies to prevent future mangrove loss and protect the mangrove species composition by limiting the permits can inhibit investmen and further development in the Delta (e.g., for construction of the settlements, infrastructure, and aquaculture ponds).

2) Save the last natural mangrove forest in the south of the Berau Delta as a protected or conservation area for the future of marine fisheries, to protect future food security for local communities.

3) Restore the other locations of disturbed mangrove forest in the Northern part of the Delta, especially in the large area of abandoned ponds near Batumbuk village.

Based on the findings in chapter 3, I recommend that the Berau District Planning Agency (Bappeda Berau) should maintain the remaining large areas of natural mangrove under the ”protection status” because such an area can be pivotal for attracting juvenile, fish and shrimp and sustain the marine communities. We found that mangrove in the Berau Delta serves as an outstanding nursery function. Especially for juvenile reef fish, that move to mangrove areas when they reach six cm because they are bigger enough to hide from predators in the shallow estuarine and coral reef areas (Mistakidis 1970).

Conservation efforts to ensure suitable migration routes of young adult shrimp between mangroves, shallow estuarine areas, seagrass beds, and coral reefs to the offshore area might be required. The important function of migration routes between different marine habitats is well recognized (Gillanders et al. 2003) to maintain the resiliency of the marine ecosystem and to sustain the marine productivity for sustainable fisheries in the Derawan Marine Conservation Area. Therefore, a continuous resource use-monitoring program in these vital marine habitats funded by the Berau Government is highly remommended from this larger perspective. Conservation program of the marine ecosystems in the Berau District should become the top priority for the Berau Government because of their marine area is the third richest biodiversity in Indonesia. The conservation program not only for marine food security in perspective of the coastal fishery, but also to protect two threatened species were listed in the IUCN document. Both green turtle (*Chelonia mydas*) and hawksbill turtle (*Eretmochelys imbricate*) were found in the Berau waters are exotic and endanger species. Protecting endangered turtle species can be integrated with economic growth, turning a win-lose or lose-lose situation into one where everyone benefits. This can be accomplished by using financial incentives to promote conservation. Through protecting critical marine habitats by Berau Government will turn endangered species from a liability into an asset for future income. The marine eco-tourism and the exclusive tourist destination are both strategics program as an alternative source of revenue for the local community.

Based on the findings in chapter 4 and 5, I recommend that fishing activities by both resident and non-resident fishermen should be better controlled. The illegal and unreported fishing activities should be reduced by monitoring their activities with community participation. A community surveillance program for fisheries activities can be set up at sub-district level, led by the fishing agency, also to increase the awareness of the ongoing changes in the area. I recommend that marine resource use should be continue monitored. Monitoring resource use with a proper design and subsequent actions by local authorities is required. The local community at a sub-district level should be actively involved to increase their social responsibility, and to contribute to the sustainable use of marine resources for future benefits. Active participation from local communities in the monitoring program of small-scale fishing activities and well-documented control data are required to improve the quality of the Berau fisheries database.

Finally, it is important to develop a transparent communication strategy, enhance coastal community participation, and start education campaigns for both fishermen and local authorities, to increase their understanding of the value of mangrove-associated fisheries and the relationships between the mangrove forests and the open-sea fisheries and conserve marine resources. To maintain and manage these marine resources in different coastal habitats there is the need to develop an integrated sea-use planning, to support sustainable fisheries not only the Derawan Marine Conservation Area but also for the future of the Sulawesi Sea.

The understanding gained from my research may serve as input to further actively manage the mangrove ecosystem and their associated coastal fisheries. Moreover, there is limited information and knowledge of access to local markets of the resident and non-resident small-scale fishermen. The need to understand the local market dynamics is important, as it drives the decisions of the fishermen and their income generating activities.

6.5 Concluding remarks

The critical observations and relevant conclusions of the thesis are as follows:

1. Mangroves, coral reefs, and the estuarine and pelagic areas in the Derawan Marine Conservation Area are critical habitats that provide various ecosystem services. The Derawan Marine Conservation Area is regarded as an area with a high marine biodiversity in Indonesia, being part of the coral triangle center (CTC) of the Sulu-Su-

lawesi Marine Ecoregion (see Appendix D.2). However, the area is threatened by anthropogenic activities. The impact of the growing human population is associated with land cover changes in the Berau Delta. Besides the potential loss of mangrove habitat, the high utilization of the intertidal and coral reef areas can trigger large societal consequences, such as a reduction in the nursery function of these habitats, which can lead to a decline in coastal fishery catches.

2. Anthropogenic and natural disturbances are present in the mangrove forest in the Berau Delta. The largest anthropogenic interference is the conversion of mangrove palms for settlements and aquaculture ponds.
3. The structural complexity of roots, related to mangrove's nursery function, is correlated with anthropogenic and natural disturbance factors. We found a negative correlation between anthropogenic disturbances and some variables associated with the root structural complexity, meaning that if the trouble was increased, the complexity decreased.
4. Juvenile shrimp and fish were relatively more abundant in AMUs with a more complex root structure and in larger AMUs compare to the small size and less stick.
5. Juvenile fish seem more affected by mangrove structural complexity than shrimp.
6. Spatial context of coastal habitat in the study area is correlated with the shrimp catch by estuary small-scale fishermen in the estuarine. The extent and the nearest distance of the different habitat were correlated with the capture size.
7. The distribution of small-scale fishery activities in the Derawan Marine Conservation Area was spatially heterogeneous in the coral reefs, pelagic and estuarine areas. The CpUE declined from the catches in the coral reefs to the estuarine area, with the lowest catches in the pelagic area.
8. Mangroves serve as a critical nursery for marine juvenile and therefore play a significant role in health of coastal fisheries, supporting the economic well-being of fishermen. Understanding the effect of both anthropogenic and natural disturbances on the mangrove structural complexity that may further affect the nursery function of this habitat for juvenile shrimp and fish is needed better to manage the remaining mangrove ecosystem for the sustainable exploitation of fisheries resources in the Derawan Marine Conservation Area. A comprehensive, spatially explicit, marine resource use plan is essential to support the sustainability of resource extraction from the Sulawesi Sea.


Human
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Summary

Food from the Sulawesi Sea, *the need for integrated sea use planning*

The growing global human population is associated with an increased demand for fishery products. Mangrove habitats are critical nursery areas for juvenile fish and shrimp by providing food and shelter. Mangroves only occur in tropical marine coastal waters, and even though most tropical waters are not as rich in fish stocks as the nutrient-rich cold water systems in the north or south, these tropical waters provide much proteins and income for local fishermen especially in a country like Indonesia. If the mangrove habitats decline in size and quality, it may affect food security in the form of reduced fish and shrimp supplies which are vital sources of protein for the local human populations, and possibly at the global level. Currently, in the tropical coastal water a decrease of marine fish and shrimp products due to overfishing. Furthermore, global climate change will indirectly affect mangrove habitat.

Considering this setting, I initiated the present study to estimate the impact of mangrove disturbance on the complexity of root systems, because the mangrove root system offers an important part of the habitat for juveniles of shrimps and many fish (the so-called nursery function of the mangroves). I assessed the effects of disturbance on the abundance of juvenile fish and shrimp, and I estimated the fishing pressure of small-scale fisheries in the Derawan Marine Conservation Area which forms a part of the coast of the Sulawesi Sea. An important feature of this coast is the delta of the Berau River, where huge mangrove forests still occur even though thirty years ago these mangroves were much more extensive than now. The following four research questions were addressed:

1. Do human disturbances in the Berau Delta affect the extent of mangrove forests in the delta, and also the root structural complexity of mangrove trees?

2. What are the relationships between mangrove attributes and juvenile fish under different levels of disturbance?

3. Do the spatial configuration of mangrove forests and other estuarine habitats influence the fishing catch rates?

4. What are the differences in the fishery pressure from the small-scale fisheries on the marine habitat?

In Chapter 2, I studied the effects of disturbance on mangrove forests extent and spatial complexity. This study focused on the structural complexity of the mangrove habitat, specifically the root structural system. Between 1990 and 2009, the area of mangrove habitat in the Berau Delta decreased by 54%, mainly from deforestation of Nypa palms at the

benefit of roads and pond construction. Further analyses indicated that over 70% of the disturbance was anthropogenic. This long-term disturbance also influenced the tree structure. Larger mangrove trees became rare, leading to a reduction in tree density, which is an important attribute in mangrove habitat complexity. Decreasing variation in the size structure of mangrove trees directly influences the spatial complexity of the root system. However, results from 64 random sampling points showed that the closer to villages, the root length was higher and the mangrove tree diameter was smaller compared to less disturbed areas. Moreover, with decreasing distance to open water, where wave action is an important disturbance factor, sapling density, root density, length, and diameter increased.

In Chapter 3, I examined the role of the mangrove root system as a nursery for juvenile fish and shrimp through an experiment with artificial mangrove units (AMU). The root system functions as a barrier to tidal currents and traps sediments. This system serves as habitat for invertebrates such as clams, worms, and other benthic organisms. The complex root system also provides shelter for juveniles of many marine species. The AMU experiment showed that the abundance and number of fish and shrimp increased with increasing complexity of the root system. Disturbances to mangroves significantly influenced the abundance of juvenile shrimp, but there was no impact on the abundance and number of fish species. Hence, I concluded that juvenile shrimp are affected more by mangrove disturbance than fish.

In chapter 4 I describe the activities of the small-scale fisheries in the Berau waters. Fishermen active in the Berau Delta not only came from the Berau District, but also from neighboring districts, other provinces, and even other countries. Additionally, illegal Chinese fishermen were present in the Berau District in 2005-2006. Fishermen from other provinces regularly fish in remote areas that are not accessible for local fishermen. From the results, I concluded that the fishing pressure in the coral reef area was higher than in the estuarine delta and the pelagic area.

In Chapter 5, I tested for a correlation between the extent of a certain habitat (i.e., mangroves, rivers and shallow estuarine areas) and the amount of wild shrimp caught by fishermen, using three fishing gears (i.e., minitrawl, gillnet, trammelnet). The amount of shrimp caught by the fishermen was influenced by the distance to the nearby habitat and the extent of this habitat, illustrating that the spatial context of a fishing location partly determines the size of the shrimp catch.

My research can contribute to formulating recommendations to conserve the remaining mangrove habitats in the Berau Delta. The abundance of fishery resources in the Derawan Marine Conservation Area can only be sustained through integrated management of mangrove habitats, based on scientific understanding of the importance of the habitat. In addition, in my thesis, I show that social pressure in the Derawan Marine Conservation Area is not only on the mangroves in the delta, by also concerns the extraction of marine resources from the coral reefs, estuarine and pelagic area through small-scale fishery activities. The findings of this thesis can be used to design better management strategies by the local authorities for sustaining the mangrove forests to contribute to a sustainable exploitation of marine resources of the Sulawesi Sea in the future.

Samenvatting

Voedsel van de Sulawesi Zee, *noodzaak van een geïntegreerde planning*

De globale groei in het aantal mensen is nauw verbonden met een toenemende vraag naar visproducten. Mangrove habitats zijn belangrijke groeiplaatsen voor juveniele vissen en garnalen doordat zij in voedsel en schuilplaatsen voorzien. Mangroves komen enkel voor in tropische mariene kustgebieden, en ook al zijn de meeste tropische wateren niet zo nutriëntenrijk als de koudere noordelijke en zuidelijke systemen, zij voorzien deze tropische wateren lokale vissers direct en indirect van proteïnen en inkomen, vooral in landen zoals Indonesië. Als de mangrove habitats afnemen in grootte en kwaliteit, kan dit de voedselvoorziening beïnvloeden in de vorm van kleinere vis- en garnaalvoorraden, die een belangrijke bron van proteïnen zijn voor de lokale bevolking, en via de handel in visserijproducten ook andere mensen van proteïnes voorzien. Momenteel is er in de meeste tropische wateren al een afname in de vangst van mariene vissen en garnalen als gevolg van overbevissing. Daarnaast kan klimaatverandering indirect het mangrove habitat treffen en daarmee de vangsten beïnvloeden.

Deze situatie in acht nemend, startte ik een studie om de impact van mangrove verstoring op de complexiteit van wortelsystemen te schatten, omdat het wortelsysteem van mangrove bomen een belangrijke habitat vormt voor juveniele garnalen en vele vissen. Ik bepaalde de effecten van verstoring op de abundantie van juveniele vissen en garnalen, en ik schatte de bevissingsdruk van kleinschalige visserijen in het beschermde Derawan mariene natuurgebied dat deel uitmaakt van de kust van de Sulawesi Zee. Een belangrijk gebied van deze kust is de delta van de Berau Rivier, waar nog steeds grote mangrovebossen voorkomen, ook al waren deze mangroves dertig jaar geleden nog wijdverbreider dan nu. De volgende vier onderzoeksvragen werden behandeld:

1. Beïnvloedt menselijke verstoring in de Berau Delta de omvang van de mangrovebossen en de complexiteit van het wortelsysteem van mangrovebomen?

2. Wat zijn de relaties tussen mangrove bomen en juveniele vissen onder verschillende niveaus van verstoring?

3. Beïnvloedt de ruimtelijke configuratie van mangrovebossen en andere estuariene elementen de hoeveelheid gevangen vis?

4. Wat zijn de verschillen in bevissingsdruk van de kleinschalige visserij-activiteiten in de Berau delta?

In Hoofdstuk 2 bestudeerde ik de effecten van verstoring op omvang en ruimtelijke complexiteit van mangrovebossen. Deze studie concentreerde zich op de structurele complexiteit van het mangrove habitat, specifiek de structuur van wortelsysteem. Tussen 1990 en 2009 nam de oppervlakte van het mangrove habitat in de Berau Delta af met 54%, vooral door ontbossing van Nypa palmen ten voordele van wegen en constructies van vijvers. Verdere analyses toonden aan dat meer dan 70% van de verstoring antropogeen was. Deze verstoring kan op lange termijn ook de boomstructuur beïnvloeden. Grotere mangrovebomen werden zeldzamer, resulterend in een afname van de boomdichtheid, wat een belangrijke factor is in de complexiteit van het mangrovehabitat. Afnemende variatie in de groottestructuur van mangrovebomen heeft een directe invloed op de ruimtelijke complexiteit van het wortelsysteem. De resultaten van 64 willekeurige plotjes toonden aan dat dichter bij dorpen de wortellengte langer wordt, de dichtheid aan zaalingen toeneemt, maar de diameter van mangrovebomen afneemt in vergelijking met minder verstoorde gebieden. Verder, met een afnemende afstand van open water, waar golfactie een belangrijke verstoringsfactor is, werd een toename in de dichtheid van jonge bomen, worteldichtheid, -lengte, en –diameter, gemeten.

In Hoofdstuk 3 onderzocht ik de rol van het mangrove wortelsysteem als een groei- en beschermplaats voor juveniele vissen en garnalen aan de hand van een experiment met artificiële mangrove units (AMU). Het wortelsysteem functioneert als barrière tegen getijdenstromingen en het houdt sediment vast. Dit wortelsysteem is een belangrijk habitat voor weekdieren, wormen en andere bentische organismen, en dient ook als schuilplaats voor juvenielen van vele mariene diersoorten. Het AMU-experiment toonde aan dat de abundantie en het aantal soorten vissen en garnalen toenam met een toenemende complexiteit van het wortelsysteem. Verstoringen aan mangroves hebben een significante invloed op de abundantie van juveniele garnalen, maar niet op de abundantie en het aantal vissoorten. Daarom concludeer ik dat juveniele garnalen meer beïnvloed worden door mangrove verstoringen dan vissen.

In Hoofdstuk 4 beschrijf ik de activiteiten van lokale visserijen in de wateren van de Berau delta. Vissers die actief zijn in de Berau delta kwamen niet enkel uit het Berau District, maar ook uit naburige districten, andere provincies en zelfs andere landen. Daarnaast waren er in 2005-2006 illegale Chinese vissers aanwezig in de Berau delta. Vissers uit andere provincies vissen regelmatig in afgelegen gebieden die niet toegankelijk zijn voor lokale vissers. Uit de resultaten kan ik ook concluderen dat de bevissingsdruk in het koraalrifgebied groter was dan in de estuariene gebieden en het pelagische gebied.

In Hoofdstuk 5 testte ik de correlatie tussen de omvang van een bepaald habitat (mangroves, rivieren en ondiepe estuaria) en de hoeveelheid garnalen die door vissers gevangen werd met drie verschillende vistuigen. De hoeveelheid gevangen garnalen werd beïnvloed door de afstand tot het dichtstbijzijnde habitat en de omvang van dit habitat. Dit illustreert dat de ruimtelijke context van een vislocatie deels de grootte van de garnalenvangst bepaald.

Mijn onderzoek kan bijdragen aan de formulering van aanbevelingen om de resterende mangrove habitats in de Berau delta te beschermen. De abundantie van visvoorraden in het Derawan mariene natuurgebied kan enkel in stand gehouden worden door geïntegreerd management van het mangrove habitat, gebaseerd op wetenschappelijk kennis over het belang van dit habitat. Daarnaast toon ik in mijn proefschrift aan dat de menselijke druk in het Derawan mariene natuurgebied niet enkel de mangroves in de delta aantast, maar ook de onttrekking van mariene hulpbronnen uit de koraalriffen, estuariene en pelagische gebieden door kleinschalige visserijen betreft. De bevindingen van dit proefschrift kunnen gebruikt worden door lokale overheden om een betere managementstrategie uit te werken om de mangrovebossen te behouden en zo bij te dragen aan een duurzame exploitatie van mariene hulpbronnen van de Sulawesi Zee in de toekomst.

Appendices

Appendix A

The description of fishing gears shown in Table 5.3, Chapter 5:

Handline towing

Handline towing or local name “kedo-kedo” is the fishing technique where a single fishing line is held in a small engine boat or sailboat for towing. Operated during the day and fishing area located in the pelagic area or near the coral reefs. Primary target fish is grouper, jack fish, and tuna.

Handline bottom

Handline bottom or called “pancing ladung” is the fishing techniques where a single fishing line is held in the hands without towing, using lures or baited hooks in the shallow area near coral reefs. Target species: grouper, napoleon, wrasses and jack fish.

Gillnet

Gillnet or “jaring insang” are vertical panels of netting typically set in a straight line. Gillnets may catch fish in three ways: wedged, gilled or tangled; encountered in shallow waters near coral reefs, estuarine or pelagic area. Target species: jackfish, mullet, rabbit fish and shrimp.

Purse seine

Purse seine “pukat cincin” is a method of fishing that employs a seine, i.e., a fishing net that hangs vertically in the water with its bottom edge held down by weights and its top edge buoyed by floats; operated by boat usually at night using light or during the day in the pelagic areas. Target species: sardine, mackerels, and tuna.

Trammelnets

Trammelnets “rengge gondrong” is a method of fishing that employs three different net mesh sizes, operated using small boats in the shallow estuarine area during the day. Target species: pomfret fish and shrimp.

Estuarine trap

An estuarine trap “jerat kepiting” is used a fishing trap or pot; operated in the estuarine habitat with mangroves. Target species: mangrove crabs.

Floating liftnet

Floating liftnet or called “bagan apung” is a method of fishing with a net that captures fish by raising the net from beneath a school of fish from the boat; operated in shallow water areas mostly in the south of DMCA. Target species: anchovies and pelagic or demersal fish.

Coral trap

Coral trap “bubu karang” or bottom pot is a method of a fishing trap with one gate constructed from bamboo; operated in the coral reefs area. Target species: reef fish.

Longline

Longline or called “rawai” is a fishing technique with a long fishing line operated in the pelagic area with baited short lines (snoods) at regulars’ intervals. Target species: catch of longline are tuna, sharks, also birds, and turtles as bycatch.

Minitrawls.

Minitrawl “pukat hela kecil” is a method of fishing used to catch a range of demersal fish. Mini trawling involving one small fishing boat towing a medium sized net. Target species: shrimp, mullet, tread fins, catfish, croakers, and crabs.

Trawls

Trawls “pukat harimau” is a commercial scale fishing activities used to catch primarily demersal fish. Trawling involves one fishing vessel towing a large net. Target species: tread fins, catfish, croakers, crabs, squids, rays and shrimp.

Others

The category others consist of many fishing gear types like casting net “jala”, gleaning “bakarang”, spear gun “panah ikan”, cyanide “racun/bore” use with a hookah compressor and blast fishing “bom ikan”.

Static liftnet

Static liftnet or “bagan tancap” is a method of fishing with a net that captures fish by raising the net from beneath a school of fish. To attract the fish, fishermen used light. Static lift-net operate from a fixed platform. Target species: anchovies, mackerels, squids, swimming crabs and other demersal and pelagic fish.

Barrier net

Barrier net or “Togo” or sero/kelong/belat is a fishing trap located along the coastline and in rivers mouths. Target species: catfish, croakers, hairtails, mullets, pony fish, crabs and shrimp.

Danish net

Danish net or push net “jaring dorong” is a small triangular fishing net with a rigid frame that is pushed along the bottom in shallow waters. Target species: shrimp and small bottom-dwelling fish.

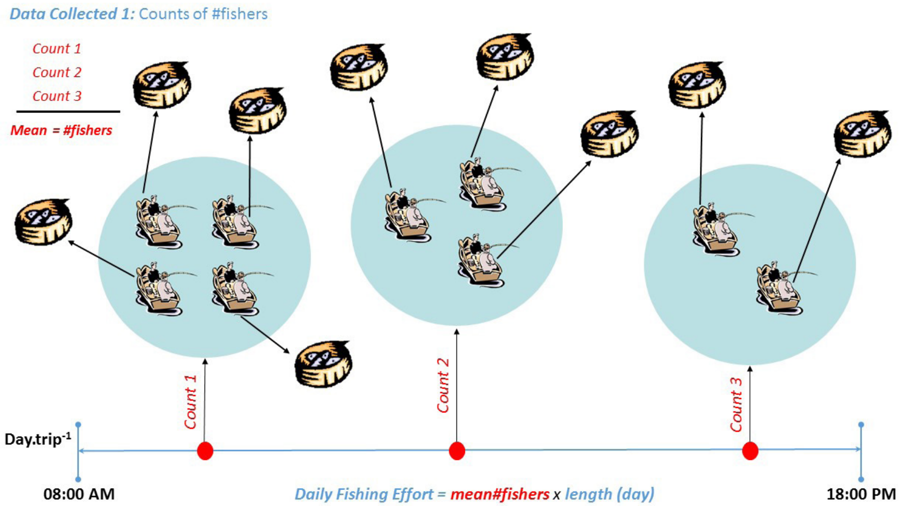
Appendix B

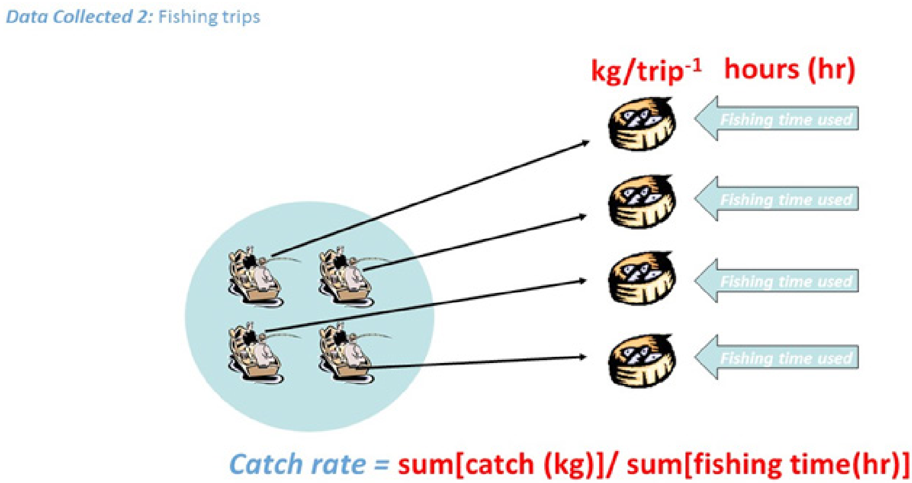
Catch categories

Catch category	English name	Latin name	Habitat
Wrasse	Napoleon fish	*Cheilinus undulatus* (Ruppell, 1835)	Coral reefs, pelagic
	Bluehead wrasse	*Thalassoma bifasciatum* (Bloch, 1791)	Coral reefs, pelagic
	Sunset wrasse	*Thalassoma lutescens* (Lay & Bennett, 1839)	Coral reefs, pelagic
Snappers	Red snapper	*Lutjanus argentimaculatus* (Forsskal, 1775)	Coral reefs, pelagic
	Grey snapper	*Lutjanus griseus* (Forsskal, 1775)	Coral reefs, pelagic
Anchovies	Anchovies	*Stolepholus indicus* (van Hasselt, 1823)	Pelagic, estuarine
	Spotty-face anchovy	*Stolephorus waitei* (Jordan & Seale 1926)	Pelagic, estuarine
Mackerel	Mackerel	*Rastrelliger kanagurta* (Cuvier, 1816)	Pelagic, estuarine
	Scombridae	*Euthynnus affinis* (Cantor, 1849)	Pelagic, estuarine
	Scombridae	*Katsuwonus pelamis* (Linnaeus, 1758)	Pelagic, estuarine
Pomfret	Black pomfret	*Brama brama* (Bonnaterre, 1788)	Pelagic, estuarine
	Silver pomfret	*Pampus argenteus* (Euphrasen, 1788)	Pelagic, estuarine
Catfish	Catfish	*Arius maculatus* (Thunberg, 1792)	Pelagic, estuarine
Grouper	Coral grouper	*Epinephelus malabaricus* (Bloch & Schneider, 1801)	Coral reefs, pelagic
	Coral trout	*Plectropomus leopardus* (Lacepède, 1802)	Coral reefs, pelagic
Jack fish	Bigeye trevally	*Caranx sexfasciatus* (Quoy & Gaimard, 1825)	Coral reefs, pelagic
	Black jack	*Caranx lugubris* (Poey, 1860)	Coral reefs, pelagic
Pelagic fish	Dolphin fish	*Coryphaena hippurus* (Linnaeus, 1758)	Pelagic, estuarine
	Barracuda	*Sphyraena* sp. (Klein, 1778)	Pelagic, estuarine
Tuna	Big aye	*Thunnus obesus* (Lowe, 1839)	Pelagic, estuarine
	Yellow fin	*Thunnus albacares* (Bonnaterre, 1788)	Pelagic, estuarine
Sharks	Black tip	*Carcharhinus limbatus* (Muller & Henle, 1839)	Coral reefs, pelagic
	Silver tip	*Carcharhinus albimarginatus* (Ruppell, 1837)	Coral reefs, pelagic
	Grey tip	*Carcharhinus amblyrhynchos* (Bleeker, 1856)	Coral reefs, pelagic
	White reef shark	*Triaenodon obesus* (Ruppell, 1837)	Coral reefs, pelagic
Rays	Spotted eagle ray	*Aetobatus narinari* (Euphrasén, 1790)	Coral reefs, pelagic
	Short-tail stingray	*Dasyatis brevicaudata* (F. W. Hutton, 1875)	Coral reefs, pelagic
Shrimp	Banana prawn	*Penaeus merguiensis* (de Man, 1888)	Pelagic, estuarine
	Indian banana	*Penaeus indicus* (Milne-Edwards, 1837)	Pelagic, estuarine
	Giant tiger prawn	*Penaeus monodon* (Fabricius, 1798)	Pelagic, estuarine
	Brown tiger prawn	*Penaeus semisulcatus* (de Haan, 1850)	Pelagic, estuarine
	Mantis shrimp	*Oratosquilla nepa* (Latreille, 1828)	Pelagic, estuarine
Crabs	Swimming blue crab	*Portunus pelagicus* (Linnaeus, 1758)	Pelagic, estuarine
	Mangrove crab	*Scylla serrate* (Forsskål, 1775)	Estuarine
Lobster	Bamboo lobster	*Panulirus versicolor* (Latreille, 1804)	Coral reefs, pelagic
Clam	Giant clam	*Tridacna gigas* (Linnaeus, 1758)	Coral reefs
	Fluted giant clam	*Tridacna squamosa* (Lamarck, 1819)	Coral reefs
Trochus	Sea snail	*Trochus niloticus* (Linnaeus, 1767)	Coral reefs
Squid	Whip-lash squid	*Mastigoteuthis flammea* (Chun, 1908)	Coral reefs
	Cuttlefish	*Sepia* (Linnaeus, 1758)	Coral reefs
Octopus	Octopod	*Octopus vulgaris* (Cuvier, 1797)	Coral reefs
Cucumber	Sausage cucumber	*Bohadschia argus* (Jaeger, 1833)	Coral reefs, pelagic
Turtles	Green turtle	*Chelonia mydas* (Linnaeus, 1758)	Coral reefs, pelagic
	Hawksbill	*Eretmochelys imbricate* (Linnaeus, 1766)	Coral reefs, pelagic
Black coral	Tree like corals	*Antipatharia* (Milne-Edwards & Haime, 1857)	Coral reefs

Appendix C

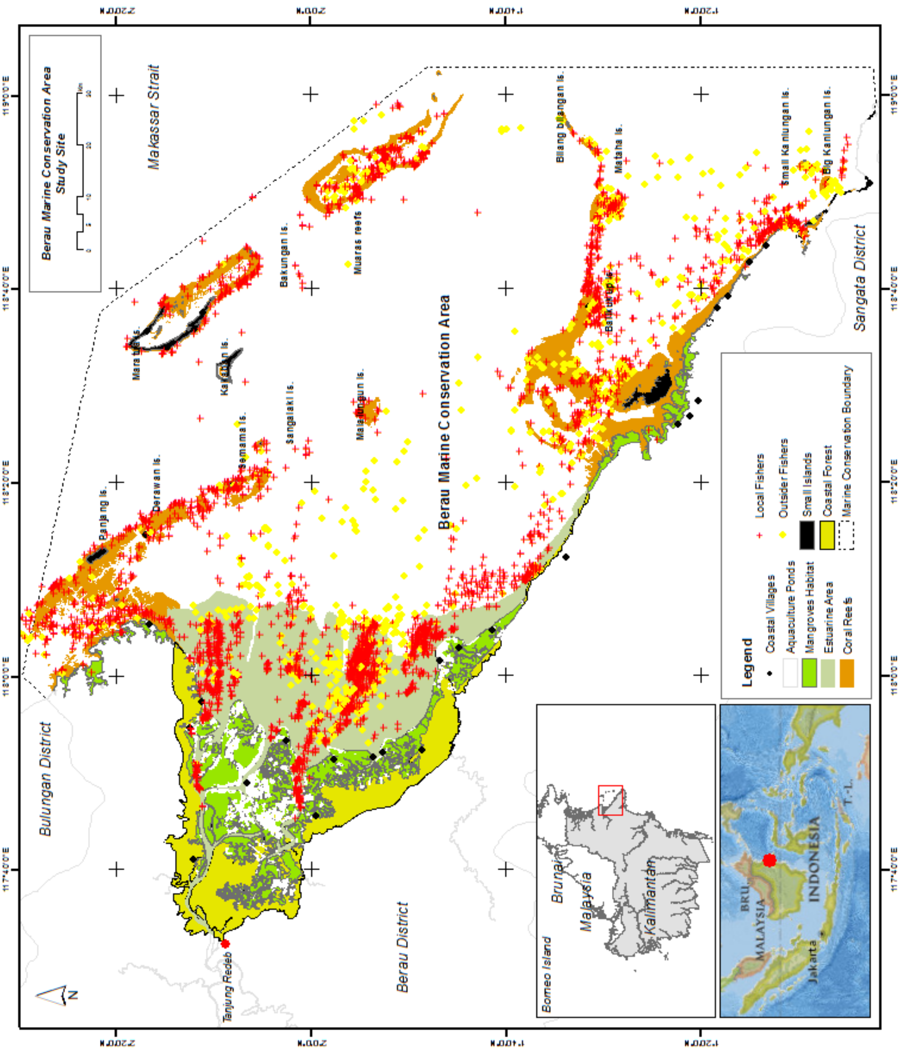
Roving creel survey, the Ilustration of roving creel survey in Chapter 5:



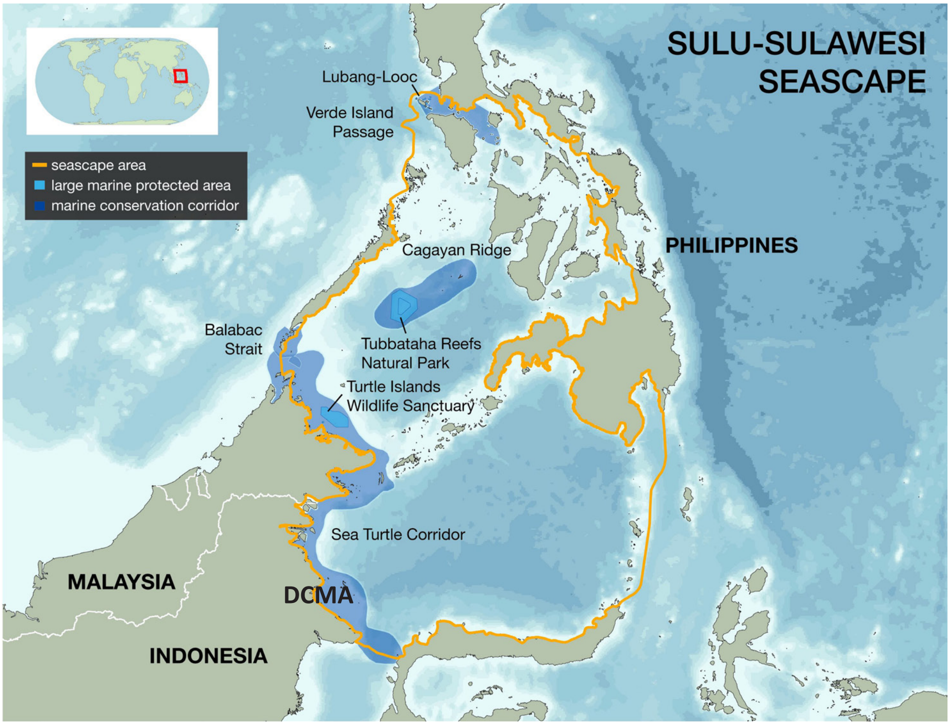


Appendix D

1. Spatial distribution map of resident and non-resident fishermen fishing in the Derawan Marine Conservation Area



2. The Derawan Marine Conservation Area (DCMA) is a part of corridor critical area for Sea Turtle in the southwest of Sulu-Sulawesi Seascape closer to the Wallace line.



Source of the SSS map: *http://www.mpatlas.org/campaign/sulu-sulawesi-seascape/*

Appendix E

(*Supplementary data*)

a) CPUE of each fishing gear type in the Derawan Marine Conservation Area

Table AE-1. Catch rates of each fishing gear type per-habitat.

Habitat type	Fishing gear type	Average CPUE *(kg.-trip^{-1})*	SD	Lower CPUE *(kg.trip^{-1})*	Higher CPUE *(kg.trip^{-1})*
Corals	Coral traps	58.4	4.0	32.4	32.4
	Gillnets	16.6	2.3	13.4	13.4
	Handline bottom	7.3	2.0	6.7	6.7
	Others	7.0	2.2	6.4	6.4
	Handline towing	6.5	2.2	5.9	5.9
Estuarine	Trawls	22.2	2.5	16.0	16.0
	Gillnets	11.5	2.3	9.6	9.6
	Minitrawls	6.1	2.3	5.6	5.6
	Estuarine ttraps	5.8	2.3	4.4	4.4
	Trammelnet	3.6	2.4	3.4	3.4
Pelagic	Gillnet	15.9	2.2	10.1	10.1
	Longline	10.2	2.0	8.6	8.6

b) Boat density for resident fishermen

Table AE-2. Trip density of each fishing gear type per-habitat.

Habitat type	Fishing gear type	Trip density *(boat.trip^{-1})*	SD	Lower density *(boat.trip^{-1})*	Higher density *(boat.trip^{-1})*
Corals	Handline towing	12.2	1.0	5.5	18.9
	Handline bottom	9.8	1.0	6.7	13.0
	Gillnets	8.5	1.0	4.8	12.3
	Others	25.5	1.0	16.5	34.5
	Coral trap	9.1	1.0	2.2	16.0
Estuarine	Gillnets	46.2	1.0	21.5	70.9
	Trammelnets	29.5	1.0	15.1	73.3
	Estuarine trap	25.6	1.0	24.6	284.8
Pelagic	Gillnets	32.2	1.0	1.0	242.5

C. Fragstat results from Landsat 5-TM year 1991 and 2009

Name	SDI	SEI	AWMSI	MSI	MPAR	MPFD	AWMPFD
Image 1991	1.1	0.8	6.4	1.4	2,823.2	1.4	1.4
Image 2009	1.5	0.9	4.9	1.6	10,903.1	1.5	1.3

ED	MPE	MPS	NumP	MedPS	PSCoV	PSSD	TLA	PD
78.2	820.4	10.5	11,985	0.2	2,213.3	232.1	127,740.3	10.7
57.5	1,559.6	27.1	4,706	0.1	958.3	260.1	127,740.3	27.1

Legend:

Name : The image of study area and year of taken
SDI : Shannon's Diversity Index
SEI : Shannon's Evenness Index
AWMSI : Area Weighted Mean Shape Index
MSI : Mean Shape Index
MPAR : Mean Perimeter-Area Ratio
MPFD : Mean Patch Fractal Dimension
AWMPFD : Area Weighted Mean Patch Factal Dimension
ED : Edge Density
MPE : Mean Patch Edge
MPS : Mean Patch Size
NumP : Number of Patches
MedPS : Median Patch Size
PSCoV : Patch Size Coefficient of Varian
PSSD : Patch Size Standard Deviation
TLA : Total Landscape Area
PD : Patch Density

Appendix F

Supplementary analysis for Chapter-5

General Linear Model (GLM) to test for differences in catch sizes of small-scale fisheries in the Derawan Marine Conservation Area (DMCA)

The goal of this analysis was to test for differences in estimated catch sizes under an influence of four explanatory variables (year, habitat, technique, and origin) that could affect the catches of small-scale fisheries in the study area.

Method:	Univariate GLM analysis
Dependent factor:	Log-Catch (Log-CPUE, $Kg.trip^{-1}$)
Explanatory factor:	Year
	Technique
	Origin
	Habitat

Method:

Catch data from all 12 fishing gears were used. Data was sorted by year, and all categorical data were coded (i.e. different codes for all habitat classes, techniques, and origin). Data was exported from Excel to SPSS, and a general linear model (GLM) was applied. All principal terms and interaction terms were included in the full model. All catch data were log-transformed (x+1) before the analysis. All terms that were not significant were eliminated from the full model, using a backward elimination procedure.

The full model was:

Log-Catch = Year + Technique + Origin + Habitat + Year*Technique + Year*Origin + Year*Habitat + Technique*Origin + Technique*Habitat + Origin*Habitat + Year*Technique*Origin + Year*Origin*Habitat + Year*Technique*Origin*Habitat

Final model (Selected model)

The final model (Table AF-1) with only significant main and interaction terms was:

Log-Catch = Year + Technique + Origin + Habitat + Technique*Habitat + Year*Technique + Technique*Origin*Habitat + Year*Origin*Habitat + Year*Technique*Origin + Year*Technique*Origin*Habitat

Results:

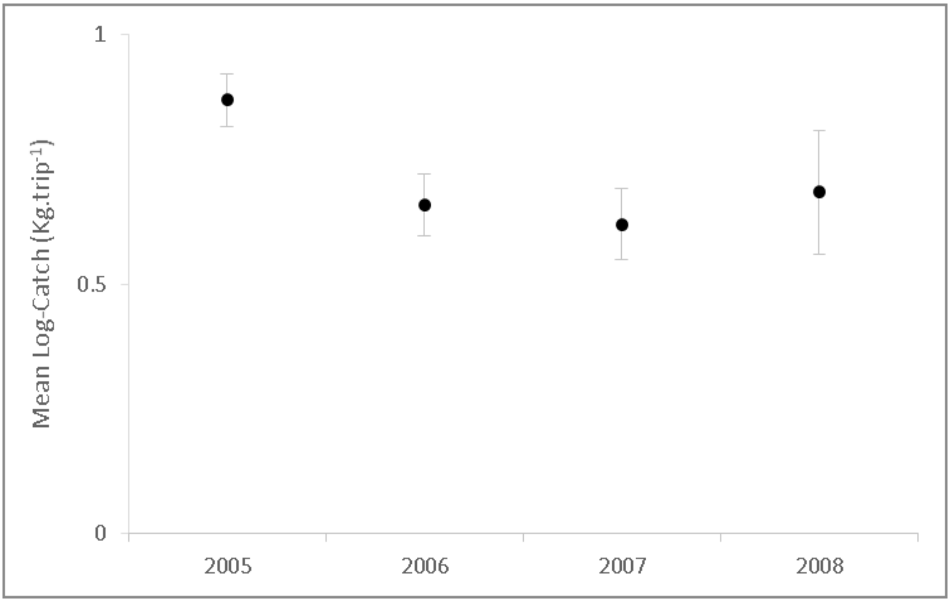


Figure AF-1. Mean catch sizes (log CPUE ± 95% CL) from year 2005 – 2008

The catches of small-scale fishermen varied significantly over the four study years for which full data were available, (Fig AF-1; $F_{1, 4367} = 3.04$, $p < .001$; Table AF-1). The catches declined from 2005 until 2007 and slightly increased in 2008, maybe because of the decline in illegal fishing activities in the study area (e.g., dynamite fishing and trawls fishing).

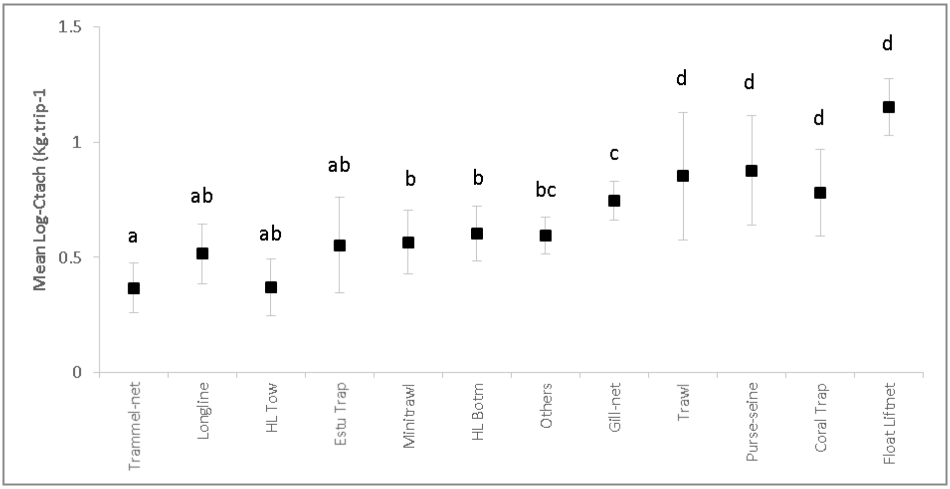


Figure AF-2. Mean catch sizes (log CPUE ± 95% CLs) over the twelve fishing gears. Mean catch sizes in in four homogeneous subset (a, b, c, d) as calculated using Post hoc Tukey HSD technique with alpha=0.5, Catches also varied over the twelve fishing techniques (Fig AF-2; $F_{11, 4367} = 5.36$, $p < .001$; Table AF-1). A post hoc Tukey HSD test showed that catch sizes of the twelve fishing gears were distributed over four sub-groups. The highest mean catch per trip was found in group-d with floating liftnets (log-catch: 1.2±0.13; untransformed catch: 14.2 $kg.trip^{-1}$) and three other techniques: trawl, purse seine and coral trap. The second largest catch size was found in group-c with gillnet (log-catch: 0.75±0.08; untransformed catch: 5.6 $kg.trip^{-1}$). Group-bc was the others-category (log-catch: 0.59±0.08; untransformed catch: 3.9 $kg.trip^{-1}$) and group-b consisted of minitrawls and handline towing. The lowest average catch per trip was found in group with e.g., trammelnets (log-catch: 0.37±0.11; untransformed catch: 3.3 $kg.trip^{-1}$).

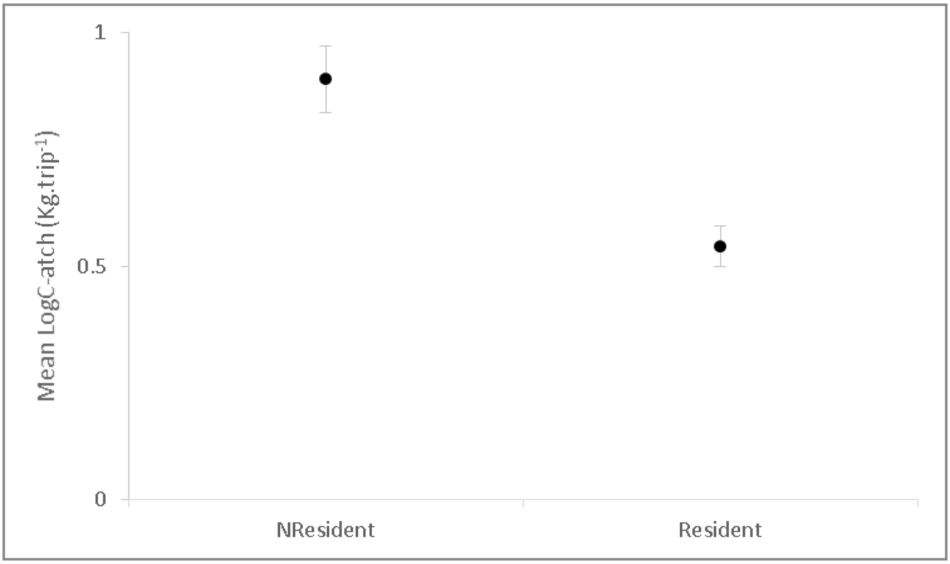


Figure AF-3. Mean catch sizes (log CPUE ± 95% CLs) of resident and non-resident fishermen.

Catches of resident fishermen were generally lower than that of non-resident fishermen (Fig AF-3, $F_{1, 4367} = 42.15$, $P < .001$; non-resident fishermen log-catch: 0.90±0.07; untransformed catch: 7.9 $kg.trip^{-1}$; resident fishermen log-catch: 0.541 ±0.04; untransformed catch: 3.5 $kg.trip^{-1}$).

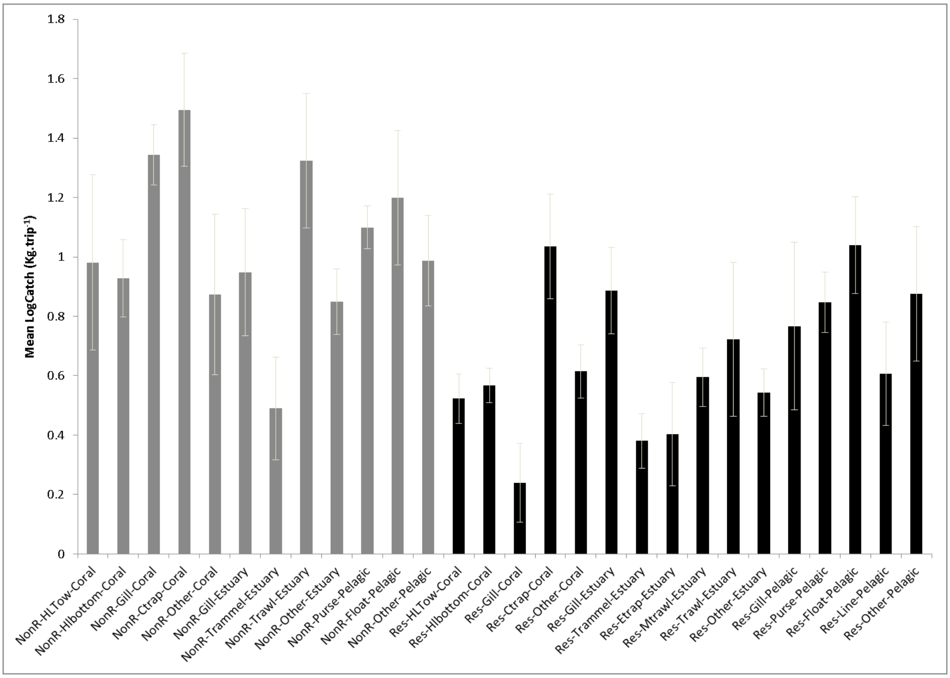


Figure AF-4. Mean catch sizes (log CPUE ± 95% CLs) over various independent variables, illustrating the interaction effect (origin technique*habitat*year) for a selected year (2005) with fishing techniques where sample n>10.*

The GLM showed (adjusted R^2=0.28) that many interaction effects were important, and we, therefore, illustrate here for convenience the most important ones (Fig AF-4). The largest catches were found in the coral habitat by non-residents using coral trap (log-catch: 1.5±0.19; untransformed catch: 31.2 kg.trip^{-1}), while resident fishermen caught less (log-catch: 1.03±0.18; untransformed catch: 10.9 kg.trip^{-1}). The second largest catches were found in the coral habitat by non-residents using gillnets (log-catch: 1.3±0.1; untransformed catch: 22.1 kg.trip^{-1}), and the third largest catches were found in the estuarine habitat by non-residents using trawls (log-catch: 1.3±0.22; untransformed catch: 21 kg.trip^{-1}). The overall impression of the 3-way interaction effect also showed that non-resident fishermen had larger catches compared to resident fishermen.

Table AF-1. ANOVA table with dependent variable: the mean Log-Catch (Kg.trip^{-1}).

Variable	Type III SS	df	Mean Square	F	Sig.
Corrected Model	450.94[a)]	168	2.68	11.60	.000
Intercept	122.98	1	122.98	531.30	.000
Year	2.11	3	0.70	3.04	.000
Technique	13.64	11	1.24	5.36	.000
Origin	9.76	1	9.76	42.15	.000
Technique * Habitat	7.74	21	0.37	1.59	.041
Year * Technique	23.43	30	0.78	3.37	.000
Technique * Origin * Habitat	6.91	13	0.53	2.30	.005
Year * Origin * Habitat	6.96	12	0.58	2.51	.003
Year * Technique * Origin	13.33	21	0.64	2.74	.000
Year * Technique * Origin * Habitat	15.51	38	0.41	1.76	.003
Error	1,010.81	4,367	0.23		
Total	3,070.07	4,536			
Corrected Total	1,461.75	4,535			

[a)] R Squared = .308 (Adjusted R Squared = .282)

Acknowledgements

I was in the middle of Muaras reef, the biggest atoll reefs area in the Southeast of the Berau Sea, interviewing small-scale fishermen and fishing for monitoring when I got satellite phone call from my former WWF Marine Program Director Ms. Lida Pet-Suede. She asked me if I still wished to do my Ph.D. abroad. That phone call was the beginning of a new adventure for me. I would like to thank Dr. Lida Pet-Suede and Prof. A.S. Sidik (Faculty of fisheries, Mulawarman University, Samarinda, Indonesia, and Project Manager of RESCOPAR in Indonesia) for opening the door that led to my Ph.D. program through RESCOPAR (Rebuilding resilience of coastal populations and aquatic resources).

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Wageningen, August 2016

Audrie J. Siahainenia

The author in Tigbauan, Iloilo, Philippines for mangrove field training at SEAFDEC Aquaculture Department, 2008

About the author

Audrie J. Siahainenia was born on April 19, 1970, in Jayapura, Papua, Indonesia. He obtained his bachelor in Marine Science in 1994 at Pattimura University, Ambon with specialization in coastal management. He conducts a research project on the existing physical condition of coral reefs and mangroves at the Kotania Bay, West Seram, Maluku by analyze spatial and spectral of Landsat-MSS data using GIS and Remote Sensing application. The project was funded by Indonesia Institute of Sciences (LIPI-P3O) Ambon, Indonesia.

He started his first job in early 1995 as a consultant at Marine Resource Evaluation Planning (MREP) project were located in two different area: Ambon Island located in Maluku and Biak Island, Papua for two years. At the beginning of 1997, He has new opportunity to working with Coastal Resource Management Project (CRMP) funded by USAID with Rhode Island University, USA. CRMP project located in two different sites: Manado, North Sulawesi were the project focus on Community Based - Coastal Resource Management (CB-CRM) and the Balikpapan Bay, East Kalimantan were focus on the Bay-City and Industry - Coastal Resource Management (BCI-CRM) as coastal spatial planner.

In August 2003, he received a Master of Science degree in Integrated Tropical Coastal Zone Management (ITCZM) with a specialization in Watershed Management through partnerships and collaborative approach at Asian Institute of Technology, Thailand. The ITCZM program is under the AIT-Danida Special Programme support by the Ministry of Foreign Affairs of Denmark for 18 months. After obtaining his M.Sc. in November 2003, he starts to working with WWF Indonesia Marine Program at Berau District, East Kalimantan to develop Marine Conservation Area (MCA) in the Derawan archipelago. He started the first partnerships initiative on the marine conservation program in East Kalimantan through collaborative approach project among six institutions: WWF, CRMP-USAID II, TNC, KEHATI, CI, and BESTARI. This initiative was a pilot project of the Sulu-Sulawesi Marine Ecoregion (SSME) program. Joint Program Marine Berau (JPMB) is the name of a collaborative program with the main goal is to develop a large scale Marine Conservation Areas in the Sulawesi Sea to protect the endanger species "the green turtle" including the other valuable marine biodiversities.

In March 2007, He received a fellowship to do Ph.D. from *Interdisciplinary Research and Education Fund* (**INREF**) of Wageningen University, the Netherlands, and WWF Indonesia Marine Programme through the ***R**ebuilding **Res**ilience of **Co**astal **P**opulations and **A**quatic **R**esources* (**RESCOPAR**) project. His Ph.D. thesis titled *Food from the Sulawesi Sea, the need for integrated sea use planning* at the Berau District, East Kalimantan, Indonesia belongs to the theme *Impacts of spatial arrangements and temporal changes of aquaculture and fisheries activities in coastal aquatic ecosystems* under the RESCOPAR program. The most significant results of his Ph.D. research are presented in this thesis.

PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

The C.T. De Wit Graduate School PE&RC PRODUCTION ECOLOGY & RESOURCE CONSERVATION

Review of literature (5.6 ECTS)

◊ Literature review for detail project proposal (2007)

Writing of project proposal (7 ECTS)

◊ Marine protected areas, shrimp farms and coastal fisheries: linkages through cascading effects (2007)

Post-graduate courses (4.8 ECTS)

◊ Competencies for integrated agricultural research; PE&RC (2007)

◊ Complexity in and between social and ecosystems; RESCOPAR- AFI (2007)

◊ Techniques for writing and presenting a scientific paper; SENSE-PE&RC (2011)

◊ Writing the PhD thesis and its propositions; RESCOPAR-PE&RC (2011)

Laboratory training and working visits (2.4 ECTS)

◊ Working visit at Mangrove Iloilo Project – SEAFDEC at Ibajay, Aklan, Philippines; SEAFDEC, Philippine (2008)

◊ Working visit at Mangrove Matang Project and University of Putra Malaysia; JIRCAS – University of Putra Malaysia (2009)

Deficiency, refresh, brush-up courses (4.3 ECTS)

◊ Resource ecology: modelling Stella (2007)

◊ MARXAN Modelling and ArcGIS DESKTOP (2007)

◊ Communicating science effectively; University of Maryland, Centre for Environment Science, USA (2009)

Competence strengthening / skills courses (3.0 ECTS)

◊ Mangrove species identification-training courses; SEAFDEC (2008)

◊ Estuarine fish and shrimp species identification-training courses; LIPI-P30 (2010)

PE&RC Annual meetings, seminars and the PE&RC weekend (2.1 ECTS)

◊ PE&RC Weekend (2007)

◊ PE&RC Day (2007)

◊ PE&RC Selling science (2010)

◊ PE&RC Day, innovation for sustainability (2011)

◊ How to writing a world-class paper (2011)

Discussion groups / local seminars / other scientific meetings (6 ECTS)

◊ RESCOPAR Research meeting, Wageningen, the Netherlands (2007)

◊ PhD PE&RC Discussion and meeting, Wageningen, the Netherlands (2007)

◊ Scale and scaling workshop, Wageningen, the Netherlands (2007)

◊ CERES Meeting in Summer School, Utrecht, the Netherlands (2007)

◊ National Mangrove Policy Forum, Bogor, Indonesia (2009)

◊ RESCOPAR Research meeting, Samarinda, Indonesia (2009)

◊ RESCOPAR Research meeting, Can Tho, Vietnam (2010)

International symposia, workshops and conferences (9.6 ECTS)

◊ Migratory birds, Aviation and Nature Conservation Symposium; Noordwijk, the Netherlands (2007)

◊ People and Sea Conference; Who Owns the Coast; Mare, Amsterdam, the Netherlands (2007)

◊ Integration Conference RESCOPAR; Wageningen, the Netherlands (2007)

◊ Learning partnership for Marine Protected Area (MPA) Networks in the Coral Triangle; Tagaytay, Philippines (2008)

◊ The planning for climate change impact in coral reefs workshop; NOAA, USA (2008)

◊ Integration Conference RESCOPAR; Samarinda, Indonesia (2009)

◊ International Symposium on Aquaculture and Fisheries Education(ISAFE); Pathumtani, Thailand (2009)

◊ Integration Conference RESCOPAR; Can Tho, Vietnam (2010)

Supervision of 5 MSc students (7.5 ECTS)

◊ Consequences of fisheries catch and effort allocation for the design of a Marine Protected Area in Berau; East-Kalimantan, Indonesia; Elke L. Venstra (2007)

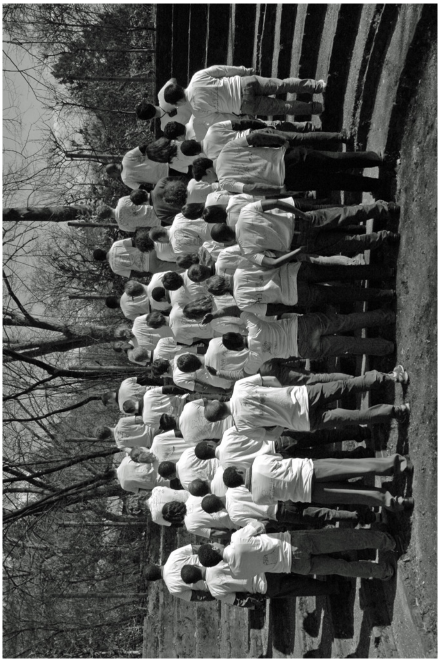
◊ Environmental conditions and resultant catch compositions of tidal barrier net fisheries in a mangrove dominated river delta; Berau, East Kalimantan, Indonesia; M.P. van Oosterhout (2008)

◊ The effect of mangrove structure on its nursery function for shrimp and fish species: an experimental approach; Berau, East Kalimantan, Indonesia; Christiaan Nijholt (2009)

◊ Mangrove's structural complexity and disturbances: a case study of the Berau Delta, East Kalimantan, Indonesia; Noor Janatun Jemali (2009)

◊ Integrated assessment of mangrove management states in Java: ecological and socio-cultural aspects: Ekaningrum Damastuti (2013)

PE&RC members for the batch of 2007



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"........, but I never walk back"

Our past will always be a part of us and we can never erase it but the most important part of it is that we don't look back in anger or full of fear. It's gone, filter your past and take out all the positive things as wonderful memories and all the bad things as lessons learned. ***You are not there anymore!***