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Social-Ecological Analysis of Marine Protected Area Management

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The candidate confirms that the work submitted is her own, except where work which has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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Abstract

Marine Protected Areas (MPAs) aim to protect coastal and marine ecosystems from environmental and anthropogenic disturbance. The effectiveness of MPA planning, management and implementation requires specific identification and deep understanding of the complex social and ecological system within and in its surroundings. This thesis aims to *first* understand how social-ecological systems of MPAs work, what indicators drive the system, how they interact and which variables emerge from this system that can be used to assess and evaluate MPA performance. I reviewed social-ecological studies of MPAs worldwide under a variety of settings and synthesised all variables that were applied. I then built a conceptual framework of social-ecological interactions, explaining possible positive and negative interactions between variables and their effect on MPA success criteria such as living coral cover and local community's knowledge and awareness.

Secondly, I used social-ecological variables to support decisions for better conservation zone management of a mangrove ecosystem in Indonesia. In this case study I demonstrated, using Spatial Multi-Criteria Analysis (SMCA) methods, how important it is to include social-ecological factors to meet and accommodate both ecosystem and local community preferences in conservation planning. More importantly, I also showed that a conservation project can be carried out sustainably and with reduced conflict between all stakeholders.

Thirdly, I showed how we can evaluate MPAs using various social and ecological indicators and variables, and generated an index to assess the value of each MPA in its effectiveness in reaching goals. I also addressed how social-ecological conditions in MPAs result in distinct effectiveness values and that certain social-ecological indicators and variables are associated with a higher MPA effectiveness value index.

Finally, I explored customary and indigenous practice and law, as specific social context variables that can improve effectiveness of MPAs by reducing conflict and increasing management strategies and efficiency to conserve local marine resources.

This thesis highlights the importance of understanding the social-ecological system of MPAs, the possible interactions among variables involved within and how to use them in conservation planning and evaluation of MPA effectiveness.

Table of Contents

List of Figures

Supporting Figures

List of Tables

Supporting Tables

List of Acronyms

AHP	Analysis hierarchy process
ANOVA	Analysis of variance
APD	Accessibility and potential disturbance
CHANS	Coupled human and natural systems
CHE	Coastal human ecology
CMV	Commercial value
CR	Consistency ratio
Em	Effectiveness Index value
FGD	Focus group discussion
IUCN	International Union for the Conservation of Nature
MoEF	Ministry of Environment and Forestry
MMAF	Ministry of Marine and Fisheries
MDS	Multidimensional scaling
MPA	Marine protected area
NGO	Non-government organization
NVC	Natural value of coastal environment
RCV	Recreational and cultural value
SEN	Social-ecological network
SES	Social-ecological system
SMCA	Spatial multi-criteria analysis

Chapter 1. Introduction

Many challenges for marine ecosystems continue to emerge with a rising number of anthropogenic disturbances and environmental stressors, such as destructive fishing activities and warming climates. The interactions within a complex system, especially between anthropogenic and environmental stressors, can affect ecosystem functioning in unpredictable ways (Custer & Dini-Andreote, 2022), decreasing the ability of the ecosystem to concurrently provide multiple functions and services (Manning et al., 2018). Thus, it is important to understand how each element within a complex system, such as biodiversity, shapes the function of the ecosystem and also how diversity within and across trophic levels, including the food chain, interact (Duffy et al., 2007). For example, an increase in sea otter predation has changed the structure of Alaskan kelp forests and dramatically increased the percentage of algal turf and sea urchin populations (Estes & Duggins, 1995). Furthermore, human interactions with marine ecosystems through fishing and tourism have significant ramifications that can change the capacity of reefs to deal with disturbances, for example, by habitat fragmentation and reducing functional diversity (Nyström et al., 2000). From these examples, important questions for understanding social-ecological systems arise: 'How many components or types of variables shape an ecosystem? ‘How do these biological and physical components interact?', 'What interactions arise from the relationships between this system and humans beings?’, and ‘What are the implications of those interactions?’. The answers to these questions will enable us to better manage the impacts created from anthropogenic and environmental disturbances in complex social-ecological systems.

The concept of conservation emerged to help protect and preserve the environment and the ecosystems within, which includes two different paradigms; *first*, protect and give no access to pristine ecosystems; and *second*, work with local communities to manage ecosystems sustainably (Russell & Harshbarger, 2003). The three main goals of conservation focus on maintaining critical ecological processes and life support systems; conserving genetic diversity; and ensuring the sustainable use of species and ecosystems (The World Conservation strategy *in* Hambler & Canney, 2013). Conservation projects such as Marine Protected Areas (MPAs) have become a commonly used tool to help preserve marine biodiversity and ecosystems from various disturbances.

An MPA is an area covering the sea and coast that is managed and protected with potentially several levels of protection, legalised by law and/or a local authority, such as local traditional customs, to sustainably protect and manage flora, fauna and cultural features (Kelleher, 1999). It covers a wide-range of areas and contexts, including human related activities inside and in its surroundings, a management plan, and policy. Thus, we need to see an MPA as a conservation tool that covers two systems, a 'governing system' and a 'system-to-be-governed' (Jentoft et al., 2007). MPAs harbour marine and coastal ecosystems, but it is also a system where we can find ecosystem users, stakeholders, institutions, and a government with a set of policies that govern it. Furthermore, MPAs are influenced by many drivers that lead to the increase or decrease of ecological and socio-economic conditions within the MPA and its surroundings. For example, stakeholder engagement such as local community participation is amongst the most important factors affecting MPA success, followed by political will, sanctions, conflict resolution, leadership and surveillance (Giakoumi et al., 2018). Therefore, studies on MPA evaluation and performance apply various frameworks and guidelines (Picone et al., 2020; Grorud-Colvert et al., 2021; Pomeroy et al., 2005), involving not only ecosystem and biodiversity indicators, but also socio-economic indicators.

Particularly in locally managed MPAs, the way an MPA is managed depends on its local cultural, ecological, political, socio-economic and institutional context (Jones, 2002). Therefore, MPA goals, objectives and the way people decide whether a certain MPA has reached its goal, vary. Overall, many studies focus on the ecological effects of MPAs, and the establishment of an MPA that leads to increased living coral cover and fish abundance is considered successful (Cabigas et al., 2012; Hilborn et al., 2004; Silva, 2006). However, many also consider that an MPA cannot be seen as successful unless it has social and economic benefits (Christie, 2004), in which both ecological and socio-economic indicators influence each other (Yates et al., 2019). Therefore, MPA evaluations must not only rely on ecological surveys, but also assess how the local community sees the MPA, their perspectives, how the MPA effects their livelihoods, and other social factors such as culture, beliefs, and knowledge (Ahmadia et al., 2015; Alder et all., 2002; Gallacher et al., 2016).

The many ecological and socio-economic benefits of MPAs include increasing reef fish biomass and total coral cover (Strain et al., 2019), improving a local community's knowledge and positive perception toward conservation (Mahajan & Daw, 2016), and supporting climate change adaptation and mitigation (Trialfhianty et al., 2020). However, these MPA benefits are threatened by numerous issues that often lead to conflict between local communities and government/authorities. One major problem that needs to be carefully assessed is resource dependency. An estimated 997 million people live near coral reef ecosystems, with a higher population growth each year than the global population average (Sing Wong et al., 2022). High population numbers put a heavy pressure on coral reefs because their livelihoods depend on the ecosystem services that coral reefs offer, such as fisheries production, tourism (Pascal et al., 2016), biochemical commercial products (Carriger et al., 2019), and pharmaceutical and genetic materials (Spurgeon, 1992). In addition, coral reefs contribute to people's identity, lifestyle, and social norms (Cinner, 2014). This leads to the exploitation of coral reef fisheries worldwide, where total landings are higher than can be sustained (Newton et al., 2007). Where livelihood diversification does not mean less fishing (Cinner, 2014), this resource dependency must be taken seriously if conservation goals are to be reached (Marshall et al., 2010; Newton et al., 2007).

Social-ecological analysis has been used for understanding the complex interaction between social and ecological attributes for many purposes, such as improving management strategies and planning. For example, social-ecological analysis can assist in determining priorities in the implementation and planning of conservation strategies by integrating social and ecological data (Guerrero & Wilson, 2017), and help in developing conservation targets and priorities (Levin et al., 2015). Several frameworks associated with the term social-ecological system, such as the Social-Ecological System (SESs) framework (Ostrom, 2009), Coupled Human and Natural Systems (CHANS) (Liu et al., 2007), Social Ecological Networks (SEN) (Janssen et al., 2006) and Coastal Human Ecology (CHE) (Aswani, 2019), have been developed to assist users in understanding system attributes and correlations between social and ecological components. The term "social-ecological system" comes from the words ‘social’ and ‘ecology’, and is an anthropocentric concept introduced to address the complexity of systems that require both ecological and social sciences to understand them (Herrero-Jáuregui et al., 2018). “Social-ecological system” defines a system that includes humans and ecosystems that interact, connect and influence one another (Ostrom & Cox, 2010). The understanding of social-ecological systems requires a trans-disciplinary scientific approach to capture the whole fundamental system and how it works. It requires knowledge drawn from many disciplines such as ecology and environmental science, management, politics, economics and psychology. Furthermore, the concept of a social-ecological system can be understood by exploring the interactions between nature and human wellbeing, which involves ecosystem functions and that benefit humans (de Groot et al., 2010). This makes social-ecological study a necessity to better understand how an MPA is working.

1.1 Marine Protected Areas in Indonesia

Indonesia is an archipelago country with more than 17,504 islands and 95,161 kilometres of coastline (Arianto, 2020). Here, over 60 million people depend on coastal and marine resources (Burke et al., 2011). Growing concerns for environmental stability and natural resource sustainability have pushed the Indonesian government to establish conservation projects in many coastal and marine areas. Currently, Indonesia has 23.9 million ha of total MPAs, covering 7.3% of Indonesia’s waters (Handayani et al., 2020). The definition of MPAs in Indonesia is outlined by national decree No. 60/2007, as *“spatially defined, marine, coastal, or small island areas that are protected and managed by a zoning system to achieve sustainable management of fisheries resources and environmental outcomes”*. This means that MPAs in Indonesia are classified and managed under a zoning system that allows and supports local coastal communities to access marine and coastal resources in sustainable ways. They can be categorised as core-zones, wilderness zones, rehabilitation zones, tourism zones, limited use zones, and sustainable fisheries zones (Lazuardi et al., 2020). These MPAs are regulated by the Ministry of Environment and Forestry (MoEF), and the Ministry of Marine Affairs and Fisheries (MMAF).

The establishment and evaluation of MPAs in Indonesia is organised by several institutions and stakeholders, including the local government, national government, and NGOs. The process of both activities involves the local community and uses various funding sources from government and donors. The establishment of MPAs has two phases; first, initiation, which can be a lengthy process where the organiser needs to assess all ecological and social conditions within and outside a proposed MPA, define its goals and objectives, and set the zones or boundaries. Second, establishment, which is the process that finalises the MPAs goal, objectives, boundaries and type of management. Later, the proposed MPA will be officially declared by MMAF in a ministry decree. The evaluation of MPAs is conducted by MMAF every five years for its management and zoning system, and every 20 years for its long-term plan (Lazuardi et al., 2020)

Apart from the diverse tribes, religions, cultures and local languages in Indonesia, it also has customary and traditional practices, including customary management of natural resources such as marine and coastal resources. For example, Bajo tribes, who live in west Indonesia and are best known as Sea People or Sea Tribe, have been living on the sea for generations. They are easily identified by the way they live (settlements in coastal areas or over the sea surface), their main occupation as traditional fishers, and with the majority of technology, knowledge, economic and social organization centering around the utilization of coastal and marine resources (Basri et al., 2017). The customary management of marine areas can be broadly categorised in regards to protection, allowed users, sanctions and resource users (Estradivari et al., 2022). For this reason, the national government of Indonesia acknowledges customary law and management, releasing a decree called *Peraturan Daerah* that allows local government and local communities to decide how to manage their own resources. However, many problems emerge when the national government decides to protect the environment and to build a conservation project such as a MPA (Hu et al., 2020; Jones et al., 2011; Gerhardinger et al., 2011) For example, in West Lombok, top-down MPA establishment has threatened the lives and livelihoods of marginalised local people, causing conflicts and eventually weakening the MPA institution (Satria & Shima, 2006). Thus, it is important to understand how modern MPAs and customary practise intersect.

1.2 Thesis aims and objectives

The primary objective of this thesis is to understand the complex interactions within social and ecological systems in coastal and marine conservation areas and how we can use them to evaluate and improve the effectiveness of MPAs in reaching their goals. This thesis comprises four main areas, aiming to answer a major question: "to what extend can coastal social-ecological analysis help us understand, plan and evaluate Marine Protected Area performance?" (Figure 1.1).

Chapter 2 explores key variables used in social-ecological studies related to MPAs around the globe, then builds a conceptual framework of social-ecological interactions using identified variables. This chapter also attempts to identify a set of important indicators that can be best used to evaluate the effectiveness of MPA performance in a variety of settings, based on IUCN's four criteria: good governance, sound planning and design, effective management, and conservation outcomes. Examining the interactions in social-ecological systems can help inform better conservation management plans (Pollnac et al., 2010). Furthermore, deciding priority indicators can assure unambiguous judgement leading to the required steps in terms of regulation, remediation or control of MPA evaluation (Beliaeff & Pelletier, 2011). This chapter is an important basis for all other chapters.

Chapter 3 presents how several social and ecological variables and criteria are applied in conservation planning. This chapter applies the analysis hierarchy process (AHP) matrix approach (Saaty et al., 1977), to determine weights for identified social and ecological criteria in a spatial multi-criteria analysis (SMCA). The SMCA assists in prioritising areas for different types of conservation zone i.e., core-zone, buffer zone and transition zone. A multi-criteria decision approach such as AHP and SMCA allows us to prioritise important areas to conserve based on preferences and criteria (Phua & Minowa, 2005).

Chapter 4 tests the identified indicators from Chapter 2 in evaluating MPA performance, comparing sites in west (Sabang) and east (Nusa Penida) Indonesia. Moreover, this chapter presents the social-ecological conditions of MPAs that have distinct effectiveness values to help explore which social and ecological aspects contribute to high or low MPA effectiveness. Exploring factors that contribute to MPA success and failure and incorporating those factors into adaptive management is crucially important to improve MPA effectiveness (Giakoumi et al., 2018).

Chapter 5 delves into the role of customary law in improving MPA effectiveness. This chapter explores present customary laws and management related to marine resources and conservation in Indonesia, and how they interact with current conservation management in my selected MPAs. There are benefits in incorporating indigenous law and practice into marine resource management (Nursey-Bray, 2011), such as increasing the effectiveness of marine resource management (Harkes & Novaczek, 2002). Thus, this chapter also tries to understand how customary law and management influence the effectiveness of conservation management and governance in MPAs.

Altogether, the four chapters discuss the function of social-ecological systems within and outside MPAs by first addressing the indicators and variables involved within the system, how they interact and influence MPA outputs, how to use them in spatial conservation planning, and in evaluating MPA effectiveness. Findings and knowledge gaps addressed in this thesis will help to improve future conservation management and strategies.

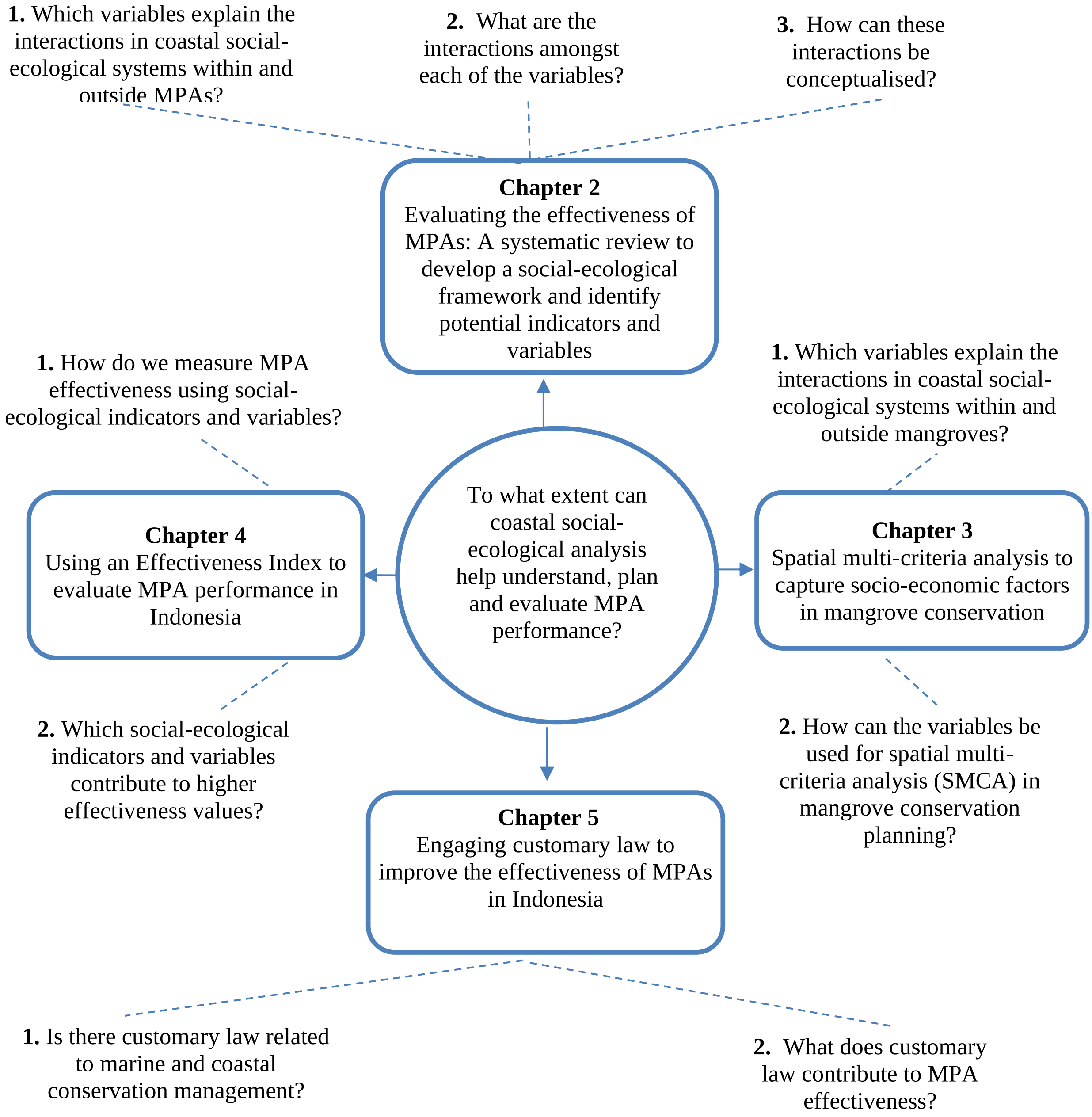

Figure 1.1 PhD chapters and research questions.

Chapter 2. Evaluating the effectiveness of Marine Protected Areas: a systematic review to develop a social-ecological framework and identify potential indicators and variables

Abstract

Marine Protected Areas (MPAs) have been widely studied to evaluate their effectiveness. However, despite complex social and ecological conditions and their interactions within and outside MPAs, our understanding of which social and ecological indicators are important and which variables are best for evaluation of MPAs under heterogeneous conditions is still limited. This systematic review aims to build a social-ecological interaction framework to show how variables in MPAs interact and identify variables for assessing MPA effectiveness. The social-ecological interaction framework helps us understand how variables interact and how to build management strategies from these interactions. For example, they can help reach such goals as to increase fish abundance, identify other variables that might influence the condition of fish abundance, or how to set up relevant and appropriate conservation objectives that do not oppose these interactions. We reviewed 74 social-ecological studies of MPAs around the globe to develop the framework. We identified a total of 39 indicators, encompassing 82 variables used to assess biophysical, socio-economic, and governance aspects of MPAs in a variety of settings. We found that 'habitat distribution & complexity', 'local value and beliefs about marine resources', and 'level of stakeholder involvement in surveillance, monitoring and enforcement' were most frequently used as indicators. The effectiveness of an MPA is often measured by an increase in fish biomass inside relative to outside its boundaries, alongside increased awareness of and support for conservation in the local community. Understanding social-ecological interactions and deciding important indicators to evaluate MPA effectiveness may help future management strategies reduce threats and increase opportunities for MPAs to reach their goals.

2.1 Introduction

There are many threats facing global marine and coastal ecosystems, home to millions of species, resulting in declining biodiversity year on year (Sala & Knowlton, 2006). The major ecological threats include climate change (Descombes et al., 2015), disruption to ecological processes (i.e., unbalanced predator-prey interactions) and diseases (Cramer et al., 2012). Moreover, human activities represent a significant direct threat to coastal ecosystems, as exploitation for food, medicine, energy and transportation often lead to degradation (Clausen & York, 2008a, 2008b; Elahi et al., 2015). Efforts are required to reduce environmental and anthropogenic disturbances and help protect marine and coastal ecosystems. As a result, Marine Protected Areas (MPAs) have been established around the globe in an effort to conserve marine and coastal biodiversity.

The International Union for the Conservation of Nature (IUCN) defines an MPA as "*a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*" (IUCN Guidelines, 2008: Chapter 2 page 8). MPAs conserve the marine biodiversity of a well-defined geographic space by preventing activities such as fishing and mining, thus allowing for several benefits such as improved fisheries; conserved biodiversity, spiritual and cultural resources; disaster risk reduction; and tourism (IUCN WCPA, 2018). However, in some locations or countries, fishing is a primary source of income for coastal communities and fishing restrictions can lead to push back from stakeholders, both when setting up new MPAs or managing existing MPAs. To solve this problem, MPA managers cannot focus on only biological or biodiversity enhancement within MPAs but must also consider the local community's socio-economic and cultural values (Christie, 2004). A lack of understanding of human and ecosystem interactions may lead to failure in MPAs reaching their goals (Aswani, 2019) or the setting of unrealistic goals.

The concept of social-ecological systems has been developed to understand the diverse and complex interactions between humans and natural resources (Berkes et al., 2000). It requires the identification of a minimum set of indicators and variables, their relations and interconnections, that can explain system function (Ostrom, 2009). Social-ecological systems (SES) developed by Ostrom (McGinnis & Ostrom, 2014;

Ostrom, 2007, 2009) and social-ecological networks (SENs) (Ekstrom & Young, 2009; Janssen et al., 2006) help us to understand how a social-ecological system works and its components interact. SES identifies four first-tier sub-systems: resource systems (i.e., the specific area covered by protection); resource units (i.e., types of animals and plants and their number); governance systems (i.e., monitoring and sanction rules); and actors or users (i.e., knowledge, dependencies). Each of these sub-systems consists of many second-tier variables. SEN evaluates dependencies and interactions between ecosystem services and social components (Bodin et al., 2017). Therefore, both frameworks can be used to identify all possible variables that may interact within a social-ecological system and enable understanding of the role a community has in shaping and influencing resource conditions and management (Bodin et al., 2017; Felipe-Lucia et al., 2022; Sayles et al., 2019). However, although these frameworks are broad enough to be applied to any social-ecological system, their broadness means that they can be difficult to apply to the specifics of evaluating MPAs. Thus, this paper attempts to incorporate the MPA evaluation concept introduced by Pomeroy et al. (2004), by grouping identified variables into four attributes (outputs, socio-economic, management and ecology) and identifying possible interactions between variables for each attribute. In this paper, we call the interaction between social and ecological systems within an MPA in relation to the effectiveness of a MPA within variety of settings, the social-ecological interaction framework. We expect the framework to help enhance our understanding of how MPA management should be determined and how to reduce anthropogenic threats from local communities within and around MPAs.

The effectiveness of an MPA is defined by the IUCN as when an MPA is able to generate benefits for both humans and ecosystems, such as improving fishing production (fish biomass and stock), increasing ecosystem resilience from climate disturbances, providing shelter to restore ecosystems (fish, coral reef, mangroves), sustaining economic and other benefits of tourism for coastal communities, saving sacred places, and promoting good stewardship (IUCN WCPA, 2018). In enhancing MPA effectiveness and performance, guidelines can assist with managing and monitoring MPAs (Grorud-Colvert et al., 2021). Most of these guidelines encompass ecological, social, management (governance) and economic aspects (Fernandes et al., 1999; Pomeroy et al., 2004). Most MPA projects around the globe use their own set of indicators to evaluate the MPAs in their locations (Grorud-Colvert et al., 2021; Zupan et al., 2018). MPA assessments have also been conducted using case-studies generated from discussions with local community groups, literature reviews, scientific judgements and expert opinion (Giakoumi et al., 2018). However, this means that many of the indicators that are used are suitable only for a particular MPA. For example, a 'religion and ethnic' indicator was used to examine whether religious and/or ethnic diversity influenced people's behaviour in utilising fisheries resources in the Solomon Islands (Aswani et al., 2013). However, this indicator would not be of use in areas where there is no religious or ethnic diversity. Similarly, a 'mangrove diversity and abundance' indicator is specific to areas that include mangrove ecosystems, but not others (Twichell et al., 2018). Thus, we require a general set of indicators that can be applied to evaluate MPAs under different settings. For this, IUCN has created criteria to assist managers and governments in examining MPA effectiveness and performance, whilst minimizing emerging conflicts, and they are widely used to evaluate MPAs around the globe (Ban et al., 2014; Grorud-Colvert et al., 2021). These criteria can be categorized into: (1) good governance; (2) sound planning and design; (3) effective management; and (4) conservation outcomes (IUCN WCPA, 2018). However, the types of indicators that can be used within each of these criteria are not well identified.

Addressing these challenges, this systematic review aims to first identify the key variables of MPAs from the literature. Second, we identify their interactions (both positive and negative) and build a conceptual framework for social-ecological interaction within MPAs. Third, we synthesise a combined set of biophysical, socio-economic and governance variables that can be applied to measure and evaluate various MPA attributes (environment, socio-economic, management, and outputs) using IUCN's four criteria (good governance, sound planning and design, effective management, and conservation outcomes).

2.2 Methods

Peer-reviewed papers were selected using the Scopus search engine and Google-Scholar with several combinations of keywords. In the Scopus search engine, the search began with 'TITLE-ABS-KEY()' followed by 'social-ecological system' and "conservation" and "marine protected area", using the script as follows:

TITLE-ABS-KEY((socialecological AND system)AND(conservation OR marineAND protected AND area))

I narrowed down the search to publications in English and only journal articles, which resulted in 228 papers. When using Google Scholar, I used the first keyword "social-ecological analysis" followed by "conservation", and "marine protected areas" to conduct a specific search for papers that apply social-ecological analysis in marine protected areas. The keywords helped to search relevant peer-reviewed papers that were not indexed by Scopus. I gathered an additional 250 papers from Google Scholar (limited to the first 250 papers). I combined the 228 papers from the Scopus database with the 250 papers from Google Scholar. Removing duplicate papers resulted in a total of 330 papers to be evaluated in this study (Figure 2.1).

Following a PRISMA checklist (Moher et al., 2010), from this initial list of 330 papers I screened each paper's title, resulting in the exclusion of 73 papers that were irrelevant to MPAs. Moving on to the abstract and full paper screening, 96 papers were excluded for several reasons, such as (1) the paper could not be accessed; (2) the paper was not related to social-ecological studies or marine protected areas; (3) the study methods used in the paper were unclear (many did not mention how their results were derived); (4) the paper was an opinion piece (Figure 2.1). All literature used in this study applied social-ecological analysis and approaches. I excluded papers that do not use social-ecological approaches or use only social or ecological variables alone for their analysis from this systematic review.

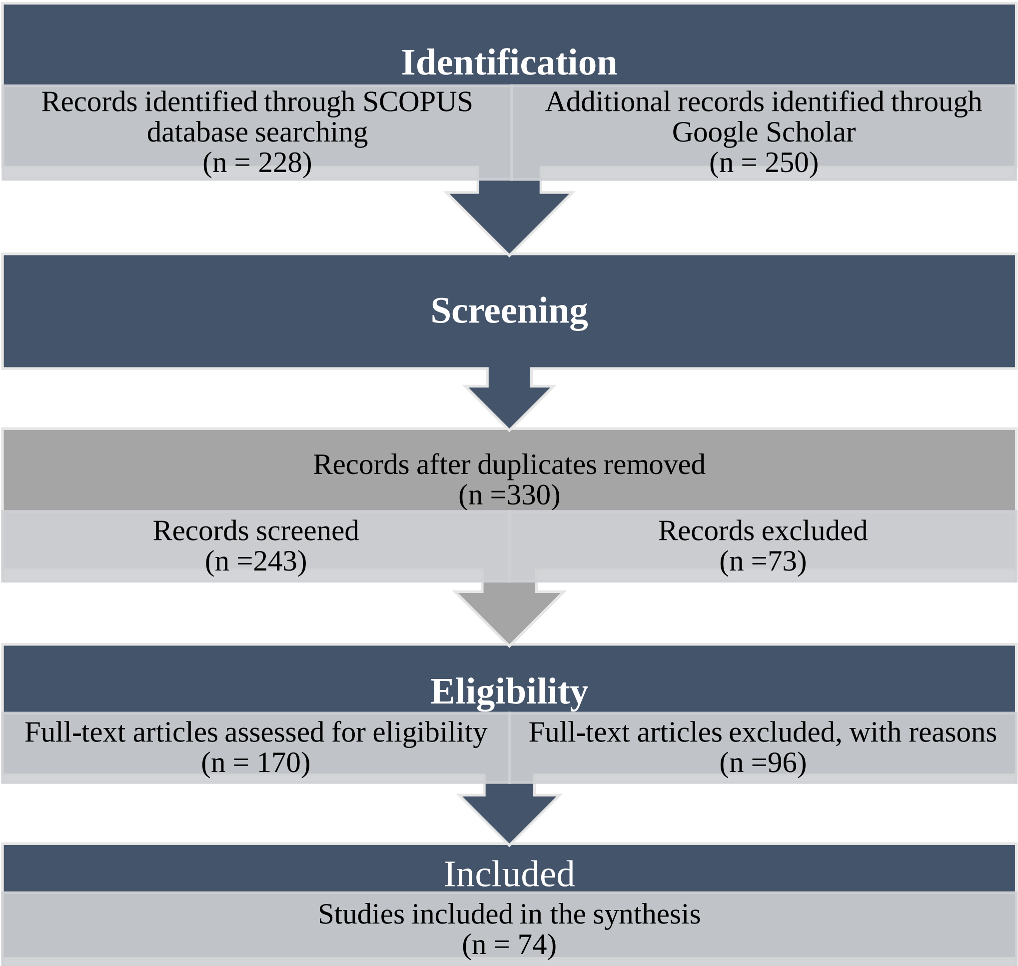

Figure 2.1 Flow chart of literature selection process in this study following a PRISMA flow diagram, adapted from Moher et al., (2010).

The final selection included 15 papers that discussed frameworks, models and concepts in SES analysis and 14 papers that explained the relationship between social-ecological variables within MPAs. Three papers used meta-data analysis involving MPAs around the globe, 20 papers contained MPA evaluations, 14 papers assessed aspects other than social-economic factors, such as customary law, and 8 papers discussed the resilience of social-ecological variables in MPAs, (Appendix 7.1 Supplementary Material Table S2.1). The case studies cited in the papers included in this review were located worldwide (Figure 2.2).

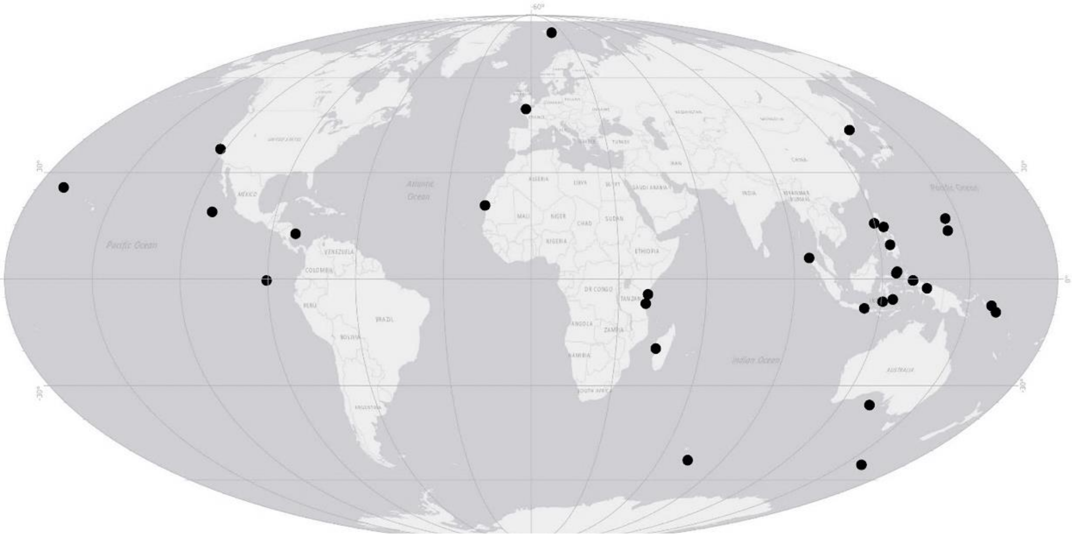

Figure 2.2 Distribution of case-studies cited in this review.

From the various applications and analyses of social-ecological variables within the MPAs, firstly, we identified each variable and categorized them into four attributes[1]: (1) ecology; (2) socio-economic; (3) management; which interact to establish an MPA, and (4) output (Pomeroy et al., 2004). This process enabled us to build connections between variables, based on the results presented in the literature from the systematic review, and create the social-ecological interaction framework to understand how different types of variables interact with conservation outputs (Figure 2.3). Secondly, we linked the variables to the IUCN's four criteria (good governance, effective management, conservation outcomes, sound planning and design). Using a Sankey diagram (Bogart, 2016), we show how each variable identified is connected to an indicator for MPA evaluation (Pomeroy et al., 2004).

[1] We use the term 'attributes' when we refer to four attributes of MPAs introduced by Pomeroy (2004); (1) ecology or ecological attributes; (2) socioeconomic attributes; (3) output attributes; (4) management attributes, and we use term 'criteria' when we refer to IUCN's four criteria; (1) good governance; (2) effective management; (3) conservation outcomes; (4) sound planning and design.

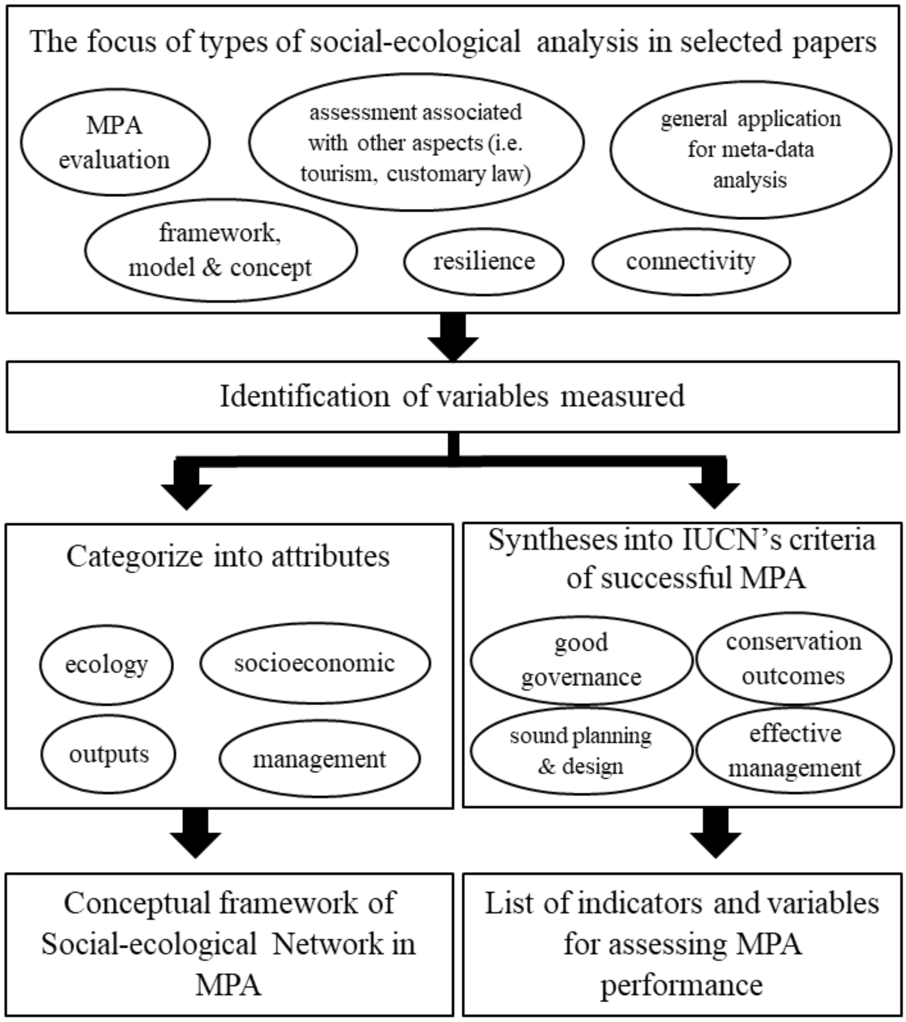

Figure 2.3 Decision-making process for building a social-ecological network framework and synthesizing indicators from social-ecological variables to evaluate MPAs.

2.3 Results

2.3.1 Social-ecological variables identified

We identified a total of 82 variables, consisting of 59 socio-economic variables and 23 ecological variables. Within the socio-economic variables, 'conservation beliefs and awareness' was most often mentioned, followed by 'sanction', 'rules and implementation', and 'participation in conservation projects', which were mentioned 17, 13, 12 and 11 times, respectively (Figure 2.4). 'Fish biomass', 'habitat quality' and 'coral cover' were the most frequently mentioned of the ecological variables. We found that socio-economic variables were more diverse and more frequently used than ecological variables, mentioned 271 times, while ecological variables only appeared 98 times in the social-ecological literature examined.

The differences in number and type of variables used depended on the objective of the study. Fourteen studies examined the correlation between socio-economic aspects and ecological aspects. In addition, we found 7 comparative studies that compared variables such as ‘fish biomass’ and ‘coral cover’ inside and outside MPAs, and two studies that used spatial analysis to evaluate MPA size and design. The selection of variables varied across the literature. MPA conditions and research objectives helped determine which type and how many variables were used. Local knowledge of a particular area and local social-ecological understanding were important before determining which methods and variables to use in evaluating MPAs (Pomeroy et al., 2004). For example, in examining ecological conditions, several factors such as ‘hurricanes’ and ‘predators present’ (e.g., crown of thorns starfish) were included to prevent bias about how coral reef damage occurred in protected areas (Mora et al., 2011). Furthermore, socio-economic variables such as ‘ethnicity’ and ‘religion’ were used to prevent bias about conflict-related interests that were often linked to a protected area’s rules such as ‘gear restrictions’ and ‘non-take zone’. The ‘distinct groups’ and ‘beliefs’ variables were related to community behaviour on using fisheries resources for commercial purposes (Aswani et al., 2013). Thus, managers must pay attention to the local distinct ‘ethnic’ and ‘beliefs’ before judging that restrictions in a MPA are the source of conflict.

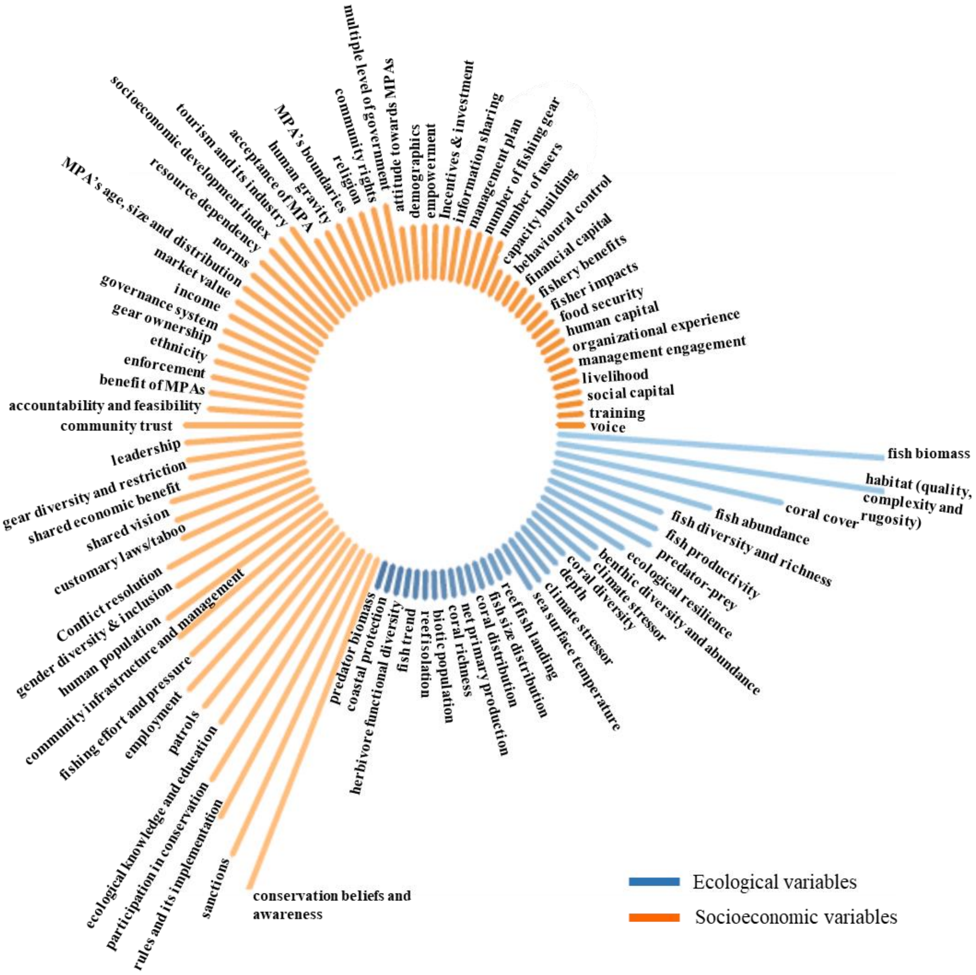

Figure 2.4 List of identified socio-economic and ecological variables in the literature. Blue lines represent ecological variables and orange lines represent socio-economic variables. The length of the line shows how many times each variable appeared in the literature (a short line indicates that the variable appeared infrequently and a long line indicates that the variable appeared frequently).

2.3.2 Social-ecological interactions between variables within MPAs

The interactions within social-ecological networks in MPAs were categorised into four different attributes according to Pomeroy et al., (2004): outputs, management, environment and socio-economic (Figure 2.5). These interactions determine MPA output variables such as 'fish diversity and richness', 'fish abundance', 'community acceptance of MPA', 'individual community's knowledge and awareness' and 'cultural value' (Figure 2.5, Ban et al., 2017; Bryan et al., 2011; Cinner et al., 2018; Cumming et al., 2015; Gallacher et al., 2016).

Social-ecological interactions between MPA outputs and other variables can be potentially positive (Figure 2.5, green line). For example, MPA outputs such as 'fish productivity' were reported as being high where the community's 'trust', 'positive perceptions' and 'participation' were also high (Ban et al., 2017). Similar to this, MPA management variables such as 'age', 'design' and 'size' were positively correlated with MPA outputs (Krueck et al., 2019). In contrast, MPA outputs can have potentially negative interactions with socio-economic variables such as 'dependency' and 'market value' (Figure 2.5, red line, (Cinner et al., 2012)). 'Management plan' (Fox et al., 2014) and the presence of 'customary law' variables can be related to both an increase or decrease in an MPA's output through their effects on conflict and resource access (Hoshino et al., 2016).

Besides potentially positive and negative interactions with outputs, there are also other connections between each variable within and outside the different MPA attributes (Figure 2.5). These connections can influence the condition of each variable. For example, 'resource dependency', which tends to negatively interact with MPA output, also influences a community's 'income/salary', 'employment', and 'the market value of resources'. These connections depend on behavioural control interacting with these variables. For example, if 'resource dependency', which explains how many people derive their livelihoods from marine and coastal ecosystems inside and outside MPAs (Marshall et al., 2010), is high and people tend to fish every day, MPA establishment will reduce people's access to resources ('rights'), this will lower their 'income' and the price of fish in the local area will change because of limited supply. However, if MPA managers or the government can modify people's 'behaviour' in fishing (time and location) by creating ‘governance arrangements’, as well as encouraging job diversification, this will likely not reduce their ‘income’.

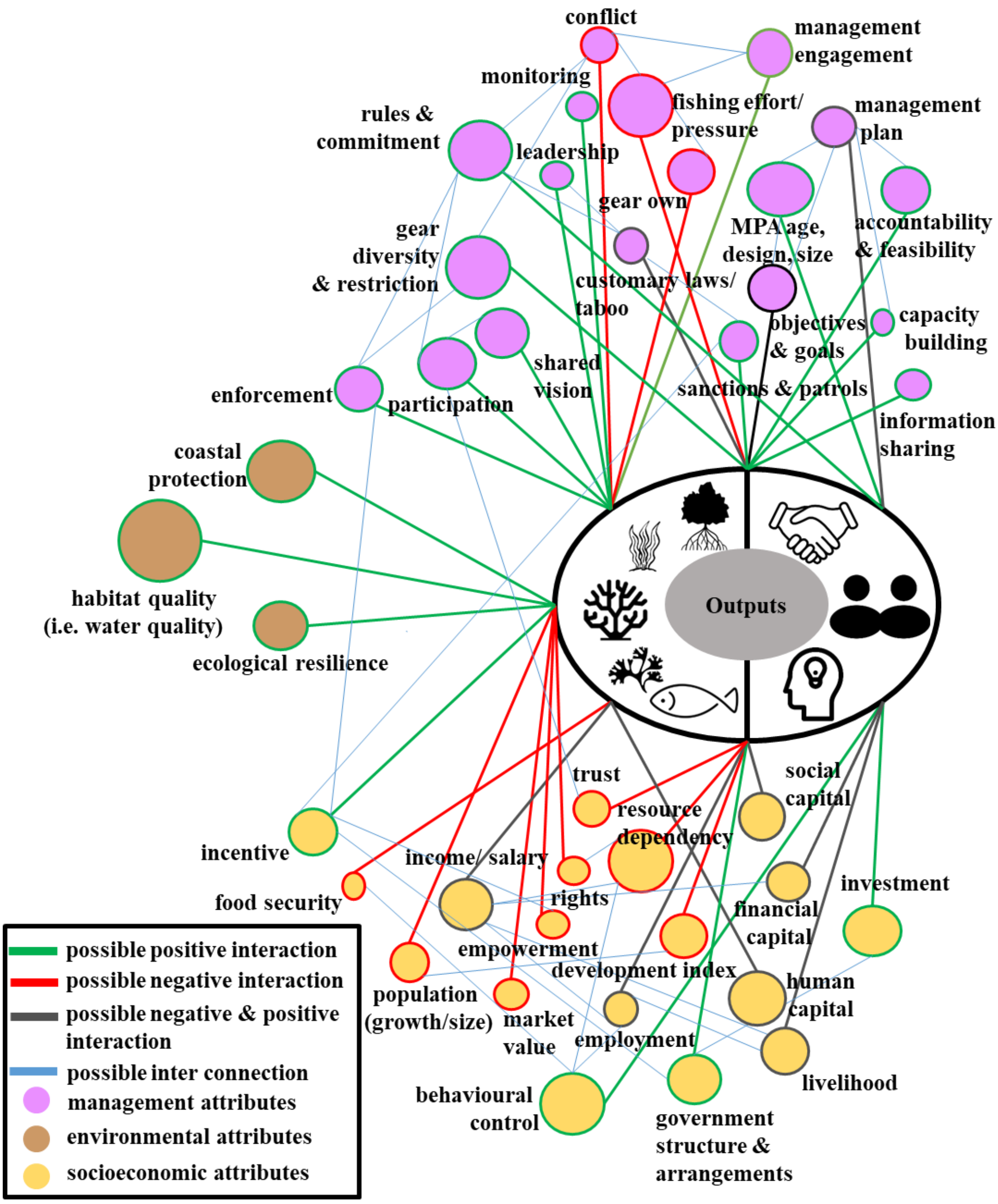

Figure 2.5 Conceptual framework of social-ecological interactions within Marine Protected Areas. Outputs of MPAs include the condition of social and ecological variables such as fish biomass, living coral cover, seagrass cover, seaweed cover, mangrove, community acceptance of the MPA, individual community's knowledge and awareness, and cultural value.

2.3.3 Indicators for assessing MPA performance

We discovered a total set of 39 indicators, accompanied by 82 identified variables, they consisted of 8 indicators for assessing biophysical conditions such as 'focal species abundance' and 'water quality', 14 indicators for assessing socio-economic conditions such as 'local marine resource use pattern' and 'perception on seafood availability', and 17 indicators for assessing the governance system such as 'enforcement coverage' and 'level of resource conflict' (Figure 2.6). The three types of indicators were associated with identified variables in this review, 24 variables for biophysical indicators, 28 variables for socio-economic indicators and 30 variables for governance indicators.

Indicator provide a specific measurement that describe information about a broader concept or trend (Riley, 2001 *in* Heink & Kowarik, 2010). In this study, I assessed indicator by measuring the identified variables to address a specific object within. For example, when addressing the 'type, level and return of fishing effort' indicator, I measured several variables such as (1) number of user; (2) number of fishing gear; (3) gear diversity; (4) fishing effort and pressure; and (5) gear ownership (Supplementary Tabel S2.3 for list of indicators, variables and unit measures).

Our review found that the assessment of MPA management effectiveness is most often measured using indicators based on biophysical condition such as habitat distribution & complexity. These indicators include the condition of habitat distribution, habitat complexity, habitat integrity, habitat composition and habitat status (quantity and quality) (Pomeroy et al., 2004). The most used variables associated with this indicator help us measure and indicate the effectiveness of conservation outcomes, such as 'fish biomass', and 'living coral cover'.

The second most used indicator is an indicator to measure the effectiveness of conservation outcomes; 'local value and beliefs about marine resources'. This indicator explains how people understand, believe and make choices regarding the use of marine resources, thus, it can help a MPA manager to understand how to integrate conservation values with local values (Pomeroy et al., 2004). This indicator associates with variables such as 'conservation beliefs and awareness', 'acceptance of MPA', and 'customary laws and taboo'.

The third most used indicators measure the effectiveness of conservation management; ‘clearly defined enforcement procedures’ (which is associated with variables ‘sanction’ and ‘gear restrictions’), ‘local understanding of MPA rules and regulations’ and ‘level of stakeholder involvement in surveillance, monitoring and enforcement’ (which is associated with the variable ‘participation in conservation’).

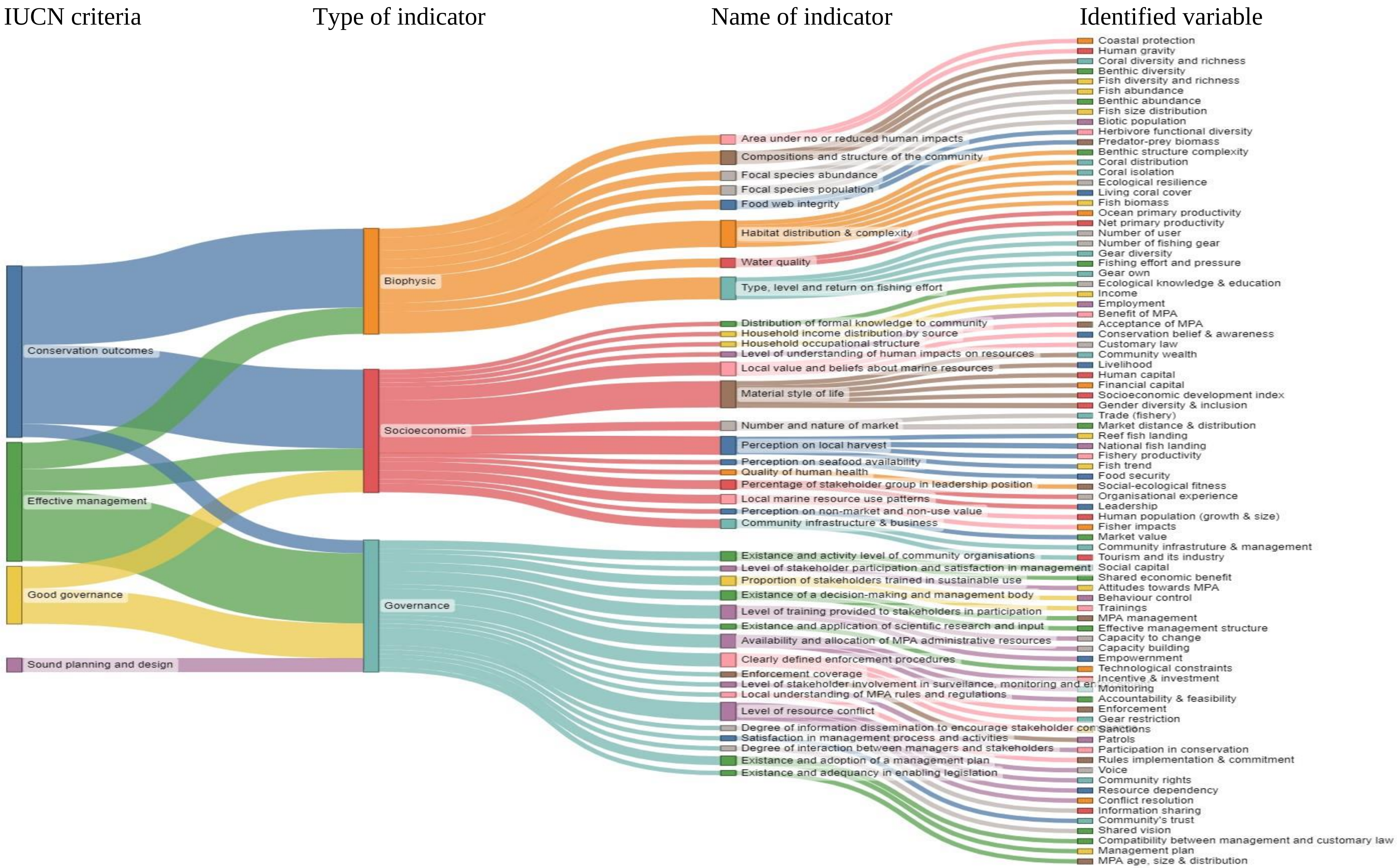

Figure 2.6 Sankey diagram showing the set of indicators, which syntheses from IUCN's criteria, for assessing the effectiveness of MPAs.

2.4 Discussion

In this review, we draw a conceptual framework of how social-ecological variables interact within an MPA (which we call a social-ecological interaction framework). Exploring the interactions can help us understand how one variable can influence others, thus, how to improve MPA management effectiveness. For example, in our social-ecological interactions framework we showed that local community participation and MPA management engagement can increase the output of MPAs, such as local community knowledge. Thus, understanding the context and human behaviour may been necessary to improve MPA management in the future.

Despite many of the views and arguments circulating regarding MPA goals and effectiveness, how to measure them efficiently (Giakoumi et al., 2018) and how to choose appropriate indicators, this review has identified a wide range of indicators in use for assessing MPA performance along with a large number of variables used to measure the characteristics of each indicator. The identified variables in this review help us to understand the attributes of each indicator mentioned by IUCN (Pomeroy et al., 2004) to assess the effectiveness of MPA performance. We showed that MPA effectiveness was most often assessed by indicators such as 'habitat distribution & complexity', 'local value and beliefs about marine resources', and 'level of stakeholder involvement in surveillance, monitoring and enforcement'. These indicators can be measured by variables such as 'fish biomass'; 'coral cover'; 'conservation beliefs and awareness' of the local community; MPA management 'rules and their implementation'; local community 'participation in conservation' and 'sanction'.

This study shows that the proportion of variables used for each category (socio-economic and ecology) is unbalanced. We found that socio-economic variables are more diverse than ecological variables (Figure 2.4). MPAs that focus on achieving biodiversity conservation goals should include more ecological indicators and their variables such as connectivity, ecologically significant areas, ecological networks and ecological resilience (Hopkins et al., 2020), as these conditions may influence an MPA's ecological outputs such as fish biomass and coral cover. Unfortunately, these ecological variables seem to be rarely used and may represent a gap in knowledge contributing to a decrease in MPA effectiveness in reaching their objectives. Thus, it is important to use a range of compatible and well understood variables to evaluate

MPAs. The number of variables and the indicators they measure, the interactions between variables within MPAs and each indicator or variable's priority must be considered before deciding on the complement of indicators and variables to use to assess MPA effectiveness.

In this review, we found several variables that were positively related to MPA output, such as enforcement. Rule enforcement is an important aspect that influences whether a regulated area or protected zone proves to be effective in increasing fish biomass (Zupan et al., 2018). Furthermore, enforcement of MPA regulations should be a priority, with other goals of MPA management - such as increasing incomes and gear diversity – being secondary (Pajaro et al., 2010). However, in many cases where fishing is a primary occupation and resource dependency is high because of a lack of income diversification, delaying activity to increase and diversify incomes could lead to poverty (Gjertsen, 2005), creating a negative interaction with MPA outputs. Another variable that was found to be positively related to MPA output was incentives (agency and government incentives), that can contribute to the effectiveness of MPAs (Dygico et al., 2013). Incentives work by enabling MPA management to engage with local communities and increases their capacity to enforce the rules and local communities' commitment to protect marine and coastal biodiversity (Tupper et al., 2015). It is important for MPAs to have full support and commitment from the local community, as we found that many successful MPAs often have strong community support, awareness, and understanding (Eisma-Osorio et al., 2007), as well as a high level of participation of the community in conservation activities (Ban et al., 2017; Trialfhianty & Suadi, 2017).

Examining the methods for selecting indicators, as well as the justification for using selected indicators, we found that the cases in the literature used a variety of methods including participatory, literature review, multi-criteria assessments and frameworks (built by experts, agencies or government). Either an MPA's objective or the approach used to identify the selected indicators determined the type and number of indicators decided upon. Participatory approaches tended to produce a more diverse range of indicators. This approach used questionnaires, interviews and focus group discussion to determine which indicators to use. It is often considered to be the best approach because it improves credibility and acceptance, increases evaluation capacity, and is able to address locally relevant issues (Heck et al., 2011). Indicators such as spawning density, information distributed, habitat distribution, species community composition and condition of cultural resources (Heck et al., 2011), that were not mentioned in the literature using non-participatory methods, were identified using this approach. Furthermore, stakeholder perceptions in deciding which indicators are best used illuminated the interactions between indicators within MPAs, such as why fishers were more concerned about increasing their income through tourism opportunities and chose it as a higher priority indicator rather than increasing the number of fish caught (Himes, 2007).

We need to carefully choose essential indicators, especially when dealing with indicators that do not belong to either social or ecology aspects but emerge from the interaction between systems (Liu et al., 2007). For example, Cinner et al., (2013) used empirical monitoring data from ecological and social surveys to investigate the social-ecological vulnerability of coral reef fisheries in Kenya, using the indicators of climate exposure, biological resistance and recovery, social adaptive capacity and social sensitivity to change. Besides, government action was included to carefully predict future vulnerability. It is important to choose a reasonable set of indicators that cover a range of attributes and criteria to enhance the opportunity to build good management strategies in the future. Therefore, despite of all of the indicators presented in IUCN guidelines (Pomeroy, 2004), this review presents and emphasises a set of indicators and variables that are relevant to assess MPAs (only for MPAs which follow IUCN guideline and criteria) and enable us to determine which indicators and variables are best for assessing the various goals of MPAs (e.g. when assessing effective management of MPAs we can use variables such as percentage of people involved in leadership positions (Figure 2.6)).

2.5 General implications

An effective MPA must be capable of generating benefits for both humans and the ecosystem (IUCN WCPA, 2018), as a result many MPAs will set their objectives using this definition, such as protecting the coastline, improving fish stocks, providing research and educational opportunities, promoting tourism, restoring damaged ecosystems and enhancing ecosystem resilience from climate disturbances (Ban et al., 2017; Cinner et al., 2013; Fox et al., 2014; Tupper et al., 2015). We have discovered factors that might increase or decrease MPA effectiveness, by first looking at the interaction between variables. Understanding these interactions may help future management strategies reduce threats and increase opportunities for MPAs to reach their goals. Complex interactions within a social-ecological interaction framework demonstrate that MPAs can differ due to local conditions. For example, the proximity of large human populations near coral reef MPAs can create conservation opportunities if stewartship facilitates human engagement towards better managing the reef (e.g., local surveillance, or the restoration of village reefs with coral fragments) (Day, 2017; Trialfhianty & Suadi, 2017). However, it becomes a threat if bomb fishing is used, which leads to damage to coral reef ecosystems (Hampton-Smith et al., 2021). Exploring all social and ecological variables within and outside MPAs can help us understand the social-ecological system and its interactions as a whole.

While we have shown that choosing an ideal set of indicators to evaluate MPAs under a variety settings is complex, it is also important to consider that MPAs change over time and an adaptable approach is needed that selects indicators that are able to continuously assess MPA effectiveness over time (Marques et al., 2013; Pajaro et al., 2010; Tupper et al., 2015). MPA conditions, such as size and age, can act as a guide to help select indicators (Pajaro et al., 2010). Engagement with stakeholders such as experts and local communities is also necessary in determining indicators (Ramos et al., 2004). MPAs which are located near human settlements with high levels of anthropogenic disturbance and ones that have low levels of anthropogenic disturbance might be differ in proportions of ecological and socio-economic indicators needed. We found more socio-economic indicators were used by MPAs with high levels of anthropogenic disturbance. However, further study on indicator proportions in evaluating MPAs effectiveness needs to be conducted before any judgement can be made.

Chapter 3. Spatial multi-criteria analysis to capture socio-economic factors in mangrove conservation

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Abstract

Mangrove forests are among the most productive ecosystems, located in tropical and subtropical coastal waters and river estuaries. Mangroves benefit both people and the environment by providing shelter for brackish-water organisms, such as fish and shrimp. They form a green-belt area that protects land from abrasion and tsunamis, along with goods and services for people, e.g., fruit, fish and charcoal. However, unmanaged use of mangrove ecosystems has resulted in a widespread decline in their function and conflicts between users. A paucity of research on mangrove management and spatial zoning is also contributing to the decline of these ecosystems. This study develops a prioritisation process with Spatial Multi-criteria Analysis (SMCA) for social-ecological mangrove management, based on a case study in Baros, Yogyakarta, Indonesia. We include social (participation and perception), demographic, economic (economic value of mangroves) and ecological criteria (water quality, mangrove density and diversity, phytoplankton diversity and density) and spatial considerations informed by remote sensing imagery. We consider the three different conservation scenarios of habitat protection areas, sanctuary areas, and restricted areas to help configure management plan options. We demonstrate how SMCA can support managers and policymakers in mapping conservation areas based on complex and diverse social-ecological data. However, further discussion with stakeholders in Baros is required to validate the produced map for future use. The involvement of stakeholders and governing bodies from the beginning or within the SMCA analysis will always be crucial in community-based prioritisations.

3.1 Introduction

Mangrove ecosystems are found in Africa, America, Asia and the Pacific region and cover an estimated 22%; 30%; 38% and 10% respectively of the total mangrove area worldwide (Vegh et al., 2014). Mangrove ecosystem services include fisheries, timber, coastal protection, tourism, recreation, carbon sequestration, biodiversity and filtration (Vegh et al., 2014). They provide nursery, spawning and feeding grounds for associated organisms such as fish and shrimp (Adeel & Pomeroy, 2002). However, these wetland ecosystems are threatened by overexploitation, pollution, urban development and land-conversion (Alongi, 2002; Giri et al., 2008), which has caused a 62% global loss of mangrove area worldwide (Goldberg et al., 2020). Effective management strategies are required to reduce these threats. Management strategies need to be matched to ecosystem service needs, for example, whether the mangrove system is to be maintained or improved for coastal protection, food provisioning, or timber production. Conserving existing mangrove ecosystems enables ecosystem services to be maintained, and it is more economical and easier to prevent mangrove loss rather than to restore degraded mangroves (Schmitt & Duke, 2015).

Indonesia's mangrove forest is one of the largest in the world, covering an area of approximately 3 million hectares; 22.6% of the total global mangrove area (Giri et al., 2011). This ecosystem contributes significant ecological and social-economic benefits to local communities. It is estimated that the total economic value of mangrove resources in Indonesia is US$3,624–US$26,734.61/ha/year (Rizal et al., 2018). This value results principally from provisioning services, such as wood, tannin, charcoal, food and material for the paper industry. It also provides protective benefits by protecting land from coastal abrasion, salt-intrusion, storm and tsunami damage and ecological benefits by providing nursery and breeding areas for a range of organisms (Rizal et al., 2018). However, the extent of Indonesian mangroves has been declining due to over-exploitation of wood resources and their conversion to brackish water aquaculture and coastal development e.g., villas, housing areas and roads (Andika et al., 2019). Management and conservation strategies are vital to halt the decline, to sustain the ecosystem, and preserve its functions for ecological and social-economic purposes. However, decision-making for mangrove conservation and management can be problematic because many parties, from the government to the local community, are involved. It can be challenging to meet the needs of every stakeholder. Thus, decision-making strategies that incorporate not only ecological factors, but also social-economic variables to reflect the needs of different stakeholders are necessary.

Multi-criteria analysis is a tool that can assist decision-making for ecosystem management. It supports mixed-data analysis with the direct involvement of stakeholders and local user groups (Mendoza et al., 2000). The approach allows researchers to combine complex multidimensional data, such as socio-economic, ecological and management information, to explore management and conservation options in a particular area (Cortina & Boggia, 2014). For example, the Analysis Hierarchy Process (AHP) – a hierarchically structured approach to multi-criteria decision making – can help to integrate heterogeneous data and specify interactions between a large number of criteria (Chen et al., 2013). While multi-criteria analysis aims to investigate a complex issue, combining it with spatial contexts allows policy makers to better understand how the outputs are spatially distributed (Boggia et al., 2018). Thus, spatial multi-criteria analysis (SMCA) approaches that can combine qualitative and quantitative data and produce maps are useful to managers and stakeholders who want to assess the benefits of conservation projects or options.

Effective management strategies are required to balance various economic, commercial uses and conservation goals. It is essential to consider both ecological and socio-economic factors in a transparent prioritisation process. Hence, multi-criteria analysis provides a powerful approach to achieving this integration (Comino et al., 2016). The ability to combine multi-criteria decision-making approach with spatial data or Geographic Information Systems (GIS) has been studied in other ecosystems worldwide, such as using SMCA in forest conservation planning (Phua & Minowa, 2005), SMCA for Marine Protected Areas (MPA) zoning and management (Habtemariam & Fang, 2016), and SMCA for assessing mangrove health (Vaghela et al., 2018). Therefore, we believe that we could use SMCA for mangrove conservation planning and SMCA is the most suitable method to facilitate and manage the complex interactions between users and managers who have different goals and reasons for managing the mangroves.

In this study, we investigated the possible social and ecological criteria to be used for SMCA analysis and to prioritise areas for different types of use. Unlike most SMCA studies that use only community perceptions (Danumah et al., 2016; Karlsson et al., 2017), which are prone to bias, we used a combination of community perceptions, mangrove economic value, and ecological observations to support the analysis. Furthermore, we applied three main management types, i.e., core-zone, buffer zone and transition zone in conservation area, akin to UNESCO's Biosphere zonation (Batisse, 1990). Specifically, our goals were to (1) understand spatial, ecological and socio-economic parameters that are suitable and applicable for conservation management planning of mangroves; and (2) demonstrate how multi-criteria analysis can be employed in spatial conservation planning for mangrove ecosystems. To demonstrate the framework, this study developed possible management and conservation options for the Baros mangrove forest.

3.2 Case study methods: incorporating socio-economic factors into SMCA

3.2.1 Study area

Mangrove restoration has been extensively undertaken in Indonesia and includes both top-down (government-driven) and bottom-up (community-driven) efforts (Turisno & Siti, 2020; van Oudenhoven et al., 2015). One such community-driven example comes from Baros, located between 07°59’25’’- 08°00’45’’S and 110°16’46’’- 110°17’22 E. The study area, which is located in Tirtohargo village, covers 281.89 hectares, with the majority of land used for farming (approx. 176.6 hectares of the total area) (Figure 3.1). A significant part of the community are farmers (67.5%), who plant various seasonal crops (Tirtohargo Village, Demographic data, 2013). Baros is located adjacent to the coast and an estuary. Therefore, salty winds and salt-water intrusion have become major threats to crops. Recognising the potential benefits of mangroves, this community established a new mangrove forest in a previously unforested coastal area in 2003. Over the following ten years, the area was expanded to a 5-hectare mangrove forest, dominated by *Avicennia* sp., *Rhizophora* sp., *Bruguiera* sp., and *Nypa fructicans* comprising 60%, 20%, 10% and 10% respectively (Trialfhianty et al., 2014). This process resulted in numerous benefits for the local community, including protecting farmland from salty winds which regularly destroy crops as well as abrasion along the coast.

In 2014, the area was designated as a conservation area managed by the local government and Ministry of Marine and Fisheries (MMAF) Indonesia. However, the conversion from a freely used area to a conservation area led to conflict between users (i.e., community) and managers (i.e., local government). Thus, to facilitate both the local government and the local community in setting up an ideal conservation zone, we propose a conservation zoning area for Baros mangrove using SMCA by incorporating heterogeneous data such as spatial, ecology and socio-economic from the local community in Baros. Ecological and socio-economic data were collected between June 2013 and February 2014. Six distinct locations were randomly chosen (inside and outside mangrove area) as stations for the field observations (Figure 3.1, Appendix 7.2 - Supplementary Material Table S3.1).

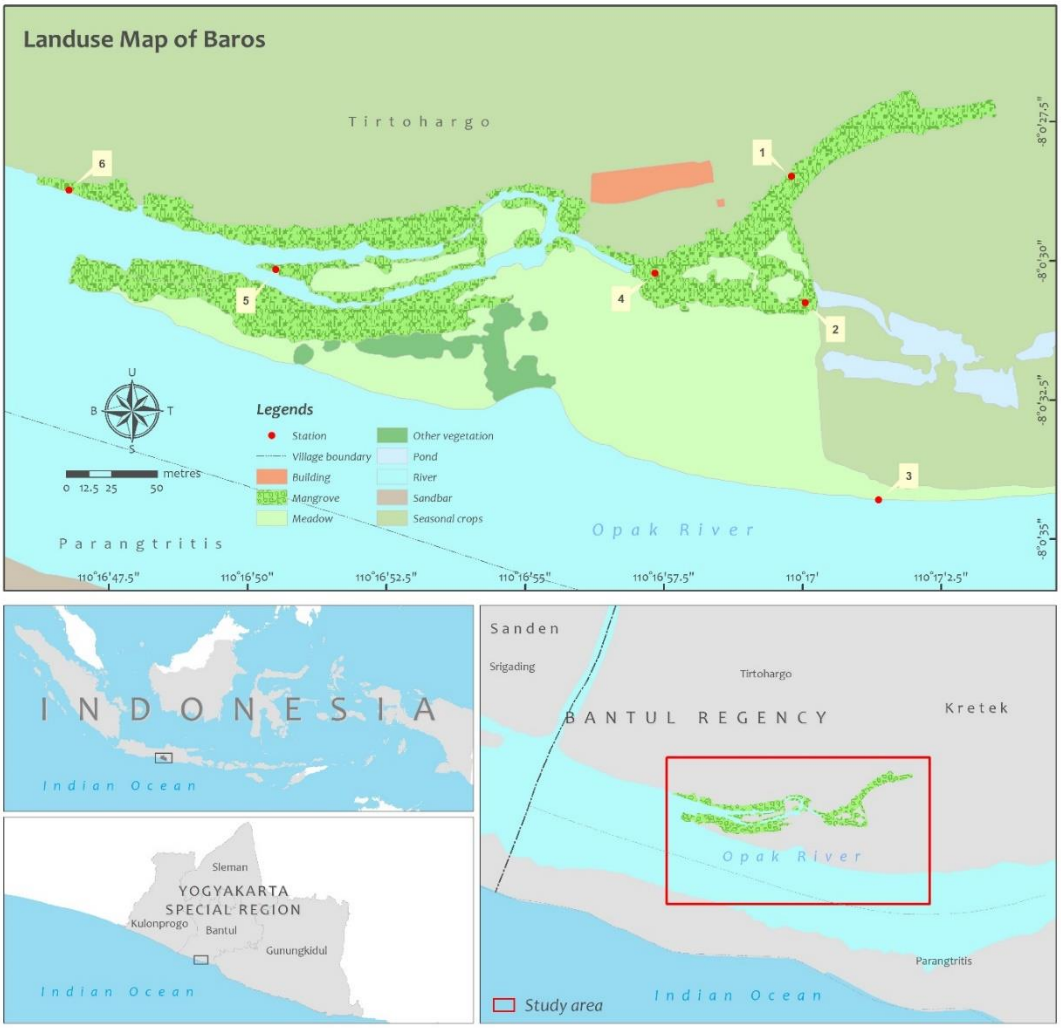


Figure 3.1 Case study location in Baros, Yogyakarta Province, Java Island, Indonesia

3.2.2 Research design

We divided the research process into five steps (Figure 3.2). In the research design step, we identified what activities mangrove users carry out and the type of benefits local people obtain from mangrove ecosystems in the area. Using a questionnaire, people were asked if they benefit from mangroves, what sort of activities they do to benefit and how often they do it. From this ecosystem services identification, we chose the criteria for management options. Finally, then we propose a zoning scenario for mangrove conservation management that has the potential to be implemented in the Baros mangrove area following Gubbay (2004). The zoning scenarios consist of various criteria that were generated from multiple parameters (Table S3.1 for a detailed parameter and its source).

The next step was data collection of ecological and socio-economic data for our SMCA. We applied an Analysis Hierarchy Process (AHP) matrix approach to determine weights for each criterion and factor. AHP allowed us to measure the importance of each parameter in each criterion in a hierarchical structure. This measurement helped with the decisions about which parameters or criterion were more or less important.

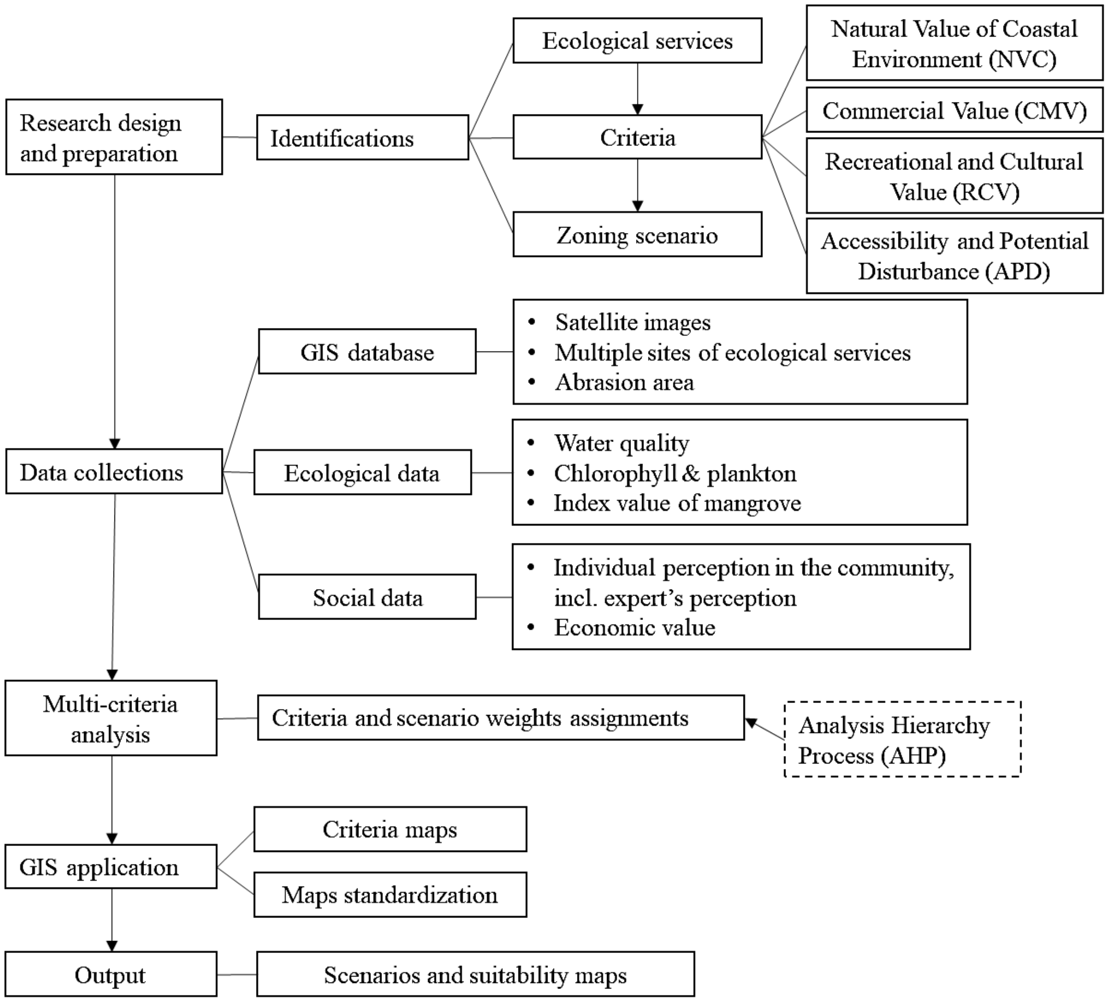


Figure 3.2 Flow chart of the study method using SMCA in the mangrove area.

3.2.3 Spatial Multi-criteria Analysis (SMCA)

3.2.3.1 Identification of criteria

Defining the criteria for conservation options (Habtemariam & Fang, 2016) is a key requirement for the spatial multi-criteria approach. These criteria can be established by examining social data, such as stakeholder preferences, to identify priority areas for various uses (Strager & Rosenberger, 2006), but also the environmental and socio-economic functions of the area (Portman, 2007). However, here, we did not only rely on stakeholders' perceptions or preferences concerning land management options. We also investigated several ecological data types that were collected to justify whether the area was suitable for such criteria. For example, we explored potential physical disturbances such as abrasion to capture the protection services of mangroves. Based on our field observations, the Baros area is prone to abrasion and flooding of coastal land, so we included Accessibility and Potential Disturbance (APD) as one of the criteria assessed in this study. Identifying criteria that are relevant for the location is important and can be undertaken by looking at either the social or ecological aspects.

Criteria used in this study included Natural Value of Coastal Environment (NVC), Commercial Value (CMV), Recreational and Cultural Value (RCV) and Accessibility and Potential Disturbance (APD). NVC describes the mangrove function as protection of farming land from salty wind and salt-water intrusion. Farmers reported that salty wind and salt-water from the sea are the biggest threats to their crops, resulting in severely damaged crops and decreasing production. If the area is to be expanded as conservation land to maintain its value/benefit, several parameters were required to build the NVC criterion. Here, we used ecological data, for instance, water quality, chlorophyll, and plankton identification, along with the significance of the mangrove to develop the NVC criterion (Table 3.1). These data described the suitability of the area for a mangrove nursery and planting, besides its function as a green-belt area for farming.

The commercial value (CMV) of the mangrove ecosystem in Baros was reported as a commercial benefit to local people. The mangroves have benefited locals in three different ways; a) they have served as a fish habitat to improve fishers' yields, b) they provided a brackish water habitat suitable for shrimp aquaculture that is an important income stream, and c) they increased biodiversity/vegetation in the surrounding terrestrial area used as a feeding area by cattlemen (grazing cows, goats and ducks). Thus, we used three parameters to build the CMV criterion: aquaculture, feedlots and traditional fishing.

The Recreational and Cultural Value (RCV) encompasses mangrove benefits for tourism and education purposes. There was a camping ground that was established to allow people to spend the night in the natural area the mangroves provide, including research and bird watching. The parameters required to develop the RCV criterion included education, research and tourism.

Table 3.1 Details of criteria, type and source of data used in this study

Criteria	*Parameter*	*Type of Data*	*Source of Data and Methods*			
			Remote Sensing Imagery	Interview/ questionnaire	Field obs.	GIS
Natural Value of Coastal Environment (NVC)	Green-belt area for farming	Water quality	-	-	X Sampling using various laboratory tools	Interpolation
	Mangrove nursery and planting	Chlorophyll & Plankton	-	-	X Sampling using a plankton net	Interpolation
		Important value index of mangrove	-	-	X Quadrant transect	
Commercial Value (CMV)	Aquaculture	aquaculture area and its economic value	-	X	X	Interpolation
	Feedlots	Feeding ground and its economic value	-	X	X	Interpolation
	Traditional fishing	Fishing ground and its	-	X	X	Interpolation

		economic value				
Recreational and Cultural Value (RCV)	Education and research	Sites and their economic value	-	X	X	Interpolation
	Tourism; bird watching and camping		-	X	X	Interpolation
Accessibility and Potential Disturbance (APD)	Coastal abrasion and flood	Area of prone disaster	X	X	X	Visual interpretation and interpolation

3.2.3.2 Identification of zoning scenario

We propose and analyse three different management zones for the conservation area in Baros (Gubbay, 2004):

1. Restricted access zone

   This area is established as a no-take and no entry zone focused on improving ecological habitat. A mangrove nursery could be located in this area to support future mangrove expansion.
2. Sanctuary zone

   This zone is highly protected and free from commercial use. However, low-risk activities, such as tourism and education/research may be allowed.
3. Habitat protection zone

   This area allows access for commercial use with clear rules regarding how the local community can access and use the area.

3.2.4 Analysis Hierarchy Process (AHP) in SMCA

3.2.4.1 Criteria and scenario weighting for AHP

Weights were given to each parameter and criterion to construct the AHP matrix, following the method introduced by Saaty (1977). The matrix has rows and columns, listing all parameters or criteria in each row and column. A matrix construction aims to calculate the weight and score of each parameter to indicate which parameter is stronger in comparison to others. Measuring the weight using the AHP allowed many criteria to be simplified and numbered. It should be noted that this comes from individual preferences or perspectives about ecosystem services. Furthermore, AHP is easily compatible with GIS ranking models (Strager & Rosenberger, 2006). The paired comparison analysis is based on the matrix (Saaty, 1977):

	A_1	A_2	...	A_n
A_1	W_1 / W_1	W_1 / W_2	...	W_1 / W_n
A_2	W_2 / W_1	W_2 / W_2	...	W_2 / W_n
:	...	...	...	
A_n	W_3 / W_1	W_3 / W_2	...	W_3 / W_n

(1)

A = parameters; criteria
W = weight

Here, we first valued each parameter within each criterion by assigning weights. Weights can be drawn from local knowledge or by asking stakeholders about their individual preferences (Strager & Rosenberger, 2006). We employed several data, such as economic calculations of mangrove services, ecological survey, and social survey to help us justify the value of each parameter. Then, each parameter within each criterion and each criterion within each scenario was subsequently weighted for pairwise comparisons and suitability rating using the Analysis Hierarchy Process (AHP) (Table 3.2).

Table 3.2 Suitability and importance value for each criterion

Comparative Importance	*Suitability Rating*	*Numerical Expression**
Equal importance	Not suitable	1
Moderate importance of one over another	Marginally suitable	3
Essential or strong importance	Moderately suitable	5
Very strong importance	Highly suitable	7
Extreme importance	Optimally suitable	9
Intermediate values		2,4,6,8

*following Saaty (1977) and Zabihi (2019)

The weight assignment was based on the importance value and suitability between each parameter. For example, here in the NVC matrix, water quality (listed in column) and chlorophyll (listed in row) were only moderately linked (given a value of 5), while water quality had a very strong importance for the value index of the mangroves (given a value of 8). An identical parameter (when a parameter/criterion is compared to itself), such as water quality (listed in row) and water quality (listed in column) is given equal importance represented by the number 1. However, not only identical parameters were given equal importance. Certain parameters, for example, traditional fishing and aquaculture, were also equally important, because they were considered as similar activities that had a similar impact on the mangroves and had a similar annual economic benefit to the community (Appendix 7.3 - Supplementary Methods F Matrix calculation 1 and 2).

A similar process of weight assignments was also applied to construct AHP matrix for each criterion within each scenario. For example, here in all matrix scenarios for Restricted Access Zone, Sanctuary Zone and Habitat Protection Zone, APD (listed in row) and NVC (listed in column) were of strong importance to each other (given value of 5) because the nature value of the mangrove ecosystem and accessibility of the mangrove ecosystem and its potential disturbance had to be strongly considered when designing the mangrove conservation zone (Appendix 7.3 - Supplementary methods F Matrix calculation 3).

In order to validate the derived scores, we calculated the Consistency Ratio (CR) for the AHP matrix based on the matrix' Eigenvalue and a Consistency Index (CI) Saaty (1977):

$$\lambda\text{max} = \sum_{j=1}^{n} \text{aij}\left(\frac{\omega\text{j}}{\omega\text{i}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

a_{ij} is A from the matrix (1)
ω = weight
λmax = maximum eigen value

$$\text{Consistency Index (CI)} = \frac{\lambda\text{max} - \text{n}}{\text{n} - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

n = number of elements

Consistency Ratio (CR) = CI/RI ……………………(4)

where RI is the random index (Table 3).

Table 3.3 Random index matrix following Saaty (1980)

Number of criteria	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The matrix calculation has a Consistency Ratio (CR) between 0.051 (5.1%) and 0.094 (9.4%) (Appendix 7.3 - Supplementary methods F). CR is the value of the Consistency Index divided by the Index of the corresponding random matrix. The assessment of the importance of each criterion may be inconsistent/unreliable if the CR value exceeds 0.1 (10%) Saaty (1977). It is important to calculate the CR and ensure that the assessment is reliable prior to making a decision.

3.3 Data collection

3.3.1 Spatial ecological and environmental data

Mangrove data were collected using a quadrat sampling method that captured a 100m^2 area in each station. The sample area was marked using a 40m rope (creating a quadrat with 10m sides), and mangrove data were collected, i.e., species, number of mangrove trees in the area and diameter of mangrove trees, following the method employed by Curtis & McIntosh (1950) (Appendix 7.3 - Supplementary Methods B*)*.

The coastal area south of Yogyakarta, where the Baros mangrove forest was established, is prone to coastal abrasion. The sandy beach material in the study area is vulnerable to change due to erosion or sedimentation (Saputro et al., 2017). Therefore, we also included data for coastal abrasion estimation in the area (as Accessibility and Potential Disturbance criterion) for future decisions in managing the Baros mangroves. These data were collected using satellite datasets, interviewing local people, undertaking a literature study and via field observation. The classification was determined based on two factors, i.e., elevation and distance from the shoreline (Naufal et al., 2019).

Firstly, we studied an abrasion susceptibility assessment in Baros (Naufal et al., 2019) (Appendix 7.3 - Supplementary Methods D). Secondly, we asked local people to identify areas affected by abrasion. Then, using Google Earth, we marked areas based on interview data. Finally, we gathered all the information above to identify mangrove areas that are susceptible to abrasion. Additional ecological data, such as water quality and phytoplankton were taken from published data (Agustina, 2014) (Appendix 7.2 - Supplementary Material C and D).

3.4.2 Spatial socio-economic data

A total of 72 respondents were identified using the snowball sampling method or chain-referral-sampling (Somekh & Lewin, 2005). We first interviewed the leader of village and asked him to separately provide a list of potential key informants most suited to answer questions related to our study. Using gatekeepers (leader of village and local NGO) to identify key informants can reduce the risk of getting false information because they (the gatekeepers) know more about the area, conservation projects, related rules and activities. Asking various gatekeepers can minimise any potential bias, leading to one reliable and accurate list of information. From the key informants, we went into the field and asked farmers/fishers/cattlemen who are currently working inside and outside mangrove area to fill out our questionnaire.

Qualitative data were collected using a questionnaire comprising open-ended questions for the respondents, and in-depth interviews, using a topic guide, for key informants. The questions in the questionnaire covered the perceptions of each individual in the community regarding mangrove benefits, their participation in mangrove conservation activities, management of the mangrove and their knowledge of the mangrove’s conditions and locations. A Likert scale (5 points from completely disagree to completely agree) was applied to record each respondent's answer to each question. The questionnaire also collected quantitative data, such as the economic value associated with the mangroves and the total number of each ecosystem service used by each individual in the community (how often and how many people benefit from mangrove ecosystem services) (Trialfhianty et al., 2014, Appendix 7.2 - Supplementary Material E and F). To calculate the economic value, people were asked by means of the questionnaire what benefit they received from the mangrove and the value associated with it. For example, if they thought that the existence of the mangrove provides a habitat for fishes and they were fishing in the area, we asked them how much profit (production minus effort) they earn from the fishing activity.

Data were processed using SPSS IBM 26 for statistical analysis. Prior to the data collection, the questionnaire was piloted with a small set of volunteers to reduce errors and misunderstandings.

3.4 Spatial analysis and prioritisation

Spatial analysis to conduct interpretation and interpolation procedures used ArcGIS Pro software to create spatial data related to the Baros mangroves (Menno-Jan Kraak & Ormeling, 2010). We created maps pertaining to each parameter and criteria, which were subsequently combined to create a conservation and management map for each scenario. Spatial data was acquired from UAV photography using fixed-wing and completed with Ground Control Points (GCPs) in 2011, high-resolution satellite imagery derived from SPOT 6 and Worldview-2 in 2013. These data were collected from *Badan Informasi Geospasial* (Geospatial Information Agency as the national map authority of Indonesia).

Interpretation, together with the digitisation of remote sensing imagery, was conducted using visual techniques to generate land use maps (Shalaby & Tateishi, 2007) and to identify vulnerability to abrasion and flooding (Marfai, 2011). Land-use maps were employed to define the zoning scenario and distinguish the boundary between mangroves and other land uses nearby, while a vulnerability map was employed to define Accessibility and Potential Disturbance (APD) criterion. The overall accuracy percentage for this map is 88 % (Appendix 7.3 - Supplementary Methods A).

Inverse distance weighting (IDW) interpolation was utilised to convert field measurement data into a spatial data set (Varatharajan et al., 2018). IDW interpolation works by predicting a value for an unmeasured area using weights based on the value of neighbouring areas. The influence of a measured point is diminished by the distance from that point (Lu & Wong, 2008). The coordinate points of the five sample locations were converted into a shapefile in ArcGIS as a parameter layer, together with the score given for each parameter as data attributes.

IDW interpolation enabled the calculation of raster format data that covers every specific location on a map (Siska & Hung, 2001). However, standardisation was required to normalise the data using fuzzy logic, so that each had the same interval on a continuous scale between 0 to 1 (Malczewski, 2004, in Hizbaron et al., 2012). A criteria map was derived by combining parameter maps of each criterion through an overlay process using the Spatial Analyst Tool in ArcGIS, which weighs the value of each parameter in each criterion according to the AHP process (Habtemariam & Fang, 2016). The last calculation defined the scenario map that combines all criteria with different weight value compositions (Habtemariam & Fang, 2016). This process applied the same technique (IDW interpolation) as described previously and it resulted in three different final maps.

3.5 Results

Three zoning scenarios consisting of various weights relating to each criterion were assigned using the AHP tool (Figure 3.3). The NVC criterion weight varies among zoning scenarios by 65.8% (read from 0.658, Figure 3) for a restricted access zone, 55.4% for a sanctuary zone and 50.8% for a habitat protection zone. These results demonstrate that the largest protected area has the largest NVC value, because it reveals which area is suitable for mangrove planting to support its function as a green-belt area for crop protection. In contrast to this, the CMV weights were decreased from 21.3% in the habitat protection zone to 15% in the sanctuary zone and 7.5% in the restricted access zone. The expansion of the protected area would diminish the commercial value of mangroves because fewer people would be able to visit the area for fishing, grazing or to set up aquaculture activities.

Interestingly, the NVC criterion had the largest value in all scenarios. If we look closely at the NVC's parameters, it consists of water quality, chlorophyll, and importance value of mangrove, from which water quality weighed 74.2%. This result showed that water quality is the most essential element that supports many activities in mangrove areas, such as fishing, aquaculture, mangrove planting and recreation.

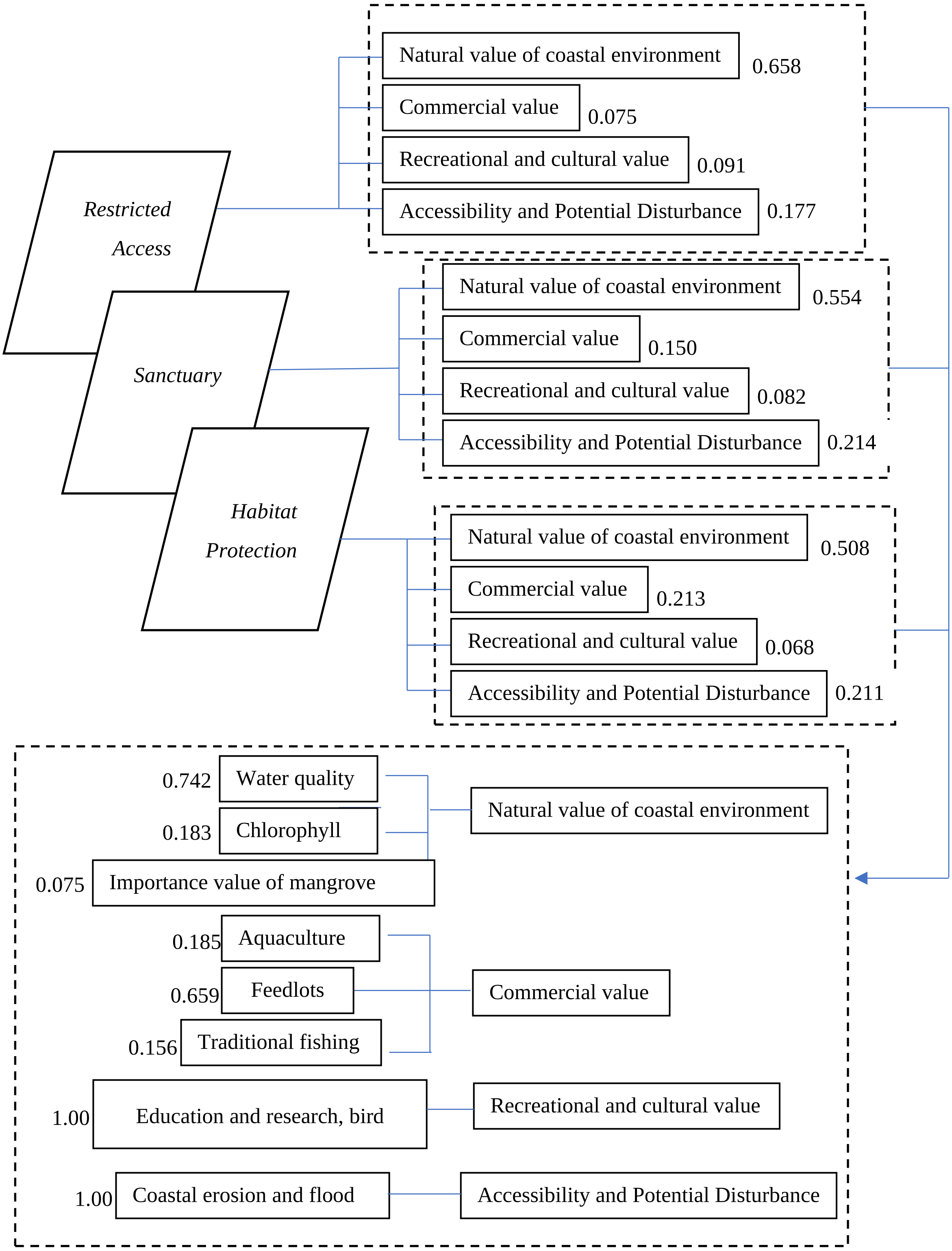
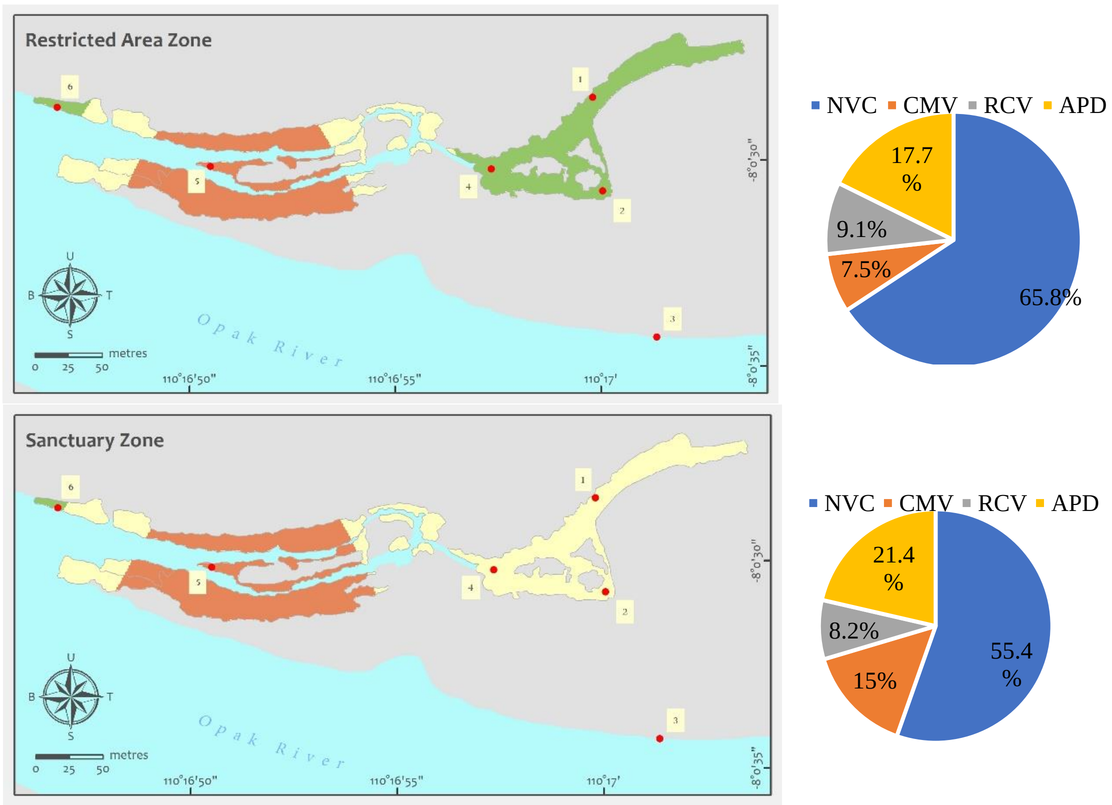
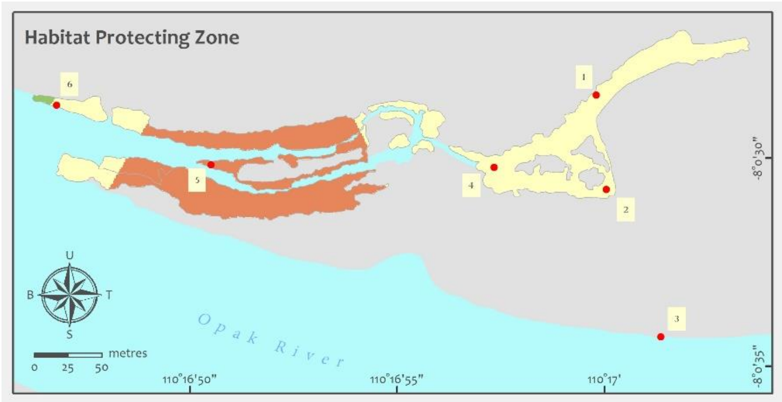


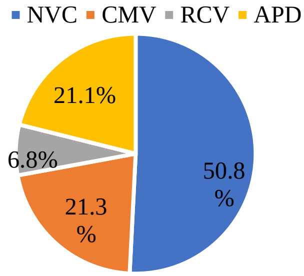
Figure 3.3. The summary of weights in each criterion and scenario in each conservation zone.

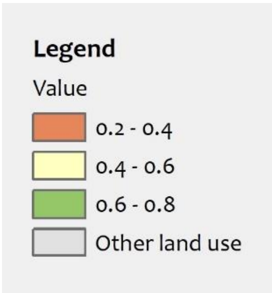
Geospatial interpretation of the spatial multi-criteria analysis results confirmed that each zoning scenario has a different management scheme based on criteria weights (Figure 3.3). We divided the suitability value into three categories. The lowest values represent areas that are suitable for utilisation, the middle value (ranging from 0.4 to 0.6) represents areas that may be used for both utilisation and protection. The highest values represent areas that are suitable for a protected area.

Both Sanctuary Zone and Habitat Protection Zone scenarios revealed results that were virtually similar (Figure 3.4), only the area suitable for utilisation in the Habitat Protection Zone scenario is bigger than in the Sanctuary Zone scenario. In all scenarios, we found that location 5 (middle area) was suitable for utilisation or commercial purposes, for instance, traditional fishing, aquaculture and feedlots. An alternative location was suitable for a buffer zone or an area that could support limited commercial purposes and encourage ecosystem protection, such as recreational and educational activities. These zones also displayed similar weight proportions with respect to the NVC, CMV, RCV and APD criteria. The Sanctuary Zone has a NVC of 55.4%. This is followed by APD (21.4%), RCV (8.2%) and CMV (15%), whereas the Habitat Protection Zone has a NVC (50.8%), followed by APD (21.1%), RCV (6.8%) and CMV (21.3%).









Values	Description
0.2 – 0.4	Suitable for utilisation
0.4 – 0.6	Moderate
0.6 – 0.8	Suitable for protected area

Figure 3.4 Map of Baros mangrove area under several scenarios, such as Restricted Area Zone, Sanctuary Zone and Habitat Protection Zone determined by its suitability value and proportion of criteria weight, such as the Natural Value of Coastal Environment (NVC), Commercial Value (CMV), Recreational and Cultural Value (RCV) and Accessibility and Potential Disturbance (APD).

The combination of the analysis in the three maps above shows a finalised map of the mangrove conservation zone (Figure 3.5), the middle area of the mangrove is suitable for commercial utilisation as a Habitat Protection Zone (sample location 5), with the area outside it appropriate for recreational and educational purposes. The outer area of the mangrove is suitable for protection with nursery and planting areas. In the protected zone (read as Restricted Area Zone on the map), shows that sample locations 1, 2, 4 and 6 need to be protected. These areas are highly suitable to support mangrove nursery and planting, and function as a green-belt to protect farming areas. Mangrove nurseries can be located in dry areas far from the river/estuary. When the seedlings are ready, they can be transferred to a muddy substrate located on the edge of the river/estuary.

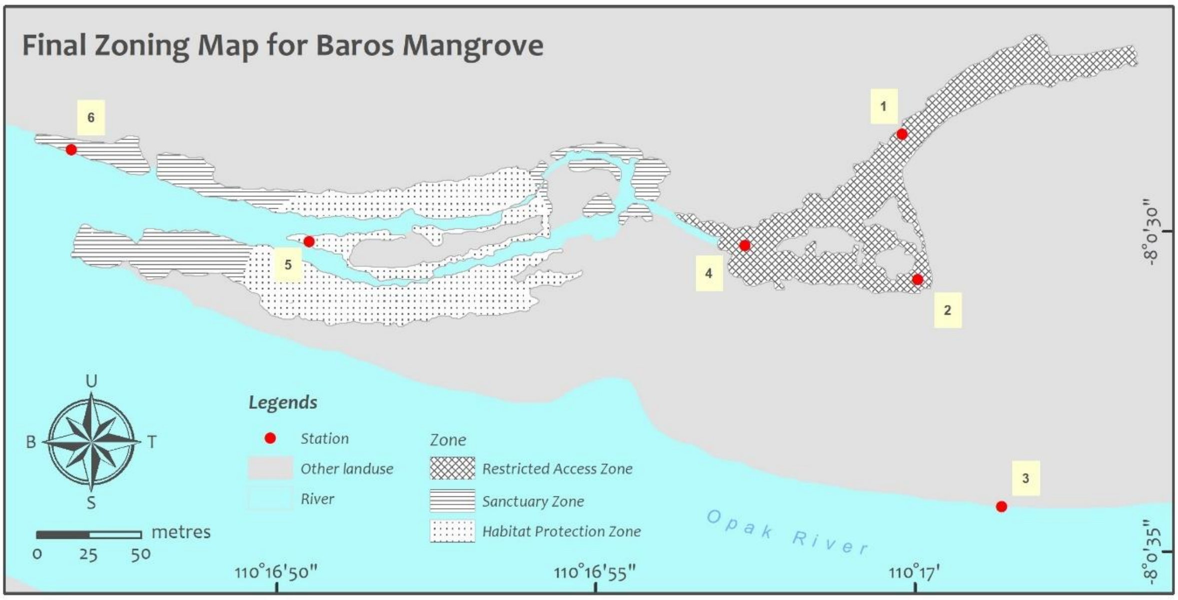


Figure 3.5 Proposed conservation zoning area for the Baros Mangrove.

3.6 Discussion

This paper presents how Spatial Multi-Criteria Analysis (SMCA) and the Analytic Hierarchy Process (AHP) can be applied for spatial planning in mangroves. A case study was conducted in the Baros mangrove area, Indonesia. The area has several specific characteristics, such as: (1) the mangrove ecosystem was established by the local community and later managed by the local government; (2) it provides both economic and ecological benefits to local people; and (3) it is used simultaneously for several activities related to commerce, recreation, and conservation. For spatial planning, we applied the SMCA method which allowed us to include both qualitative and quantitative data drawn from social, economic and ecological surveys. We were thus able to include local stakeholder values. The inclusion of local stakeholder values in conservation planning is critical to understand human influence on resources, examine multiple-use objectives and identify and resolve conflicts within the area (Pomeroy & Douvere, 2008). Spatial analysis that is supported by quantitative and qualitative data suggests that the management scenarios identified here should be well-understood by various stakeholders from various backgrounds, because they highlight which areas need to be protected or utilised. The outcomes of this study may also be suitable for future decision-making about management-related conservation for a particular area. It is imperative that effective decisions are made, with the aim of ensuring that conservation projects achieve good outcomes for both the local community and the environment. By examining the result of this study, we argue that the common approach to conservation zoning introduced through biosphere reserves may not be appropriate for certain ecosystems in specific areas due to their particular ecological or socio-economic conditions.

The SMCA in this study follows the methods of several other case studies conducted by Habtemariam & Fang, 2016; Raaijmakers et al., 2008; Strager & Rosenberger, 2006. SMCA is a proven approach to combine multi-criteria decision analysis and spatial analysis to achieve effective management decisions under several scenarios or options. The method supports decision-making in complex environments and combines both quantitative and qualitative data (Varatharajan et al., 2018). SMCA also has been widely used in intra-disciplinary studies, including land suitability for crops (Rahman & Saha, 2008); land-suitability for construction (Jamali et al., 2014); determining natural hazard susceptible areas (Karlsson et al., 2017); urban land-use planning (Mosadeghi et al., 2015) and for mangrove management such as mangrove vulnerability assessment (Omo-Irabor et al., 2011) which also includes social and ecological data into its analysis. Most of the studies in SMCA included various quantitative and qualitative data into the analysis to create a detailed and specific goal, either in management or conservation. Thus, the method in this study that uses SMCA and AHP tool with various data, and includes socio-economic data in the assessment, can also be applied to any spatial planning for any purposes including conservation in mangrove areas, not only in Indonesia but also in other parts of the world with similar environments.

The use of various data in conservation planning to support the decision-making process for future management is essential. Spatial analysis and planning also help to clarify management objectives and reduce conflict by involving stakeholder perceptions and interests to support the analysis (Collie et al., 2013). In this study, we also included ecosystem services data by asking respondents what sort of benefits they obtain from the mangroves. Integrating ecosystem services data into spatial planning can reduce the trade-offs between ecological and socio-economic aspects (Grêt-Regamey et al., 2017), thus, strengthening the analysis for future management options. Furthermore, the inclusion of socio-economic value in this study also helps to provide reliable data and analysis. For example, the Baros mangrove area has a total feedlots value of US$1,458.23/ha/year (Appendix 7.2 - Supplementary Material F) that is higher than fishing or aquaculture economic value. Thus, under CMV criterion, feedlots has the highest weight among all parameters. Our study revealed that the use of various quantitative and qualitative ecological and socio-economic data is vital and will better support local conservation management planning and decision-making.

Using the AHP tool in SMCA has a potential drawback, because AHP is not capable of addressing uncertainty inherent in the social data (such as individual perceptions in the community and expert's perceptions). Although we have calculated the Consistency Ratio (CR) to ensure that we had a reliable judgement, we need a sensitivity analysis included in the process of assigning weights in AHP. Thus, we recommend including matrix sensitivity or weight sensitivity (Chen et al., 2010; 2013) for future studies using AHP tool in SMCA. In this case, we need to emphasise that although the final result of this study has proposed what we believe to be an ideal mangrove conservation zone, it is important to validate the result with all stakeholders (local community, managers and local government) before any action can be taken to avoid disagreement and conflict in the future.

Biosphere reserves, with the concept of spatial zoning for conservation, were introduced by UNESCO (1996). These reserves have a core-zone (non-take zone) surrounded by a buffer zone, where low-impact human activities are possible. Beyond the buffer zone is an outer area, known as a transition zone, that allows medium-impact activities, such as small-scale farming and selective fishing (Coetzer et al., 2014). This concept is used for protected areas around the globe, where managers plan for a non-take zone protected by a buffer and transition zone, supposedly to enable resource accumulation in the core with spill-over into the buffer or transition zones and to build cooperation between human use and conservation where both activities are possible (Jaisankar et al., 2018).

In contrast, this case study discovered the opposite. The outer area is suitable for a protected area and the middle is most suited to commercial activity (Figure 3.5). Mangrove nurseries must be protected from anthropogenic disturbance, for instance, waste, destructive human activities and are frequently located in areas far from the river/estuary. In this study, the area that would be identified as a buffer zone following the UNESCO approach would be more suited to be a core habitat because the area is essential for the survival and preservation of biological diversity (Semlitsch & Jensen, 2001). Similar to this, the conservation zone in Matang Mangrove Forest also showed that most of the restricted and protected areas are in the outer zone, whereas the productive zone (cultivation zone) is located in the centre area of the mangrove (Otero et al., 2019). In additional, landward buffer zones need to be placed to maintain mangrove development (Harty, 2004) and all human settlement needs to be located at least >10 km from the outer mangrove zone (Vaghela et al., 2018). These discoveries make zoning for mangrove conservation potentially different to what is used for other ecosystems or other local contexts. Thus, further studies on spatial conservation zoning in mangrove forests are crucial.

3.7 General Implications

Mangrove ecosystems are unique as they are located at the interface of estuaries, the sea, and land ecosystems. A study involving a mangrove suitability index showed that most mangroves can only survive with muddy substrate (Chakraborty et al., 2019). Furthermore, the juveniles of mangrove trees need to be protected from strong waves while receiving brackish water from the river and sea. Thus, mangrove conservation planning can be difficult if not supported by multi-disciplinary knowledge that involves ecology and social sciences, including stakeholder perceptions and local understanding of mangrove socio-cultural and economic dimensions (Borges et al., 2017).

In this study, we developed a multi-use zoning plan for mangroves in Baros. We believe that our approach could be applied elsewhere, particularly for areas with heterogeneously distributed mangroves. The Baros mangrove area is approximately 5-hectares and has benefited locals by providing shelter for fish, blocking salty wind onto croplands, providing space for shrimp aquaculture, and providing a natural venue for tourism. The extent of ecosystem services provided by mangroves and the size of mangrove area in different places might require different approaches depending on the services present (e.g. firewood availability in larger mangroves (Christensen et al., 2008) that was not considered for Baros) and the preferences of the community. These different considerations are particularly relevant for old-growth mangrove forests, where sustainable management requires considering the biodiversity and socio-economic value of old versus restored mangroves, accessibility, and wider ecosystem impacts beyond the local scope that we discuss here. Yet, considering multiple factors, including social, cultural, ecological, and community values, and their spatial context, will always be a crucial component of mangrove management.

Chapter 4. Using an Effectiveness Index to evaluate MPA performance in Indonesia

Abstract

Marine Protected Areas (MPAs) provide benefits by protecting and allowing biodiversity to be restored. Many problems emerge when the wish to protect and restore the environment conflicts with the need for access to resources. This study aims to evaluate the effectiveness of MPAs by measuring their outcomes and exploring the ways local communities understand the existence of MPAs. We used a set 21 indicators accompanied by 27 variables to measure MPA effectiveness in two different management schemes: restricted zone (core-zone) and non-restricted zone within two MPAs. We summarised each variable measured, weighted them based on qualitative and quantitative survey data, and used an Effectiveness Index to calculate the final value. Our findings showed that higher values of the Effectiveness Index were related to higher values for conservation outcome indicators, such as focal species abundance, habitat distribution and complexity, the level of understanding of human impacts on resources, and distribution of formal knowledge in the community. In contrast, lower values of the Effectiveness Index were related to lower values of the distribution of formal knowledge in the community, the level of understanding of human impacts on resources, the level of resource conflict, satisfaction in management process and activities, and proportion of stakeholders trained in sustainable use of marine resources. This study suggests that local community support is key to increasing the effectiveness of MPAs.

4.1 Introduction

The goal of every conservation effort is to protect the environment and prevent biodiversity decline. However, the way people view conservation is changing (Doak et al., 2014). Initially, conservation efforts focused on reducing the rate of extinctions (Soulé, 1985). More recently, the focus has shifted to protecting habitat whilst developing the economy and livelihoods of local people (Sene-Harper et al., 2019). Conservation is now seen as a tool that can build sustainable livelihoods (Kareiva & Marvier, 2012). Marine Protected Areas (MPAs) are one such conservation tool that can enable the protection of marine areas and their biodiversity as well as support the provision of ecosystem services and cultural values (Dudley, 2008). A review of 12,971 studies of conservation tools around the globe indicates that protected areas are the most effective conservation tool for delivering positive outcomes (Godet & Devictor, 2018), including climate mitigation and adaptation. It is reported that MPAs can increase carbon sequestration, biodiversity, coastal protection, fish catch, income (Jacquemont et al., 2022), and increase coral reef resilience against coral disease and coral bleaching (Mellin et al., 2016). However, among the many success stories of MPAs, there are also various studies that show that MPAs can also fail because they don't provide benefits to local communities or become a threat to lives and livelihoods by preventing access to resources (Bennett & Dearden, 2014; Kangalawe & Noe, 2012). Thus, the effectiveness of any conservation tool, such as MPAs, needs to be assessed considering both ecological and social outcomes.

Effectiveness of MPAs can be measured by various methods, often broken down into several categories of tools, indicators and variables. Indicators and variables help managers or researchers examine which aspects need to be assessed before deciding on final MPA performance. A recent database shows that there are currently 40 different methodologies used to assess MPAs in over 100 countries (Ford et al., 2021). These methodologies use various tools, indicators, variables and types of data to try and evaluate the effectiveness of MPAs and decide whether the MPA has successfully reached its goals. This evaluation is important to enhance a protected area's performance and anticipate any future threats (Leverington et al., 2008). An MPA is considered effective when it can reach its proposed goals and objectives, therefore, it is important that an MPA's objectives are clearly defined to allow progress to be evaluated (Pendleton et al., 2018).

Indonesia is an archipelago country, with the majority of its people living near coastal areas and dependent on coastal and marine resources (Hoegh-Guldberg et al., 2009). Indonesia defines MPAs as "*spatially defined, marine, coastal, or small island areas that are protected and managed by a zoning system to achieve sustainable management of fisheries resources and environmental outcomes*" (PP RI No. 60/2007 *in* Lazuardi et al., 2021). MPA evaluation in Indonesia has been conducted by the Ministry of Marine Affairs and Fisheries (MMAF) using a tool, known as EVIKA, following several frameworks introduced by Courrau et al. (2006), Pomeroy et al.

(2004), Tempesta & del Mar Otero (2013), and Stolton et al. (2007). EVIKA uses 24 indicators grouped into four categories: input, output, process and outcome (Ministry of Marine Affairs and Fisheries, 2020). The final assessment categorises MPAs into three conditions: (1) managed minimally, (2) managed optimally; (3) managed sustainably. A recent report of MPA management effectiveness in Indonesia, showed that the majority of MPAs in Indonesia are managed minimally, which means that the MPA management process has been implemented, but the goals of MPAs have not been achieved (Ministry of Marine Affairs and Fisheries, 2022).

It is important to understand that evaluating MPA effectiveness is different to evaluating MPA management effectiveness (Mascia et al., 2014). In this study, we see MPAs as systems whose existence can influence socio-economic, ecological and environmental aspects. Therefore, we do not refer to the category of "indicator" as management input, output and process as per the MMAF. We use our review study on global MPA evaluation (*Chapter 2*), and apply selected indicators to assess biophysical, socio-economic and governance aspects within and outside MPAs, including community livelihoods, coastal protection, and compatibility of customary law with MPA rules and restrictions. The goal of this study is to not only evaluate MPA effectiveness, but also to compare the socio-economic and ecological conditions of MPAs and compare their effectiveness between locations. In addition, we further explore which aspects contribute to higher effectiveness values for MPAs and which aspects act as barriers to the improvement of MPA effectiveness, so that more attention can be paid to them in the future. This evaluation draws on how the community (including villagers, NGOs, and local government as respondents) see the performance of MPAs.

4.2 Methods

4.2.1 Study site

This study was located in two MPAs in Indonesia; MPA Sabang, Weh Island, Aceh (coded with A) and MPA Nusa Penida, Bali (coded with B) (Table 4.1). Both ecological and social data were collected in three villages from each MPA. One village was located inside the MPA non-take zone area and two villages were located outside the MPA non-take zone (Figure 4.1). The selection of study sites were purposively sampled to compare the MPA's conditions inside and outside of the core zone or non-take zone.

Table 4.1 Study site location and its type of MPA zone.

Code	Site	Location	Village	Type of MPA
A	1	Sabang, Aceh	Ieu Meulee	Non core-zone
A	2	Sabang, Aceh	Ujung Kareung	Non core-zone
A	3	Sabang Aceh	Anoi Item	MPA core-zone
B	1	Nusa Penida, Bali	Toyapakeh	MPA core-zone
B	2	Nusa Penida, Bali	Batununggul	Non core-zone
B	3	Nusa Penida, Bali	Sakti	Non core-zone

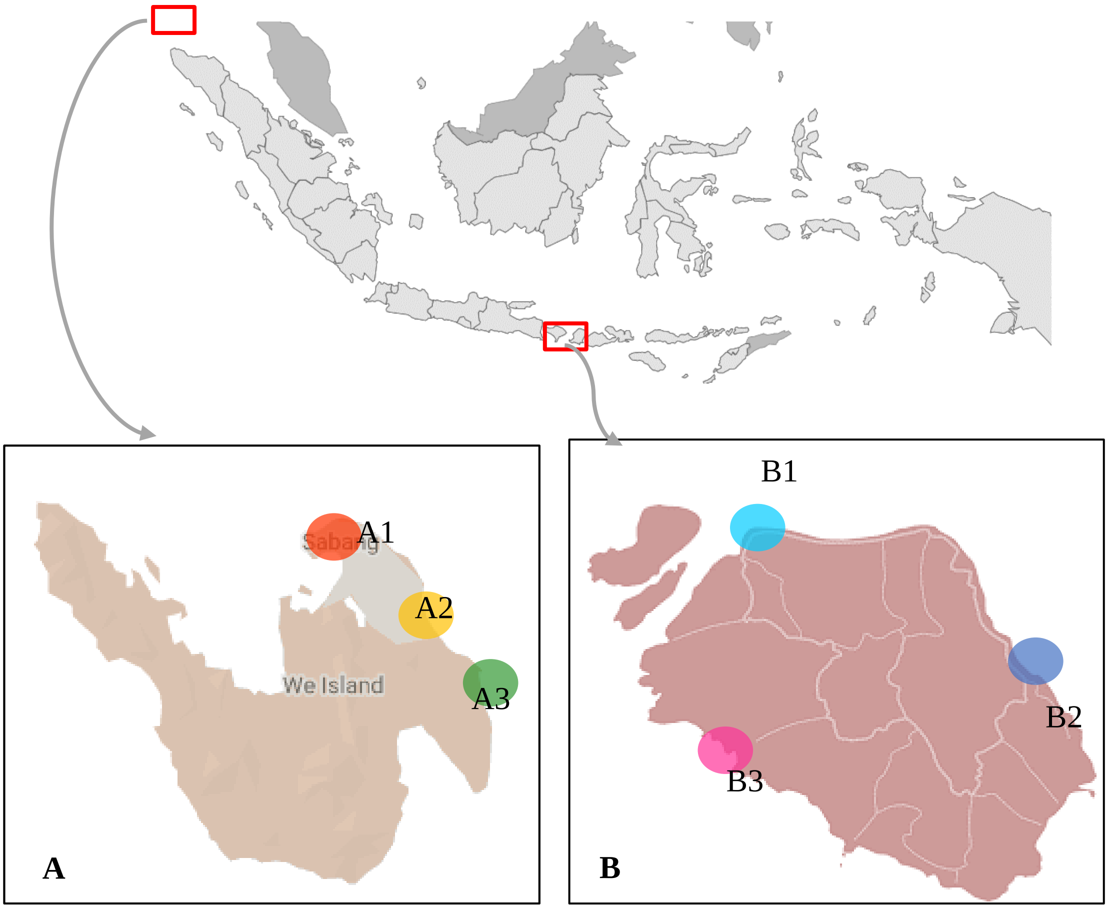


Figure 4.1 Study location in two MPAs in Indonesia; (A) Sabang, includes A1 for Ieu meulee; A2 for Ujung kareung; and A3 for Anoi itam; (B) Nusa Penida, includes B1

for Toyapakeh, B2 for Batununggul, and B3 for Sakti. Different colours indicate different sites, these colours will be used throughout all figures in this paper.

4.2.2 Research design

The study design comprises several steps; first is identification. We identified the type of MPA, its goals and objectives. Here we selected MPAs managed by the Ministry of Marine and Fisheries Indonesia, both MPAs have similar goals and objectives, as set out by government regulations (*Peraturan Pemerintah*) and both have been evaluated by the government and received criteria 3 green level rating, which translates as a conservation area managed minimally (criteria are created by application of the government tool and range from 1 to 5: 1 = conservation area initiated, 2 = conservation area established, 3 = conservation area managed minimally, 4 = conservation area managed optimally, and 5 = self-reliant conservation area). Next, we identified indicators and their variables to assess MPA effectiveness. The set of indicators and their identified variables were drawn from IUCN's criteria of effective MPAs (*Chapter 2*). We also used criteria taken from the literature related to each indicator. Then, we weighted the criteria and calculated a final score for each variable in each indicator. The final calculation for the Effectiveness Index value follows the framework from Lee & Abdullah (2019) (Figure 4.2).

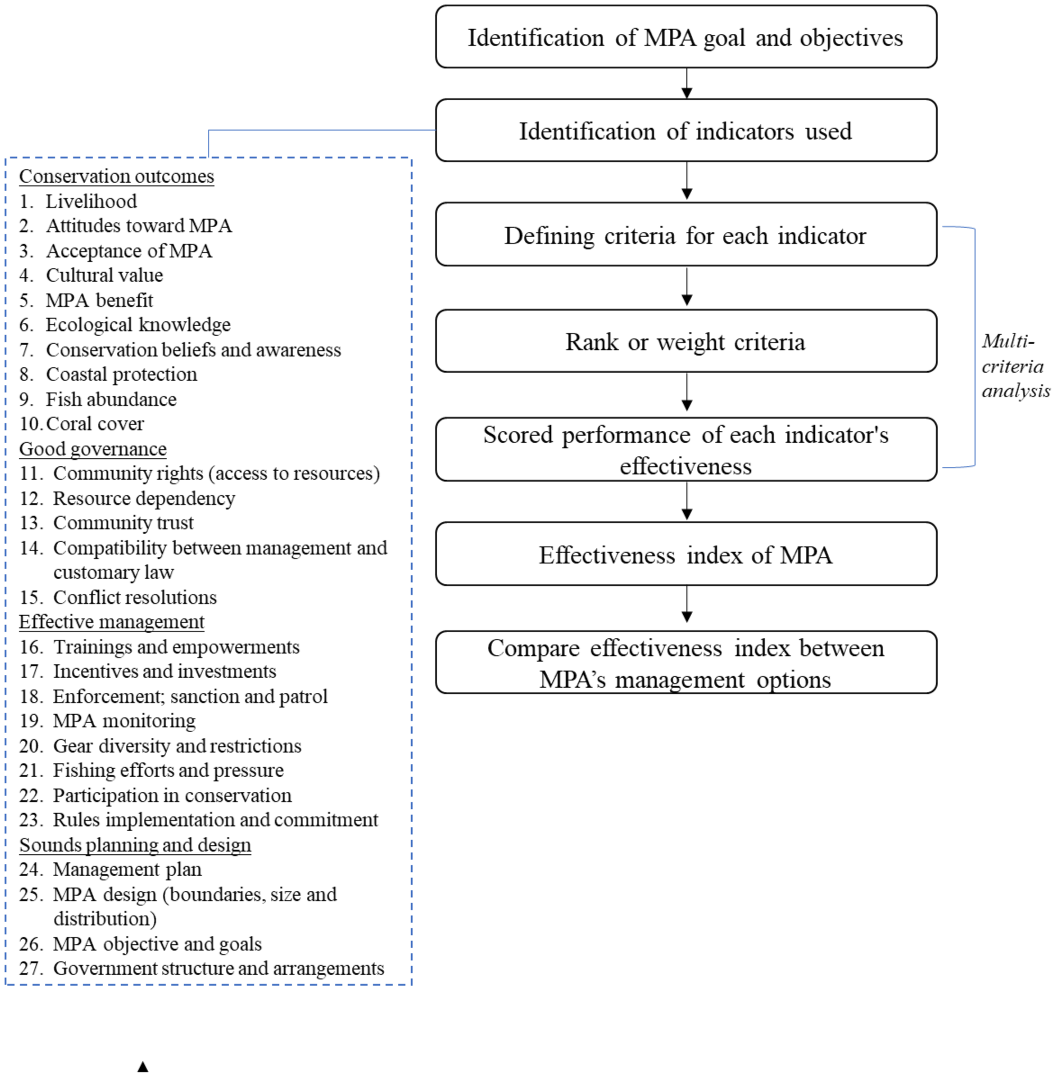


Figure 4.2. Framework for evaluating MPA effectiveness

4.2.3 Effectiveness Index

Criteria for each indicator and variable used were taken from the literature and constructed using a rating-scale questionnaire, which scored against a Likert-type scale (Lee & Abdullah, 2019) ranging from 1 to 5 points: 1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree. The criteria were adapted and depended on the type of variable in each indicator, i.e., for the 'benefit of MPA' variable, the structured questions were 1 = doesn't benefit the community at all; 2 = few benefits; 3 = neutral; 4 = benefits the community; 5 = completely benefits the community (Appendix 7.4 - Supplementary Material A). For our open-ended questions, we applied sub-criteria taken from the literature to help us decide the rank and weight of each criteria (Appendix 7.4 - Supplementary Material A).

We calculated each response from the ordinal Likert-scale data, then divided the frequency of each response with the total frequency in each population and weighted them using the rank below (following Wu (2007) on transforming Likert data to a numerical score).

Table 4.2 Rank value for variable responses

Response x frequency	0-0.2	0.3-0.4	0.5-0.6	0.7-0.8	0.9-1
Rank	1	2	3	4	5

Then we calculated a population mean using the formula as follows:

$$\frac{\sum_{i=1}^{n}(x_i * w_{i)}}{\sum_{i=1}^{n} w_i}$$

where;

x = frequency of response

w = weight

The score of MPA effectiveness ranged from 1 to 5, where 1 implies the lowest effectiveness and 5 the highest effectiveness (modified from Lee and Abdullah, 2019). We then calculated the overall Effectiveness Index as follows:

$$Em = \frac{ƒa + ƒb + ƒc}{27}$$

where *Em* is the MPA Effectiveness Index value; and fa, fb and fc represent the mean scores of each of the variables (Lee & Abdullah, 2019).

We used Multidimensional scaling (MDS) analysis to visualise the relationship between final MPA effectiveness indices between locations (core-zone and non core-zone) and means of variables between sites using R (R Development Core Team, 2022). MDS allows researchers to observe similarities and dissimilarities by plotting each computed data on two different dimensions and analyse the distance between each categorised data (Chen et al., 2008).

4.2.4 Field observation

Surveys were conducted inside and outside MPA areas using three times replicates of a 50-metre transect in two to seven metres water depth in each site. Fish data were first captured, then coral data, using a line intercept transect method (English et al., 1994) and underwater visual census (Hamilton et al., 2004). Fish abundance data were generated from video footage, we then counted how many fish were within 2.5 metres from centre to the right and 2.5 metres from centre to the left. VLC video software was used to extract video frames from video footage for every 5-second interval. Coral cover was analysed using CPCe (Kohler & Gill, 2006). We performed a parametric statistical analysis to help us understand the distribution of living coral cover and fishes in the six study sites. The statistical analysis of the data was carried out using one-way ANOVA and Tukey HSD (Honest Significant Differences).

Surveys were carried out using interviews, Focus Group Discussions (FGDs) and questionnaires. A combination of random sampling and snowball sampling (Parker et al., 2019) was used to determine the respondents. We first interviewed the leader of the village, the government and the MPA manager and then asked them for a list of potential key informants who were most suited to answer questions related to the MPAs. Getting this information from three different sources helped to overcome possible bias in using gatekeepers, but working with gatekeepers is required as this information is not available from other sources. Key informants were leaders of groups such as fishers, farmers, divers, businessmen and sea police. An in-depth semi-structured interview was carried out with all key informants in person. All key informants were also asked to attend an FGD where they could discuss, clarify and explain important information related to the study.

Participants in the questionnaire were chosen randomly. We used a map of the village and selected houses (by circling houses with a pen). This was done by choosing one house at a randomly selected point in the village, then selecting three to five houses to the left (repeated) until the target number of respondents was reached. We visited respondents in their houses or invited them to a meeting with a small number of attendees (considering the Covid-19 rules in place in the villages at the time of the survey), and asked them to fill out the questionnaire. Ethical approval (under ethical application number BIOSCI 21-003) was gained from the University of Leeds before the survey commenced. Key informants and all respondents were given a participant's information sheet and asked to sign a consent form before any interview or questionnaire was undertaken. A total of 360 respondents participated in this study. We conducted a non-parametric statistical analysis (Kruskal-wallis) to understand the distribution of socio-economic data between six study sites.

4.3 Results

4.3.1 The social-ecological condition of MPAs

Our results show that the MPAs in this study have different socio-economic characteristics. MPA Nusa Penida is located on Bali island, which is central to the tourism industry in Indonesia. Marine attractions are one of the greatest contributors to the tourism industry in Bali. Therefore, MPA Nusa Penida and its core-zone are surrounded by dive sites and other water attractions such as the Marine Walk. There are fishers in MPA Nusa Penida, however most of them work part-time as fishermen and prioritise more of their time towards tourism jobs such as dive boat driver, dive guide and snorkelling guide. We found that more than 50% of our respondents had either a full-time or a part-time job related to tourism.

In contrast, the three study sites located in MPA Sabang were dominated by people working as fishers, farmers and in the private sector; the proportions in these roles were evenly distributed between three study sites. Sabang is also well known for tourism activities, however, the popular dive locations were far from our study sites. We found only one dive shop inside MPA Sabang and one dive site located near the MPA core-zone that was rarely visited by tourists.

We constructed the following hypotheses, in order to explore the differences between various socio-economic conditions; occupation, income and education of the population in the six study sites:

H_0: There is a significant difference in socio-economic conditions between each study site

H_1: There is no significant difference in socio-economic conditions between each study site

Over three socio-economic variables, we found that two of them; education and occupation, have p-values < 0.05, which indicates that the education background and type of occupation between the six populations is different. In contrast to this, the distribution of income between the six study sites is similar (Appendix 7.4 - Supplementary Material B). Both the villages in the core-zone of MPA Sabang and the core-zone of MPA Nusa Penida had a well-educated population with more than 50% attending junior high school to university. The other villages in the non core-zones, such as Ieu meulee in MPA Sabang and Batununggul in MPA Nusa Penida, had the lowest education levels with more than 50% of the population only attending elementary school or not attending school. Overall, both MPA Sabang and MPA Nusa Penida had a similar income distribution with more than 60% having a minimum of the standard national income per month.

The ecological conditions in both MPAs showed that MPA Sabang had an overall higher fish abundance and living coral cover than MPA Nusa Penida, with an average 8,603 fishes and 3,064 total point count of living coral cover found in the three sites in Sabang, whereas only 5,361 fishes and 793 total point count of living coral cover were found in Nusa Penida. A one-way ANOVA test showed that both fish numbers and coral cover in the six study sites was significantly different with a p-value < 0.05. We explored further with a Tukey HSD test to understand the data distribution and we found that both MPA Sabang core-zone and MPA Nusa Penida core-zone were significantly different to the others (Appendix 7.4 - Supplementary Material B). We found that the core-zone of MPA Sabang (Anoi itam) had the highest fish abundance and living coral cover of all sites and the core-zone MPA Nusa Penida (Toyapakeh) had the lowest living coral cover but the second highest fish abundance (Figure 4.3 (A) and (B)).

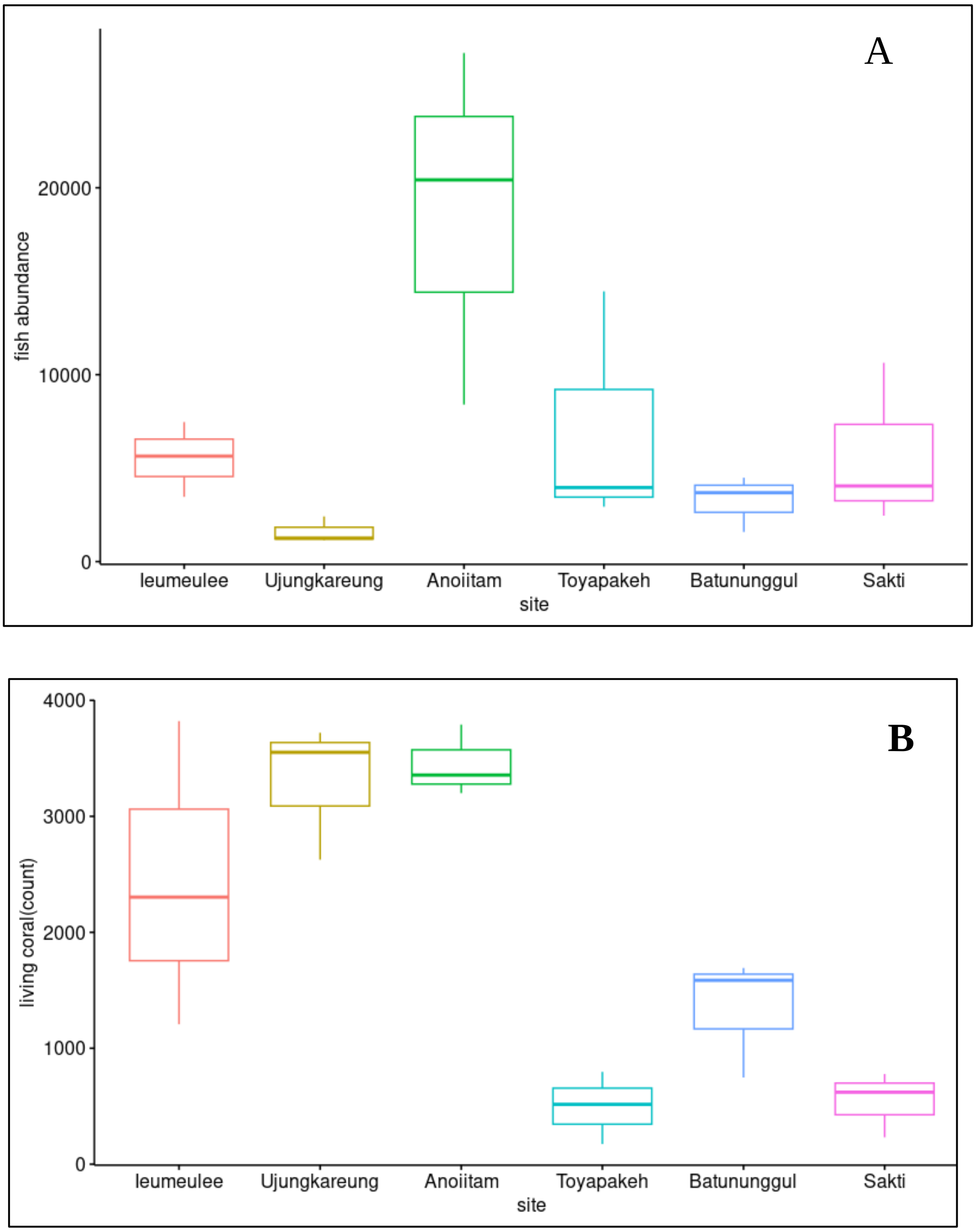


Figure 4.3 Boxplot analysis showing the distribution of (A) fish abundance and (B) living coral data in the six study sites.

Both MPAs have a long history of management. MPA Sabang is managed based on customary law led by the *Panglima Laot*. The *Panglima Laot* is a sea commander in Aceh, it refers to a man who has the authority to enforce customary law related to the sea. It can also be seen as an institution which has an organisational structure consisting of a chairman (the *Panglima Laot* himself), vice chairman, secretary, treasurer, and deputy. Even before the conservation concept was introduced to the local community in 2013, they already had certain rules to protect biodiversity, such as restrictions on certain fishing gear, prohibitions on using bombs and cyanide, and they managed the times when fishers were allowed to fish, for example by restricting fishing every Friday. These rules were introduced by the *Panglima Laot* based on *musyawarah* (meeting for fishers to discuss what is the best or not for their environment and life related to fishing activities). When the conservation concept was introduced to the community, the NGO and the local government helped them to introduce more specific rules, such as what kind of species they were allowed to be catch and what type of fishing gear was harmful to the environment. The final rules were then decided by the *Panglima Laot*, he has final say over which rules suit the community and which do not. This process means that each *Panglima Laot* can make different decisions, resulting in different areas having different rules. For example, in Ieu Meulee, the *Panglima Laot* did not approve the restricted zone because they felt it would make it harder to fish and would have an impact on livelihoods. Whereas, in Anoi itam the *Panglima Laot* there approved the restricted zone in their area because they felt that fishers could catch fish in other areas and the area protected would generate more fish for them in the future.

Similarly, MPA Nusa Penida also has customary laws called awig-awig. The awig-awig follows the concept of Tri Hita Karana, the three elements that must be kept in balance and which contains commands, prohibitions and permissibility for human relations, humans with nature, and humans with their God. Awig-awig includes the concept of Nyepi Segara where communities cannot touch the sea for a day to give the sea a rest. Unlike in Sabang, awig-awig in Nusa Penida did not provide detailed rules to regulate fishing activity. So the introduction of conservation rules in 2014, such as fishing gear restrictions, restrictions on the type of fish that can be caught and the location of a core-zone, made a huge difference to the local community. The differences in local conditions and management history may have led to differences in marine biodiversity including living coral cover and fish abundance. In both MPAs, we found that both core-zones had a higher fish abundance than non core-zones, however, the living coral cover in Sabang core-zone was higher, while the living coral cover in Nusa Penida core-zone was low. Thus, we can only evaluate the present condition of each MPA and its surroundings, we cannot compare the conditions before and after the existence of the MPA. What we found in Nusa Penida core-zone, with high fish abundance and low living coral cover, could be the result of the coral reef community being restored.

4.3.2 MPA Effectiveness Index

We analysed the responses for each of the variable measured (Appendix 7.4 - Supplementary Material A) and calculated the final Effectiveness Index (Lee & Abdullah, 2019) of the MPA in each of the six study sites (Table 4.3). In general, Ieu meulee (A1) and Sabang MPA core-zone (A3, Anoi itam) have the highest Effectiveness Index with a value of 3.3 for both A1 and A3. The lowest Effectiveness Index was for Nusa Penida MPA core-zone (Toyapakeh, B1) with a value of 2.6. The total Effectiveness Index for the MPA in Nusa Penida was 2.9, while for MPA Sabang it was 3.3.

Table 4.3 The Effectiveness Index of each indicator and variable measured in the six study sites.

Type of indicator	Type of variable	Effectiveness Index					
		A1	A2	A3	B1	B2	B3
		Non core zone	Non core zone	Core zone	Core zone	Non core zone	Non core zone
Conservation outcomes							
Household income distribution by source	Income	2	2	2	2	2	2
Level of stakeholder participation and satisfaction in management	Attitudes toward MPA	4	3	4	3	3	4
Local value and beliefs about marine resources	Acceptance of MPA	4	4	5	4	4	5
	Cultural value	5	5	5	5	5	5
	Conservation beliefs and awareness	4	4	4	3	4	5
Level of understanding of human impacts on resources	Benefit of MPA	4	4	4	3	4	4

Distribution of formal knowledge to community	Ecological knowledge	4	4	4	3	4	4
Area under no or reduced human impacts	Coastal protection	2	2	2	1	3	2
Focal species abundance	Fish abundance	2	1	4	3	1	2
Habitat distribution & complexity	Living coral cover	3	4	3	1	2	1
Sub-mean value		3.4	3.3	3.7	2.8	3.2	2.9
Good governance							
Level of resource conflict	Community rights (access to resources)	5	5	5	2	3	4
	Resource dependency	2	3	3	3	1	3
	Conflict resolution	5	5	4	3	4	4
Satisfaction in management process and activities	Community's trust	4	4	4	3	4	5
Existence and adoption of a management plan	Compatibility between management and customary law	4	4	3	3	3	4
Sub-mean value		4	4.2	3.8	2.8	3	4
Effective management							
Proportion of stakeholders trained in sustainable use	Trainings and empowerments	2	3	3	1	3	2
Availability and allocation of MPA administrative resources	Incentives and investments	1	1	1	2	2	2
	MPA monitoring	4	4	4	4	4	4
Clearly defined enforcement procedures and coverage	Enforcement; sanction and patrol	2	2	2	3	3	3
	Gear diversity and restrictions	5	5	5	4	4	3
Type, level and return on fishing effort	Fishing efforts and pressure	1	1	1	2	3	3

Level of stakeholder involvement in surveilance, monitoring and enforcement	Participation in conservation	2	2	2	2	1	2
Local understanding of MPA rules and regulations	Rules implementation and commitment	4	3	4	2	2	2
Sub-mean value		2.6	2.6	2.8	2.5	2.8	2.6
Sound planning and design							
Existence of a decision-making and management body	MPA management	4	3	4	2	4	4
Existence and adequacy in enabling legislation	MPA design (boundaries, size and distribution)	4	4	4	3	3	3
Existence and adoption of a management plan	Management plan	3	3	3	3	3	3
Availability and allocation of MPA administrative resources	Government support	2	1	2	1	2	2
Sub-mean value		3.3	2.8	3.3	2.3	3.0	3.0
Final mean value		3.3	3.2	3.4	2.6	3.0	3.1
		Sabang = 3.3			Nusa Penida = 2.9		

There are differences in how respondents scored each variable across study sites and MPAs, but overall we did not find any significant difference in scoring tendency for each variable measured. For example, we ran the non-parametric analysis Kruskal-wallis for the income variable, measured from 1 to 5; 1 being “not at all financially stable livelihood” and 5 being “completely financially stable livelihood”. The results produced a p-value > 0.05, indicating no significant difference in scoring tendency between respondents in the six different study sites. This was also the case for MPA acceptance and MPA benefits where we asked respondents whether the MPA benefited them and did they agree with the MPA (Figure 4.4).

We received various responses when we asked respondents about the effectiveness of the MPA in their village. In MPA Nusa Penida, respondents felt that the effectiveness of the MPA was lacking because so many people come and go (for tourism business purposes) and do not understand or respect the boundaries and rules in place for the MPA, or the general conservation activities on the island more broadly. In Nusa Penida MPA core-zone, Toyapakeh, many respondents felt that it was unfair to set up a core-zone in their village, and that they were discriminated against because they are minority (the only Muslim village on the island surrounded by Hindu villages). Putting a core-zone in their area made it impossible for them to carry out activities related to the water, which is the source of their livelihoods. They also felt that the core-zone area could have been put in another location with higher marine biodiversity.

> "The core-zone set up in Toyapake is nothing but for political purposes, not related to conserving the marine biodiversity at all"
>
> FGD Nusa Penida, 2021

In Sabang MPA, respondents generally felt that the goal of the MPA and rules for conservation were similar to their customary laws that were managed and maintained by the *Panglima Laot*. When we asked about access to resources, whether it was it limited or not due to the setting up of the MPA and the core-zone in their village, respondents did not feel that the MPA limited their activities related to the water. This was because of the strong customary law that had already existed for hundreds of years in the area, which communities were used to.. Respondents felt they had full access to the resources they needed. This contrasts with the situation in Nusa Penida, where setting-up the core-zone in Toyapakeh has resulted in respondents feeling that they do not have access to resources at all.

In Nusa Penida, awig-awig customary law needs to be obeyed by people regardless of religious faith (because the law is related to the Hindu faith). One example of the rules in awig-awig is the requirement to perform Nyepi. There are two Nyepi in Nusa Penida; Nyepi Segara, where people cannot touch the sea or do any activities in the sea; and Nyepi where people must stay at home, cannot go outside, and must turn all lights off. Both rituals are performed to provide rest for the water, land and themselves. However, unlike customary law in Sabang that needs to be performed at all times, Nyepi in Nusa Penida is only one-day long (24 hours) once or twice a year. However, people in both MPAs agreed that customary law is more effective than any other law;

> "Customary law is more effective in regulating the community than local government regulations or the rules in conservation itself, because the people here are very obedient to customary law"
>
> FGD Sabang, 2021

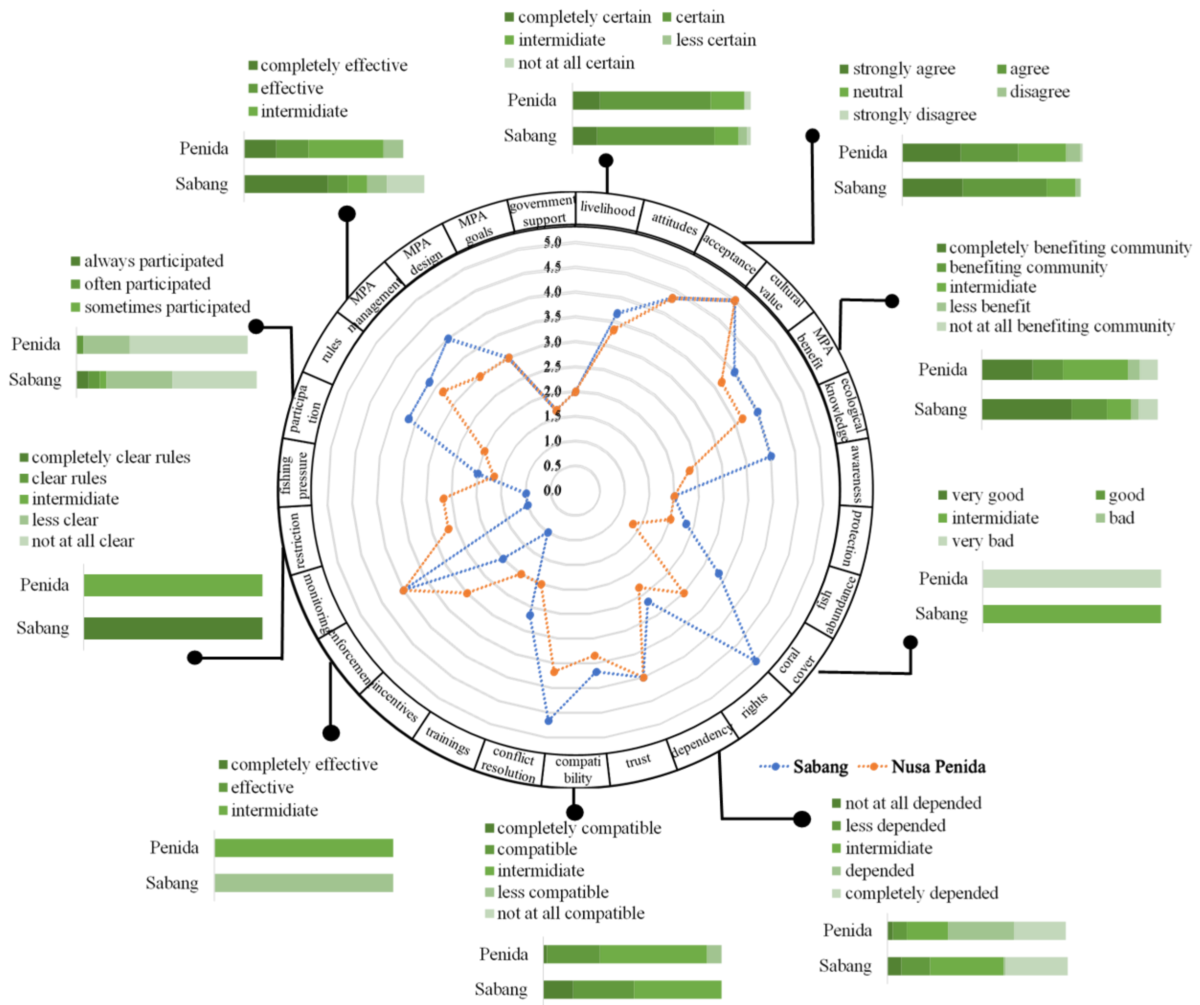


Figure 4.4 An overview of variable responses and effectiveness index scores in MPA Sabang and MPA Nusa Penida. A red dot inside the circle represents the Effectiveness Index score for MPA Nusa Penida for each variable, it should be read as: the Effectiveness Index for livelihood is 3.3 (black dash-line). A blue dot represents the Effectiveness Index for MPA Sabang for each variable, it should be read as: the Effectiveness Index for livelihood is 3.6 (black dash-line).

4.3.3 Comparing MPA effectiveness and its measured indicators and variables

We explored the similarity between all indicators measured in each study site using MDS (Figure 4.5). Villages that sit in the same MPA, for example, Ieu meulee (A1), Batununggul (A2) and Anoi itam (A3) from MPA Sabang, tended to group closely together. Similarly, Toyapakeh (B1), Batununggul (B2) and Sakti (B3) from MPA Nusa Penida also grouped closely together. However, we can clearly see that Toyapakeh was quite far away from the others. This showed that the value of indicators measured in Toyapakeh that contribute to the MPA Effectiveness Index were quite different from the other sites, with Toyapakeh having the lowest Effectiveness Index with a value of 2.9.

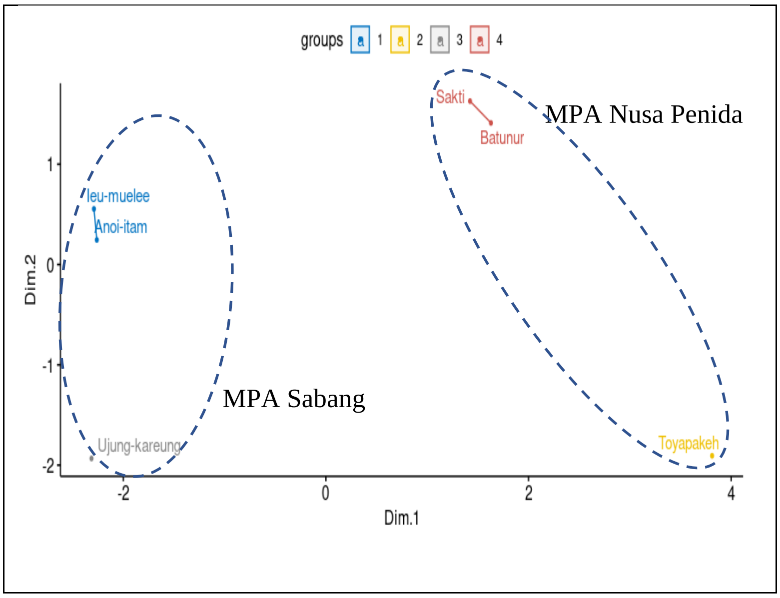


Figure 4.5 MDS analysis showing two dimensions of mean indicator scores across the six different sites.

We explored the similarity between each category of indicators in the six study sites (Figure 4.6) and found that the categories of indicators that belong to conservation outcomes, sound planning and design and good governance, were grouped together. Whereas effective management was dissimilar to the other three indicator categories. These results indicate that the variable values of conservation outcomes are close and similar to other variables for MPA planning and design, and MPA governance. We investigated the indicators within each of the broader categories to investigate these patterns further. We found that fish abundance values (how many fishes were found in each site) were similar to the values for conditions of fishing effort and pressure, coastal protection and the participation of local communities in conservation actions and efforts. The other closely related group in the MDS showed that resource access scores were similar to the condition of MPA design, MPA monitoring, and gear and fishing restrictions. Scores for local community trust for MPAs were closely related to MPA enforcement, local community commitments, resource dependency and cultural value. However, our analysis cannot determine how and in what ways these indicators are related or how they might influence one another.

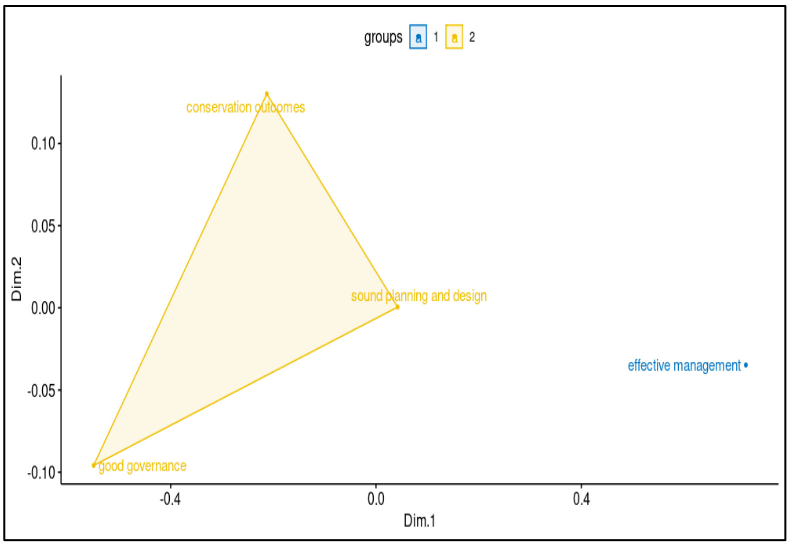


Figure 4.6 MDS analysis showing two dimensions of Effectiveness Index scores for the four categories of indicators.

4.4 Discussion

Our study found that both Sabang and Nusa Penida MPAs are not yet effective and have not reached their goals of protecting and increasing biodiversity and improving livelihoods for local communities. There are many factors that contribute to the effectiveness of an MPA. Overall, we found that higher values for the Effectiveness Index were related to higher values for conservation outcome indicators, such as focal species abundance, habitat distribution and complexity, level of understanding of human impacts on resources, and distribution of formal knowledge to community. Two distinct conditions were found in the MPA core-zones, where MPA Sabang core-zone had the highest value for the Effectiveness Index and MPA Nusa Penida had the lowest value for the Effectiveness Index. This lowest value for the Effectiveness Index was impacted by the lowest scores for the distribution of formal knowledge to community, level of understanding of human impacts on resources, level of resource conflict, satisfaction in management process and activities, and proportion of stakeholders trained in sustainable use. This finding supports the work of others who have found that the majority of conservation projects in Asia have failed because of the lack of support and awareness from local communities (Ban & Frid, 2018; Perera & de Vos, 2007; White & Vogt, 2000).

The reproductive populations of vulnerable species can be improved by MPAs (Hamilton et al., 2011) and several studies have shown that living coral cover, and density and biomass of fish are increased significantly in protected areas (Magdaong et al., 2014; Sciberras et al., 2013; Walmsley & White, 2003). Similar to our findings, a recent report on fish and coral monitoring in MPA Sabang indicates that the highest living coral cover and fish abundance can be found in Anoi itam with a value of 68.1% ± 2,2 SE and 50,576.67 no. ha^{-1} ± 10,408.12 SE, respectively (Muhidin, et al., 2019). However, these numbers are changing over time as the researchers found that living coral cover is now lower after the mass bleaching event in 2015. This indicates that climate change and the warming ocean brings massive threats to coral communities. Thus, it is important to record events (i.e. period of bleaching events or any environmental disturbances such as storms or tsunamis) when evaluating MPAs to address causes and threats that might reduce MPA performance in protecting ecological attributes such as coral reefs, and then build strategies to address those problems in the future.

The establishment of MPAs can bring a positive change to local communities, as they can facilitate learning and knowledge sharing to prevent conflict (Mahajan & Daw, 2016). Our findings suggests that MPAs with higher Effectiveness Index scores have better local community knowledge, attitudes towards MPAs, conflict resolution and local community participation in conservation activities.

There are many methods and evaluation designs for assessing MPA effectiveness, even the best designs vary by factors such as level of precision needed, time and funding, which makes trade-off between methods and MPA evaluation designs inevitable (Margoluis et al., 2009). This study tries to evaluate the effectiveness of MPAs by including both qualitative and quantitative data from 21 selected indicators accompanied by 27 variables and comparing them to other MPA evaluation methods to address these challenges. The study sites were selected to include MPAs that have been evaluated by government to enable exploration not only of the results of evaluation but also the conditions of both MPAs. The results of EVIKA evaluation in MPA Sabang and Nusa Penida showed that both MPAs are managed minimally, with management that has been implemented but has not yet achieved the goals for each MPA (Ministry of Marine Affairs and Fisheries, 2022). Whereas this study showed that MPA Nusa Penida is less effective with an Effectiveness Index value of 2.9 and MPA Sabang has intermediate effectiveness with an effectiveness value of 3.3. Our evaluation agrees with the EVIKA evaluation in that both MPAs are not yet effective and have not reached their goals. The evaluation conducted by EVIKA and in our study has several components within the measurement of effectiveness that are different (Appendix 7.4 - Supplementary Material C). However, there are several similar variables used between the two studies, such as local community participation, socio-economic conditions, community commitment, and MPA monitoring. The result of the evaluation made by the government or other organisations may differ because of different methods, data, how data are collected and the sources of data. We argue that there is no right or wrong in choosing MPA evaluation methods and designs, however, the methods chosen need to enable us to address locally relevant problems and issues, and they need to be used not only to evaluate MPAs, but also to build comprehensive and adaptable management strategies in the future.

The larger an MPA the larger the area under protection. It is recommended that MPA size needs to be more than a thousand hectares in order to adequately protect habitats and allow larval export to unprotected zones (Halpern & Warner, 2003). Other studies have found that there are no significant relationships between coral cover and fish abundance with MPA level of protection, size and age (Magdaong et al., 2014; Maliao et al., 2009). However, we found that the MPA with the higher Effectiveness Index had higher values for variables measuring its design, size and distribution. Both of the MPAs in this study are considered ineffective and both had less than a thousand hectares for the total core-zone area.

Many factors contribute to MPA effectiveness including enforcement, community support and management (Walmsley & White, 2003). Similar to this, we found that MPAs with higher Effectiveness Index scores following higher values for coral cover and fish abundance, had better management, rules implementation, and fishing gear restrictions. While most MPAs have been found to be struggling financially (Maypa et al., 2012), we found that government support, incentives or investment in MPAs is not related to a higher Effectiveness Index value, but customary law is. Our findings suggest that MPA management supported by local customary law makes a significant contribution to the overall Effectiveness Index of an MPA.

4.5 General Implications

The effectiveness of MPAs were evaluated in this study using a set of indicators and identified variables from the literature on social-ecological studies of MPAs worldwide (*Chapter 2*). MPAs are complex social-ecological systems and so indicators are required that include both social and ecological aspects in order to evaluate MPA effectiveness. The set of indicators and accompaning variables used in this study may be applicable to the study of MPA evaluation worldwide, however, the identification of the specific social and ecological conditions in each MPA must be carried out prior to indicator selection and effectiveness evaluation. For example, customary law, customary management and indigenous practice is evident in both MPAs in this study and so indicators were selected to capture their roles in MPA effectiveness. Other MPAs may not have customary management and so these indicators will not be applicable. The indicators for MPA evaluation used in this study follow the guidelines for MPA effectiveness measurement published by IUCN. Each indicator has been adjusted to the MPA objectives addressed by IUCN. Other MPAs that have a locally or regionally specific goals may need to develop specific indicators to assess MPA effectiveness.

Chapter 5. Engaging Customary Law to Improve the Effectiveness of Marine Protected Areas in Indonesia

Abstract

Customary law has been acknowledged worldwide for its ability to increase the effectiveness of conservation projects such as Marine Protected Areas (MPAs). However, our understanding of how customary law supports, interacts with, and complements conservation remains limited. Here, we explore the role of customary law in helping MPAs achieve their goals in Indonesia. We characterise how customary and regulatory conservation management intertwine when local communities manage their natural resources. We studied two MPAs located in the west (Sabang Island) and east (Nusa Penida Island) of Indonesia. There, we gathered both quantitative and qualitative data from a total of 360 respondents using questionnaires, in-depth interviews, and focus group discussions to investigate community knowledge of and perspectives on customary or *adat* law, the history of *adat* law and how it is currently applied, and the practise of both *adat* and regulatory conservation management. Our analysis assessed quantitative data using statistical analysis in R, and qualitative data with thematic analysis in NVivo. Most of our respondents were positive about the application of *adat* law to manage and protect the environment, thus customary law was found to be effective in supporting the goals of MPAs. However, our findings suggest that the full integration of customary law and regulatory conservation management can be difficult to achieve, as they rely on different principles for deciding policy and implementing sanctions. If integration is to be achieved, we suggest both systems need to be: (1) flexible; (2) widely communicated; and (3) clearly written.

Glossary of keywords used throughout this chapter:

Keyword	Meaning
Adat law/ customary law	Written and unwritten law decided through customary deliberations and agreed upon by all customary stakeholders, has been influenced by outside ideas, policies, and knowledge
Indigenous law	Written and unwritten law decided through customary deliberations and agreed upon by all customary stakeholders, not influenced by outside ideas, policies, and knowledge

Desa *adat*	Customary village authority authorized to make customary laws. It is responsible for managing all matters related to religion, ceremonies and cultural activities.
Desa dinas	Official village authority in charge of administrative affairs. Under the umbrella of national law and directly responsible to the official state administration
Awig-awig	Customary law produced by a customary village in Bali
Pecalang	Customary village authority's security forces
Pecalang segara	Customary village authority's security forces responsible for marine related territory
Panglima Laot	Sea commander in Aceh, it refers to a man who has the authority to enforce customary law related to the sea. It can also be seen as an institution which has an organisational structure consisting of a chairman (*Panglima Laot* himself), vice chairman, secretary, treasurer, and deputy
Musyawarah	A joint discussion with the intention of reaching a decision on problem solving; or negotiations; or deliberation
Nyepi	A Balinese one-day religious ritual dedicated to connecting to God through fasting, silence and meditation
Nyepi segara	A Balinese religious ritual by residents in Nusa Penida that involves not touching, crossing or doing any activities in or on the sea, to give the sea a short break

5.1 Introduction

Customary and indigenous laws have helped people manage their environment and natural resource use for centuries. They are known for their advantages in resolving conflict between users (Campbell et al., 2012), supporting biodiversity conservation and protection (McClanahan et al., 2006; Gutiérrez et al., 2011), and having wide acceptance among local communities (Johannes, 2002). Similarly, in Indonesia, the governance of natural resources has relied on customary law, called '*adat* law', since the 1200s (Abdullah et al., 2018). *Adat* law differs from indigenous law in that it applies to a narrower set of situations and has changed over time through the influence of outside knowledge (Holleman, 2013), while indigenous law covers a wider range of circumstances and is less influenced by religious perspectives or external knowledge. *Adat* law is known by many names throughout the many islands that make up Indonesia. In the east, such as in Maluku, Papua, and Bali, *sasi* and *awig-awig* are the *adat* laws that have been used for decades to help people manage their natural resources. These *adat* laws hold similar principles to modern fisheries management, and support species and coastal habitat protection and conservation (Harkes & Novaczek, 2002).

Marine protected areas (MPAs) encompass ocean and coastal areas that are managed and protected with potentially several levels of protection, typically legalised by law and/or by a local authority such as through local traditional customary law. MPAs aim to sustainably protect and manage flora, fauna and cultural features such as wrecks and temples (Kelleher, 1999). MPAs are often managed locally because of the importance of their cultural, ecological, political, socio-economic and institutional context for management effectiveness (Jones, 2002). MPAs in Indonesia are classified and managed under a zoning system that allows and supports local coastal communities to access marine and coastal resources sustainably. These MPAs are regulated by the Ministry of Environment and Forestry (MoEF) and the Ministry of Marine Affairs and Fisheries (MMAF). They usually contain several zones such as a core-zone, wilderness zone, rehabilitation zone, tourism zone, limited use zone, and sustainable fisheries zone (Lazuardi et al., 2020). Apart from the diverse tribes, religion, culture and local languages in Indonesia, the country also has deep-rooted customary and traditional practices to manage marine and coastal resources, called customary management. The customary management or *adat* management of marine areas in Indonesia can be broadly categorised into zones for protection, certain types of permitted users, and sanctions (Estradivari et al., 2022).

The presence of *adat* law is important, because it often serves to combine the legal authority of local and national government with the ethics of local customs (Harkes & Novaczek, 2000). While *adat* law may have similar functions to more formal regulatory conservation institutions, it also has advantages, including low-cost implementation and voluntary compliance in local communities (Colding & Folke, 2001). However, the question of whether conservation management through *adat* law can be combined with more regulatory forms of management to achieve effective conservation is still pertinent. Integration challenges can arise because of tensions and conflicts between customary and regulatory forms of management. Thus, this study aims to explore the role of customary law in helping conservation projects, specifically MPAs, achieve their goals. It is divided into several explorative steps, including (1) documenting customary law related to marine resources management and conservation; (2) understanding the way customary management and conservation management interact; and (3) understanding the contribution of customary law to MPA effectiveness.

5.2 Methods

5.2.1 Study area

This study was carried out in two MPAs, in the west (Sabang Island) and east (Nusa Penida Island) of Indonesia. Both Nusa Penida and Sabang MPAs were officially designated in 2014, when management was transferred from a Non-Government Organisation (NGO) to local and national government control through MMAF. The MPAs are considered locally managed marine areas, which are described as ‘managed by the government with significant decentralization and influences from a private organization’ (Yunitawati & Clifton, 2021, p.3). Primary data on knowledge of and perspectives on customary or *adat* law, the history of *adat* law, and how it is currently applied, and the practise of both *adat* and regulatory conservation management were collected in six villages, three of them located in Nusa Penida, Bali, and three in Sabang, Aceh. We selected the village locations such that one village was located in the core-zone of the MPA and the other two villages were located outside the core-zone (Figure 5.1). This design enabled a wide range of local community members from different socio-economic backgrounds (e.g., differentiated by gender, education, etc.) in various types of MPA locations to be included.

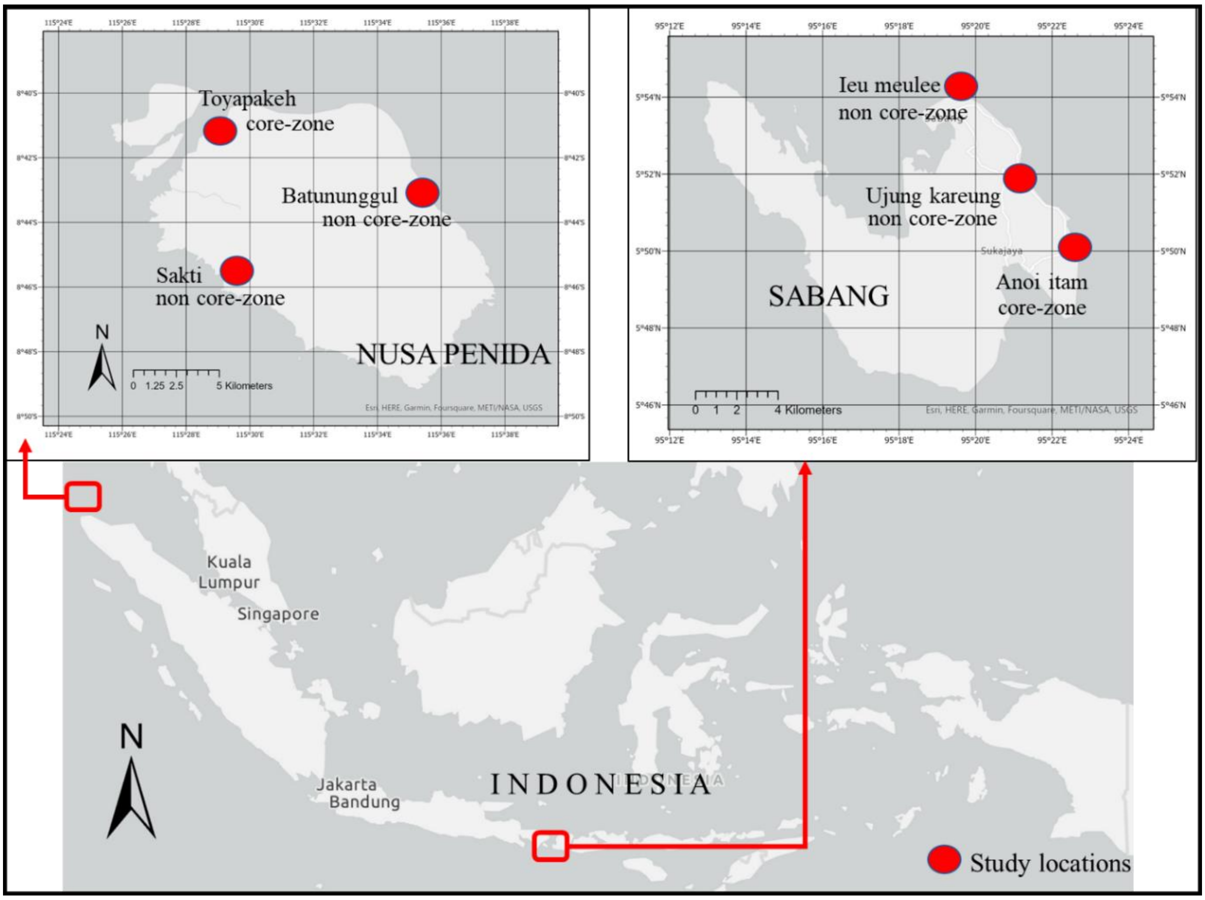


Figure 5.1 Study location in two MPAs in Indonesia.

5.2.2 Data collection and analysis

We collected a combination of qualitative and quantitative data using questionnaires, in-depth interviews, and focus group discussions. A total of 360 people participated in this study, selected using a combination of random sampling for the questionnaires and snowball sampling (Parker et al., 2019) for the in-depth key informant interviews and focus group discussions. Key informants included NGO staff, *adat* representatives of a village, official village representatives, and MPA managers employed by the government, who were all interviewed in person using a semi-structured approach. Participants in the focus group discussions included members of the local community from groups concerned with MPAs and coral reef use and management, such as fishers, farmers, people who work in tourism (e.g., dive instructors), and people who work in local governance (both official and *adat*). Respondents for the questionnaire were chosen randomly from the study communities. We used a map of the village to select houses by choosing one house at random, then counted three to five houses to the left until the number of required respondents was achieved. In the questionnaire, we asked respondents about their knowledge of customary law in their area, its rules and sanctions, and whether they think the application of customary law is effective in supporting conservation projects. In contrast, for in-depth interviews and focus group discussions we explored more specific details about customary law, its history, management and issues, depending on the type of respondent participating. For example, for NGO respondents, we did not ask about the history of customary law, as this question was more suitable for the leader of the *adat* village authority, *Pecalang* or *Panglima Laot*. Instead, we asked questions about the MPA's management and the NGO's role.

We used NVivo *v. 20.1.6* (QSRInternational, 2022) to assist us with a thematic analysis (Boyatzis, 1998) of the qualitative data to understand the role of customary law in helping conservation projects and how customary management and conservation management interact. Thematic analysis is used to identify, analyse, and draw patterns that capture information in relation to the research questions (Braun & Clarke, 2006). These patterns, delivered using themes and codes (Appendix 7.5 – Supplementary Material **Table S5.1** Codes and Themes), are causally related (Boyatzis, 1998). Here, a code is a word or phrase that identifies a process, issue, role or place (Castleberry & Nolen, 2018), related to history, conflict, and the benefit of rules. A theme is a pattern in the codes that captures important meaning related to the research questions (Braun & Clarke, 2006). We used an inductive coding approach, where the specific research question evolves through the coding process (Braun & Clarke, 2006). First, we prepared the data, translated from the original language (Bahasa Indonesia) to English, and read through all of the data. Then we initiated codes that characterised (i) patterns within the text that had meaning for management, conservation, or law-related contexts; (ii) the use of local language terms (in Acehnese and Balinese) and how they were used to describe activities, policies, or laws related to conservation and customary management; and (iii) points of conflict that emerged for issues identified by respondents (adapted from Nursey-Bray (2023) and Yanow (1999)).

Themes were built using the codes to address our research questions and to enable us to draw patterns and connections and explore interactions between the codes. We carefully selected the observed codes and grouped them into suitable themes. We observed four themes that included: (i) rules and prohibitions [RP], (ii) decision making [DC], (iii) management organization [MO], and (iv) actors and institutions [AI]. Within each theme, we assessed two categories, conservation management (coded with CN) and customary law management (coded with CL). In order to understand the regulations and their implementation within both regulatory and customary conservation management in marine environments in Indonesia, we distinguished several components of regulatory conservation management [CN] such as rules and prohibitions [CN-RP], decision-making [CN-DC], management organizations [CN-MO], and customary law management [CL]. Further, we then conducted a non-parametric Spearman correlation in *R v. 4.3.0* (R Development Core Team, 2022) to understand the relationship between the local community's knowledge and their perspective on the effectiveness of customary law.

5.3 The history of customary law/*adat* law and customary management in governing marine and coastal resources in Indonesia

There is little knowledge on how and when *adat* law formed in Indonesia, but it is believed to be an unwritten and uncodified law that has circulated among local communities since the Kingdom Era in the 1200's (Abdullah et al., 2018). The first mention of *adat* law was in 1893 by Christiaan Snouck Hurgronje in his book *De Atjehers*, meaning The Acehnese (Davidson & Henley, 2007). It is also assumed that only the indigenous law of Malayo-Polynesians was present in Indonesia before Hindu civilization arrived in the fifth century, after which religion and foreign law influenced customary law until the present day (Holleman, 2013). Similar to the history of Northern Asian areas (i.e., Pakistan), customary law applied to the management of natural resources. In recent decades, this law has been changing due to the increase in people's education and knowledge, the presence of NGOs, and the influence of government regulations governing the same areas as *adat* (Bilal et al., 2003). *Adat* law in Indonesia has been evolving and changing with the influence of outside wisdom, science, and knowledge that have been brought to the country (Holleman, 2013). The divergent histories of the islands in this study (Bali and Aceh) have also influenced *adat* law for their local communities, and made them dissimilar. Aceh has Syariah law, mostly influenced by Islamic law inherited from the Muslim kingdom era, while Bali has *awig-awig,* influenced by Hindu law inherited from the Hindu kingdom era. The way that they have legalised *adat* law using *musyawarah* (the Indonesian National

Dictionary defines *musyawarah* as ‘a joint discussion with the intention of reaching a decision on problem solving; or negotiations; or deliberation’) also influences present day *adat* law, with changing issues and problems circulating among local communities, rendering *adat* a dynamic and evolving living law.

> “We do the *musyawarah* to discuss issues and problems. From this discussion we make customary law, we write down what are the prohibitions and what are the sanctions and who will be given the punishments”, Interview Sabang, 2021.

In Aceh, the *Panglima Laot* (sea commander) authority was created during the Kingdom of Sultan Iskandar Muda as an official institution (van Engelenhoven, 2021). *Panglima Laot* refers to a locally elected person who manages fisher communities and fishing activities, including determining landing sites and boat mooring locations, deciding what fishing gear is allowed, and specifying fishing grounds for each fisher community. A group of *Panglima Laot* on an island have a customary authority area with a defined size decided through *musyawarah* (i.e., one island such as Sabang can have more than ten *Panglima Laot*). In addition, there are rules that relate to what is now understood as conservation measures, such as prohibiting destructive coastal and marine activities (i.e., using explosives to catch fish), prohibiting destructive fishing gear such as trawl nets in certain areas, and determining sanctions for violators (Nurasa et al., 1994). They also collect ‘tributes’ from outsider ships that enter Aceh waters, protect the sea, and resolve any conflicts in the area. The *Panglima Laot* institution not only applies to the sea; there is also a *Panglima Laot* (*Lhok*) who guards lakes, forests, and other areas surrounding the local community. We found that the duties of the *Panglima Laot* remain the same up to the present day, they are responsible for the safety and protection of their sea territory. However, their duty is somewhat ‘local’, resolving problems that emerge within the local community. Official reporting, monitoring, and patrolling are in the hands of local government (e.g., district, provincial) (Estradivari et al., 2022). Any local issues that involve the relationship between countries falls outside the scope of the *Panglima Laot*. Larger scale issues, particularly international issues, which involve other islands or other countries, are the responsibility of the national government of Indonesia.

> "Inside the sea commander organisational structure, there is a chairman, vice chairman, secretary, treasurer, and deputy. Each sea commander has a territory and members of fishers. The members do not have to be people in this village, there are also members from villages that are not in a coastal area", Interview Sabang, 2021.

Similar to the *Panglima Laot* in Aceh, in Bali they call people who guard the sea *Pecalang*. *Pecalang* comes from the word '*celang*' which means sharp eyesight. Historically, *Pecalang* existed to maintain the security of an area, including the sea, who they call *Pecalang Segara* (*segara* means water). Unique to Nusa Penida in Bali is the concept of *Nyepi Segara,* which is based on local wisdom and traditional practises that allow the sea to rest.

> "*Nyepi Segara* in Bali is intended to give space to the sea for a short break (24 hours). No one can ride a boat, or even touch the water. Before *Nyepi* we do what in Balinese is called *Mulat Sarire*, it means we improve ourselves a month before. It is commonly called *Yasekerti* here, which means we do not act arbitrarily, we do not say bad things, we do not behave in bad ways. Before and after we carry out the ceremony for *Nyepi* Segara", Interview Nusa Penida, 2021.

Aceh also has the *Dewan Syariah* (Syariah Council), influenced by Islamic law, to regulate provincial laws, and has legalised *Qanun* (a decree) that is separate from state law. Similarly, in Bali, the authorities have distinguished between customary (*adat*) and official (*dinas*) law since the colonial era (Davidson & Henley, 2007). Their local wisdom and beliefs have been influenced by Hindu practice, namely *Tri Hita Karana*. The *Tri Hita Karana* creed emphasises the balanced and harmonious relationship between humans, the environment, and the creator (Trialfhianty & Suadi, 2017). It is understood that these three elements are connected and need to be balanced and maintained to enable a good and stable life. The practice influences not only *adat* governance, but also official governance. The 'Vision of the Bali Governor', called *Nangun Sat Kerthi Loka Bali*, contains the following: "*Maintaining the sanctity and harmony of Bali's nature and its contents to create a prosperous and happy life that is in accordance with Bung Karno's Trisakti Principles for the nature and the people of Bali, namely Politically Sovereign, Economically Independent, and having Personality* *in Culture Patterned, Comprehensive, Targeted, and Integrated Development within the frame of the Unitary State of the Republic of Indonesia based on the values of Pancasila which was first articulated on June 1, 1945"* (Bali government, 2023). The vision has 22 points or decrees, one of which is to develop and organize areas and environments so that they are green, beautiful, and clean. Therefore, although there is separation between official and *adat* laws, in reality it is hard to distinguish between them, as they carry the same ideas and concepts from Hindu practice. Since the national government released decentralization decree number 32 in 2004, both Aceh and Bali's governments have the authority to produce decrees (called *Peraturan Daerah*), distinct from national law, enabling the inclusion of local influences into local official law.

In Indonesia, like in many countries across the Pacific (Pulea, 1993) and in Africa (Sunde, 2014), customary law is widely accepted and believed to be effective in managing natural resources and protecting biodiversity. It is also increasingly recognised that customary resource owners need to be involved in planning and decision-making for conservation from the very beginning if it is to be successful (Lam, 1998). Thus, there have been attempts over the years to codify *adat* law to incorporate it into national law and consensus. However, these efforts have been met with conflicts and rejection because of concerns over a loss of flexibility (the flexibility of customary law will be discussed later) and the potential misinterpretation of local beliefs and customs (van Engelenhoven, 2021). In Indonesia, the term *adat* was introduced by Islamic merchants to refer to indigenous customs or all matters that were beyond accepted (Islamic) law (van Engelenhoven, 2021). So, *adat* was not a system of law, but rather the system outside the law. Nevertheless, ways of acknowledging and incorporating customary law, and its benefits, into state law are needed to both support conservation efforts, but also to give local communities the freedom to perform their indigenous and customary management.

5.4 Customary management versus conservation management in Indonesian waters

A pluralist legal system in Indonesia is inevitable, considering the diverse tribes, histories, cultures, and local languages present in the country. Legal pluralism is when a community or society is operated by two or more forms of law (Craig & Gachenga, 2010). It has its advantages, where local wisdom and customary law are acknowledged by outside society and the state. The recognition of customary law, customary community, and local wisdom is well-defined and well-recognized by the Indonesian government (Utomo, 2010). The national government has released several decrees to support *adat* law in the country (reviewed by Utomo (2010)):

- Law No. 45/2009 on Fisheries, Article No. 6: Fisheries management should take into account *adat* law (custom) and traditional knowledge, including community participation;
- Law No. 27/2007, on Management of Coastal Areas and Small Islands, Article 60: In management of coastal areas, the public has the right to manage its natural resources based on existing customary law; and
- Government Regulation No. 60/2007 on Conservation of Fish Resources, Article 9: the determination of aquatic conservation areas is based on social and cultural criteria, including local wisdom and customs.

When it comes to the implementation of the law however, especially for conservation projects such as MPAs, Indonesia is facing dualism, we found that the local community is often confused about which activities are allowed or not allowed by customary versus national law. For example, in Nusa Penida (Toyapakeh village), in principle, the core-zone is protected by national law from any activities, and any visitors require a permit. However, the core-zone is in an area where the ferry from Nusa Penida to Nusa Lembongan traverses and many tourism activities, such as diving and snorkelling, are carried out. The ferry has also become an important transportation link to connect people using both islands for activities such as trading and praying in the temple. Since the location of the core-zone is not clearly defined and signposted, many of these activities are still running, and the local community (especially within Toyapakeh village) was opposed to the idea of locating a core-zone in their waters. This issue is experienced by many conservation areas across Indonesia, where a combination of customary and national law causes tensions and conflict within local management (Nugroho et al., 2019).

Our analysis revealed the role of actors and institutions [AI] in both regulatory conservation and customary law implementation (Figure 5.2). Overall, we found that customary law management was mostly organized by *adat* law and included the *Pecalang* and *Panglima Laot*. Regulatory conservation management involved a variety of actors such as government officials, as well as the *Panglima Laot* and *Pecalang*. NGOs were involved in all components of management in both customary and regulatory conservation management (Figure 5.2).

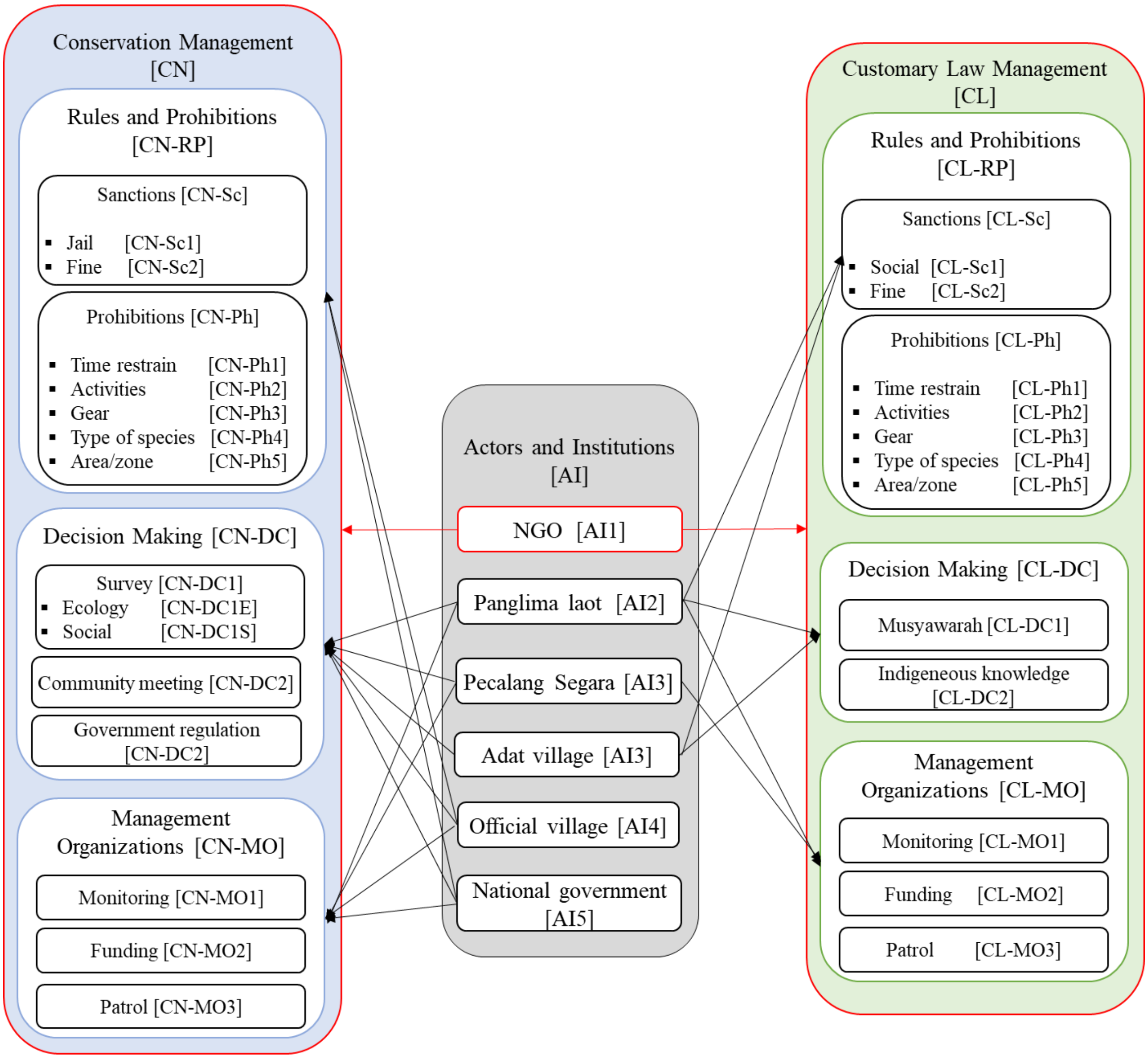


Figure 5.2 Thematic analysis showing the components of Conservation Management [CN] (left side) and Customary Law Management [CL] (right side), and how Actors and Institutions [AI] (middle) relate to each component. Black arrows show connections between themes or components, red arrows show how NGOs connect to all components within conservation management and customary management.

The rules and prohibitions [RP] in customary law [CL-RP] and regulatory conservation [CN-RP] in Sabang and Nusa Penida are very similar (Figure 5.2), likely because the rules have been influenced by one another. When conservation was introduced to Sabang and Nusa Penida, there was discussion about whether a certain rule was suitable or not for the local community that already had customary laws for managing their resources, including governing coastal and marine areas. For example, in Sabang, for tourism actors who had businesses along the customary zone (a zone that is specifically managed by the *Panglima Laot*), it was decided that they should not prohibit fishers from carrying out fishing activities in the customary zone area. In Nusa Penida, there is a core protection zone and a marine tourism zone. For marine tourism, the hours for activities were determined and set so that fishers and tourism would have different time periods to carry out their activities. Fishers can catch fish from 11 a.m. to midnight, whereas tourism activities, such as snorkelling and diving, can only be carried out from early morning to 11 a.m. (Appendix 7.5 – Supplementary Material A). We found that conservation rules implemented in different areas changed depending on how a compromise was reached between conservation and local community needs. However, we found that sanctions between regulatory conservation [CN-Sc] and customary law [CL-Sc] were dissimilar, where conservation managed by local government had two kinds of sanctions for those who violated the rules: jail and fines (Fig. 2). Customary management or *adat* law had sanctions embedded in social custom (e.g., not being allowed to enter the sea or village) and fines. This included fishing gear detention for a week and a fine of Rp3,500,000 (Appendix 7.5 – Supplementary Material A).

The decision-making process [DC] includes how a MPA is initiated, established, and run by local government and local communities, including how they decide rules, and the roles of each party. In both locations, Nusa Penida MPA and Sabang MPA, the MPAs were initiated with the support of NGOs. The NGOs visited the areas, had meetings with the local community, surveyed marine conditions (ecological surveys and social surveys) and completed all essential documents and conditions to establish an MPA, following national government regulations.

> "Indeed, the zoning process itself was a long process. We had meetings up to 66 times with the community. So, we were back and forth, revising the result of focus group discussions again and again, until they were all agreed. Originally, the core-zone was 500 meters wide. But it needed to be

> reduced to 20 meters to make fishers agree with the zonation, because it is in fact their fishing ground. We looked into the regulations from national government that the zone needs to be at least 2% of the total marine area, so this zoning was acceptable", NGO Interview Nusa Penida, 2021.

Adat also plays an important role in MPA establishment, because community meetings for regulatory conservation decision-making intrinsically include and consider the local communities' engrained customary knowledge and culture.

> "Custom regulates the placement of conservation areas, not all of them have to have a non-take zone because it is unfair for the community/fishers", Interview Sabang, 2021.

In Nusa Penida, there is also a sacred zone where many activities such as fishing, diving, and snorkelling are prohibited. This no-activity area is located in front of a large temple and was established at the request of the community. In *adat* law, community meetings use local indigenous knowledge to make decisions. This zone is an example of how *adat* law can establish rules differently to regulatory conservation, depending on local beliefs and customs.

The management organisations [MO] that govern MPAs differ. The way *adat* law manages MPAs [CL-MO] is slightly different compared to MPAs managed by the local government [CN-MO]. MPAs managed through *adat* rules and leadership rely on the help of the whole community including members (fishers) and non-members (other local communities who live nearby). In Bali, *adat* governance supports conservation through the *Pecalang* who guards the sea. In Aceh, *adat* law supports conservation through the *Panglima Laot*. The local community takes part in *Pecalang* activities as reporters. For example, they will report violations to the *Pecalang* or *Panglima Laot* who will immediately go to the location to admonish and hand out sanctions. Therefore, both *Pecalang* and *Panglima Laot* carry out enforcement of *adat* law in their own territory.

> "It is a matter of custom. If there are tourists who might damage coral reefs, the sanctions will depend on the area in each customary village authority (Desa *Adat*), therefore the authority of the customary village is

first, then if the problem cannot be resolved, it will be brought to the official village authority (Desa *Dinas*)", Interview Nusa Penida, 2021.

"It is customary to have back up when something goes wrong. Unite the community, bureaucratic support. Traditional villages are self-help but have power. The official village authority is accountable to the central government, the customary village authority to the community", Interview Nusa Penida, 2021.

When MPAs are managed by the local community (called locally managed MPAs), then conservation will entirely build on *adat* rules to support MPA management. However, even when the MPA is managed by the local government or through an official village authority (e.g., Desa *Dinas*), *adat* institutions are still involved by providing assistance to official staff with patrols and monitoring, and convening community meetings. It is almost impossible not to involve *adat* leaders, as it is key to gaining local community trust. Unlike official government units or NGOs that receive funds from the Indonesian government or donors, *adat* implementation relies on community funding. This supports a well-managed *adat* organisation, including a treasurer who manages monthly finances to support activities such as monitoring and patrols, without relying on donors or the government.

"We do not have anything to support us financially, we are self-funded having a monthly group contribution which is five thousand rupiah per person per month", Interview Sabang, 2021.

It is important to consider the roles of actors and institutions [AI] in the context of MPA management. A*dat* and official village leadership are two different things: the official village authority is recognised and regulated by the government, but *adat* leaders have a strong influence on local people. Therefore, in many cases, the government works alongside *adat* leaders to help officials undertake conservation work regulated by national government. For example, they created POKMASWAS, a law enforcement group, legally appointed by MMAF, but formed on the initiative of the community who are aware of the importance of protecting marine and fishery resources. This group includes *adat* members (*Panglima Laot* and *Pecalang)* who have the duty to protect the sea and carry out conservation related activities. In both locations (Aceh and Nusa Penida), there is a patrol once a month. Local NGOs, *adat* members and MMAF staff assist with the patrol, some using their own budgets (collective budgets from NGOs and members of fishing groups), others using official government budgets. In addition, MPA monitoring is carried out once a year. The leader of an *adat* authority, who is respected, feared, and obeyed by the people, can be a bridge between national/official conservation goals and the local community. They play a substantial role in supporting conservation by facilitating the transfer of conservation ideas, rules, and prohibitions that are understood and obeyed by the local community.

> “I told the community that this concept (core-zone) is not far from the existing customary concept. In fact, I said yesterday that there are still sacred areas where we made them, now we just made them again but this time its inspired by the outsider’s conservation idea and concept”, Interview *Panglima Laot* Sabang, 2021.

In terms of the connection between regulatory conservation and *adat* law, we found that NGOs have a greater role than other actors (drawn by red lines in Fig. 2). All the work related to conservation in Sabang and Nusa Penida was carried out by an NGO with the help of both *adat* and official village government. NGOs made a significant contribution to the initiation of the MPAs, providing technical input, logistical, and financial support before their management roles were transferred to the local government and MMAF (Yunitawati & Clifton, 2021).

> “We assist in activities in the field, for example training, capacity building, assisting tourism groups, and MPA monitoring, which we do every year. We also helped establish the MPA in Nusa Penida in the first place. We help propose MPA zoning and accommodate the voice of the community. For example, if they do not wish a particular zone to be protected, we try to discuss it with them and find a better solution”, Interview NGO Nusa Penida, 2021.

The idea of integrating customary law and regulatory conservation management is widely accepted (Aswani & Hamilton, 2004; Cinner & Aswani, 2007; Boli et al., 2014; Kittinger et al., 2014). Although integration might be possible, here we find that it can be difficult to do in practice when local and indigenous wisdom for resource management is dominant. The national government of Indonesia has realised this, which is why they acknowledge customary law (if present). In particular, our study finds that the integration of decision-making and sanctions faces difficulties. *Adat* laws governing the use and management of natural resources, including the marine ecosystem, will prioritise the interests of local people or people's wellbeing above all else. Moreover, where violations occur, punishments and sanctions will depend on the situation and local conditions. So, they will not put a person in jail, rather, they will use fines if someone has the money to pay, or social customs such as banning someone from entering their village. This flexibility to find the best solution for each case means that customary law is often unwritten and draws on local knowledge and social customs, which can be difficult to incorporate into more regulatory forms of management.

However, as has been mentioned previously, customary law can and does evolve under the influence of outside wisdom and knowledge (Holleman, 2013), including conservation knowledge. Communication and awareness raising, particularly when the leader of the *adat* or the traditional village authority is involved, can help with the integration process. Individuals embedded in and responsible for *adat* law can often become a 'bridge' (Trialfhianty & Suadi, 2017) between the local community and institutionalised conservation efforts. If integration between customary law and regulatory forms of conservation management is to be reached, our analysis in Indonesia suggests that both systems need to be: (1) flexible, allowing for a balance between social, environmental, cultural, and local community wellbeing interests above political agendas; (2) widely communicated, with links established between customary councils, local and national government, and other stakeholders, including NGOs; and (3) clearly written, as codifying unwritten customary law would serve to make it visible. However, this will inevitably create tensions with the need for flexibility. The use of *musyawarah,* or community meetings, to address matters and conflicts that fall outside of written laws will be important, with clear communication of their discussions to all stakeholders.

5.5 The effectiveness of customary law in supporting Marine Protected Areas

The majority of the local community in Nusa Penida and Sabang agree that *adat* law is effective in supporting MPAs, with more than 80% of respondents agreeing in all locations, except for Toyapakeh village, which is located in Nusa Penida (Figure 5.3). Similarly, knowledge of customary law in local communities is high, except in Toyapakeh village (Figure 5.3). The Spearman correlation test shows a very strong correlation between the variables 'knowledge of the existence of customary law' and the 'effectiveness of customary law related to the MPA' (*p-value* < 0.001). The more people know about customary law and its practise, the more they believe that customary law is effective in protecting and conserving the environment, especially their marine environment. This is similar to a study in the Pacific that also reported that written and unwritten customary conservation and management laws are important to effectively protect marine biodiversity and the environment (Pulea, 1993).

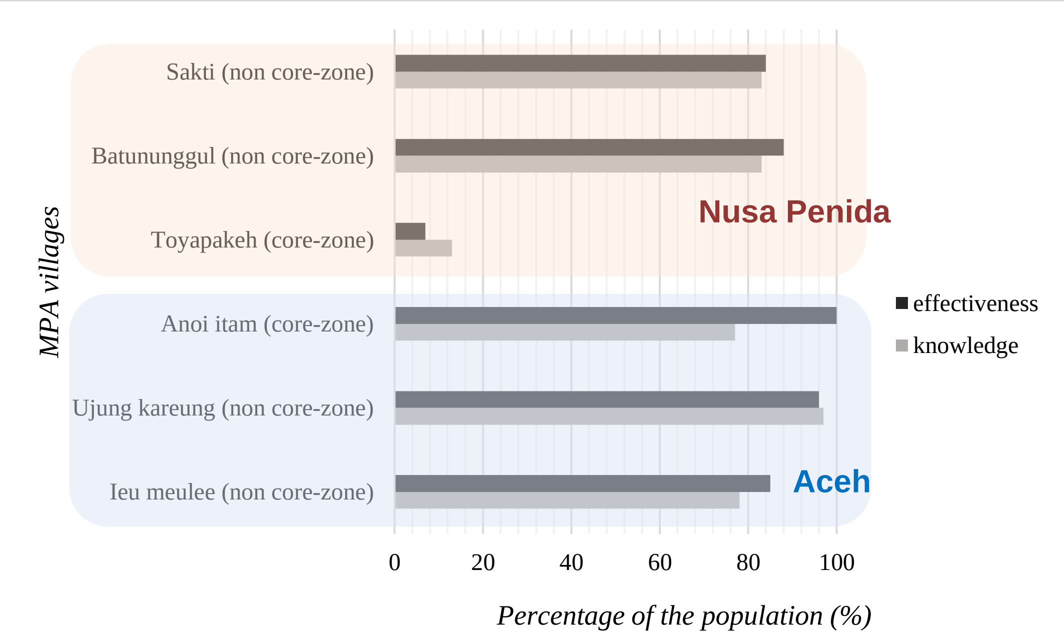


Figure 5.3 Percentage of respondents who affirm to have knowledge of customary law and those who believe it is effective in supporting MPA management.

Toyapakeh is situated in north Nusa Penida, where the core-zone of the Nusa Penida MPA is located. This village is demographically unique, because the majority of the villagers are Muslim, compared to the surrounding Hindu villages. The *awig-awig* customary law legalized by the *Desa Adat* is most influenced by Hindu practice. As such, it is possible that many people in Toyapakeh do not understand how customary law works in Nusa Penida, have very little knowledge about customary law and do not agree with the customary laws that are being used to support MPAs.

> "Customary law is not functioning properly, it needs cooperation from all parties", Open-ended questionnaires Toyapakeh village, Nusa Penida, 2021.

Elsewhere, there is compatibility between customary law and conservation, so local communities are positive about the enforcement of rules and prohibitions both inside and outside the MPA. However, most of the local community believes that the implementation of customary law regarding protection of the marine environment is more effective and respected by local people (Figure 5.3).

> "The implementation of customary law is more effective than the rules in conservation itself", Open-ended questionnaires Sabang, 2021.

> "Effective because customary law is stronger in society", Open-ended questionnaires Nusa Penida, 2021.

This support comes not only from how customary law is created, but also because people feel that customary law better understands their situation and that decisions are made based on local values. When dealing with problems within the community, the *Panglima Laot* is believed to use a traditional approach, a sense of justice and propriety, incorporating religious values and conscience, especially if a management challenge falls outside of what is covered by national law (Nasir et al., 2022).

> "Fishing communities are very obedient to customary law because customary law prioritises deliberation and consensus", Open-ended questionnaires Sabang, 2021.

However, the effectiveness of customary law is threatened by tourism. On islands such as Bali or Sabang, where people from outside are free to come and enjoy the many attractions, including diving and snorkelling, it is important that local knowledge and wisdom is communicated effectively to prevent violations of the law. In the local communities, both in Bali and Sabang, most respondents agreed that outsiders who had limited knowledge of customary law often broke it.

> "It [customary law] is effective because all Balinese people do not do activities that can damage the environment, except people from outside Bali", Open-ended questionnaire, 2021.

5.6 General implications

Our findings are similar to experiences of *adat* law elsewhere in Indonesia, such as *sasi* in East Indonesia, which also plays a significant role in helping communities manage their marine resources (Harkes & Novaczek, 2002). Villages performing *sasi* are found to be more effective in managing local marine resources and contribute positively to the development of marine management institutions (Harkes & Novaczek, 2002). However, as in our cases, this effectiveness of customary law in managing the marine environment and supporting conservation goals to protect biodiversity and promote sustainable use must be balanced with more regulatory forms of governance. While it is clearly written in the decree (law no. 45/2009 article 6; law no. 27/2007 article 60; government regulation no. 60/2007 article 9) that the national government acknowledges customary law and supports local community management of their own resources, in practice, legal pluralism in Indonesia is often challenging. The national government typically considers itself more knowledgeable about conservation issues than local people, and so gives more rights to policy makers to resolve the problems related to conservation issues (Nugroho et al., 2019). Integration of customary and regulatory laws is also made more difficult in Indonesia because of the many policies and legalisation drafted by sectoral ministries, which tend to maintain sectoral interests over local or national interests (Nurhidayah, 2010).

It is important to continue to find ways to reconcile not only between regulatory conservation and customary laws but also between actors and institutions involved within planning, management and implementation. Tensions and conflicts may have profound effects on the sustainability of community-based marine management and conservation projects that acknowledge customary or traditional practice (Techera, 2010). Future MPA management processes need to incorporate and accommodate multiple actors and their perspectives (Nursey-Bray, 2023). This will need to include commitments to develop good management systems using both customary and regulatory conservation knowledge, both customary and regulatory actors, and both conservation and livelihood objectives. Furthermore, our findings suggest that both customary and regulatory conservation must be clearly stated and widely communicated to avoid conflict, particularly, when outsiders can come in and use marine resources without knowing about and understanding customary laws.

5.7 Conclusions

Customary law plays an important role in increasing the effectiveness of conservation actions such as MPAs. Our study finds that the majority of local people have good knowledge on the application of customary law in their village to manage and protect the marine environment and believe that it is effective in supporting the objectives of MPAs. Customary law can therefore act as a bridge between regulatory forms of conservation and the local community by facilitating the transfusion of conservation knowledge and communicating goals and objectives. However, the integration of customary and regulatory conservation management poses challenges. There are differences in the ways that policy is decided and what sanctions are imposed; customary law prioritises deliberation and consensus focused on local people's wellbeing above all else. Furthermore, there are often tensions and conflicts between the actors and institutions involved, because of differences in knowledge and their expectations for what roles they should play in conservation planning, management, and implementation. Rule breaking does not only occur within local communities, especially in places where tourism brings outsiders into a village. Outsiders are usually not cognisant of local rules and cannot be held accountable, so how to communicate the, often unwritten, customary rules to such outsiders poses a particular challenge. Ultimately, integration needs to recognise and incorporate rule flexibility to allow for differences in local contexts and local autonomy in decision-making. It needs clear channels for communication between all stakeholders from local to national level, including NGOs, and flexibility needs to be balanced against the codification of local customary laws to make them more visible.

Chapter 6. Discussion

The fundamental purpose of this thesis is to understand the intricate connections between social and ecological systems in coastal and marine conservation areas, and how we use them to evaluate and enhance the efficiency of MPAs in achieving their goals. Overall, I find that social-ecological systems within and around MPAs are complex, governed by various social and ecological variables that are interconnected with positive and negative interactions. Identifying and measuring variables can be used to better design spatial conservation planning processes and evaluate MPA effectiveness. In addition, variables can also serve to comprehend the whole social-ecological system and reduce conflicts, for a range of MPA objectives (Figure 6.1). Thus, understanding MPAs using social-ecological analysis can uncover many factors that influence their performance and help synthesize future management strategies.

A key aim in focusing on social-ecological systems is to build and analyse a concept (in this case, the concept of an MPA being a tool for conservation) that is adaptable, stable, applicable, and transformable (Ostrom & Cox, 2010). Thus, in Chapter 2, I identified variables in social-ecological system of MPAs, how they interact, and what indicators emerge that can be used to measure MPA performance. I identified 39 indicators accompanied by 82 variables that can be used to evaluate MPA effectiveness; and developed a social-ecological interaction framework to conceptualise the relationship between variables within environmental attributes, socio-economic attributes, ecological attributes, and how they interact with MPA outputs. I then used all identified indicators and variables to design the studies in Chapters 3, 4 and 5. I found many studies that use local community knowledge and perception to help design and determine the indicators used in assessing MPA performance (Pajaro et al., 2010; Gallacher et al., 2016; Heck et al., 2011; Himes, 2007b). In these studies they argue that the method of choosing indicators based on a local community's perception is cost-affective, straightforward, and relevant to the present time and local conditions. However, we need to be aware that bias can emerge when using perceptions. For example, when asking about MPAs, none of the key informants were able to consistently determine what "MPA" means to them and how to prioritise MPA performance measures (Himes, 2007a). Thus, I argue in Chapter 2 that we need to have general guidelines (for example, taken from IUCN) incorporated with many case-studies to be able to first capture the many possible variables and indicators to evaluate MPAs, and then categorise them. So, when we are trying to evaluate a certain MPA objective (i.e. conservation outcomes), we know which indicators and variables are possible and suitable to use. Furthermore, people can claim that their framework and indicators for assessing MPAs is the best, but without an understanding of how the social-ecological system of an MPA functions, it is impossible to choose an ideal set of indicators that are relevant to assess MPA effectiveness. We need to understand how variables within the system work and influence each other and use a social-ecological system approach to understand how the whole system functions (Palomo & Hernández-Flores, 2019).

In Chapter 3, I used social-ecological factors, such as water quality; chlorophyll and plankton density; index value of mangroves; local community's perceptions and mangrove economic value, to help plan for a conservation zone in a mangrove ecosystem. I reveal that the outer area of the mangrove conservation zone is suitable for a protected area, because the area is critical for the survival and preservation of biological diversity. The mangrove ecosystem is a unique ecosystem because it consists of many zones with community structures of different types of mangrove trees and different types of substrate (Kathiresan & Bingham, 2001). This makes understanding mangrove ecology very important in determining conservation zones and the degree of protection for each zone as we need to look beyond the diverse vegetation and tidal inundation zones, and also evaluate the surrounding marine and terrestrial ecosystems including the water catchment area (Jin-Eong, 1995). This chapter also shows how important it is to include social-ecological factors to meet and accommodate both ecosystem and local community preferences in conservation planning. More importantly, the chapter provides an example of how a conservation project can be carried out sustainably and with reduced conflict between all stakeholders. To achieve this a variety of stakeholder goals for natural resource utilisation need to be integrated into an overall utilisation decision support system, which then provides an appropriate framework for mangrove management planning in the future (Christensen & Hjortsø, 2008).

Chapter 4 evaluates MPA performance using the social and ecological indicators identified in Chapter 2 and demonstrates the effectiveness of two MPAs in reaching their goals. Many studies apply evaluation frameworks that are limited to MPA conditions, for example, evaluation frameworks that focus on ecological indicators are only useful for MPAs whose objectives are only focused on ecological outcomes, or MPAs that are multi-use sites (means that the framework will not work if an MPA is a single-use site) (Hopkins et al., 2020). In this Chapter, I used an Effectiveness Index, derived from both qualitative and quantitative data, to calculate the value of each indicator used. Furthermore, it is important to use a comprehensive approach that includes indicators connected to socio-cultural, socio-economic, nature conservation and management objectives (Picone et al., 2020). Therefore, I argue that the use of an effectiveness value index in Chapter 4 accompanied by identified social and ecological indicators and variables from Chapter 2 is compatible with MPAs under various conditions. Furthermore, the findings in Chapter 4 present how social-ecological variables differ between MPAs that have distinct effectiveness values and which social-ecological variables are associated with higher MPA Effectiveness Index values. The highest MPA Effectiveness Index is associated with good conditions of living coral cover, fish abundance, local community knowledge, local community acceptance of an MPA, the existence of clear conservation rules and implementation of rules such as fishing gear restrictions, and the existence of local indigenous practice and customary law. These findings are similar to another study that found that the effectiveness of MPAs depends on their location and management (Jameson et al., 2002). MPAs are considered effective if they are located in a favourable environment allowing ecological sustainability and survival of marine species (i.e. characterised by high living coral cover or fish abundance) (Fidler et al., 2021; Muallil et al., 2019; Turnbull et al., 2018). Furthermore, effective MPAs often have strong community management capacity, allowing the MPA to deliver ecological goods and services to targeted users (Jameson et al., 2002).

Chapter 5 provides a detailed insight into how customary law improves the effectiveness of MPAs. This chapter presents a strong case for local knowledge and a community's perspective on the effectiveness of customary law in protecting marine resources and environments. I also demonstrate that the majority in these local communities believe that customary law and indigenous practice is effective in supporting MPA management. This chapter also investigates further the interactions between customary management and conservation management, how the two systems operate, and the possibility of combining both systems to manage coastal and marine resources sustainably by conserving and preserving the biodiversity of existing ecosystems. Therefore, it is important to include customary law and indigenous practice in a collaborative approach to achieve MPA goals. For example, the 'Sea Country' in Australia has begun to operate indigenous-led management regimes that are considered effective in conserving and managing ecological and cultural resources (Gould et al., 2021). The customary law case study in Chapter 5 and other literature showing indigenous-driven management approaches (e.g. Rist et al., 2019) have shown that allowing indigenous people to manage their marine and coastal environment is not only a basic human right, but can also improve modern management regimes in conserving and protecting the environment.

My thesis emphasises that social-ecological analysis is not only important to help understand social and ecological variables and their interactions within and surrounding MPAs, but can also help in evaluating and designing future management strategies. Understanding the social-ecological system of MPAs provides good management strategies by calculating social adaptive capacity, indices for ecological health, and the impact of overfishing, tourism and pollution, which can then help decision makers in evaluating priorities to improve MPA effectiveness (López-Angarita et al., 2014). For example, in exploring the linkage between tourism and MPAs, social-ecological analysis can be used to evaluate how community actors see tourism development and how they might adapt to changes in the future by building the capacity of the local community (Wu & Tsai, 2016). Furthermore, we can understand the quality of MPA performance by examining the interconnections of various complex social and ecological variables within and surrounding MPAs, such as demography, conservation beliefs, and local community knowledge of conservation, which influences participation of local communities in conservation projects and their management (Twichell et al., 2018). Overall, the study of social-ecological systems for MPA management in this thesis has enriched our knowledge of the use of social-ecological analysis, the types of variables within the system that can be used to determine indicators in assessing MPA effectiveness, their use in MPA evaluation and design applications, and as a result helps increase our understanding of how interconnections occur and how to anticipate the consequences arising from interactions between variables that might influence MPA effectiveness or performance in the future.

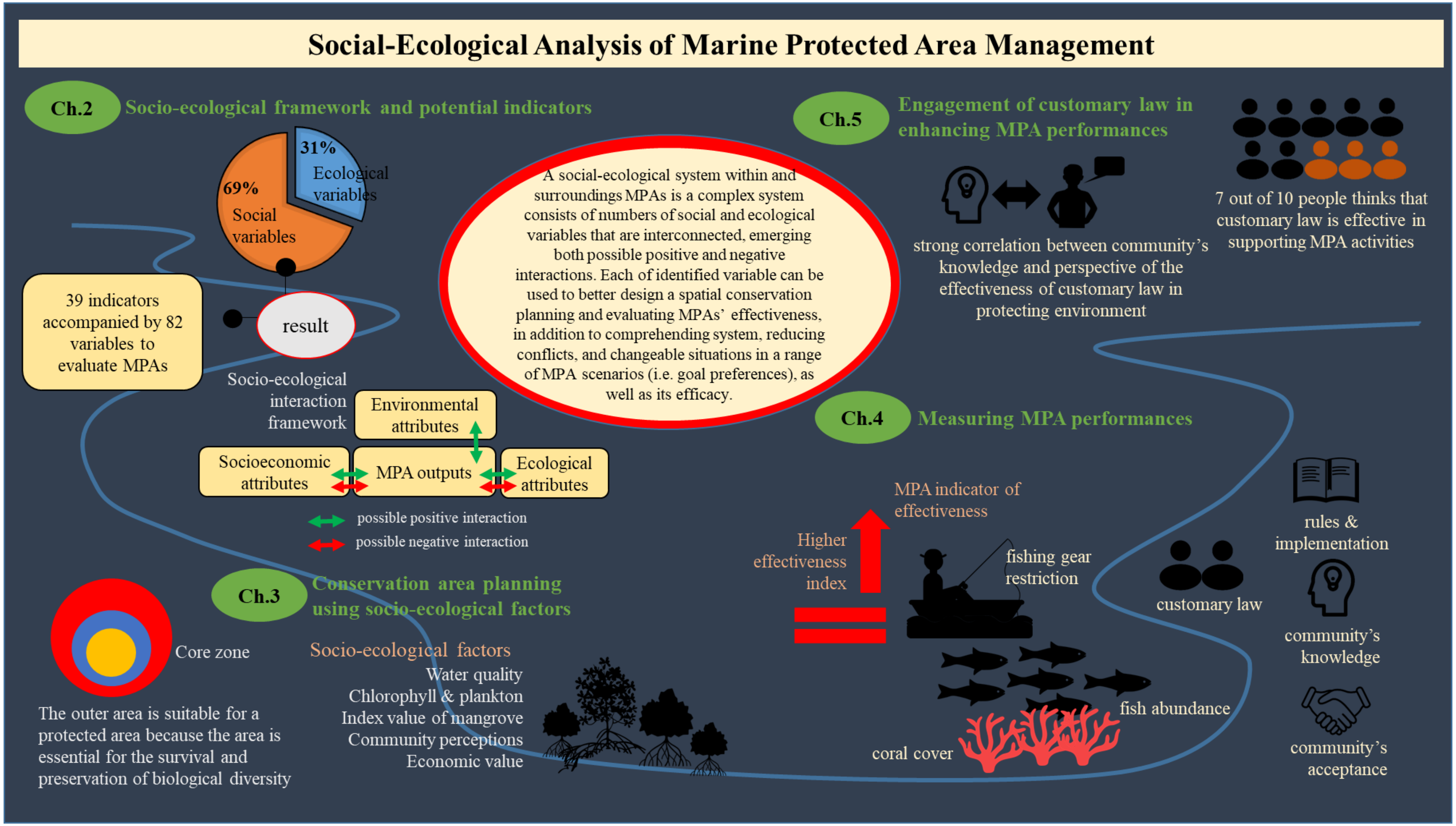


Figure 6.1 Infographic showing the results and findings of study in this thesis.

6.1 Variables and indicators within an MPA's social-ecological system

Complex systems in social-ecological science comprise of a huge variety of variables (Ostrom, 2009). With a growing body of literature identifying key variables governing the social-ecological system of MPAs, such as local community empowerment and attitude (de Oliveira Júnior et al., 2021); habitat complexity and protected area size (Turnbull et al., 2018); fish diversity and abundance (Zupan et al., 2018), I synthesised the biophysical, socio-economic, and governance factors involved in the management of MPAs (Chapter 2). The aim of Chapter 2 was to categorise the aims of MPAs (according to IUCN) using indicators and their many associated variables, and to consider how to measure MPA effectiveness using the identified indicators and variables. Whilst the key indicators for assessing MPAs are well known (Meehan, et al., 2020; Pajaro, et al., 2010; Himes, 2007), my study identified which indicators and variables are possible and suitable to use when measuring the various aims of MPAs. For example, when assessing conservation outcomes, we can include biophysical indicators such as focal species abundance, which consists of variables including fish abundance, benthic abundance and living coral cover. We can also include socio-economic indicators such as local value and beliefs about marine resources, which consists of variables such as conservation beliefs and awareness, and customary law.

These findings also helped me to identify local community perception and economic value as important variables to be used in MPA planning (Chapter 3) (Trialfhianty et al., 2022). Further, it allowed me to expand the toolkit for social-ecological MPA evaluation with local community participation, knowledge and conservation rules and implementation (Chapter 4), expanding on previous evaluations that rely only on ecological variables such as fish abundance and living coral cover (Zupan et al., 2018) or MPA age and size (Turnbull et al., 2018). Finally, Chapter 2 highlighted the importance of how customary law interacts with local conservation management, which can help improve its effectiveness (Chapter 5) (Trialfhianty et al., 2024, *manuscript in review)*.

The findings of Chapter 2 show that social variables are more numerous than ecological variables, with a higher proportion of this type of variable found in the literature (69% of the total identified social-ecological variables). This finding suggests that the management of social-ecological systems is fundamentally concerned with its social surroundings (Leenhardt et al., 2015).

With regards to the application of identified social and ecological variables for Chapters 3, 4 and 5, I also used more social variables than ecological variables because I found that the social dimension is more complex, often consisting of governance attributes, management attributes and economic attributes. Thus, understanding fundamental drivers of human behaviour and their values related to economic activities, resource use and ecosystem services is critically important for reaching conservation effectiveness, especially ecological effectiveness. For example, in Chapter 3, I calculated the economic value of a mangrove ecosystem in Baros. The result of this study gave me insight into how people in the surrounding area use mangrove ecosystem services to generate economic benefits. This enabled me to plan a conservation zone that can not only support ecological protection, but also economic activities for local people's well-being without harming the environment. Furthermore, understanding fundamental human values is essential because they have impacts on individual and institutional behaviour and decisions (Dunham et al., 2018) As I presented in Chapter 5, indigenous beliefs, practice, and law can support conservation projects through activities that protect environment (i.e. Nyepi Segara) and local rules that allow the marine ecosystem to function sustainably (i.e. environmentally friendly fishing practices).

The identified variables are often considered, either individually or combined, as indicators because of their ability to respond to management action, thus, they can be used as a tool to assess the effect of that action (Meehan et al., 2020). When focusing on mangrove conservation (Chapter 3), I used several ecological variables that are applicable to mangrove ecosystems and their services, such as water quality and mangrove density and diversity, to analyse which area has a better quality of mangrove biodiversity. The mangrove study revealed that mangrove nursery areas located in the outer zone were suitable for a protected area and the middle area was most suited to commercial activity. The result of the study is contradictory to the Biosphere reserves concept introduced by UNESCO (1996), where conservation areas have a core-zone in the middle (non-take zone) surrounded by a buffer zone, where low-impact human activities are possible (Coetzer et al., 2014). Thus, it is important to understand how an ecological system works in a conservation area. I argue that the best location of a conservation zone cannot be generalised when involving different types of ecosystem (e.g. muddy substrate, coastal, river or marine ecosystem). In Chapter 4, I used living coral cover and fish abundance as variable to study the effectiveness of MPAs that contain no mangrove ecosystems. In Chapter 5 I analysed the local indigenous practice and customary law in marine resource use, such variables will not be applicable for MPAs that have no customary law. In all three chapters, I show how important it is to use relevant indicators and variables either to assess the effectiveness of MPA management or to plan conservation actions. Similarly, in another study conducted in the Mediterranean Sea where trawling has become the biggest threat to biodiversity protection of marine ecosystems, they use various benthic assessments (e.g. macro algae, seagrass and sea urchin abundance) to monitor the effectiveness of MPA protection (Fraschetti et al., 2022). Thus, key to ensuring that MPAs can effectively protect marine and coastal ecosystems is the selection of a suitable, compatible and balanced suite of indicators and variables for MPA evaluation (Geldmann et al., 2021; Pendred et al., 2016).

6.2 Social-ecological interaction framework

This thesis began with reviewing the range of variables that build the social-ecological system within and surrounding an MPA and then analysed their interactions. The possible positive and negative interactions between variables are presented in a social-ecological interaction framework. The main objective for this framework is to understand the contributing factors that can influence an MPAs output. By doing so the framework can assist many MPAs in achieving their effectiveness, for example, by considering how the inclusion of the social dimension helps us to understand which factors influence the social acceptance of MPAs (Boubekri et al., 2022) and how conservation zone placement in high-fishing-intensity areas might lead to low social benefits (Li et al., 2020). While a social-ecological framework (Ostrom, 2009) can help examine the relationship between socio-economic variables such as livelihood diversity, conflicts and resource dependence, and how they influence resource management and poverty (Gurney et al., 2014), a better framework is needed that places emphasis on the MPA’s challenges related to social and ecological conditions.

Thus, this social-ecological interaction framework is designed in the hope that it can be used in future social-ecological studies related to MPAs.

Developing consistent evidence for MPA evaluation can be done by first understanding the social-ecological system and its interactions through case studies (Ban et al., 2013). MPA evaluation can be carried out by first selecting suitable indicators that can explain which factors are best at describing the effectiveness of an MPA (Gallacher et al., 2016). In Chapter 4, I identified 27 variables to help measure the effectiveness of two different MPAs. These included ten variables to assess the conservation outcomes of an MPA (e.g. coral cover and costal protection); five variables to assess good governance of an MPA (e.g. community rights and conflict resolution); eight variables to assess the effective management of MPAs (e.g. law enforcement and local community participation); and four variables to assess MPA planning and design (e.g. management plans and MPA design). These variables not only helped me to explain the effectiveness of MPAs, but also to identify which variables are associated with high values for MPA outputs such as fish abundance and local community engagement (i.e., the existence of customary law and management practice in marine resource use). This finding is similar to another study that revealed that local community engagement is the most critical element driving MPA success, and its absence influences MPA failure (Giakoumi et al., 2018). Furthermore, the social-ecological variable analysis in Chapter 4 is also able to reveal which components of conservation outcomes indicators are closely related to the components in MPA management attributes, such as conservation planning, design and governance. This finding supports other literature that has observed how MPA input indicators such as effective governance and management are likely to improve MPA outcomes (Bennett & Dearden, 2014).

6.3 Spatial conservation planning and evaluation using social-ecological indicators and variables

In a complex ecosystem within an MPA, social-ecological studies can help conservation projects to decide priorities, plan, and address management strategies for implementation in the future (Guerrero & Wilson, 2017). I show how an existing mangrove conservation zone is ineffective in Chapter 3, and propose an improved zoning arrangement that has more socio-economic and ecological value. The study began by first understanding the complex social-ecological system in a local mangrove ecosystem to identify the indicators and variables involved and define the priorities for a mangrove conservation plan. This was done by examining the behaviour of the local community in extracting benefits from mangrove habitats (Vegh et al., 2014), evaluating the economic benefits of mangrove ecosystem services (Trialfhianty et al., 2014), and exploring the life cycle of mangroves from juvenile to adult to understand different environmental requirements (i.e., soil substrate) (Kathiresan & Bingham, 2001). The application of a social-ecological analysis helps to emphasize the priorities and goals of conservation management projects (Castillo-Eguskitza et al., 2019), with particular focus on local community behaviour, perspective and response (Levin et al., 2015). Here in Chapter 3, the use of multi-criteria analysis in conservation planning by incorporating various social-ecological variables has helped in understanding local community preferences and ecological priorities related to mangrove conservation goals and objectives. The lack of ecological coherence can reduce ecological performance of MPAs, resulting in a disruption in the flow of ecosystem services and a reduction in environmental benefits (Rees et al., 2018). Thus, in Chapter 3, I show that the outer area of the mangrove ecosystem that has soil substrate and is protected from excess water from coastal and river zones is suitable for core-zone management, as it better supports a critical nursery for mangrove juveniles.

A huge variety of MPA evaluation methods have been developed using a wide range of structured frameworks to assess MPA objectives globally (Pomeroy et al., 2005), at national level (EVIKA by Indonesian government (Hakim et al., 2020)), and for specific regions (MOSE in France, (Picone et al., 2020)) using both quantitative and qualitative data (Horigue et al., 2014). The underlying fundamental goal of these assessments is similar, which is to evaluate the effectiveness of MPA projects in achieving their goals, although their approach to the measurement of indicators and variables, the process of evaluating indicators (i.e. how data are being collected), and their analysis (including perspective and judgement) vary. In Chapter 4, I explored explicitly how MPA evaluations carried out at the national level (Indonesia) are distinct from the MPA evaluation method carried out by this study, which is supported by a social-ecological approach. Both methods use different indicators and variables (although we find several similar indicators used in both, such as local community participation and socio-economic conditions), and were carried out using different data collection approaches. However, both assessments showed a similar result for MPA effectiveness in Sabang and Nusa Penida (which is, both MPAs are not yet effective and have not yet achieved their goals). However, the analysis in this study, which uses a social-ecological approach, showed a more in-depth assessment by its ability to divide the two MPAs (Sabang and Nusa Penida) into two different categories based on quantitative values (MPA Nusa Penida is less effective with an Effectiveness Index value of 2.9 and MPA Sabang has intermediate effectiveness with an effectiveness value of 3.3). Furthermore, it can more specifically address local problems and issues by uncovering indicators related to the resource system, resource unit, government system, actors and their interactions that influences outputs in the whole social-ecological system setting (Ostrom & Cox, 2010). From this analysis, I argue that the most suitable and effective MPA evaluation method is the one that allows us to not only assess the effectiveness of an MPA, but also enables us to address locally related problems and issues, and develop effective, more comprehensive, and adaptable management strategies for the future.

6.4 Benefits, implications, challenges and the future of social-ecological studies of MPAs

The study presented in this thesis identifies many advantages of using social-ecological indicators and variables that emerge from understanding the social-ecological system (Table 6.1). The significant benefit from a social context is the ability of MPAs to avoid conflict and threats that could reduce MPA effectiveness. Many possible negative interactions between social variables and the outputs of MPAs emerge. For example, the social-ecological interaction framework (Chapter 2) reveals that resource dependency of local people on marine resources may have a negative impact on MPA outputs, such as fish abundance and living coral cover. Accordingly, in Chapter 4, I assessed the dependency of local people to understand the issues that could drive conflict regarding MPA zoning in Nusa Penida, addressed the interactions between resource dependency and MPA failure, and then highlighted the importance of local management. To explore this discovery in more depth, I show in Chapter 5 how customary practice and management can help reduce conflict related to MPA management and practice in Sabang. My results align with other research that has shown the social-ecological associations with conflict resolution by identifying the underlying factors for the current conflict (Karimi & Hockings, 2018).

Although this thesis was able to identify many advantages of using social-ecological systems approaches in improving many aspects of MPA management such as MPA planning and evaluation, the implications of using this approach in different case studies with different MPA conditions (i.e., MPAs that differ in age and size) may vary. Thus, for complex systems that differ regionally it can be a challenge when applying a social-ecological approach to study conservation (Leenhardt et al., 2015). Therefore, it is critical to identify MPA conditions, i.e., the social and ecological conditions, in the specific setting of an MPA before carrying out any study.

Further challenges in the use of social-ecological analysis for MPAs that I identified in this thesis are political views and preferences (Table 6.1). Although social-ecological studies can accommodate social and ecological priorities, when dealing with a complex social structure in a local community, it is hard to make reliable judgements. In Chapter 5, I discovered that the local community in Toyapekeh village was opposed to the core-zone placement in front of their village. They felt that they were powerless to make decisions even though they had tried to give their views to the MPA manager (currently managed by both a local NGO and government). They felt that they were a minority, being a group of Muslim villages surrounded by Hindu villages that have strong political power over the island. Thus, in some cases, incorporating local community priorities does not automatically mean that we can bring their voices into consideration for MPA management planning or evaluation. The political will and power of the MPA management and government policies can hinder the application of social-ecological studies for MPAs. Similar situations may arise in China, where political will governs any formation of MPAs from designation to planning and implementation (Li & Fluharty, 2017). In the end, the result of social-ecological studies may not be applicable to MPA management implementation if there is no support from the government. The government holds a lot of power over the process due to its role in shaping and establishing rules that provide for allocation of resource access and use (Palomo & Hernández-Flores, 2019).

Table 6.1 Benefits and challenges in using social-ecological studies for MPA management.

	Type of benefit or challenges	Aspect/Actor	Methods of identification
Benefits	Accommodating social and ecological priorities	Social/Local community	Interview and focus group discussion
	Economic benefit	Economic/all stakeholders	Economic valuation: Direct benefits, indirect benefits, optional benefits and existence benefits
	Reducing cost	MPA management	Cost-benefit
	Preserving biodiversity of critical area for survival	Ecology and ecosystem	Ecological survey
	Reducing conflict	Social/Local community	Interview and focus group discussion
	Strengthening accurate and targeted goals	MPA management	Focus group discussion
	Improving sustainability and resilience	Ecology and ecosystem	Ecological survey and focus group discussion
	Reducing threats	Social and ecology	Social-ecological interaction framework
Challenges	Integrating conservation management and local management practice (i.e. customary management)	Social and culture	Interview and focus group discussion

	Diverse and complex social-ecological conditions of MPAs at regional level	Social and ecology	Social and ecological survey
	Political views and preferences	Social and culture	Interviews and focus group discussion
	Changes in social-ecological conditions (i.e. climate change)	Social and ecology	Social and ecological survey

The future of social-ecological studies of conservation projects such as MPAs relies on how well the analysis can explain and identify a complex system that is built from diverse variables that have many possible positive and negative interactions, with varied consequences for MPA objectives. Thus, social-ecological studies of MPAs need to be comprehensive, but also adaptable by using a more flexible approach that is suitable in the local context (Ferro-Azcona et al., 2019), as well as integrated, co-developed and involving trans-disciplinary methods and analysis (Schmidt et al., 2022). For example, a Structural Equation Model (SEM) analysis can be used to explain the possible interactions of social and ecological variables with an MPA's output by representing in detail the strengths and weaknesses of each relationship between social and ecological dimensions within an MPA (Malaeb et al., 2000). Furthermore, a series of decision-making maps created by spatial analysis can help in designing a conservation plan that supports long-term social and ecological resilience (Noble et al., 2021).

Social-ecological studies of MPAs not only deal with the complex system and the conditions of its present variables and dimensions, but also a changeable environment. The changing climate and political conditions (Table 6.1) that influence MPA management can be a core problem. For example, in Chapter 5, I explain how customary management and practice in Sabang is changing over time due to the influence of outside wisdom and knowledge. This change illustrates that social-ecological studies conducted in the present may differ from future studies. Another study conducted in the Adaman Sea, Thailand shows that climate change has resulted in a decline in fish catch, suggesting that the identification of socio-economic and biophysical stressors in social-ecological studies will be important for improving the adaptive capacity of the local community within conservation areas (Bennett, 2013). It is possible that in the future, where many local-based studies reveal problems and issues in studies of MPAs, we will have a huge range of various sets of indicators and variables allowing us to understand social-ecological MPA systems in detail, helping us to address the complicated issues that emerge from these changes (i.e. climate change and political change).

6.5 Concluding remarks

The objective of conservation projects is not only to increase biodiversity, sustaining and improving the resilience of ecosystems, but also to improve the welfare of local communites. Thus, social-ecological analyses can assist in supporting MPA management by addressing the complex social and ecological systems within and in their surroundings. Social-ecological analysis can also help us to understand how the system works, explore the unique ecological and social variables within the system and anticipate the consequences that emerge from the interactions between them. Furthermore, the use of social-ecological analysis in understanding MPA management can help to identify conflicts and threats that decrease MPA effectiveness. However, the benefits of using social-ecological analysis to study MPAs can be challenged by many internal and external factors such as political views and preferences of MPA stakeholders, including central government, changes in social and ecological conditions of MPA ecosystems due to climate change, and the difficulties of integrating local and central management practices. Overall, the findings of this thesis show that social-ecological analysis is critical for understanding the complexity of MPAs, which are characterised by a range of unique ecosystems from muddy substrate to rocks to sandy substrate, distinct plant and animal species, and varied social-ecological conditions such as demography, and the political and economic context of the local community. Thus, MPA management, planning, and objectives cannot be generalised and must be examined and determined locally. However, despite the variations and the importance of local research on MPAs, we still need a generic set of indicators and variables that are suitable for assessing MPA performance. This was established in this thesis by examining various social-ecological case studies of Indonesian MPAs.

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Chapter 7. Appendix

7.1. Appendix 7.1 – Supplementary Material for Chapter 2

Table S2.1 The Application of Social-Ecological Analysis in the Marine Protected Area literature.

Focus and objective	Literature
Evaluating MPAs	(Ban et al., 2017; Blythe et al., 2017; Bryan et al., 2011; Christie, 2004; Cinner et al., 2012; Fleischman et al., 2014; Fox et al., 2014; Gladstone, 2000; González et al., 2008; Gurney et al., 2016; Krueck et al., 2019; López-Angarita et al., 2014; Oldekop et al., 2016; Twichell, Pollnac, & Christie, 2018; Pomeroy, Mascia, & Pollnac, 2007; Pomeroy, Parks, & Watson, 2004; Cinner et al., 2014; Brueckner-Irwin et al., 2019; Pelletier, D., 2020; Tebet et al., 2018)
Assessment associated with other aspects	
Institutions or customary law/taboos	(Bartlett, 2009; Cinner, Marnane, & McClanahan, 2005; Hoshino et al., 2016)
Ecosystem services Fisheries (fishes, coral, seagrass)	(Kittinger et al., 2015; Cullen-Unsworth et al., 2014; D'Anna & Murray, 2015; Johnson et al., 2019; Kittinger et al., 2013; Leslie et al., 2015; Wahyudin et al., 2018)
Tourism	(Blanco, 2011; Kurniawan et al., 2019; Lacitignola, Petrosillo, & Zurlini, 2010; Wu & Tsai, 2016)
General application for meta-data analysis	(Ban et al., 2015; Cinner et al., 2016; Pollnac et al., 2010)

Resilience	(Berkes & Turner, 2006; Brewer et al., 2013; Cinner, Fuentes & Randriamahazo, 2009; Cinner et al., 2013; Cumming et al., 2015; Cumming, Morrison, & Hughes, 2017; Jones, Qiu, & De Santo, 2013; McClanahan et al., 2009)
Connectivity	
Relation between variables	(Aswani et al., 2013; Barnes et al., 2019; Cinner et al., 2018; Cinner et al., 2009; Hicks et al., 2015; Mora et al., 2011; Palomo, Martín-López et al., 2011; Twitchell et al., 2018; Scyphers et al., 2014; Kaplan et al., 2015; Daw et al., 2011; Dalton et al., 2015; Castrejón et al., 2020; Chan et al., 2019)
Framework, model and concept	(Aswani, 2019; Ban et al., 2013; Glaser et al., 2012; Kittinger et al., 2012; Leenhardt et al., 2017; Miller, Caplow, & Leslie, 2012; Österblom et al., 2013; Palomo et al., 2014; Rees et al., 2018; Stevenson & Tissot, 2014; Collier, C. E., 2020; Cornu et al., 2014; Ferraro et al., 2019; Micheli et al., 2013; Palomo et al., 2019)

Table S2.2 List of IUCN's criteria to evaluate MPA performance.

Good Governance
5. Recognizes and promotes the rights of indigenous peoples and local communities. 6. Has clearly defined, legitimate, equitable and functional governance arrangements. 7. Fairly represents and addresses the interests of civil society, rights holders and legitimate stakeholders. 8. Has governance arrangements and decision-making processes that are transparent and appropriately communicated, and responsibilities for their implementation are clear.
Sound Planning and Design

1. Meets the IUCN MPA definition and is accurately assigned to an IUCN PA category.
2. Has clear, long-term conservation goals and objectives, based on a sound understanding of natural, cultural and socio-economic values and context.
3. Is well-sited and with a defined boundary.
4. Has a management plan, or equivalent documentation, with a periodic plan review and amendment process for updating/refining goal and objectives, conservation targets and management prescriptions in response to changing needs and conditions.
5. Is not vertically zoned
6. Individually, or as part of a network of MPAs, incorporates significant no-take areas; and where in a network, the no-take areas are distributed across MPAs.
7. Is large enough to achieve the conservation objectives and goals individually or as part of a network of MPAs.

Effective Management

1. Has well-constructed and defined objectives and goals for nature conservation.
2. Addresses the threats to marine biodiversity and so overall, has activities and uses that are compatible with, and support the conservation objectives and goals
3. Has extractive activities (where these occur) that have low ecological impact, are compatible with the MPA's objective(s), are compatible with the IUCN definition and categories, and that are well managed as part of an integrated approach.
4. Does not have any environmentally damaging industrial activities or infrastructural developments located in, adjacent to, or otherwise negatively affecting it.
5. Regulates fisheries activities (where these occur) that are low impact, assessed and managed to the highest standards, and that do not impact the ecological integrity of the area, species levels and trophic structure. Any fishing gear used should not significantly impact other species or other ecological values.

6. Has adequate resourcing, including staff capacity, as this is shown to be a key determinant for management effectiveness and success. 7. Has sufficient investment in compliance. 8. Addresses the threats to marine biodiversity and so overall, has activities and uses that are compatible with, and support the conservation objectives and goals. 9. Has monitoring to track performance and inform adaptive management. Such monitoring should be standardized across MPAs in the network to document and demonstrate management effectiveness, and to report that conservation goals, objectives, and defined biodiversity conservation targets are being achieved.
Conservation Outcomes
1. Meets or exceeds the stated nature conservation objectives and goals. 2. Demonstrates successful long-term conservation of major natural values, with associated ecosystem services and cultural values

Taken from IUCN WCPA (2018)

Reference

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Table S2.3 List of identified indicators, variables, their definitions and measurement

Type of indicator	Name of indicator	Identified variable	Definitions	Measurements
Biophysical	Area under no or reduced human impacts	Coastal protection	Strategies implemented to safeguard coastal areas from erosion, flooding, and other natural hazards. This can involve physical structures (like seawalls, breakwaters, and dunes), natural solutions (like restoring mangroves and wetlands), and regulatory approaches (like zoning laws and land-use planning).	The availability of technology and systems to support coastal areas from climate-related hazards (e.g. breakwaters, existence of mangrove ecosystem).
		Human gravity	Broad-scale human impacts on coral reefs.	Intensity of human impacts in the surrounding seascape, measured as a function of human population size and accessibility to reefs.
	Composition and structure of the community	Coral diversity and richness	Coral diversity refers to the variety of coral species within a specific area, while richness indicates the number of different species present.	Use surveys (like belt transects or quadrats) to identify and count species within a defined area. The Shannon-Wiener or Simpson's Diversity Index can quantify diversity.
		Benthic diversity	The variety of organisms living on or in the seabed, including plants, animals, and microorganisms.	Conduct surveys to sample benthic organisms and analyze species composition and richness.
		Fish diversity and richness	Fish diversity refers to the range of fish species in an area, and richness measures the number of species present.	Employ visual surveys, catch data, or underwater photography to

				document fish species. Calculate diversity indices.
	Focal species abundance	Fish abundance	The total number of individual fish present in a specific area or ecosystem.	Use catch per unit effort (CPUE) from fishery data or underwater visual census techniques.
		Benthic abundance	The total number of benthic organisms (e.g., mollusks, crustaceans) present in a given area.	Count individuals in benthic samples collected through quadrats or cores.
		Fish size distribution	The range and frequency of different sizes of fish within a population.	Measure and record the sizes of fish caught or observed, and create size frequency distributions.
		Biotic population	A community of living organisms in a specific habitat.	Use population surveys and assessments (e.g., mark-recapture studies) to estimate population size.
	Food web integrity	Herbivore functional diversity	The range of roles and functions performed by herbivorous species in an ecosystem.	Assess the roles of different herbivore species in the ecosystem, using traits such as feeding strategies.
		Predator-prey biomass	The balanced proportion of predator and prey population in the area	Estimate biomass through catch data or ecological modeling, focusing on trophic interactions.
	Habitat distribution & complexity	Benthic structure complexity	The physical characteristics of the seafloor habitat that influence biodiversity and species interactions.	Use metrics like rugosity or 3D mapping of habitats to quantify structural complexity.
		Coral distribution	The geographical spread of coral species across different regions.	Map coral locations using GPS and remote sensing techniques to analyze patterns of distribution

		Coral isolation	The degree to which coral populations are separated from one another, affecting genetic exchange.	Assess genetic diversity through sampling and molecular analysis to determine gene flow between populations.
		Ecological resilience	The capacity of an ecosystem to recover from disturbances or changes.	Monitor ecosystem recovery after disturbances, using metrics such as biodiversity recovery rates.
		Living coral cover	The percentage of the substrate that is covered by living coral.	Use underwater surveys and photography to estimate the percentage of substrate covered by live coral.
		Fish biomass	The total mass of fish in a specific area, often used as a measure of fishery health.	Calculate biomass using weight estimates of fish collected through catch data or underwater observations.
	Water quality	Ocean primary productivity	The rate at which primary producers (like phytoplankton) convert sunlight into organic matter.	Measure chlorophyll-a concentrations via satellite or water sampling to assess productivity levels.
		Net primary productivity	The amount of organic matter available for consumption after accounting for energy used by producers.	Estimate through biomass measurements of primary producers and their growth rates.
	Type, level and return on fishing effort	Number of users	The total number of individuals or entities utilizing a specific resource.	Conduct surveys or stakeholder interviews to quantify the number of people utilizing a resource.
		Number of fishing gear	The variety or quantity of fishing equipment used in a specific area or fishery.	Inventory of types of fishing gear used in a community or area through surveys.

		Gear diversity	The range of different types of fishing gear used within a fishery, impacting catch efficiency and selectivity.	Assess the range of gear types used, categorizing them by their fishing methods and target species.
		Fishing effort and pressure	The amount of labour, time, and resources expended in fishing activities and its impact on fish populations.	Monitor effort through catch records, days fished, and gear used, correlating with catch data.
		Gear ownership	The number of fishers or people who own the fishing gear (e.g. boat, fishing rod).	Survey fishers to determine ownership rates and types of gear.
Socio-economic	Distribution of formal knowledge to community	Ecological knowledge & education	The understanding of ecological principles and practices necessary for effective conservation.	Assess through surveys that gauge understanding of ecological concepts and management practices.
	Household income distribution by source	Income	The earnings generated by individuals or communities (not specifically on fisheries resources only).	Collect data through household surveys to measure income sources and amounts.
	Household occupational structure	Employment	Job opportunities available in fisheries, tourism, and related sectors.	Use labor force surveys to gather information on employment rates in fisheries and related sectors.
	Level of understanding of human impacts on resources	Benefit of MPA	The advantages provided by Marine Protected Areas, such as biodiversity conservation and enhanced fish stocks.	Use socio-economic surveys to assess perceived benefits among local communities.
	Local value and beliefs	Acceptance of MPA	The extent to which local communities support and accept the establishment of Marine Protected Areas.	Measure through community surveys that gauge support and attitudes toward MPAs.

	about marine resources	Conservation belief & awareness	The understanding and attitudes of communities towards conservation efforts and their importance.	Use household (??) surveys to assess awareness of conservation issues and belief systems.
		Customary law	Traditional rules and practices governing resource use and management in local communities	Document traditional regulations through interviews with community leaders.
	Material style of life	Community wealth	The overall economic resources and assets held by a community.	Measure through asset inventories, income surveys, and economic assessments.
		Livelihood	The means by which individuals or families sustain themselves, often through fishing, tourism, or agriculture.	Assess through surveys that evaluate sources of income and resource use.
		Human capital	The skills, knowledge, and experience possessed by individuals that contribute to economic productivity.	Measure skills and education levels through surveys or workforce assessments.
		Financial capital	The monetary resources available for investment and economic activity.	Assess through economic surveys that evaluate financial assets and resources.
		Socioeconomic development index	A composite measure that assesses a community's economic and social development.	Create a composite index based on multiple socioeconomic indicators (e.g., income, education, health).
		Gender diversity & inclusion	The representation and involvement of different genders in decision-making processes and resource management.	Use demographic surveys to assess gender representation in decision-making and management roles.
	Number and nature of markets	Trade (fishery)	The exchange of fish and fish products, both domestically and internationally.	Measure trade volumes and values through market surveys and catch data.

		Market distance & distribution	The geographic proximity of fishing communities to markets and the distribution of fish products.	Analyze geographic data to determine distances from fishing communities to markets.
	Perceptions on local harvests	Reef fish landing	The amount of fish caught and brought to shore from reef ecosystems.	Use landing records from fishers and markets to quantify catch data.
		National fish landing	The total amount of fish caught and reported across a country.	Aggregate data from regional fisheries agencies to calculate national landings.
		Fishery productivity	The efficiency and output of a fishery, often measured by the amount of fish harvested per unit of effort.	Measure through catch data and stock assessments, often calculated as CPUE.
		Fish trend	Changes in fish populations or catch rates over time, indicating sustainability or depletion.	Use time-series data to analyze trends in fish populations and catches over time.
	Perception on seafood availability	Food security	The availability and access to sufficient, safe, and nutritious food for all individuals.	Assess through surveys that evaluate access to food and nutritional status.
	Quality of human health	Social-ecological fitness	The ability of social and ecological systems to adapt and thrive in changing conditions.	Use indicators that assess both social and ecological system health, often through modeling.
	Percentage of stakeholder group in leadership position	Organisational experience	The knowledge and capabilities developed by organizations over time, influencing their effectiveness in management.	Survey organizations to assess their history, capacities, and experiences in resource management.
		Leadership	The ability of individuals or groups to guide and influence communities or organizations towards achieving goals.	Evaluate leadership structures and effectiveness through surveys and interviews.
	Local marine resource use patterns	Human population (growth & size)	The number of people living in a specific area and the rate at which this number increases.	Use demographic data from censuses or surveys.

		Fisher impacts	The effects of fishing activities on marine ecosystems, including fish populations and habitats.	Assess through ecological studies examining the effects of fishing practices on ecosystems.
	Perception of non-market and non-use value	Market value	The worth of fish and fish products in economic terms determined by community's perspective	Determine through economic valuation analyses of non-market and non-use value of fish product.
	Community infrastructure & business	Community infrastructure & management	The physical and organizational structures that support community activities and resource management.	Inventory and assess infrastructure quality through surveys and site assessments.
		Tourism	The economic activities related to travel and recreation, particularly in coastal areas.	Collect data on tourism metrics (visitors, revenue) through industry reports and surveys.
Governance	Existence and activity level of community organizations	Social capital	The networks, relationships, and trust that facilitate cooperation within a community.	Measure community networks and trust levels through social surveys.
		Shared economic benefit	The equitable distribution of financial gains derived from resources among community members.	Assess through surveys and economic analysis of benefit-sharing mechanisms.
	Level of stakeholder participation and satisfaction in management	Attitudes towards MPA	The perceptions and feelings of individuals or communities regarding Marine Protected Areas.	Measure through public opinion surveys and focus groups.
	Proportion of stakeholders trained in	Behaviour control	The influence of regulations and norms on individuals' actions regarding resource use.	Evaluate through studies examining compliance with regulations and community norms.

	sustainable use	Training	Educational programs aimed at enhancing skills and knowledge related to fisheries management and conservation.	Track training participation and outcomes through program evaluations.
	Existence of a decision-making and management body	MPA management	The processes and strategies used to oversee and regulate Marine Protected Areas.	Assess management effectiveness through performance indicators and stakeholder feedback.
		Effective management structure	A well-organized system for decision-making and resource management that leads to positive outcomes.	Evaluate organizational structures and processes through assessments and audits.
	Level of training provided to stakeholders in participation	Capacity to change	The ability of a community or organization to adapt to new conditions or challenges.	Measure adaptability through surveys that assess community and organizational responses to change.
		Capacity building	Activities aimed at improving the skills and resources of individuals or organizations to enhance their effectiveness.	Assess training and development programs through evaluations and feedback.
		Empowerment	The process of enabling individuals or communities to take control of their resources and decision-making.	Measure through surveys evaluating decision-making authority and participation levels.
	Existence and application of scientific research and input	Technological constraints	Limitations imposed by the availability or use of technology in fisheries and conservation.	Identify limitations through surveys and assessments of available technology.
	Availability and allocation of MPA administrative resources	Incentive & investment	Motivations and financial commitments made to encourage sustainable practices and resource management.	Track funding sources and investment levels through financial reports.
		Monitoring	The ongoing process of collecting data to assess the status of resources and the effectiveness of management measures.	Establish protocols for regular data collection and assessment, using

				indicators of ecological and social parameters.
		Accountability & feasibility	The responsibility to report on actions taken and the practicality of proposed management strategies.	Evaluate governance structures through assessments of transparency and effectiveness.
	Clearly defined enforcement procedures	Enforcement	The implementation of laws and regulations to ensure compliance with resource management practices.	Measure compliance with regulations through monitoring and reporting violations.
		Gear restriction	Regulations limiting the types or methods of fishing gear that can be used to protect resources.	Assess adherence to gear restrictions through compliance checks and surveys.
		Sanctions	Penalties imposed for non-compliance with fishing regulations.	Track instances of sanctions imposed for non-compliance through enforcement records.
	Enforcement coverage	Patrols	Regular monitoring activities conducted to ensure compliance with regulations and protect resources.	Measure the frequency and effectiveness of patrols through monitoring reports.
	Level of stakeholder involvement in surveilance, monitoring and enforcement	Participation in conservation	The involvement of community members in conservation activities such as monitoring and patrol.	Survey community involvement in conservation activities such as monitoring and patrol.
	Local understanding of MPA rules and regulations	Rules implementation & commitment	The process of enforcing established rules and the dedication to adhere to them.	Assess through evaluations of adherence to established rules and regulations.

	Level of resource conflict	Voice	The ability of individuals or groups to express their opinions and influence decision-making processes.	Measure through surveys that evaluate opportunities for community input in decision-making.
		Community rights	The rights of communities to manage and benefit from their natural resources.	The degree to which individuals feel that they are able to gain access to resources.
		Resource dependency	The extent to which individuals or communities rely on natural resources for their livelihoods.	Assess reliance on resources through surveys measuring usage and income.
		Conflict resolution	The methods and processes used to settle disputes over resource use and management.	Evaluate effectiveness of conflict resolution mechanisms through case studies and surveys.
	Degree of information dissemination to encourage stakeholder compliance	Information sharing	The exchange of data and knowledge among stakeholders to improve resource management.	Measure through surveys that assess the flow of information among stakeholders.
	Satisfaction in management process and activities	Community's trust	The level of confidence that community members have in MPA	Assess levels of trust through surveys evaluating relationships between community members and leaders.
	Degree of interaction between managers and stakeholders	Shared vision	A common understanding and agreement on goals and objectives within a community or organization.	Evaluate through workshops and stakeholder engagement processes assessing alignment on goals.

	Existence and adoption of a management plan	Compatibility between management and customary law	The alignment of formal management practices with traditional rules and practices.	Assess alignment through legal analyses and community consultations.
		Management plan	A strategic document outlining objectives, actions, and measures for resource management.	Evaluate the existence and effectiveness of management plans through assessments and stakeholder feedback.
	Existence and adequacy in enabling legislation	MPA age, size & distribution	The duration since the establishment of Marine Protected Areas, their physical extent, and their geographic spread.	Collect data from geographic and historical records to analyze the characteristics of MPAs.

7.2. Appendix 7.2 – Supplementary Material for Chapter 3

Table S3.1 Coordinates of five survey stations in Baros mangroves.

Station	*Coordinate*	*Description*
I	08°00'33.6"S110°17'02.2"E	Located nearby land area which receive regular nutrient and waste from land-based activities such as farming. Muddy substrate with high density of mangrove dominated by *Rhizophora apiculata*
II	08°00'30.3"SE 110°17'00.2"E	Muddy substrate with low density of mangrove species.
III	07°46'04.5"S 110°22'46.0"E	Located in Opak river as an outer area of mangrove. However, some mangrove-related activities are present.
IV	08°00'33.8"S110°17'02.4"E	High density of mangrove with muddy substrate.
V	08°00'29.4"S110°16'49.8"E	High density of mangrove, muddy substrate, deep water during high tide.
VI	08°00'29.1"S110°16'49.2"E	High salinity (6‰), deep water during high tide, dominated by *Avicennia lanata*.

Table S3.2 Important value of various mangrove species in Baros.

Species	*Pi*	*Fi*	*Rfi*	*Important Value*
Rhizophora apiculata	6	0.75	42.86	77.16
Avicennia lanata	7	0.88	50.00	177.81
Mangrove associate				
Thespesia populnea	1	0.13	7.14	16.24

Table S3.3 Each parameter of water quality in Baros water

Parameter	*Station*						*Optimum value for organism**
	1	2	3	4	5	6	
Water temperature (°C)	29.30	29	29.30	28.60	29	29.20	20-30
pH	7.28	7.36	7.40	7.30	7.22	7.20	7-8.5
Salinity (‰)	0.30	0.40	0.30	0.30	0.40	0.40	
TSS (mg/l)	0.97	0.70	0.93	0.87	0.87	0.69	< 50

DO (mg/l)	8.28	6.62	7.02	7.40	7.37	7.39	> 4
CO_2 (mg/l)	85.10	85.10	69.20	55.30	75.40	54.70	< 5
Alkalinity (mg/l)	68.50	73.80	63.36	86.20	77.20	75.80	30 – 500
Nitrate (mg/l)	0.52	0.09	0.34	0.42	0.16	0.05	0.9 – 3.5
Phosphate (mg/l)	0.31	0.23	0.48	0.32	0.29	0.27	0.09 – 1.8

*Optimum value for organism based on UNESCO, WHO and UNEP (1996)

Table S3.4 Phytoplankton conditions in each station.

	Station					
	1	2	3	4	5	6
Density index	99	79	91	111	129	129
Diversity index	0.66	1.01	0.89	1.16	0.96	0.86
Evenness index	0.65	0.57	0.49	0.59	0.58	0.60
Dominance index	0.67	0.53	0.60	0.51	0.59	0.56

Table S3.5 Percentage of community's participation on mangrove related activities.

Participation		Involvement				Total	Percentage (%)
		No	Percentage (%)	Yes	Percentage (%)		
Seeking knowledge	never	16	26.7	4	6.7	20	33.3
	only once	1	1.7	0	0.0	1	1.7
	seldom	7	11.7	13	21.7	20	33.3
	often	2	3.3	13	21.7	15	25.0
	always	0	0.0	4	6.7	4	6.7
Outreach program	never	12	20.0	3	5.0	15	25.0
	only once	4	6.7	2	3.3	6	10.0
	seldom	6	10.0	16	26.7	22	36.7
	often	4	6.7	10	16.7	14	23.3
	always	0	0.0	3	5.0	3	5.0
Planning	never	12	20.0	2	3.3	14	23.3
	only once	5	8.3	2	3.3	7	11.7
	seldom	7	11.7	14	23.3	21	35.0
	often	2	3.3	14	23.3	16	26.7
	always	0	0.0	2	3.3	2	3.3
	never	7	11.7	1	1.7	8	13.3

Mangrove planting	only once	6	10.0	3	5.0	9	15.0
	seldom	6	10.0	14	23.3	20	33.3
	often	7	11.7	13	21.7	20	33.3
	always	0	0.0	3	5.0	3	5.0
Monitoring	never	4	6.7	1	1.7	5	8.3
	only once	2	3.3	1	1.7	3	5.0
	seldom	8	13.3	6	10.0	14	23.3
	often	11	18.3	17	28.3	28	46.7
	always	1	1.7	9	15.0	10	16.7
Giving contributions (funds)	never	22	36.7	9	15.0	31	51.7
	only once	0	0.0	8	13.3	8	13.3
	seldom	4	6.7	5	8.3	9	15.0
	often	0	0.0	11	18.3	11	18.3
	always	0	0.0	1	1.7	1	1.7
Fund rising program	never	21	35.0	10	16.7	31	51.7
	only once	2	3.3	6	10.0	8	13.3
	seldom	2	3.3	8	13.3	10	16.7
	often	0	0.0	8	13.3	8	13.3
	always	1	1.7	2	3.3	3	5.0
Security	never	5	8.3	0	0.0	5	8.3
	only once	1	1.7	0	0.0	1	1.7
	seldom	4	6.7	7	11.7	11	18.3
	often	15	25.0	18	30.0	33	55.0
	always	1	1.7	9	15.0	10	16.7
Expanding networking	never	9	15.0	1	1.7	10	16.7
	only once	3	5.0	2	3.3	5	8.3
	seldom	7	11.7	7	11.7	14	23.3
	often	7	11.7	14	23.3	21	35.0
	always	0	0.0	10	16.7	10	16.7
Developing new program	never	10	16.7	3	5.0	13	21.7
	only once	2	3.3	1	1.7	3	5.0
	seldom	5	8.3	6	10.0	11	18.3
	often	7	11.7	13	21.7	20	33.3
	always	2	3.3	11	18.3	13	21.7

Table S3.6 The distribution of respondent's knowledge on mangrove Baros based on their age

Knowledge	Age												
	18- 30		31 - 40		41 - 50		51 - 60		>60		Total		
	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Total
Not knowing	0	0	0	0	0	0	1	0	0	0	1	0	1
Less knowing	0	0	0	0	0	0	0	0	3	0	3	0	3
Moderate	0	1	2	0	0	0	2	0	0	0	4	1	5
Knowing	2	6	4	3	4	4	2	4	5	1	17	18	35
Knowing everything	0	15	0	0	1	0	0	0	0	0	1	15	16
Total	2	22	6	3	5	4	5	4	8	1	26	34	60
Percentage (%)	3.3	36.7	10.0	5.0	8.3	6.7	8.3	6.7	13.3	1.7	43.3	56.7	100

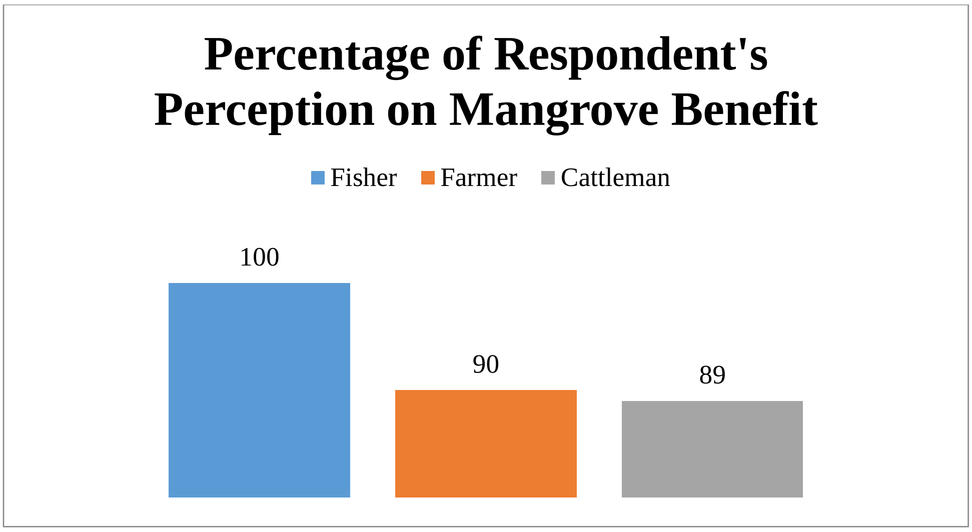

Figure S3.1 Diagram chart of respondent's perception on mangrove's benefit

Table S3.7 Total Economic value of mangrove benefit in Baros

Type of Benefit	*Economic value (USD/ha/year)*	*Percentage (%)*
Direct benefit		
a. Fishing	1,116.66	11.7
b. Tourism	257.90	
Indirect benefit		
a. Green-belt function	6,326.16	
b. Feedlots	1,458.23	78.2
c. Erosion prevention	1,400.69	
Optional benefit	11.87	0.1

Existence benefit	1,168.86	10

1 USD = IDR 14,373

Table S3.8 Weight value of each parameter used on GIS interpolation

Station	*Traditional fishing*	*Mangrove nursery and planting*	*Feedlots*	*Aqua-culture (shrimp)*	*Tourism: bird watching and camping*	*Education and research*	*Green-belt area for farming*
I	0	5	1	3	0	4	4
II	0	5	2	3	4	4	4
III	5	0	2	0	4	4	0
IV	1	4	2	2	4	4	4
V	3	4	0	2	0	4	0
VI	5	3	2	2	4	4	4

7.3. Appendix 7.3 – Supplementary Method for Chapter 3

A. Map accuracy assessment

The tentative land use map derived from the interpretation process is then assessed to generate an accuracy value. Slovin's formula is used to calculate the number of sample points such as follows (Sevilla, 1984 in Handayani, 2020):

$$n = \frac{N}{1 + N.e^2} \quad \text{................................ (5)}$$

where n = minimum number of samples

N = number of population

e = tolerance limit of error (10 per cent)

By using this formula, the required sample points for accuracy assessment are 100 points based on 187,465 sqm of population size (N) using 10 per cent of the tolerance limit of error (e).

Table S3.9 Land use area of the tentative map

No	Land use	Area (sqm)	Σ Sample points (n)
1	Building	1,081	1
2	Mangrove	15,218	8
3	Meadow	22,748	12
4	Other vegetation	1,966	1
5	Pond	2,518	1
6	Rice field	80,215	42
7	River	63,201	34
8	Sandbar	518	1
	Population size (N)	187,465	100

We use the image-to-image correction technique (Short, 1986 in Danoedoro, 2012) with high-resolution satellite images acquired in 2013 released by Badan Informasi Geospasial (Geospatial Information Agency/BIG) of Indonesia as a reference map. The sample points distribution (Figure S3.2) is defined by purposive stratified sampling considering the area with the most stable land use/not easily changed and the representation of each land use (Danoedoro, 2012).

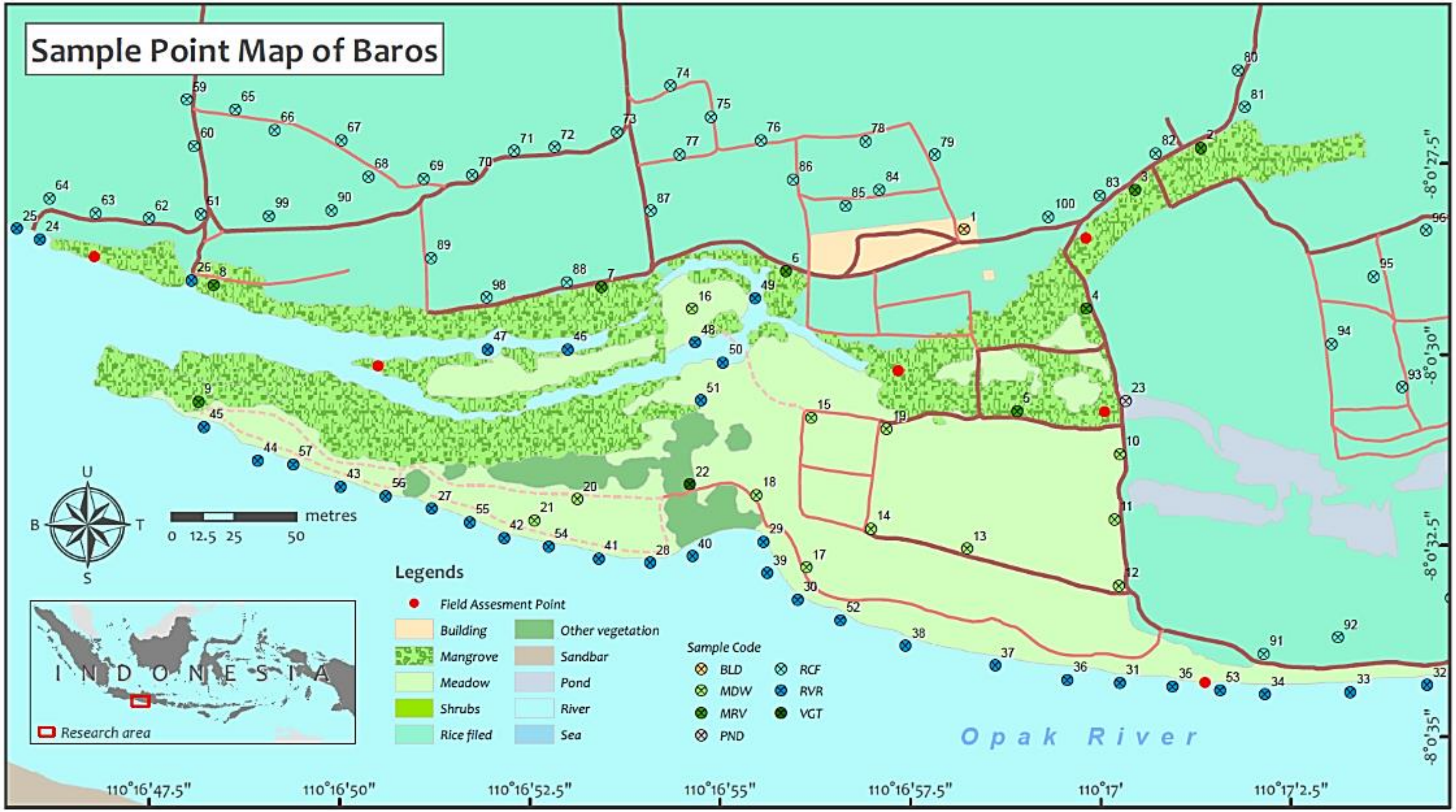

Figure S3.2 Sample point map of Baros

We plot all the sample points result in the error matrix as follows:

Land use class		Producer								
		Building	Mangrove	Meadow	Other vegetation	Pond	Rice field	River	Sandbar	Total
User	Building	1								1
	Mangrove		6					3		9
	Meadow			8						8
	Other vegetation		1		1		2			4
	Pond					1				1
	Rice field		1				41			42
	River			1				30		31
	Sandbar			3				1	0	4
	Total	1	8	12	1	1	43	34	0	100

The result above is then used to generate the Kappa coefficient with formula such as follows (Mather & Tso, 2016):

$$\hat{k} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})} \quad \text{.........................} \ (6)$$

where $\hat{k}$ = the Kappa coefficient

r = the number of columns (and rows) in a confusion matrix

x_{ii} = entry (i, i) of the confusion matrix

x_{i+} and x_{+I} = the marginal totals of row i and column j, respectively

N = the total number of observations

This formula resulted Kappa coefficient (kˆ) as 0.83 with the overall accuracy of 88 per cent.

B. Mangrove survey

Data were collected using a quadrant sampling method within a 100m^2 area in each sample location. The sample area was marked using 40m rope, mangrove data such as tree species, individual tree counts and diameter of each tree were collected to calculate several values, following Curtis and McIntosh (1950):

$$Fi = \frac{Pi}{\sum P} \text{ ....(7)}$$

$$FRi = \left(\frac{Fi}{\sum F}\right) x\ 100 \text{ ....(8)}$$

Where, Fi = frequency of species i

Pi = number of plots where species i occurs

FRi = relative frequency of species i

∑F = total number of all species

∑P = total number of plots

$$Ci = \frac{BA}{A} \text{ , where BA = } \frac{\pi DBH2}{4} \text{ .... (9)}$$

$$RCi = \left(\frac{Ci}{\sum C}\right) x\ 100 \text{ .... (10)}$$

Where,

Ci = covered area for species i

BA = basal area (cm)

DBH = diameter of mangrove (cm)

A = total area of the plot (m2)

∑C = covered area for all species

RCi = relative coverage of species i

$$Di = \frac{ni}{A} \text{ .... (11)}$$

$$RDi = \left(\frac{ni}{\sum n}\right) x\ 100 \text{ .... (12)}$$

Where,

Di = density of species i (individual/ha)

ni = counts per species i

∑n = total number counts for all species

A = total area of sample

RDi = relative density of species i

Important value index = RD + FR+ RC .... (13)

The important value index of mangrove area ranged between 0-300. This number showed the dominance level of individual mangrove species in a particular area. The calculation above (11) follows Curtis (1959).

C. Water quality survey

Table S3.10 Method for assessing water quality

Parameter	*Method*	*Equiptment*	*Material*
Temperature	Insitu	Termometer Hg scale 0-100ºC	-
pH	-	pH meter	-
Salinity	-	Refractometer	-
TSS	Gravimetric	Paper filter (2,5µm), analytic scale	-
DO	Winkler	Erlenmeyer, oxygen bottle, pipette	$MnSO_4$, oxygen reagent, H_2SO_4, starch, and 1/80 N $Na_2S_2O_3$.
CO_2	Alkalimetric	Erlenmeyer, oxygen bottle, pipette	Phenolphthalein (PP) and 1/44 N NaOH
Alkalinity	Alkalimetric	Erlenmeyer, oxygen bottle, pipette	Phenolphthalein (PP), 1/50 N H_2SO_4 and methyl orange (MO).
Nitrate	Spectrophotometry		
Phosphate	Spectrophotometry		

D. Susceptibility assessment

We categorised the level of susceptibility to abrasion in Baros as follows:

(1) High level: shore area with a distance of 0–100 metres from the shoreline and elevation of 0-25 metres above sea level

(2) Moderate level: beach area with a distance of >100-400 metres from the shoreline and an elevation of 25-35 metres above sea level

(3) Low level: beach area with a distance of >400-500 metres from the

shoreline and elevation of >35 metres above sea level

E. Questionnaire

GENERAL

1) Did you help develop the mangrove area of Baros mangrove?
   If so, what kind of assistance did you contribute? ________________
2) Are there any changes that occurred before/after the mangrove area in Baros mangrove?

   ____
3) What are the benefits of the mangrove area in Baros mangrove that you feel?

   ____
4) Do you use the mangrove area in Baros?
   If yes, proceed to question number 5. If not, it is enough.
5) What kind of use do you do?

   ____
6) Where is exactly the part of mangrove area that you use?

   ____
7) How long have you been using the mangrove area for this activity?

   ____
8) Are the results of your use of the mangrove area used to increase your income?

   ____

FARMER

1) How much area of paddy field/plantation do you have (m2)?

   ____
2) What types of plants do you produce on the land?

   ____
3) How much does it cost to buy/rent rice fields/plantations (per m2)?

   ____
4) In one year how many times do you do planting activities (from planting seeds to harvesting)?

   ____

5) Has the area changed after the mangrove area was in Baros mangrove?

   If yes, from ________ m^2 to __________ m^2

6) Did the amount of production (harvest) change after the mangrove area was located in Baros mangrove?

   If yes, from ________ kg to __________ kg

7) What is the frequency with which you irrigate your fields/plantations (per week)?

   ____

8) How much does it cost you to irrigate your fields/gardens?

   ____

Operational Cost (one planting period)

Type of plant	Number of seeds	Price of seeds	Amount of fertilizer	Price of fertilizer	Number of harvests (kg)	Price of plants harvested (Rp/kg)

CATTLEMAN

1) Do you feed your livestock in the mangrove area?

   If yes, the question is continued to number 2. If not, it is completed.

2) What kind of livestock do you have?

   ____

3) How many cattle do you have?

   ____

4) When exactly do you go to the mangrove area to feed your livestock?

   ____

5) How much feed does your livestock need at a time (kg/day)?

   ____

6) What is the price of animal feed that is usually sold in the market (Rp/kg)?

AQUACULTURE

1) What types of fishery commodities do you cultivate in the mangrove area?
2) How much mangrove area do you use for cultivation activities?
3) How many fishery commodities do you cultivate?
4) What is the size of the commodity that you are cultivating?
5) What components do you need to set up a cultivation unit?
6) What components do you need to run a cultivation business every day?
7) How much do you have to spend to buy the components mentioned above?

Cultivation Production

No.	Type of commodity cultivated	Quantity	Size (kg)	Selling price (Rp)

*one harvest period

FISHERS

1) Do you carry out fishing activities in the mangrove area?

   If yes, continue to question number 2. If not, it is sufficient.
2) How many trips/fishing activities do you take in one month?
3) How much time do you spend doing fishing activities?

____

4) When exactly do you do fishing activities? (morning, evening, afternoon)

____

5) What components do you need to carry out fishing activities? (example: supplies, gasoline)

____

6) How much do you have to pay for these components each time you catch fish?

Supplies, Rp ____________

Gasoline, Rp________________

Others, Rp________

7) Where do you sell the catch?

____

Catch Production (average in one day fishing)

No.	Type of fishing gear	Type of catch (type of fish, crab or shrimp)	Quantity (kg)	Selling price (Rp)

Matrix calculation

1) AHP matrix on Natural Value of Coastal Environment (NVC) criterion

	Water quality	Chlorophyll	Important value index of mangrove
Water quality	1	5	8
Chlorophyll	1/5	1	3
Important value index of mangrove	1/8	1/3	1

	Priority	Rank

Water quality	0.742	1
Chlorophyll	0.183	2
Important value index of mangrove	0.075	3

CR = 0.046 (4.6%)

2) AHP matrix on Commercial Value (CMV) criterion

	Feedlots	Traditional fishing	Aquaculture
Feedlots	1	5	3
Traditional fishing	1/5	1	1
Aquaculture	1/3	1/1	1

	Priority	Rank
Feedlots	0.659	1
Traditional fishing	0.156	3
Aquaculture	0.185	2

CR = 0.03 (3%)

3) AHP matrix for zoning scenario

Zoning	Criteria	NVC Natural Value of Coastal Environment	CMV Commercial Value	RCV Recreational and Cultural Value	APD Accessibility and Potential Disturbance
Restricted Access Zone	NVC Natural Value of Coastal Environment	1	7	6	5
	CMV Commercial Value	1/7	1	4	2
	RCV Recreational and Cultural Value	1/6	¼	1	1
	APD Accessibility and Potential Disturbance	1/5	½	1	1
Sanctuary Zone	NVC Natural Value of Coastal Environment	1	2	6	5

	CMV Commercial Value	½	1	1	3
	RCV Recreational and Cultural Value	1/6	1	1	2
	APD Accessibility and Potential Disturbance	1/5	1/3	½	1
Habitat Protection Zone	NVC Natural Value of Coastal Environment	1	2	4	5
	CMV Commercial Value	½	1	1	3
	RCV Recreational and Cultural Value	¼	1	1	5
	APD Accessibility and Potential Disturbance	1/5	1/3	1/5	1

Zoning	Criteria	Priority	Rank
Restricted Access Zone	NVC Natural Value of Coastal Environment	0.658	1
	CMV Commercial Value	0.075	4
	RCV Recreational and Cultural Value	0.091	3
	APD Accessibility and Potential Disturbance	0.177	2
CR = 0.094 (9.4%)			
	NVC	0.554	1

	Natural Value of Coastal Environment		
Sanctuary Zone	CMV Commercial Value	0.150	3
	RCV Recreational and Cultural Value	0.082	4
	APD Accessibility and Potential Disturbance	0.214	2
CR = 0.051 (5.1%)			
Habitat Protection Zone	NVC Natural Value of Coastal Environment	0.508	1
	CMV Commercial Value	0.213	2
	RCV Recreational and Cultural Value	0.068	4
	APD Accessibility and Potential Disturbance	0.211	3
CR = 0.064 (6.4%)			

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7.3. Appendix 7.3 – Supplementary Material for Chapter 4

Table S4.1. Type of indicator and variable measured for successful MPA criteria adapted from IUCN

IUCN Criteria of Successful MPA	Type of indicator	Type of variable	Definition	Measurements
Conservation outcomes	Household income distribution by source	Income	The means by which individuals or families sustain themselves	Income for each individual in a household. The regional minimum wage is a baseline for setting a value. The response is divided into five levels (the highest is completely certain and the lowest is not certain). The regional minimum wage is placed in the middle of the level, which means any individual who earns below the minimum wage is ‘less’ to ‘not at all certain’. And the individual who earns more than the minimum wage has a ‘certain’ to ‘completely certain’ income.
	Level of stakeholder participation and satisfaction in management	Attitudes toward MPA	The perceptions and feelings of individuals or communities regarding MPAs.	The degree to which individuals in a local community are willing to be involved in an MPA project’s activities (e.g. helping protect MPA, patrols, increasing other people

				awareness, helping in coral reef planting)
	Local value and beliefs about marine resources	Acceptance of MPA	The extent to which local communities accept the establishment of MPAs.	The degree to which individuals agree on placing MPA in their village or area
		Cultural value	The cultural value held by local communities and how it aligns with formal conservation practice	Assessed using eight cultural value criteria developed by Yang & Chuan (2022), includes (1) maintaining creative spirit of the nation; (2) prevents social disputes in rural areas; (3) informality of procedures; (4) territoriality of jurisdiction; (5) operational internal control; (6) maintains consistency; (7) politically significant;
		Conservation beliefs and awareness	The understanding and attitudes of communities towards conservation efforts and their importance.	The degree to which individuals' belief and awareness that MPAs can increase ecological condition (i.e. fish stocks and living coral cover)
	Level of understanding of human impacts on resources	Benefit of MPA	The advantages provided by MPAs, such as biodiversity conservation and enhanced fish stocks	The degree to which individuals believe that the existence of MPA is important to protect the environment and generate benefits for community

	Distribution of formal knowledge to community	Ecological knowledge	The understanding of ecological principles and practices necessary for effective conservation.	The degree to which individuals understand MPA existences, functions and its benefits
	Area under no or reduced human impacts	Coastal protection	Strategies implemented to safeguard coastal areas from erosion, flooding, and other natural hazards. This can involve physical structures (like seawalls, breakwaters, and dunes), natural solutions (like restoring mangroves and wetlands), and regulatory approaches (like zoning laws and land-use planning)	Assessed using five types of criteria of coastal protection developed by Nicholls et al (1995), includes (1) no protection; (2) seawall; (3) coastal wetland (mangrove, seagrass, marshes), (4) beach nourishment, and (5) breakwater
	Focal species abundance	Fish abundance	The total number of individual fish present in a specific area or ecosystem.	Assessed using line intercept transect (LIT), calculated as a total fish found in the area
	Habitat distribution & complexity	Living coral cover	The percentage of the substrate that is covered by living coral.	Assessed using line intercept transect (LIT), calculated as a percentage of living coral cover found in the area
Good governance	Level of resource conflict	Community rights (access to resources)	The rights of communities to manage and benefit from their natural resources.	The degree to which individuals feel that they are able to gain access to resources
		Resource dependency	The extent to which individuals or communities rely on natural	The degree to which individuals' occupations are

			resources for their livelihoods.	dependent to the marine resources
		Conflict resolution	The methods and processes used to settle disputes over resource use and management.	The availability of conflict-based resolution in the local community, assessed by five criteria: (1) no rules or institution to manage the conflict; (2) less defined and managed conflict resolution and no written rules: (3) well defined and managed conflict resolution and clear written rules; (4) good conflict resolution, well-organised and clear written rules; (5) excellent conflict resolution, completely well-organised and clear written rules
	Existence and adoption of a management plan	Compatibility between management and customary law	The availability of customary law/practice and how it aligns with formal conservation practice	The degree to which individuals agree that customary law is effective in protecting environment and ecosystem
	Satisfaction in management process and activities	Community's trust	The level of confidence that community members have in MPA	The degree to which individuals trust that the existence of an MPA in their area can generate benefits for community
Effective Management	Proportion of stakeholders trained in sustainable use	Trainings and empowerments	Educational programs aimed at enhancing skills and knowledge related to	The availability of trainings and empowerment activities in local communities, assessed by five

			fisheries management and conservation.	criteria: (1) No trainings or empowerment-related programs; (2) Few trainings and empowerment-related programs; (3) Sometimes received trainings and empowerment-related programs; (4) Received trainings and empowerment-related programs; (5) Always received trainings and empowerment-related programs
	Availability and allocation of MPA administrative resources	Incentives and investment	Motivations and financial commitments made to encourage sustainable practices and resource management.	The availability of incentives and investments from various donor or government in the local communities, assessed by five criteria: (1) No incentive and investment for MPA program; (2) Few incentives or investment for MPA program; (3) Enough incentive and investment for MPA program; (4) Good incentive and investment for MPA program; and (5) Excellent incentive and investment for MPA program
		MPA monitoring	Regular monitoring	The degree to which MPA

			activities conducted to ensure compliance with regulations and protect resources	monitoring happen periodically. Assessed using criteria: (1) no monitoring at all; (2) little monitoring (at least one after designation); (3) intermediate (at least once every 3 years); (4) happened somewhat periodically, scheduled, low evaluation (at least once every 2 years); (5) happens periodically, scheduled and evaluated (at least once a year)
	Clearly defined enforcement procedures and coverage	Enforcement; sanctions and patrol	The implementation of laws and regulations to ensure compliance with resource management practices. Penalties imposed for non-compliance with fishing regulations.	Assessed using eight criteria developed by Leverington, et al., (2008); Stokes (2010); Hockings (2006), includes: (1) Clearly defined regulations, enforcement procedures and sanctions; (2) Adequate number and variety of patrols per time period per unit area; (3) Availability of tools or facilities; (4) Enforcement skills; (5) Adequate levels of enforcement staff; (6) Institutional support and commitment to enforce the law; (7) Availability

				of budget to enforce the law; (8) The staff have excellent capacity/ resources to enforce protected area legislation and regulations
		Gear diversity and restrictions	The range of different types of fishing gear used within a fishery, impacting catch efficiency and selectivity. Regulations limiting the types or methods of fishing gear that can be used to protect resources.	The availability of rules controlling the diversification and restriction of fishing gear. Assessed by five criteria: (1) no written law on controlling fishing gear; (2) unclear written law and little information distribution on controlling fishing gear; (3) clearly written law but little information distribution on controlling fishing gear; (4) clearly written law and good information distribution on controlling fishing gear; (5) clear written law and excellent information distribution on controlling fishing gear.
	Type, level and return on fishing effort	Fishing effort and pressure	The amount of labour, time, and resources expended in fishing activities and its impact on fish populations.	Number of fishers and their fishing trips in each week. Assessed by five criteria; (1) no fishing effort or pressure; (2) low fishing efforts and pressure; (3) intermediate

				fishing efforts and pressure; (4) high fishing efforts and pressure; (5) extremely high fishing efforts and pressure.
	Level of stakeholder involvement in surveilance, monitoring and enforcement	Participation in conservation	The involvement of community members in conservation activities and decision-making processes.	Number of individuals who participate in conservation activities such as patrols, protecting conservation areas, planting coral, beach clean-up.
	Local understanding of MPA rules and regulations	Rules implementation and commitment	The process of enforcing established rules and the dedication to adhere to them.	The degree to which conservation rules and commitments are being implemented at the local community level.
Sound Planning and design	Existence of a decision-making and management body	MPA management	The processes and strategies used to oversee and regulate Marine Protected Areas.	The degree to which MPA managers are actively managing the MPA project. The measurement relys on the extent to which local communities see whether the management is effective or not. Assessed by five criteria; the lowest is ‘not at all effective’ and the highest is ‘completely effective’.
	Existence and adequacy in enabling legislation	MPA design (boundaries, size and distribution)	The duration since the establishment of MPAs, their physical extent,	The degree to which MPA has a clear boundary (with marking area), adequate

			and their geographic spread.	size and distribution (as required by the widely acceptable rules, i.e. IUCN)
	Existence and adoption of a management plan	Management plan	A strategic document outlining objectives, actions, and measures for resource management.	The availability of MPA objectives and goals that are clearly defined and written. Assessed by five criteria: (1) not at all clear or defined; (2) less clear and defined; (3) intermediate clear and defined; (4) clear and defined; (5) completely clear and defined.
	Availability and allocation of MPA administrative resources	Government support	Motivation and financial commitments made to encourage sustainable practices and resource management.	The availability of government support. Assessed by five criteria: (1) not at all supported MPA project; (2) less support to the MPA project; (3) intermediate support of MPA project; (4) support to the MPA project; (5) high levels of supportto the MPA project.

B. Variable responses

1. Livelihood

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Not at all certain	C	12	2	11	2	10	16
	P	0.20	0.33	0.18	0.03	0.17	0.27

Less certain	C	30	54	34	47	42	23
	P	0.50	0.90	0.57	0.78	0.70	0.38
Neutral	C	14	2	9	10	8	15
	P	0.23	0.03	0.15	0.17	0.13	0.25
Certain	C	2	2	4	0	0	1
	P	0.03	0.03	0.07	0.00	0.00	0.02
Completely certain	C	2	0	2	1	0	5
	P	0.03	0	0.03	0.02	0.00	0.08
Population mean		0.44	0.41	0.44	0.44	0.39	0.45
Effectiveness Index		2	2	2	2	2	2

C = count; P = count/population

2. Attitudes toward MPA

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Not willing to be involved	C	9	20	8	14	4	0
	P	0.15	0.33	0.13	0.23	0.07	0.00
Less willing to be involved	C	5	8	0	3	4	1
	P	0.08	0.13	0.00	0.05	0.07	0.02
Neutral	C	9	12	5	30	28	12
	P	0.15	0.20	0.08	0.50	0.47	0.20
Willing to be involved	C	1	8	15	5	8	14
	P	0.02	0.13	0.25	0.08	0.13	0.23
Strongly willing to be involved	C	36	12	32	8	16	33
	P	0.60	0.20	0.53	0.13	0.27	0.55
Population Mean		0.77	0.55	0.81	0.57	0.69	0.86
Effectiveness Index		4	3	4	3	3	4

3. Acceptance of MPA

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Strongly agree	C	14	15	32	8	12	39
	P	0.23	0.25	0.53	0.13	0.20	0.65

Agree	C	26	33	25	21	23	13
	P	0.43	0.55	0.42	0.35	0.38	0.22
Neutral	C	14	12	3	23	18	8
	P	0.23	0.20	0.05	0.38	0.30	0.13
Disagree	C	6	0	0	8	6	0
	P	0.10	0.00	0.00	0.13	0.10	0.00
Strongly disagree	C	0	0	0	0	1	0
	P	0.00	0.00	0.00	0.00	0.02	0.00
Population Mean		0.76	0.81	0.90	0.70	0.73	0.90
Effectiveness Index		4	4	5	4	4	5

4. Cultural value

No.	Sub-criteria	A1	A2	A3	B1	B2	B3
1.	Maintain the creative spirit of a nation	X	X	X	X	X	X
2.	Prevent social disputes in rural areas	X	X	X	X	X	X
3.	Informality of procedure	X	X	X	X	X	X
4.	Territoriality of jurisdiction	X	X	X	X	X	X
5.	Operational internal control	X	X	X	X	X	X
6.	Maintained constancy	X	X	X	X	X	X
7.	Politically significant	X	X	X	X	X	X
8.	Contribute to the construction of sound laws	X	X	X	X	X	X

Yang & Chuan (2022).

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Strong significance impact	X	X	X	X	X	X
4	Significant impact	-	-	-	-	-	-
3	Intermediate impact	-	-	-	-	-	-
2	Less impact	-	-	-	-	-	-
1	Not at all significance	-	-	-	-	-	-
	Effectiveness Index	5	5	5	5	5	5

5. MPA’s benefit

Criteria	Site

		A1	A2	A3	B1	B2	B3
Not benefiting at all	C	11	6	3	12	3	3
	P	0.18	0.10	0.05	0.20	0.05	0.05
Less benefit	C	4	3	0	7	6	0
	P	0.07	0.05	0.00	0.12	0.10	0.00
Neutral	C	6	11	8	29	24	14
	P	0.10	0.18	0.13	0.48	0.40	0.23
Benefiting community	C	1	19	16	4	13	13
	P	0.02	0.32	0.27	0.07	0.22	0.22
Completely benefiting community	C	38	21	33	8	14	30
	P	0.63	0.35	0.55	0.13	0.23	0.50
Population mean		0.77	0.75	0.85	0.56	0.70	0.82
Effectiveness Index		4	4	4	3	4	4

6. Ecological knowledge

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Not knowing at all	C	7	0	10	5	5	3
	P	0.12	0.00	0.17	0.08	0.08	0.05
Limited knowledge	C	7	0	4	11	7	6
	P	0.12	0.00	0.07	0.18	0.12	0.10
Intermediate knowledge	C	5	7	13	28	19	7
	P	0.08	0.12	0.22	0.47	0.32	0.12
Good knowledge	C	7	23	4	13	8	19
	P	0.12	0.38	0.07	0.22	0.13	0.32
Very good knowledge	C	34	30	29	3	21	25
	P	0.57	0.50	0.48	0.05	0.35	0.42
Population mean		0.78	0.88	0.73	0.59	0.71	0.79
Effectiveness Index		4	4	4	3	4	4

7. Conservation beliefs and awareness

Criteria	Site					
	A1	A2	A3	B1	B2	B3

Strongly agree	C	12	7	32	9	11	38
	P	0.20	0.12	0.53	0.15	0.18	0.63
Agree	C	29	28	24	16	24	13
	P	0.48	0.47	0.40	0.27	0.40	0.22
Neutral	C	14	24	2	28	17	9
	P	0.23	0.40	0.03	0.47	0.28	0.15
Disagree	C	5	1	2	7	5	0
	P	0.08	0.02	0.03	0.12	0.08	0.00
Strongly disagree	C	0	0	0	0	3	0
	P	0.00	0.00	0.00	0.00	0.05	0.00
Population mean		0.76	0.74	0.89	0.69	0.72	0.90
Effectiveness Index		4	4	4	3	4	5

8. Coastal protection

Location	Key area	Criteria of type of protection				
		No protection	Seawall	Coastal wetland (mangroves, seagrass, marshes) or other natural beach protection	Beach nourishment	Break-water
A1	Harbours or area to land the boat	X	-	-	-	-
	Urban	X	-	-	-	-
	Tourism areas	-	X	-	-	-
	Industrial	N/A	N/A	N/A	N/A	N/A
	Other coastline	N/A	N/A	N/A	N/A	N/A

A2	Harbours or area to land the boat	-	-	-	-	X
	Urban	X	-	-	-	-
	Tourism areas	X	-	-	-	-
	Industrial	N/A				
	Other coastline	N/A				
A3	Harbours or area to land the boat	X	-	-	-	-
	Urban	X	-	-	-	-
	Tourism areas	-	X	-	-	-
	Industrial	N/A	N/A	N/A	N/A	N/A
	Other coastline	N/A	N/A	N/A	N/A	N/A
B1	Harbours or area to land the boat	X	-	-	-	-
	Urban	X	-	-	-	-
	Tourism areas	X	-	-	-	-
	Industrial	N/A	N/A	N/A	N/A	N/A
	Other coastline	N/A	N/A	N/A	N/A	N/A
B2	Harbours or area to	-	X	-	-	-

	land the boat					
	Urban	X	-	-	-	-
	Tourism areas	-	X	-	-	-
	Industrial	N/A	N/A	N/A	N/A	N/A
	Other coastline	N/A	N/A	N/A	N/A	N/A
B3	Harbours or area to land the boat	X	-	-	-	-
	Urban	X	-	-	-	-
	Tourism areas	-	-	X	-	-
	Industrial	N/A	N/A	N/A	N/A	N/A
	Other coastline	N/A	N/A	N/A	N/A	N/A

Nicholls et al. (1995)

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Completely protected	-	-	-	-	-	-
4	Protected	-	-	-	-	-	-
3	Intermediate protection	-	-	-	-	X	
2	Less protected	X	X	X	-	-	X
1	Not at all protected	-	-	-	X	-	-
	Effectiveness Index	2	2	2	1	3	2

9. Fish abundance

Site	Count	Percentage (%)	Effectiveness Index
A1	5522	21	2

A2	1609	6	1
A3	18677	72	4
B1	7118	44	3
B2	3252	20	1
B3	5713	36	2

10. Living coral cover

Site	Count	Percentage (%)	Effectiveness Index
A1	2444	53	3
A2	3300	61	4
A3	3449	50	3
B1	495	7	1
B2	1342	20	2
B3	544	9	1

11. Community's rights (access to resources)

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Full access	X	X	X	-	-	-
4	Has access	-	-	-	-	-	X
3	Intermediate	-	-	-	-	X	-
2	Less access	-	-	-	X	-	-
1	No access at all	-	-	-	-	-	
	Effectiveness Index	5	5	5	2	3	4

12. Resource dependency

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Not at all depended	C	1	11	2	0	3	3
	P	0.02	0.18	0.03	0.00	0.05	0.05
Less depended	C	2	15	11	6	0	9
	P	0.03	0.25	0.18	0.10	0.00	0.15
Neutral	C	26	22	26	29	0	12

	P	0.43	0.37	0.43	0.48	0.00	0.20
Depended	C	0	0	1	20	14	32
	P	0.00	0.00	0.02	0.33	0.23	0.53
Completely depended	C	31	12	20	5	43	4
	P	0.52	0.20	0.33	0.08	0.72	0.07
Population mean		0.41	0.64	0.51	0.52	0.29	0.52
Effectiveness Index		2	3	3	3	1	3

13. Community's trust

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Not at all trust	C	12	7	32	8	12	38
	P	0.20	0.12	0.53	0.13	0.20	0.63
Less trust	C	29	28	24	17	24	13
	P	0.48	0.47	0.40	0.28	0.40	0.22
Neutral	C	14	24	2	28	17	9
	P	0.23	0.40	0.03	0.47	0.28	0.15
Trust	C	5	1	2	7	5	0
	P	0.08	0.02	0.03	0.12	0.08	0.00
Completely trust	C	0	0	0	0	2	0
	P	0.00	0.00	0.00	0.00	0.03	0.00
Population mean		0.76	0.74	0.89	0.69	0.73	0.90
Effectiveness Index		4	4	4	3	4	5

14. Effectiveness and compatibility between management and customary law

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Not at all effective	C	0	0	0	0	0	0
	P	0.00	0.00	0.00	0.00	0.00	0.00
Less effective	C	0	0	0	5	3	6
	P	0.00	0.00	0.00	0.08	0.05	0.10
Neutral	C	33	15	40	54	38	16
	P	0.55	0.25	0.67	0.90	0.63	0.27

Effective	C	18	28	15	1	19	34
	P	0.30	0.47	0.25	0.02	0.32	0.57
Completely effective	C	9	17	5	0	0	4
	P	0.15	0.28	0.08	0.00	0.00	0.07
Population mean		0.72	0.81	0.68	0.59	0.65	0.72
Effectiveness Index		4	4	3	3	3	4

15. Conflict resolutions

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Excellent conflict resolution, completely well-organised and clear written rules	X	X	-	-	-	-
4	Good conflict resolution, well-organised and clear written rules	-	-	X	-	X	X
3	Well defined and managed conflict resolution and clear written rules	-	-	-	X	-	-
2	Less defined and managed conflict resolution and no written rules	-	-	-	-	-	-
1	No rules, no institution who manage the conflict	-	-	-	-	-	-
	Effectiveness Index	5	5	4	3	4	4

16. Trainings and empowerments

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Always received trainings and empowerment-related programs	-	-	-	-	-	-
4	Received trainings and empowerment-related programs	-	-	-	-	-	-
3	Sometimes received trainings and empowerment-related programs	-	X	X	-	X	-
2	Less received trainings and empowerment-related programs	X	-	-	-	-	X

1	Not at all received trainings and empowerment-related programs	-	-	-	X	-	-
	Effectiveness Index	2	3	3	1	3	2

17. Incentives and investments

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	More incentive and investment for MPA program	-	-	-	-	-	-
4	Good incentive and investment for MPA program	-	-	-	-	-	-
3	Enough incentive and investment for MPA program	-	-	-	-	-	-
2	Less incentive and investment for MPA program	-	-	-	X	X	X
1	No incentive and investment for MPA program	X	X	X	-	-	-
	Effectiveness value	1	1	1	2	2	2

18. Law enforcement; sanction and patrol

No.	Sub-criteria	Site					
		A1	A2	A3	B1	B2	B3
1	The staff have excellent capacity/resources to enforce protected area legislation and regulations	-	-	-	-	-	-
2	Availability of budget to enforce the law	-	-	-	X	X	X
3	Institutional support and commitment to enforce the law	0	0	0	X	X	X
4	Adequate levels of enforcement staff	X	X	X	0	0	0
5	Enforcement skills	0	0	0	0	0	0
6	Availability of tools or facilities	0	0	0	X	X	X
7	Adequate number and variety of patrols per time period per unit area	0	0	0	0	0	0

8	Clearly defined regulations, enforcement procedures and sanctions	X	X	X	X	X	X

Leverington, et al., (2008); Stokes (2010); Hockings (2006).

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Completely effective law enforcement	-	-	-	-	-	-
4	Effective law enforcement	-	-	-	-	-	-
3	Intermediate law enforcement	-	-	-	X	X	X
2	Less law enforcement	X	X	X	-	-	-
1	Not at all effective law enforcement	-	-	-	-	-	-
	Effectiveness Index	2	2	2	3	3	3

19. MPA monitoring

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Happened periodically, scheduled, and evaluated (at least once a year)	-	-	-	-	-	-
4	Happened less periodically, scheduled, less evaluated (at least once every 2 years)	X	X	X	X	X	X
3	Intermediate (at least once every 3 years)	-	-	-	-	-	-
2	Less monitoring (at least one after designation)	-	-	-	-	-	-
1	No monitoring at all	-	-	-	-	-	-
	Effectiveness Index	4	4	4	4	4	4

20. Gear diversity and restrictions

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Clear written law and great information distribution on controlling fishing gear	X	X	X	-	-	-

4	Clear written law and good information distribution on controlling fishing gear	-	-	-	X	X	-
3	Clear written law and less information distribution on controlling fishing gear	-	-	-	-	-	X
2	Less clear written law and less information distribution on controlling fishing gear	-	-	-	-	-	-
1	No written law on controlling fishing gear	-	-	-	-	-	-
	Effectiveness Index	5	5	5	4	4	3

21. Fishing efforts and pressure

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
1	Highly high fishing efforts and pressure	X	X	X	-	-	-
2	High fishing efforts and pressure	-	-	-	X	-	-
3	Intermediate fishing efforts and pressure	-	-	-	-	X	X
4	Low fishing efforts and pressure	-	-	-	-	-	-
5	No fishing efforts and pressure	-	-	-	-	-	-
	Effectiveness Index	1	1	1	2	3	3

22. Participation in conservation

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Not at all participated	C	27	27	30	41	48	30
	P	0.45	0.45	0.50	0.68	0.80	0.50
Less participated	C	13	30	23	15	9	22
	P	0.22	0.50	0.38	0.25	0.15	0.37
Sometimes participated	C	5	0	2	0	0	0
	P	0.08	0.00	0.03	0.00	0.00	0.00
Often participated	C	6	3	2	1	1	5
	P	0.10	0.05	0.03	0.02	0.02	0.08
Always participated	C	9	0	3	3	2	3
	P	0.15	0.00	0.05	0.05	0.03	0.05
Population mean		0.46	0.33	0.35	0.30	0.27	0.36

Effectiveness Index	2	2	2	2	1	2

23. Rules implementation and commitment

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Clear written rules, great implementation and commitment	-	-	-	-	-	-
4	Clear written rules, good implementation and commitment	X	-	X	-	-	-
3	Clear written rules, less implementation and commitment	-	X	-	-	-	-
2	Less clear written rules, less implementation and commitment	-	-	-	X	X	X
1	No written rules, no implementation and commitment	-	-	-	-	-	-
	Effectiveness Index	4	3	4	2	2	2

24. MPA management

Criteria		Site					
		A1	A2	A3	B1	B2	B3
Not at all effective	C	7	20	10	17	2	2
	P	0.12	0.33	0.17	0.28	0.03	0.03
Less effective	C	5	13	2	7	4	9
	P	0.08	0.22	0.03	0.12	0.07	0.15
Neutral	C	4	7	8	31	25	19
	P	0.07	0.12	0.13	0.52	0.42	0.32
Effective	C	1	5	14	3	15	14
	P	0.02	0.08	0.23	0.05	0.25	0.23
Completely effective	C	43	15	26	2	14	16
	P	0.72	0.25	0.43	0.03	0.23	0.27
Population mean		0.83	0.54	0.75	0.49	0.72	0.71
Effectiveness Index		4	3	4	2	4	4

25. MPA design (boundaries, size and distribution)

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Completely clear MPA boundaries (with marking), adequate size and distribution	-	-	-	-	-	-
4	Clear MPA boundaries (no marking), adequate size and distribution	X	X	X	-	-	-
3	Clear MPA boundaries (no marking), less adequate size and distribution	-	-	-	X	X	X
2	Less clear MPA boundaries, less adequate size and distribution	-	-	-	-	-	-
1	No MPA boundaries, no adequate size and distribution	-	-	-	-	-	-
	Effectiveness Index	4	4	4	3	3	3

26. MPA objective and goals

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Completely clear and defined	-	-	-	-	-	-
4	Clear and defined	-	-	-	-	-	-
3	Intermediate	X	X	X	X	X	X
2	Less clear and defined	-	-	-	-	-	-
1	Not at all clear and defined	-	-	-	-	-	-
	Effectiveness Index	3	3	3	3	3	3

27. Government supports

Value	Criteria	Site					
		A1	A2	A3	B1	B2	B3
5	Completely support the MPA program	-	-	-	-	-	-
4	Support the MPA program	-	-	-	-	-	-
3	Intermediate support	-	-	-	-	-	-
2	Less support the MPA program	X	-	X	-	X	X
1	Not at all supported MPA program	-	X	-	X	-	-

Effectiveness value	2	1	2	1	2	2

References

Leverington, F., Hockings, M., Pavese, H., Lemos Costa, K. and Courrau, J., 2008. Management effectiveness evaluation in protected areas: a global study: supplementary report No. 1: overview of approaches and methodologies.

Stokes, E.J., 2010. Improving effectiveness of protection efforts in tiger source sites: Developing a framework for law enforcement monitoring using MIST. Integrative Zoology, 5(4), pp.363-377.

Hockings, M., 2006. Evaluating Effectiveness: A framework for assessing management effectiveness of protected areas. IUCN.

Nicholls, R.J., Leatherman, S.P., Dennis, K.C. and Volonte, C.R., 1995. Impacts and responses to sea-level rise: qualitative and quantitative assessments. Journal of Coastal Research, pp.26-43.

Yang and Chuan, 2022 Evaluation and Analysis of Traditional Customary Law Based on the Perspective of Big Data.

C. Statistical test

1. Kruskal-wallis test

Kruskal-Wallis rank sum test

data: Education by Site
Kruskal-Wallis chi-squared = 49.914, df = 5, p-value = 1.443e-09

Kruskal-Wallis rank sum test

data: Income by Site
Kruskal-Wallis chi-squared = 3.8464, df = 5, p-value = 0.5717

Kruskal-Wallis rank sum test

data: Age by Site
Kruskal-Wallis chi-squared = 41.124, df = 5, p-value = 8.858e-08

Kruskal-Wallis rank sum test

data: occupation by site
Kruskal-Wallis chi-squared = 35.184, df = 5, p-value = 1.382e-06

2. One-way ANOVA and Tukey HSD (fish data)

```
> summary(one.way)
            Df    Sum Sq   Mean Sq F value Pr(>F)
site         5 549930594 109986119   4.206 0.0193 *
Residuals   12 313790835  26149236
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> TukeyHSD(one.way)
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = fish ~ site, data = ecology)

$site
                                diff       lwr        upr     p adj
Batununggul-Anoiitam     -15424.6667 -29449.05 -1400.2874 0.0284226
Ieumeulee-Anoiitam       -13155.0000 -27179.38   869.3792 0.0707110
Sakti-Anoiitam           -12964.3333 -26988.71  1060.0459 0.0762423
Toyapakeh-Anoiitam       -11559.3333 -25583.71  2465.0459 0.1313028
Ujungkareung-Anoiitam    -17067.6667 -31092.05 -3043.2874 0.0146227
Ieumeulee-Batununggul      2269.6667 -11754.71 16294.0459 0.9929671
Sakti-Batununggul          2460.3333 -11564.05 16484.7126 0.9898680
Toyapakeh-Batununggul      3865.3333 -10159.05 17889.7126 0.9321822
Ujungkareung-Batununggul  -1643.0000 -15667.38 12381.3792 0.9984459
Sakti-Ieumeulee             190.6667 -13833.71 14215.0459 1.0000000
Toyapakeh-Ieumeulee        1595.6667 -12428.71 15620.0459 0.9986481
Ujungkareung-Ieumeulee    -3912.6667 -17937.05 10111.7126 0.9289372
Toyapakeh-Sakti            1405.0000 -12619.38 15429.3792 0.9992663
Ujungkareung-Sakti        -4103.3333 -18127.71  9921.0459 0.9149350
Ujungkareung-Toyapakeh    -5508.3333 -19532.71  8516.0459 0.7699387
```

3. One-Way ANOVA and Tukey HSD (coral data)

```
summary(one.wayc)
            Df   Sum Sq Mean Sq F value   Pr(>F)
site         5 26319379 5263876   12.11 0.000239 ***
Residuals   12  5215797  434650
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> TukeyHSD(one.wayc)
  Tukey multiple comparisons of means
```

```
  95% family-wise confidence level

Fit: aov(formula = coral ~ site, data = ecology)

$site
                               diff        lwr         upr      p adj
Batununggul-Anoiitam     -2107.00000 -3915.1058  -298.89417 0.0195997
Ieumeulee-Anoiitam       -1005.33333 -2813.4392   802.77250 0.4634305
Sakti-Anoiitam           -2905.33333 -4713.4392 -1097.22750 0.0017187
Toyapakeh-Anoiitam       -2953.66667 -4761.7725 -1145.56084 0.0014934
Ujungkareung-Anoiitam     -149.33333 -1957.4392  1658.77250 0.9997127
Ieumeulee-Batununggul     1101.66667  -706.4392  2909.77250 0.3730121
Sakti-Batununggul         -798.33333 -2606.4392  1009.77250 0.6803681
Toyapakeh-Batununggul     -846.66667 -2654.7725   961.43916 0.6290500
Ujungkareung-Batununggul  1957.66667   149.5608  3765.77250 0.0313243
Sakti-Ieumeulee          -1900.00000 -3708.1058   -91.89417 0.0375303
Toyapakeh-Ieumeulee      -1948.33333 -3756.4392  -140.22750 0.0322551
Ujungkareung-Ieumeulee     856.00000  -952.1058  2664.10583 0.6190799
Toyapakeh-Sakti            -48.33333 -1856.4392  1759.77250 0.9999989
Ujungkareung-Sakti        2756.00000   947.8942  4564.10583 0.0026683
Ujungkareung-Toyapakeh    2804.33333   996.2275  4612.43916 0.0023121
```

Table S4.2 The list of each variable and its source of data

No.	Indicators	Source of data
1.	Income	Questionnaire
2.	Attitudes toward MPA	Questionnaire
3.	Acceptance of MPA	Questionnaire
4.	Cultural value	Questionnaire
5.	Benefit of MPA	Questionnaire
6.	Ecological knowledge	Questionnaire
7.	Conservation beliefs and awareness	Questionnaire
8.	Coastal protection	Field observation
9.	Fish abundance	Field observation
10.	Living coral cover	Field observation
11.	Community rights (access to resources)	Interview and Focus Group Discussion
12.	Resource dependency	Questionnaire
13.	Community's trust	Questionnaire
14.	Compatibility between management and customary law	Questionnaire
15.	Conflict resolutions	Interview and Focus Group discussion
16.	Trainings and empowerments	Interview and Focus Group discussion
17.	Incentives and investments	Interview and Focus Group discussion
18.	Law enforcement; sanction and patrol	Interview and Focus Group discussion
19.	MPA monitoring	Interview and Focus Group discussion
20.	Gear diversity and restrictions	Interview and Focus Group discussion
21.	Fishing efforts and pressure	Interview and Focus Group discussion

22.	Participation in conservation	Questionnaire
23.	Rules implementation and commitment	Interview and Focus Group discussion
24.	Management plan	Interview and Focus Group discussion
25.	MPA design (boundaries, size and distribution)	Interview and Focus Group discussion
26.	MPA management	Interview and Focus Group discussion
27.	Government support	Interview and Focus Group discussion

7.4. Appendix 7.4 – Supplementary Material for Chapter 5

Table S5.1 Codes and Themes

Name of Codes	Files	References
Activities related to conservation	2	3
Benefits of the rules	5	8
Education and human resources	1	1
Increase fish abundance	1	1
Sustaining foods	1	1
Tourism	1	1
Ceremony	3	4
Conflict	6	19
Critics	4	21
Customary rules	3	5
Funding	3	4
History	10	51
Knowledge of conservation	2	2
NGO	3	4
Obstacle	4	23
Organizer	9	26
Patrol	8	9

Philosophy	5	7
Decision making	6	19
People background	2	8
Prohibition	3	3
Actions	4	9
Fishing gear	4	8
Places	2	6
Time restrains	7	11
Types of animal species	2	4
Roles	3	11
Sanctions	8	18
Violation	5	7
Zoning	2	3

A. Law regulation and prohibitions

- Laot Lhok Pante Timu Gampong Anoi Itam

Point A: Days it is forbidden to go to sea

a. Every Friday, Thursday afternoon at 18.00 WIB to Friday at 14.00 WIB (after Friday prayers).
b. Eid al-Fitr for 3 (three) days starting from the evening of the feast at 18.00 WIB until the third Eid al-Fitr at 18.00 WIB.
c. Eid al-Adha for 3 (three) days starting from the eve of the feast until the third night at 18.00 WIB.
d. Commemorating the Tsunami Disaster Day on December 26 starting from December 25 at 18.00 WIB until the end of the Tsunami Disaster Warning event in Gampong Anoi Itam.
e. Commemorating Indonesian Independence Day on August 17 starting at 08.00 WIB in the morning until 12.00 WIB (after the flag ceremony).
f. Every Khanduri Laôt Lhôk Gampong Anoi Itam according to the Circular of Panglima Laôt Lhôk Pante Timur Gampong Anoi Itam.

Point B: Activities or business which violate laôt Laôk *Adat* Lhôk Pante Timur Gampong Anoi Itam law

a. Poisoning or poisoning fish using traditional and chemical poisons.
b. Catching fish using trawlers and Japanese trawlers.
c. Catching fish using nets with assistive devices (boats, duck shoes, boats and other aids) up to the low tide limit of 30 days a month.
d. Bombardment at sea.
e. Disposal of toxic wastes (garbage) at sea.
f. Taking and moving coral reefs without the permission of *Panglima Laot* Lhok Anoi Itam.
g. Taking and catching ornamental fish and marine biota that have been protected by law and Reusam Gampong Anoi Itam.
h. Taking fish using a compressor machine either during the day or at night.
i. It is prohibited to fish using longlines from a depth of 50 m to the beach.

Point C: Determining the area of the Lhok Pante Timur Gampong Anoi Itam conservation area concerning activities that should not be performed

a. All prohibitions according to Point A of the Law on *Adat* Laôt Lhôk Pante Timur Gampong Anoi Itam.
b. All activities according to Point B are activities or businesses that violate the customary laws of Laôt Lhôk Pante Timur Gampong Anoi Itam.
c. Within the special area (Zona Core Fortress Conservation Area Laôt Lhok Pante Timur Gampong Anoi Itam) it is not permissible to carry out any business activities day or night, such as taking or damaging marine biota by way of peek fishing (tyres), netting, menuba (small fish at low tide), shooting, except fishing by boat, boat and fishing on the reef.
d. All conservation or research activities must have an official or verbal statement to Panglima Laôt Lhôk Gampong Anoi Itam, no later than two days before the activity is carried out.
e. All activities that use labour are prioritized by local workers, whether they have certificates or not.
f. All participants in activities related to diving, snorkeling, must wear clothes in accordance with Islamic Sharia law, both women and men.

g. The boundaries of the special area (Zona Core Fortress Conservation Area) start from Batee Dua towards the north along the coast to the south to the boat mooring area, the boat in front of the Gampong Anoi Itam Mosque.

Point D: Sanctions for violation of following days, activities or business which violate Laôt Lhôk *Adat* Law, and Gampong Anoi Itam conservation area

Sanctions For Point A

- Withhold fishing gear for 1 (one) week.

If the same violator repeats the violation a second time, fishing gear will be detained for 1 (one) week plus a fine of Rp. 600,000.- And if after the detention period of the fishing gear (after 7 (seven) days), the violator has not taken the fishing gear back, then the fishing gear is outside the responsibility of the Laot Lhok Pante Timu Anoi Itam Customary Law Institute.

Sanctions For Point B

- Fishing equipment and tools will be confiscated. The catch will be confiscated and sold to cash members of Gampong Anoi Itam fishermen. A fine of Rp. 3.500.000,-

Sanctions For Point C

- Fishing equipment and tools will be confiscated. All losses to the Protected Area must be compensated. A fine of Rp. 3.500.000,-

➢ Ujung Kareung customary law

a. No-Sea Day

1) Friday: abstain from going to sea for one day starting from Thursday at 6 pm until after Friday prayers for all activities
2) Eid al-Fitr Day: abstinence from going to sea for 3 days starting from the asr call to prayer on the day of meugang to the zhuhur call to prayer on the third feast day
3) Eid al-Adha: abstinence from the sea for 3 days starting from the asr call to prayer day until the midday call to prayer from the third Raya
4) Tsunami warning day: abstinence from sea for one day from after Fajr prayer until after Asr prayer on December 26 each year.

5) Republic of Indonesia Independence Day: abstain from going to sea for half a day starting after the morning prayer until the Independence Day ceremony ends on August 17 each year.
6) Khanduri Laot Day: abstinence from going to sea for 3 days starting from one day at 6 pm before Khaduri Laot day until the third day after midday prayer.

b. Rules for Fishing Gear and Environmental Maintenance
1) Trawlers are not allowed to use fishing gear
2) Do not use explosives and anesthetic (cyanide) fishing gear
3) Cannot use compressors
4) Not allowed to use Japanese trawling gear (muroami)
5) Cannot use fishing nets
6) No Robot Lights allowed (0-4 mil)

b. Marine Biota Protection
1) It is forbidden to catch ornamental fish
2) It is forbidden to take shellfish (Kima)

c. Beach Protection
1) It is forbidden to cut down trees along the coast
2) Do not take pebbles and beach sand
3) It is forbidden to burn the roots of trees along the coast
4) It is forbidden to carry out beach reclamation activities

d. Social custom
1) If there are fishermen in Ujung Kareung who are lost at sea, then other fishermen in the Lhok Ujung Kareung area are obliged to help and look for them for a maximum of 3 consecutive days
2) If there are residents who die in Gampong Ujong Kareung, fishermen are not allowed to go to sea before the body is buried, except for fishermen who have already gone to sea.
3) If there are survey or research activities in the Lhok Ujong Kareung area, a report must be made to the Keuchik and *Panglima Laot*

4) If there are physical development activities of any kind along the coast of Lhok Ujong Kareung, they must be reported to the Keuchik and *Panglima Laot*
5) For tourism actors who have businesses along the Lhok Ujong Kareung beach, they should not prohibit fishermen from carrying out fishing activities in the area.
6) If a fisherman anchors the trawl at FADs without the permission of the FAD owner, sanctions will be imposed, fish confiscation after being caught and a monetary fine equal to the cost of making one FAD.

- Bali customary law
    1) For minor offences, those who damage coral reefs will be arrested by Pecalang Segara, given a warning and must sign a statement.
    2) If caught a second time for the same violation, the violator will be summoned to a large village meeting and must bring 25 kg of rice. [This is a social punishment and it's very effective for embarrassment.]
    3) If the offence is done 3 times, all official needs related to Pakraman villages, such as marriage legalization, will not be served.
    4) Will be expelled from Pakraman/customary village

B. Chi-square and Spearman correlation test

```
Kruskal-Wallis rank sum test
data:  Knowledge by Location
Kruskal-Wallis chi-squared = 125.14, df = 5, p-value < 2.2e-16
kruskal.test(Effectiveness~Location, data=effectiveness)

    Kruskal-Wallis rank sum test
data:  Effectiveness by Location
Kruskal-Wallis chi-squared = 49.203, df = 5, p-value = 2.017e-09
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Spearman correlation between knowledge to effectiveness of customary law

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> corr$p.value
[1] 7.397229e-10
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