Social-ecological resilience of mangrove-shrimp farming communities in Thailand

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Abstract

Tropical coastlines are regions of extraordinary productivity and host a diversity of interlinked ecosystems which are vital for humanity, including mangrove forests. These environments provide a clear example of how societies and natural ecosystems interact to form complex 'social-ecological systems'. Yet, although humans depend on mangrove forests in so many ways, these ecosystems are proving to be highly vulnerable under increased human pressures. This research focuses on the rapid social and ecological change brought about by the expansion of shrimp aquaculture in coastal mangrove areas of Thailand. Like in many other parts of the world, the intensification of shrimp aquaculture along the coast of Thailand over the past few decades has come with high social and ecological costs, including widespread conversion of mangrove forests, negative biophysical changes, and loss of coastal livelihood. The overarching aim of this research was to show how studying shrimp farming in mangrove areas as a social-ecological system can advance understanding of some selected drivers of resilient social-ecological systems, and how they are related. Integrating approaches from the natural and social sciences, the research draws on mixed methods combining biophysical sampling of mangrove ecosystem change, semi-quantitative household surveys, and qualitative participatory approaches.

The first research chapter of this thesis (Chapter 4) assesses the influence of mangrove to shrimp pond conversion on ecosystem carbon storage on the southern Andaman sea coast of Thailand. The assessment was based on field inventories of forest structure and soil carbon stocks in mangrove forests and abandoned shrimp pond sites. While the results showed that mangrove conversion for shrimp farming results in a large land-use carbon footprint, the observed pattern of mangrove recovery in abandoned shrimp ponds demonstrates the high resilience capacity of mangrove forests. The second research chapter (Chapter 5) analyses shrimp farming diversity along the Gulf of Thailand coast. The research examines shrimp farmer behaviour in relation to production intensity, and its embeddedness in the wider socio-economic context of shrimp farming households. Shrimp farming intensity was found to be associated with a combination of technical, social, and ecological factors, and a range of different combinations of variables were important in influencing the adoption of farming at a particular intensity, relating to subjective culture and values, risk perceptions, and socio-economic conditions. The final research chapter (Chapter 6) uses participatory methods to explore the different forms of knowledge and perceptions of ecosystem health and ecosystem service delivery among mangrove-dependent communities on Thailand's Andaman sea coast. The communities were shown to have high dependency on mangroves and hold a wealth of local ecological knowledge. Strong cultural and religious links among user-groups have facilitated greater communication and social cohesion and this could have a positive effect on community resilience by enabling collective synthesis and use of their ecological knowledge. The research also shows how periods of abrupt environmental change can bring coastal communities together, creating opportunity for self-organisation, environmental education, and capacity building, which plays a significant role in the sustainability of natural resources, livelihoods and social resilience.

This thesis generates important contributions to the study of social-ecological systems and provides new findings that are relevant to inform sustainability and natural resource management decisions. The findings of this research are also timely to inform implementation of Thailand's National Economic and Social Development Plan (2017-2021), which calls for developing environmentally-friendly coastal aquaculture, and encouraging community forest management though creating participatory networks of forest restoration and protection.

I hereby declare that this thesis is my own work and any material which is not my own work has been properly acknowledged.

Acknowledgements

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I am indebted to the people of Koh Klang for welcoming me into their community. Thank you for your hospitality and for sharing your local wisdom. I further thank all of the participants and interviewees in Koh Klang and Chanthaburi who engaged in this research and gave up their valuable time to make this research possible.

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Acronyms and abbreviations

AGB	Aboveground biomass
AHPND	Acute hepatopancreatic necrosis disease
BD	Bulk density
BGB	Belowground biomass
C	Carbon
°C	Degree Celsius
CC	Climate change
CBEMR	Community Based Ecological Mangrove Restoration
cm	Centimetre
CO_2	Carbon dioxide
CP	Charoen Pokphand
dbh	Diameter at breast height
DMCR	Department of Marine and Coastal Resources
DNP	Department of National Parks and Wildlife Conservation
EMR	Ecological Mangrove Restoration
EMS	Early Mortality Syndrome
ES	Ecosystem services
FAO	Food and Agriculture Organisation
g	Gram
GAP	Good Aquaculture Practice
GNF	Global Nature Fund
GPS	Geographical Positioning System
H	Height
ha	Hectare
HPM	Hepatopancreatic microsporidiosis
IAC	Integrative agent-centred
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
kg	Kilogram
K-W	Kruskal-Wallis
LOI	Loss on Ignition
L	Length
l	Litre
LB	Leaf biomass
LEK	Local Ecological Knowledge
MAP	Mangrove Action Project
m	Meter
m^2	Square meter
Mg	Megagram
mg	Milligram
ml	Millilitre
MoNRE	Ministry of Natural Resources and Environment

n	Number
NGO	Non-governmental organization
No.	Number
OC	Organic carbon
OM	Organic matter
Pg	Petagram
PL	Post-larvae
PRB	Prop root biomass
RFD	Royal Forestry Department
SE	Standard error
SES	Social-ecological system
SOC	Soil organic carbon
SOM	Soil organic matter
sp.	Species
SPF	Specific pathogen free
t	Ton
TEK	Traditional Ecological Knowledge
THB	Thai Baht
TOC	Total organic carbon
UNEP	United Nations Environment Programme
US	United States
WD	Wood density
WV	Wood volume
yr	Year

Chapter 1 Introduction

1.1 Background

In tropical and subtropical regions, mangrove forests are an important part of a diverse seascape dominated by functionally interlinked ecosystems, including seagrass meadows and coral reefs (Tomlinson 2016; Spalding et al. 2010; Berkström et al. 2012; Ogden 1988). These ecosystems are not only highly dependent on each other (Duke and Wolanski 2001; Mumby et al. 2004; Berkström et al. 2013), but they support the livelihoods and wellbeing of hundreds of millions of people because of the wide range of ecosystem services they provide (Costanza et al. 1997, 2014; Wells and Ravilious 2006; Ewel et al. 1998; Barbier 2016; MA 2005). Benefits to people include provision of habitat and nursery grounds for species of fish and invertebrates, supply of protein and building materials, erosion control and coastal protection against storms and ocean waves, water quality regulation, recreation and ecotourism (Mazda et al. 2006; Beck et al. 2001; Thampanya et al. 2006; Mumby and Hastings 2008; Nagelkerken et al. 2015; Huxham et al. 2017; McIvor et al. 2012; Rönnbäck 1999; Lee et al. 2014; Barbier et al. 2011). More recently, a growing body of research has highlighted the valuable role that vegetated coastal ecosystems, including mangrove forests, play in sequestering and storing carbon (C) from the atmosphere (Fourqurean et al. 2012; Mcleod et al. 2011; Bouillon et al. 2008; Alongi 2014; Siikamäki et al. 2012). Thus, mangroves are also significant in terms of mitigating global climate change; one of the most pressing issues of our time (IPCC 2014).

The coastal environment provides a clear example of how societies and natural ecosystems interact to form complex 'social-ecological systems' (Berkes and Folke 1998; Liu et al. 2007). Yet, although humans depend on coastal ecosystems in so many ways, these ecosystems are proving to be highly vulnerable under increased human pressures (Duke et al. 2007; Myers and Worm 2003; Halpern et al. 2008). Half of the world's coastal ecosystems are now in decline or lost completely (Davidson 2014; Duarte et al. 2008; Millennium Ecosystem Assessment 2005). Mangroves in particular face huge threats from land use change throughout their range (Hamilton and Casey 2016; Richards and Friess 2016; Valiela et al. 2001). The rapid growth of the shrimp aquaculture industry has been held responsible for much of the decline in mangroves in Southeast Asia over the past 30 years (Hamilton 2013; Valiela et al. 2001; Barbier and Cox 2004; Barbier and Sathirathai, 2004). Widespread conversion and degradation of mangrove forests to make space for aquaculture ponds has led to negative social-ecological feedbacks, such as salinization of rice fields, coastal pollution, fishery declines, and the potential loss of the C sink function of the forests (Primavera 1997; Vandergeest 2007; Valiela et al. 2001; Flaherty and Karnjanakesorn 1995; Pendleton et al. 2012). Societies are now faced with a decline in vital ecosystem services and the traditional income sources which are so closely associated with healthy functioning ecosystems.

Understanding the coastal environment as a coupled social–ecological system is crucial in addressing pathways for social and ecological resilience, given the current patterns of global environmental change (Olsson et al. 2004). This study focuses on the rapid social and ecological change brought about by the expansion of shrimp aquaculture in coastal mangrove areas of Thailand. Like in many other parts of the world, the intensification of shrimp aquaculture along the coast of Thailand over the past few decades has come with high social and ecological costs. The industry has been characterised by abrupt social-ecological dynamics: boom and bust periods driven by disease epidemics in cultured shrimp (Flegel 2012; Leaño and Mohan 2012), coupled with negative biophysical changes and a year-on-year drop in market price for shrimp (Lebel et al. 2002; Hall 2011b; Huitric et al. 2002; Barbier and Cox 2004; Piamsomboon et al. 2015).

1.2 Study aim and research questions

Using social-ecological resilience theory as a conceptual framework, the overarching aim of this research is to show how studying shrimp farming in mangrove areas as a social-ecological system can advance understanding of some selected drivers of resilient social-ecological systems, and how they are related. The study was guided by the following key research questions:

RQ1. What is the impact of shrimp farming and shrimp pond abandonment on mangrove ecosystem carbon stocks?

RQ2. What are the current patterns of shrimp farming diversity along the Gulf of Thailand coast, and how does this diversity relate to farmers' behaviour and social-ecological conditions?

RQ3. How do coastal communities affected by social and environmental change define coastal ecosystem health and the associated ecosystem services, and how do perceptions of ecosystem health and ecosystem service delivery change over time in relation to ecosystem management strategies and socio-demographic determinants?

Underpinning this research is the recognition that i) human and natural ecosystems are treated together because they co-exist to form a social-ecological system (Folke et al. 2002), ii) social-ecological systems are subject to co-evolving processes (Berkes and Folke 1998), and iii) natural ecosystems ultimately support people because of the goods and services that they provide (MA 2005; Costanza et al. 1997).

1.3 Case studies

Coastal Thailand offers a special case for investigating social-ecological resilience and human-environmental relationships because the natural environment and rich coastal resources are deeply embedded in its cultural history. However, since the mid-1980s, intensification of the shrimp culture industry, through the use of synthetic feeds, fertilizers and pesticides, has resulted in several challenges for coastal communities, particularly in the past decade. Large areas of coastal habitat, including mangrove forests, have been removed or degraded, leading to widespread environmental degradation, reduced water quality, declining fisheries, the emergence of various diseases, and loss of coastal livelihood (Vandergeest 2007; Valiela et al. 2001; Flaherty and Karnjanakesorn 1995; Barbier et al. 2008; Hamilton 2013; Barbier and Sathirathai 2004). Thailand's coastline is also exposed to the effects of climate change, including changing seasons, coastal erosion and coral bleaching events (Phongsuwan 2011; Bennett et al. 2015). Due to their high dependence on fisheries and coastal resources (Panjarat 2008), coastal communities in Thailand are particularly vulnerable to these changes (Bennett et al. 2015).

Empirical work of this thesis was done in two coastal provinces in Thailand: Chanthaburi on the Gulf of Thailand coast, and Krabi on the southern Andaman sea coast. At the local scale, the work focuses on active shrimp farming communities in the subdistricts of Khlung and Laem Sing in Chanthaburi province, and mangrove-dependant fishing communities located on the island Koh Klang in Krabi Province, where shrimp farming rapidly expanded through the 1990s and ended in the late 2000s. The fieldwork took place during two trips to the study areas; the first was between September and October 2016, and the second from January to May 2017. The two regions identified for case studies have distinct ecological and cultural histories involving many changes to the land and ecology. These areas have sustained livelihoods based around mangrove forests for many generations. This is an important aspect of the study because it allowed analysis of the accumulated traditional knowledge of local people on mangrove ecosystem health and management. In addition, it provided the opportunity to study the dynamics brought about by intensification of the shrimp farming sector over recent decades, and the rapid deforestation, environmental degradation, and changing social structures, which has challenged livelihoods and traditional mangrove use.

1.4 Research approach

Understanding shrimp farming in mangrove areas as a social-ecological system requires interdisciplinary research integrating various techniques and disciplinary lenses of analysis from the social and ecological sciences (Ostrom 2009). This study therefore adopts mixed methods (Creswell and Clark 2017) to understand the social and ecological dimensions of current and past shrimp farming in mangrove areas, and also to capture a wide range of knowledge and perspectives of ecosystem health from different groups of people. The methods used in this study integrate different types of variables and data, of qualitative and quantitative nature, in the analysis of interactions. The methods vary from biophysical sampling of mangrove ecosystem change, interviews and surveys with shrimp farmers, local communities and key informants, and participatory methods to engage with coastal communities for knowledge elicitation.

1.5 Thesis structure

Chapter 1 introduces the background and scope of the research, and the overarching aim and key research questions addressed in the thesis.

Following this, **Chapter 2** reviews the key literature and introduces the major concepts which this study is based. The literature review comprises two main sections. The first section presents the overall theoretical framework used in this thesis: social-ecological resilience. This section presents the concept of social-ecological resilience, and how this concept is applied to the analysis of human-environmental interactions in relation to global environmental change. The second section of the literature review sets the background for the research chapters, Chapters 4, 5 and 6, by reviewing the literature on the study topics and identifying knowledge gaps relevant to the key research questions. This section starts with an overview of mangrove forests and their ecological role as global C sinks, which is particularly relevant to RQ1. This is followed by a comprehensive overview of the rise and fall of shrimp farming in mangrove areas, focusing on industrial transformation and sustainability of the industry in Thailand. This section sets up the problem that is investigated in all research chapters but is particularly relevant to RQ2. The second section of the literature review ends by an overview of the impact of shrimp farming development and subsequent decline on mangrove ecosystem structure and function, and the wider implications for social-ecosystem resilience in Thailand, which is of particular relevance to RQ1 and RQ3.

Chapter 3 introduces the overarching methodology used in this thesis. It starts with background information specific to the study regions. This is followed by an overview of the mixed methods applied in the research chapters and ethical considerations.

Chapter 4, *Preservation and recovery of mangrove forest carbon in abandoned shrimp ponds,* addresses RQ1: What is the impact of shrimp farming and shrimp pond abandonment on mangrove ecosystem C stocks? This research chapter focuses on mangrove forests and explores changes in ecosystem processes and function arising from their conversion for shrimp farming. Specifically, this research assesses the influence of mangrove to shrimp pond conversion on mangrove ecosystem C storage on the island Koh Klang on the southern Andaman sea coast of Thailand. The assessment was conducted based on field inventories of forest structure and soil C stocks in mangrove forests and along a chrono-sequence of abandoned shrimp pond sites in former mangrove forest areas. A chrono-sequence approach enabled analysis of the potential C losses and gains over time after shrimp ponds are abandoned. This chapter advances current understanding of the role of mangroves as C sinks and how human disturbances influence this globally important ecosystem function. The observed patterns of C recovery in abandoned shrimp ponds suggests that mangrove C pools can rebuild naturally in abandoned ponds over time in areas exposed to tidal flushing. The quantitative ecological data collected in this research chapter compliments and sets a background for the in-depth qualitative analysis of social-ecological change on Koh Klang presented in Chapter 6 of this thesis.

Chapter 5*, Characterizing shrimp-farm production intensity in Thailand: beyond technical indices,* addresses RQ2: What are the current patterns of shrimp farming diversity along the Gulf of Thailand coast, and how does this diversity relate to farmers' behaviour and social-ecological conditions? This research chapter uses a case study of shrimp farming in Chanthaburi province on the Gulf of Thailand coast, to examine shrimp farmer behaviour in relation to production intensity, and its embeddedness in the wider socio-economic context of shrimp farming households. The integrative agent-centred (IAC) framework was used as a basis for designing a structured survey to collect semi-quantitative data for a range of explanatory variables that potentially drive shrimp farmer behaviour. The results illustrate that levels of shrimp farming intensity are in fact an indicator of a diversity of socio-economic conditions and behavioural choices, which need to be targeted by sustainability policies differentially and beyond the technical sphere. In showing this, the chapter concludes that national standards aimed at achieving aquaculture sustainability should be designed to reflect the diversity needed to support such a diverse sector and should be adjustable to better represent different socio-economic contexts.

Chapter 6, *Local perceptions and ecological knowledge in relation to ecosystem health and ecosystem service delivery in coastal Thailand,* addresses RQ3: How do coastal communities affected by social and environmental change define coastal ecosystem health and the associated ecosystem services, and how do perceptions of ecosystem health and ecosystem service delivery change over time in relation to ecosystem service-related policies and socio-demographic determinants? The social-ecological importance of mangrove ecosystems is strongest in this chapter. The analysis was based on qualitative data derived from interviews and workshops with community members of different age, occupation, and proximity to coastal ecosystems. The chapter is significant because it highlights the importance of mangrove ecosystems at the local level and that socio-economic factors can influence the degree of reliance of people on particular mangrove ecosystem services locally. Through analysing the human dimensions of mangrove-dominated ecosystems, this chapter contributes to our understanding of how drivers of global mangrove loss, such as shrimp farming, interact at a local level.

Chapter 7 integrates the findings from the research Chapters 4, 5, and 6 and discusses the wider implications of the research in light of the overall aim of this thesis. Finally, **Chapter 8** critically reviews the research methodology adopted for this research.

1.6 Chapter contributions

All of the chapters in this thesis received input from the academic supervisors. Some of the research chapters received contributions from additional collaborators. An outline of the contributions of others to the research chapters, along with the proposed target journals for publication is given below.

Chapter 4: *Preservation and recovery of mangrove forest carbon in abandoned shrimp ponds.* This chapter is being prepared as a Research Article for submission to *Nature Geoscience*. The article authorship includes Angie Elwin, Jacob Bukoski (University of California, Berkeley), Vipak Jintana (Kasetsart University, Bangkok), Elizabeth Robinson (University of Reading), and Joanna Clark (University of Reading). I played a leading role in the research design, fieldwork, data analysis and writing of the research chapter. Joanna Clark and Elizabeth Robinson provided overall supervision and contributed with ideas to the research design, data analysis and with revisions to the manuscript. Vipak Jintana, who acted as a host academic supervisor during the fieldwork phase of this research, supported the fieldwork in Thailand and contributed with comments to improve the manuscript. Jacob Bukoski provided mangrove ecosystem carbon data (soil C and above and below ground tree C) for 2 of the 5 plots per transect in the Krabi mangrove sites. This data was collected by Jacob Bukoski in 2015. Additional mangrove ecosystem C data was collected and processed by me in 2017 from the remaining plots along each Krabi mangrove transect. All abandoned shrimp pond ecosystem C data was collected by myself in 2017, and I analysed the combined dataset and wrote-up the findings. Jacob Bukoski also contributed with important comments to improve the manuscript. Additional fieldwork support was provided by Jim Enright (Mangrove Action Project, Thailand) who also provided comments on the manuscript.

Chapter 5: *Characterizing shrimp-farm production intensity in Thailand: beyond technical indices.* This research chapter has been submitted as a Research Article to *Ocean and Coastal Management* and is currently under review (May 2019). The authorship includes Angie Elwin, Vipak Jintana, and Giuseppe Feola. I played a leading role in the research design, fieldwork, data analysis and writing of the article. Giuseppe Feola contributed with ideas to the research design, methodology, interpretation and framing of the results, and provided important comments to improve the manuscript. Fieldwork in Thailand was supported by Vipak Jintana who assisted me with survey data collection. Vipak Jintana also provided comments on the manuscript. Overall supervision was provided by Joanna Clark and Elizabeth Robinson, who also assisted with the development of the study and provided comments on the manuscript. Additional fieldwork logistics were supported by the Department of Marine and Coastal Resources, Thailand. Informants that participated in this study provided their time and important input. Informants included shrimp farmers in Chanthaburi Province, local shrimp farming cooperative officials, village heads, Provincial representatives from the local government Mangrove Management Unit, and representatives from the Department of Marine and Coastal Resources in Bangkok.

Chapter 6: *Local perceptions and ecological knowledge in relation to ecosystem health and ecosystem service delivery in coastal Thailand*. This research chapter is being prepared as a Research Article to submit to *Ecosystem Services*. The authorship includes Angie Elwin, Joanna Clark, Giuseppe Feola, Vipak Jintana, and Elizabeth Robinson. I played a leading role in the research design, fieldwork, data analysis and writing of the article. Joanna Clark, Giuseppe Feola and Elizabeth Robinson provided overall supervision, contributed ideas to the research design, data analysis, framing of the results, and provided important comments on the manuscript. Fieldwork was supported by Vipak Jintana who also provided feedback to improve the manuscript. Additional fieldwork support was provided by Jim Enright (Mangrove Action Project, Thailand). Informants that participated in this study, including community members, the local government head of Klong Prasong, village heads, inshore fishers and mangrove resource collectors, and local leaders of environmental groups, provided their critical time and important input to the research.

Chapter 2 Literature Review

2.1 Theoretical framework: social-ecological resilience

This first section of the literature review sets the theoretical background to the approach used in this thesis to study shrimp farming in mangrove areas through a social-ecological resilience lens.

2.1.1 Social-ecological systems

All ecosystems on Earth have been influenced by human activities (Vitousek et al. 1997; Goudie 2018). The inevitable interaction between human systems and ecological systems is the basis for the widely agreed view that, in light of the many global challenges we face today, the environment is best understood as an integrated *social-ecological system* (Liu et al. 2007; Berkes 2017). Defined by Folke et al. (2006), social-ecological systems (SES) are "*complex, linked systems of people and nature*".

The concept of integrated social and ecological systems first arose in the late 1990s (Berkes and Folke 1998) in recognition that widespread environmental problems, such as biodiversity loss and natural resource degradation (Vitousek et al. 1997), were driven by human interaction with nature. Thus, there was a need for more integrated studies of societies and ecosystems, and their interactions and feedbacks (Liu et al. 2007). Social-ecological systems (SES) exist across a range of different ecological, socioeconomic, political, demographic and cultural contexts. Common examples from the SES literature include; agricultural systems (Hoogesteger 2015), small-scale fisheries (Basurto et al. 2013; Leslie et al. 2015; Wilson et al. 2007; Fuller et al. 2017), and forestry (Oberlack et al. 2015).

Social-ecological systems are inherently complex. They are characterised by complex interactions and feedbacks between ecological variables (such as biodiversity and landscape configuration), social variables (such as socioeconomic processes, governance structures, and social networks), and variables that flow between the two systems (such as ecosystem services (MA 2005)). SES dynamics are shaped by a range of local to global-scale processes, such as cultural values, policies, power distribution, resource exploitation, and changes in land-use, markets and demand for natural resources (Berkes et al. 2006; Nayak and Berkes 2019). Features of SES include non-linearity and spatial and temporal thresholds (the point between alternative system states; Walker and Meyers 2004), legacy effects and time lags (slow drivers and delayed impacts; Walker et al. 2012), heterogeneity (spatial, temporal and organisational variation), surprises and resilience (the capacity to maintain similar function and structure for continuous development when faced with pressures and disturbances; Folke et al. 2006; Gunderson and Holling 2002).

2.1.2 Social-ecological systems as complex adaptive systems

Given the complexity of social-ecological systems, they have been conceptualised and studied as complex adaptive systems (Levin 1998; Gunderson and Holling 2002). Complex adaptive systems (CAS) are based on, "*complex behaviour that emerges as a result of interactions among system components (or agents) and among system components (or agents) and the environment. Through interacting with and learning from its environment, a complex adaptive system modifies its behaviour to adapt to changes in its environment*" (Potgieter and Bishop 2001). Complex adaptive systems are characterised by their co-evolutionary dynamics and capacity to self-organise following a disturbance, and where large-scale configurations emerge from local, small-scale patterns (Hartvigsen and Levin 1997; Levin 2005). Self-organisation acts to stabilise a CAS influenced by economic, political, or cultural perturbations, by allowing pressure variables to vary within a range without producing catastrophic change to the system (Cross et al. 2003). These ideas are linked to the 'adaptive renewal cycle' proposed by Holling in 1986 and the 'panarchy' concept later developed by Gunderson and Holling in 2002. The adaptive renewal cycle is a conceptual model which suggests that all complex systems, ecological or social, experience cyclical changes comprising four phases: exponential change (exploitation phase), growing rigidity (conservation phase), readjustments and collapse (release or creative destruction phase) and reorganization and renewal phase (Holling 1986, Gunderson and Holling 2002). 'Panarchy' (Gunderson and Holling 2002) draws on the linkages among adaptive cycles across different hierarchical scales.

The CAS approach enables understanding of how co-evolutionary processes and dynamics of SES interact across different hierarchical levels and different geographical and organisational scales (Figure 2.1; Berkes 2017; McLeod and Leslie 2009). In the coastal environment, organisational scales can range from the small-scale individual fisher or tourist, to businesses (e.g. local fish markets) and larger-scale institutions (e.g. coastal management bodies). Geographically, scales of interactions can range from the locally used mangrove forest, its connected coastal ecosystems, or the wider marine environment.

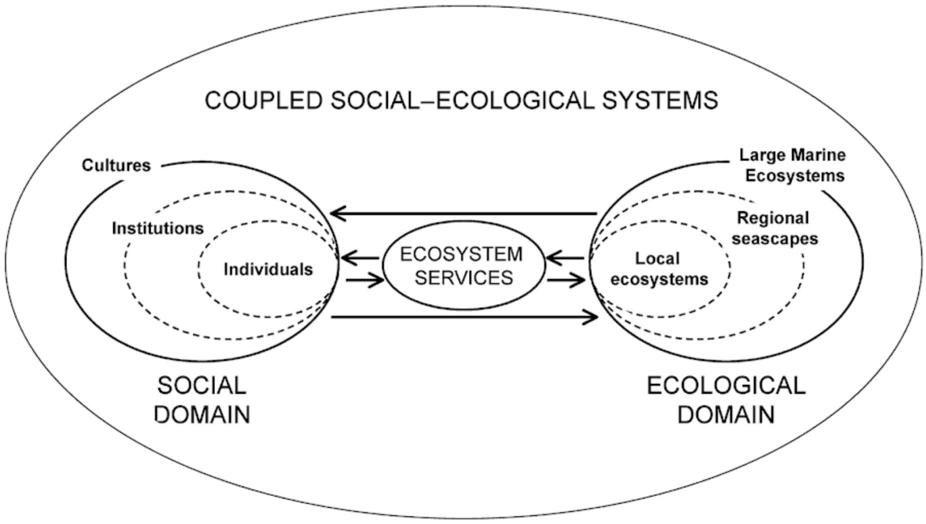


Figure 2.1. Dynamic human and ecological systems referred to as "coupled social-ecological systems". Interactions between the social and ecological domains occur over multiple geographic and organizational scales. While some domains may be relatively smaller in scale, such as individuals and situations, they are not necessarily all nested. For example, cultures occur at geographic scales that are parallel to or larger than institutions. Ecosystem services represent a key connection between domains, and the flow of services is affected by both social and ecological factors. Figure and caption from McLeod and Leslie (2009).

A key link between social and ecological systems is the delivery of ecosystem services, the flow of which are affected by multiple social and ecological factors (McLeod and Leslie 2009). Ecosystem services (ES) are the various goods and services provided by ecosystems to society, which in turn contribute to the well-being and economic wealth of people and societies (Costanza et al. 1997; Millennium Ecosystem Assessment 2005; de Groot et al. 2012). Defining and valuing ES is a rapidly growing research field due to the need to identify potential trade-offs arising from the management of natural resources (Costanza et al. 2017). Ultimately, natural resource managers aim to ensure a reliable flow of ES to stakeholders within a SES (Biggs et al. 2015; Folke et al. 2004; Mace et al. 2012). However, ES are spatially and temporally dynamic (Fisher 2009), and differences in cultures and livelihoods may affect the way people value ecosystems locally and different ES preferences (Biggs et al. 2012; Robards et al. 2011). Much of the research on ES focuses on global scale valuation (Rivera-Monroy et al. 2017;

Costanza and Folke 1997; Daily et al. 1997) which can lead to a lack of understanding of the local scale ecosystem benefits (Alongi 2002). In particular, few studies have attempted to understand local perspectives of the benefit of mangrove forests (but see de Souza Queiroz et al. 2017; Rönnbäck et al. 2007). Consideration of ES trade-offs is particularly relevant in the field of mangrove forest use and management (Orchard et al. 2016) given the wide range of goods and services they provide (Brander et al. 2012; Lee et al. 2014; Walters et al. 2008). Chapter 6 of this thesis presents a more comprehensive review of the literature on mangrove ecosystem services and local perspectives of their delivery. The review argues that there is a need for more context-dependant understanding of ecosystem service delivery which accounts for small scale differences influenced by different social and ecological contexts (Hedden-Dunkhorst et al. 2015; Vo et al. 2012).

2.1.3 Frameworks for studying social-ecological systems

Research on SES aims to understand the linkages between social and environmental change, and if or how social-ecological relationships can be sustainable. SES research has grown over the past two decades (Partelow et al. 2018), and several frameworks have been developed for comparing and defining system components, interactions and outcomes (Ostrom 2009; Binder et al. 2013). Some of the main frameworks (see Binder et al. 2013 for a review) include The Social-Ecological Systems framework (Ostrom 2007, 2009), The Ecosystem Services framework (Boumans et al. 2002; Limburg et al. 2002; de Groot et al. 2002), The Human-Environment Systems framework (Scholz and Binder 2003, 2004; Scholz et al. 2011), The Vulnerability framework (Turner et al. 2003), The Sustainable Livelihoods Approach (Scoones 1998; Ashley and Carney 1999) and The Conceptual Framework for Ecosystem-based Management (McLeod and Leslie 2009). These frameworks vary significantly in their purpose (Binder et al. 2013). For example, some focus on linkages between the environment and human wellbeing (The Ecosystem Services framework), while others focus on environmental problems related to human activities (The Human-Environment Systems framework) or livelihood strategies (The Sustainable Livelihoods Approach).

Ostrom's SES framework (SESF), which is presented in section 2.1.5 in this thesis as an overall way of organising the research chapters, provides a common set of multi-tier variables to use in the analysis of SES. The SESF recognises the hierarchical qualities of complex SES and represents the social and ecological systems as equal in depth (Binder et al. 2013). The SESF can be used to characterise a SES, analyse its complexity and functioning, and test relationships between system component interactions and SES outcomes (McGinnis and Ostrom 2014).

The SESF is structured into tiers of nested variables. In the first tier, the variables include the Resource Systems, Resource Units, Users, Governance Systems, Interactions and Outcomes. The higher-tier variables in the framework are sub-categories of the first-tier. For example, a Resource System, such as shrimp production in mangrove forests, can be broken down into several subcomponents, such as size of the resource system, its productivity, or location. All of the multi-tier variables interact to produce outcomes and feedbacks within an external social, economic, and political setting. The framework recognises that each variable potentially plays a role within the complex system, however the relative influence of a particular variable may differ across contexts. Researchers applying the SESF can examine which variables are most influential in different contexts.

2.1.4 Application of the Social-Ecological Systems Framework

The SESF has been applied to the study of SES in a variety of different contexts and sectors, but most commonly research has focused on common-pool resource systems, such as fisheries (Blythe et al. 2017, London et al. 2017, Nakandakari et al. 2017; Partelow 2015, 2018), agriculture (Hoogesteger 2015), or forestry (Fleischman et al. 2010, Oberlack et al. 2015). The SESF has also been used recently in combination with other concepts, such as Ecosystem Services (Ban et al. 2015, Partelow and Winkler 2016, Rova and Pranovi 2017) and Resilience (Risvoll et al. 2014, Arlinghaus et al. 2017).

A recent review by Partelow et al. (2018) highlights the wide range of mixed methods, analytical tools and disciplinary approaches that have been applied in research engaging with the SESF. Beyond the sectors of fisheries, agriculture and forestry, there has been some use of the SESF in other contexts, such as research on pond aquaculture systems in Indonesia (Partelow et al. 2018b), marine ecosystem management (Cinner et al. 2012, Stevenson and Tissot 2014, Ban et al. 2015, 2017), and marine and coastal systems (Schlüter et al. 2013, 2018). Partelow et al. (2018), for example, examined pond aquaculture (milkfish and seaweed) in a community-based mangrove setting, comparing two units of analysis: community level and pond level. They found that production capacity and stability was hindered by pond conditions, which in turn influences social and economic conditions. They also highlight that the common pool resources within the system (waterways and mangrove forests) lack formal and informal institutional mechanisms for governing their provision, which were shown to be important for determining production outcomes.

2.1.5 Conceptualising shrimp farming communities as a social-ecological systems

In the empirical research presented in chapters 4, 5, and 6 of this thesis, mangrove shrimp-farming communities are conceptualized as social-ecological systems, whereby complex interactions and feedbacks occur between humans and ecosystems (reviewed in section 2.1.1). A requirement of the project was therefore the need to find suitable approaches to the integration of different disciplines in order to analyse interactions between social and ecological processes. Interdisciplinary research approaches are well suited to addressing such complexities and thus are increasingly being adopted in research, as well as in policy and environmental management strategies (Stone-Jovicich et al. 2018). The SES framework is well suited to meet the challenge of interdisciplinary research because, in formalising the relationships between nature and society, it offers a foundation which takes into account the interplay between the two systems.

The SES framework was used in this research to conceptualize shrimp farming in mangrove areas as the social-ecological system (Figure 2.2) because it draws on both societal (social, economic, cultural, political) and natural (biological, chemical physical) structures and processes that are relevant for the focus of this research. However, the use of the SES framework is restricted to aiding the structuring of the research design, project planning, and shaping of the research questions. On this basis, it served as a starting point for operationalising the interdisciplinary research.

When designing the research questions, consideration was taken of the multiple different variables potentially driving feedbacks and outcomes within the larger structure of the social-ecological system. In the context of the social-ecological system examined in this research, the outcomes (e.g. resilience, farm productivity, ecosystem health, ecosystem service delivery) may be determined by the interaction between the resource system (shrimp aquaculture landscape), the resource units (mangrove forests, waterways), the resource users (e.g. shrimp farmers, local communities, non-government organisations, local knowledge systems, past experiences), and the governance system (e.g. regional decision-makers, local authorities, and policies that determine the management of the coastal environment and the shrimp farming industry).

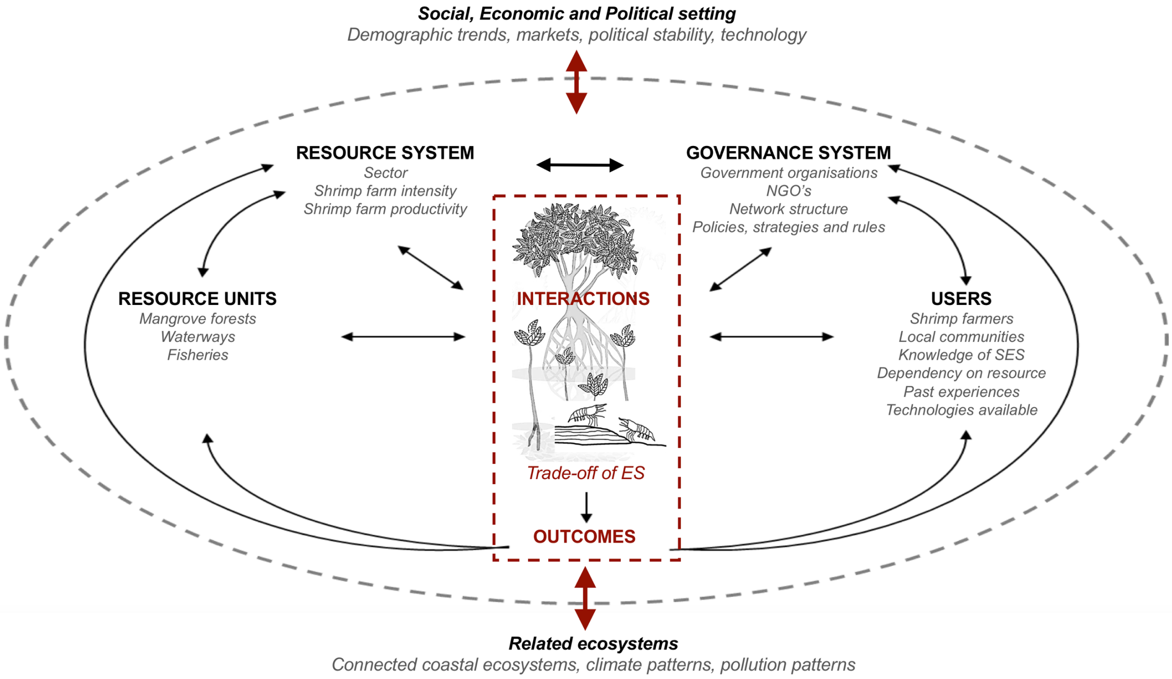


Figure 2.2. Conceptualisation of the interacting variables potentially driving feedbacks and outcomes within a mangrove shrimp-farming social-ecological system. Adapted from Ostrom's (2009) SES framework.

The SESF presents a general understanding of SES interactions, and some of the interactions outlined in the framework were studied in different research chapters in this thesis. In Chapters 4 and 6, for example, I focus on the mangrove forests as the resource unit, looking at their function and importance as a resource, their capacity to deliver ecosystem services, and ability to regenerate in abandoned shrimp pond areas. Chapter 6 specifically focuses the mangrove-dependent community as resource users, along with their knowledge of the social-ecological system, history of past experiences, socioeconomic attributes, social capital and self-organization activities. Chapter 5 focuses on shrimp farming as the resource system and looks at variables such as productivity and intensity of farms, along with the shrimp farmers as resource users, their past experiences, socioeconomic attributes, social norms, dependence on natural resource and their self-organization activities.

2.2 Resilience

One measurable outcome in the study of social-ecological system dynamics is the level of *resilience* within the system. Resilience thinking focuses on change as an inevitable feature of a system, and refers to complex, nonlinear, and mutually enforcing processes within and between systems (Walker et al. 2004, Folke 2006).

2.2.1 Ecological resilience

The concept of resilience emerged from the ecological sciences in the 1970s. Historically, ecological systems were assumed to be static, stable, linear, and predictable (Holling and Meffe 1996). However, interest in ecosystem behaviour and the analytical use of resilience grew in the early 1970s, and work on theoretical models in ecology (Holling 1973; May 1977) gave rise to the idea that ecosystems may exhibit more than one 'stable state'. Holling in particular emphasised the role of external drivers of change and the potential for 'ecological surprises' in influencing the amplitude and frequency of the apparent fluctuation between states on temporal and spatial scales (Holling 1973). Early studies of ecosystem functional responses to disturbance (Holling 1961; Lewontin 1969; Rosenzweig 1971; May 1972) demonstrated that an ecosystem may become increasingly vulnerable to environmental perturbations due to loss of 'resilience', which Holling (1973) defined as, '*a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationship between populations or state variables*'. Resilience thinking also embraces features of complex adaptive systems (Hartvigsen et al. 1998; Levin 1998), drawing on the importance of renewal, self-organisation, learning and development following disturbance as an integral feature of resilience (Cumming and Norberg 2008).

Concepts of ecological resilience and thresholds referenced in early studies comparing changes in ecosystem state with different management regimes (Holling 1978; Clark et al. 1979), offer a means for understanding how ecosystems respond to disturbance and how they may return to pre-disturbance states with intervention following anthropogenic disturbance. These ideas are now forming the basis for policy and legislative frameworks concerned with 'adaptive ecosystem management' (Standish et al. 2014). From an ecosystem management perspective, Holling's ideas recognise two important things. Firstly, that the removal of a disturbance (e.g. unsustainable logging) does not necessarily result in ecosystem recovery. Furthermore, when ecosystem disturbance is severe or long-term, the system may be unable to fully recover on its own (i.e. without actions, such as replanting).

2.2.2 Social-ecological resilience

While resilience thinking first gained traction in the ecological sciences, the ideas have evolved over the past two decades to embrace a holistic understanding of social and ecological systems (Walker et al. 2004). Interest in the interaction and dynamics between social and ecological sciences was first promoted in the 1990s with the creation of the Resilience Alliance by the Beijer Institute in Stockholm (Resilience Alliance 2018). Based on theories about the co-evolutionary relationships between people and nature (Norgaard 1994), the concept of social-ecological resilience was developed as a framework for addressing change (Berkes and Folke 1998, Folke et al. 2005, 2010). Social-ecological resilience focuses on the capacity of a system to absorb disturbances (such as logging, or natural disasters) so as to preserve its fundamental structure, processes, and feedbacks (Holling 1973; Walker et al. 2004). A resilient social-ecological system has the capacity to self-organise through learning and adaptation (Carpenter et al. 2001; Folke et al. 2002; Berkes 2017). This relates in part to how well ecosystems can regenerate when faced with disturbances, so to continue to deliver essential ecosystem services that support human livelihoods and wellbeing (Folke 2006). Although shocks and stresses can result in non-linear behaviour and sudden shifts in social-ecological state, in resilient systems, ecological, social and economic perturbations may also potentially create positive feedbacks, encouraging new opportunities, innovation, and pathways to development (Folke 2006).

A social-ecological resilience lens has been used previously to conceptualize human-mangrove systems (Brown 2007; Glaser et al. 2010; Máñez et al. 2014). Mangrove social-ecological systems have been studied in Vietnam (Adger 2000; Orchard et al. 2016) and Sri Lanka (Jonsson 2017), for example. However, this research takes a novel approach by using social-ecological resilience theory to study resilience of mangrove shrimp-farming communities at the local level in Thailand. Applied to shrimp aquaculture in coastal areas, resilience thinking provides a basis for understanding different scales, from single units, such as farms or producers, to mangrove forests, waterways and landscapes, and their interrelationships through natural resources, ecosystem, services, disease, and human management (Bush et al. 2010).

The context for the empirical research in this thesis is shrimp farming in coastal mangrove areas of Thailand. The final section of the literature review sets the background for the empirical research by reviewing the key literature and identifying knowledge gaps relevant to the research questions. The section starts with an introduction to mangrove forests and their importance. This is followed by an overview of the development of shrimp farming in mangrove areas, focusing on industrial transformation and sustainability of the industry in Thailand. Finally, an overview of the impact of shrimp farming development and subsequent decline on mangrove ecosystem structure and function is presented, and the wider implications for social-ecosystem resilience in Thailand.

2.3 Introduction to mangrove forests

2.3.1 Mangrove ecological functions and global importance

Mangrove forests are a unique intertidal ecosystem that thrive on dynamic subtropical and tropical coastlines where the land meets the sea, often in association with seagrass meadows, coral reefs and intertidal mudflats (Tomlinson 2016; Spalding et al. 2010; Figure 2.3). The 69 'true' tree and shrub species of mangrove have distinct morphological and physiological attributes, such as aerial roots and salt-excreting leaves, which enable them to thrive in saline and saturated environments (Duke 2017). Globally, mangroves cover around 150,000 square kilometres of coastline, which is about half of their historic range (Spalding et al. 2010). Situated in the intertidal zone, mangroves provide valuable functions for both the land and sea (Barbier and Strand 1998; Field et al. 1998; Lee et al. 2014). Along the shoreline, these forests protect the coast from erosion, storm surges and ocean waves (Mazda et al. 2006; Thampanya et al. 2006; McIvor et al. 2012). Mangroves also play a vital role in coastal biodiversity through providing important habitat and spawning grounds for thousands of fish and invertebrate species (Pathirana et al. 2008; Nagelkerken et al. 2000; Barbier 2006). A key feature of mangroves is their extensive root system which is advantageous because it enables them to maximize water gain and acts to stabilize the forest against storms and tidal forcing (Alongi 2012). The intricate root structure also stabilizes the land from erosion and acts as a barrier for nutrient-laden agricultural run-off. In coastal communities, mangrove wood has multiple purposes and is widely used for fuel and construction (posts, beams, roofing, fishing gear) (Walters et al. 2008).

Figure 2.3. Global mangrove distribution in 2000. Source: Giri et al. 2011.

2.3.2 Mangrove ecosystem carbon

Mangroves are a highly productive ecosystem (Bouillon et al. 2008; Alongi 2012) and are increasing recognised globally as important carbon (C) sinks that can contribute to climate change mitigation (Alongi 2012; Siikamäki et al. 2012; Murdiyarso et al. 2015). Figure 2.4 shows a budget of the major pathways of C flow through a typical mangrove ecosystem. On average, mangroves have a mean whole-ecosystem C stock of 956 t C ha^{-1} (Alongi 2014), which is around 2.5-5 times higher than the mean ecosystem C stock found in temperate, boreal and upland tropical forests (200-400 t C ha^{-1}; Pan et al. 2011). Most of mangrove ecosystem C is produced *in situ* by photosynthesis and plant productivity (Alongi 2014). Ecosystem C storage in mangroves worldwide is very much dominated by belowground C pools (Kristensen et al. 2008; Donato et al. 2011; Kauffman et al. 2011). The main source of organic matter within the soils is belowground root growth and tree litter (leaves, branches, propagules) (Alongi 1998): dead roots comprise around one-third of the total soil C pool (Alongi et al. 2003, 2004). Belowground organic-rich deposits can form up to several meters deep (Fujimoto et al. 1996; Macintyre et al. 1995; Twilley et al. 1992) and can account for as much as 98% of the total C stored by the ecosystem (Donato et al. 2011).

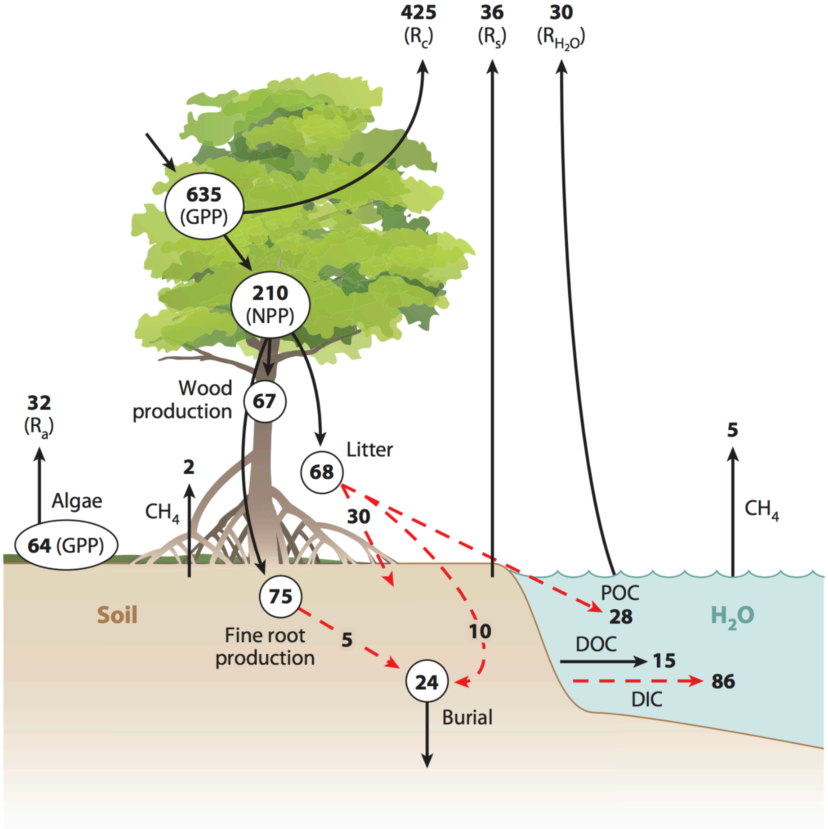


Figure 2.4. Budget of the major pathways of carbon flow through the world's mangrove ecosystems. Solid black arrows represent mean values based on numerous empirical data. Dashed red arrows represent either mean values estimated indirectly (by difference) or pathways suggested from the most recent literature. All values are in Tg C y–1. The budget assumes a global mangrove area of 138,000 km² (Giri et al. 2010). Abbreviations: DIC, dissolved inorganic carbon; DOC, dissolved organic carbon; GPP, gross primary production; NPP, net primary production; POC, particulate organic carbon; Ra, algal respiration; Rc, canopy respiration; Rs, soil respiration; RH2O, waterway respiration. Figure and caption source: Alongi 2014.

Globally, mangrove organic C stocks in the top meter of soil range from around 3 to 46 mg C cm^{-3}, and the variability is driven mainly by tidal amplitude and minimum temperature (Rovai et al. 2018; Figure 2.5). High levels of organic C are stored within mangrove soils due to low rates of organic matter decomposition, resulting from a dominance of sub-oxic and anoxic soil conditions (Kristensen 2007). Microbial decomposition of organic matter is generally slow in mangrove soils because the detritus is rich in tannins, lignin and cellulose (Lee et al. 1990; Benner et al. 1990; Marchand et al. 2005). Under oxic conditions, these compounds can be easily degraded, however anoxic soil conditions, such as those found in intertidal mangrove environments, slows the decomposition process (Kristensen et al. 2008; Ray et al. 2011; Osland et al. 2012).

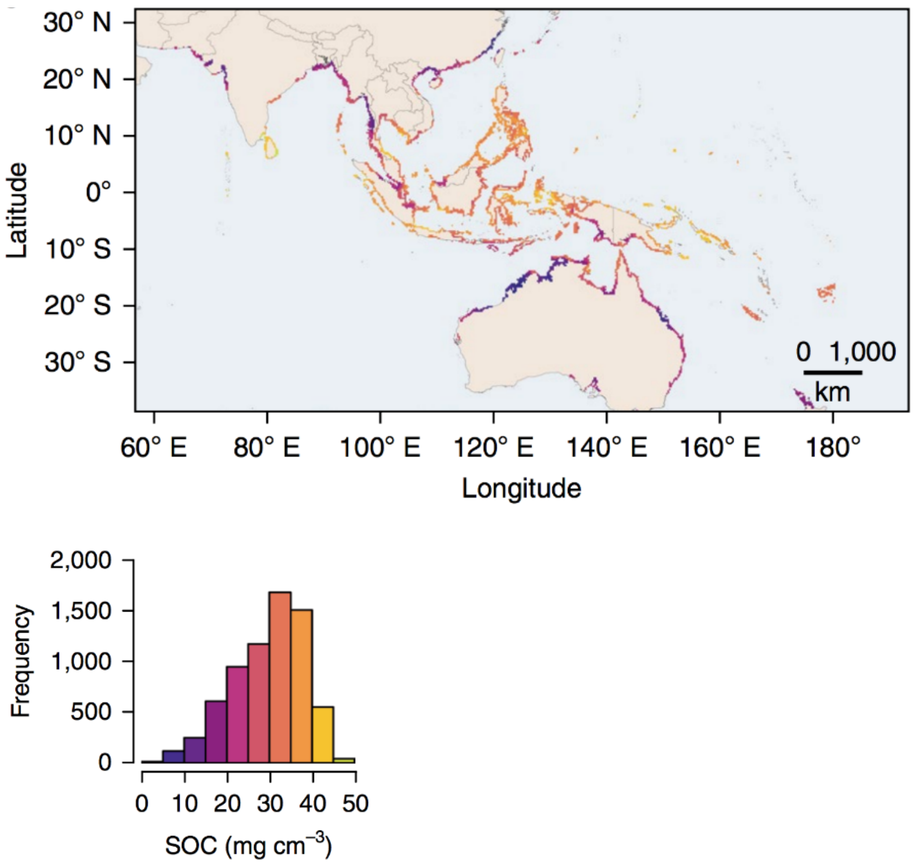


Figure 2.5. Predicted mangrove soil carbon density (mg cm^{-3}) for Southeast Asia/Australasia. Colours correspond to spatial distribution of SOC density. Source: Rovai et al. 2018.

2.3.3 Mangrove threats and decline

The intertidal location of mangroves exposes them to both terrestrial and marine threats, and despite being among the most productive and C rich ecosystems of Earth (Alongi 2014), mangrove forests are also one of the world's most threatened (Duke et al. 2007). Human activities over the past half century have greatly modified the ecological structure and function of mangrove forests, and significantly challenged their existence (Duke et al. 2007). The expansion of aquaculture is one land-use change that has substantially driven global mangrove loss since the 1980s (Richards and Friess 2016; Valiela et al. 2001). Hamilton (2013) and Hamilton and Casey (2016) estimate that 52% of historical mangroves have been lost in the eight countries that host around half of the world's mangroves. They attribute around 28% of this loss to their conversion for aquaculture. Other major human threats to mangroves include the conversion of natural habitat into agriculture lands for rice and oil palm production, as well as urban development (Richards and Friess 2016). Mangroves are also sensitive to climate-related changes, including increasing sea temperatures, sea level rise, and ocean acidification (IPCC 2012).

The literature commonly states that globally mangroves have been disappearing at a rate of 1-3% per year (Giri et al. 2011; Valiela et al. 2001; Hamilton 2013). More recent estimates (Hamilton and Casey 2016) show that the rate of global mangrove loss has slowed to 0.4% annually. For Southeast Asia, Richards and Friess (2016) estimate that mangrove loss was at a rate of 0.18% per year between 2000-2012. Part of the apparent slowing down of net mangrove loss is thought to be driven by new mangrove growth since the 1970s (i.e. deforestation is offset by growth of mangrove in new areas). Hamilton (2013) estimated that 13% of current mangrove area in the 8 countries hosting 45% of global mangrove cover is classed as new mangrove (i.e. growth in areas not previously occupied by mangroves post-1970s).

The conversion of mangroves to other land uses, such as aquaculture ponds, not only results in a dramatic areal decline in natural habitat but has the potential to reverse the C sink function of the forests (Pendleton et al. 2012). This is because pond construction changes the topography of the land therefore altering key biophysical variables controlling CO_2 flux from the soils to the atmosphere, such as soil temperature, soil moisture content, and the duration of tidal inundation (Fuentes and Barr 2015; Lovelock et al. 2011; Cameron et al. 2018). During the pond building process, excavated pond soils are usually piled up under aerobic conditions to form dykes, thus increasing oxidation of the mangrove soil C stock (Lovelock et al. 2011; Sidik and Lovelock 2013). Some studies suggest that mangrove conversion results in the loss of over 50% of soil C and up to 90% of total ecosystem C (Kauffman et al. 2014; Murdiyarso et al. 2015; Kauffman et al. 2017; Bhomia et al. 2016; Castillo et al. 2017). Yet, large uncertainties exist regarding the magnitude of C loss, and the implications for natural CO_2 sinks and C reservoirs globally.

The conversion of aquaculture land back into mangrove forests, either through natural regrowth or assisted rehabilitation or restoration, may stimulate C storage in the future. Restoration or rehabilitation of mangroves in abandoned aquaculture farm areas has taken place through a number of projects around the world (Matsui et al. 2010; Primavera et al. 2011, Brown et al. 2014). Yet, although the vital C storage function of mangroves has become more evident in recent years in the context of climate change (Alongi 2014; Donato et al. 2011), the push to preserve the remaining mangroves or promote their restoration has been limited by the lack of economic incentives and accepted methodology for valuing the C stored by mangroves (Jerath et al. 2016).

2.3.4 Mangroves of Thailand

Mangroves are a dominant ecosystem on Thailand's 2, 600 km long coastline (Spalding 2010; Giri et al. 2011). Thailand has around 230, 000 ha of mangrove forest, the most extensive of which (85%) occurs on the Andaman Sea coast (Giri et al. 2011; Figure 2.6), with the Provinces Phang Nga and Krabi supporting the greatest area, representing 18.5 and 15.5 percent of total mangrove cover (DMCR 2018). Thirty-five true mangrove species are found in Thailand. Dominant mangrove species belong to the genera *Avicennia, Bruguiera, Ceriops, Lumnitzera, Rhizophora, Sonneratia,* and *Xylocarpus*. Five additional terrestrial plant species and pure halophytes (species that can tolerate saline conditions), known as 'associate mangrove species' can also be found in Thailand (Duke et al. 2014).

Mangrove products are used directly for subsistence and commercial purposes in Thailand. Uses include wood for charcoal, building materials, firewood, and traditional fishing gear (Kridiborworn et al. 2012; Sathirathai 1998). Mangroves also provide wild food sources such as fish, crabs, snails, and other edible species, along with educational and recreational services. In providing nursery grounds and refuge area for many marine organisms, mangrove forests are also vital for the productivity of both inland freshwater fisheries and near shore and marine fisheries in Thailand (Barbier 2007).

Figure 2.6. Distribution of mangrove forests in Thailand, 2000. Mangrove distribution data source*:* Giri et al. 2011. http://data.unep-wcmc.org.

According to the Forest Act 1941, Thailand's mangroves are classified as forests, and all forest is owned by the central government who monopolise control and management of natural resources in Thailand (Beresnev and Phung 2016; Webb 2008). Established in 2002, the Department of Marine and Coastal Resources (DMCR), within the Ministry of Natural Resources and Environment (MoNRE), is the main agency responsible for management of mangrove forests. However, because they lie between the land and the sea, many other agencies and government departments also share responsibility for their management and regulation. These include:

- Department of National Parks and Wildlife Conservation (DNP) (within MoNRE)
- Royal Forestry Department (RFD) (within MoNRE)
- Ministry of Interior
- Department of Fisheries
- Ministry of Agriculture and Cooperatives

Such complex governance arrangements for mangrove forests are typical in Southeast Asia, due to their intertidal location and wide-ranging uses (Friess et al. 2016). Influenced by both social and ecological interactions, coastal resources such as mangrove forests are complex social-ecological systems making their governance difficult (Partelow et al. 2018, Schlüter et al. 2018). Overlapping policy aims and responsibilities among ministries and departments can lead to incoherent and conflicting policy development (Rice 2011; Friess et al. 2016), and Thailand is no exception, as the following sections illustrate.

2.4 Introduction to shrimp farming in Thailand

2.4.1 Industrial transformation and sustainability

Shrimp aquaculture has been a traditional livelihood practice on coastal landscapes in Asia for centuries (Deb 1998), but the adoption of industrial techniques in shrimp culture began in South Asia in the 1970's (Hall 2004). The construction of ponds to rear shrimp in brackish waters within mangrove forests was a method pioneered in Japan and Taiwan (Flaherty and Karnjanakesorn 1995). At this time, total aquaculture produce contributed less than 5% of the world fish supply. However, subsequent technological advances in the shrimp farming industry, such as the development of shrimp feed and larvae production, led to rapid expansion of the aquaculture industry in the mid 1980's (Lebel et al. 2002). The growth in the global tropical seafood market around this period led to enormous profits from shrimp exports, mainly from Asian countries to the EU, US, and Japan (Vandergeest 2007).

The semi-intensive shrimp farming sector steadily grew in Thailand up until the 1980s, aided by help from the Department of Fisheries who established hatcheries to rear shrimp larvae in the early 1970s (Katesombun 1992). In the early 1980s, improved technology, increased international demand for shrimp, and high potential profits set the conditions for widespread intensification of shrimp farming (Szuster 2006). Intensive shrimp farming was dominated by the production of the species *Penaeus monodon* (giant tiger shrimp), and ponds were stocked with very high densities with the use of processed feed, fertilizers, and antibiotics (Flaherty and Karnjanakesorn 1995). Many of the shrimp farms were modest, family-run operations, and shrimp farmers were typically former fisher-folk and agriculturalists, with very little prior experience in aquaculture (Flaherty et al. 2000). The industry developed virtually unregulated in

Thailand until 1987, and by 1991, the country had become the leading producer of giant tiger shrimp (FAO 2002). During this period, the Thai government aimed largely at maximising productivity and economic returns within a very short time scale. Although such an approach was satisfactory through the 1980s and 90s, over the longer term, the industry suffered negatively from a socio-economic and environmental perspective, largely because of the profound implications for the long-term integrity of coastal ecosystems in Thailand (Huitric et al. 2002). Undervaluing of the economic contribution of mangrove forests and associated habitats, coupled with weak environmental governance, led to widespread environmental degradation, social conflicts, and increased exposure of coastal communities (Huitric et al. 2002; Primavera 1997).

2.4.2 Role of the State

Spiralling growth of the Thai shrimp aquaculture sector during the 1980s and 1990s was associated with widespread occupation and destruction of mangrove habitat (Barbier and Sathirathai 2004). Mangroves were converted into ponds for farming shrimp, and between 1961 and 1996, around 55 percent of the country's mangrove was cleared, reducing area cover from 372, 356 ha to 167, 584 ha (Barbier and Cox 2004). Forest destruction was facilitated by low national environmental awareness, contrary government policies, and lack of control on shrimp pond expansion. In the 1980s and 1990s, government sectors were seen to both regulate and support the shrimp farming industry. For example, in 1987, the Royal Forestry Department developed and introduced the Land-Use Plan (MIDAS 1995), which partitioned the mangrove forests into 'Conservation' and 'Development' zones. On paper, this restricted the shrimp industry from accessing the 42, 768 ha of mangrove area allocated for conservation (Huitric et al. 2002). Mangroves in 'Conservation' zones were to be maintained in their present condition in accordance with the National Reserved Forest Act 1964, however monitoring and enforcement was difficult. Shrimp farmers continued to encroach on these protected areas (Beresnev and Phung 2016), and coastal waterways were freely utilized by farmers for supplying pond water and discharging wastewater (Huitric et al. 2002).

While the Royal Forestry Department aimed at protecting mangrove forests, contrary policies were introduced such as the Government of Thailand's Export Promotion, which encouraged expansion of the shrimp farming industry into mangrove areas by allocating large areas of mangrove 'Development' zones to private shrimp farming and aquaculture investors (Sudtongkong and Webb 2008). This contributed to the decline of mangrove forests in Thailand through the 1990s and 2000s (Huitric et al. 2002).

The shrimp farming industry suffered drops in yield in the mid 1990s (Figure 2.7), partly due to disease problems resulting from high stocking densities and poor pond water management (Ahmed 1997; Kautsky et al. 2000). Severe overcrowding of farms, along with the use of communal waterways along the coast, facilitated the rapid spread of shrimp disease. The effect of disease was largely masked because farmers could abandon affected ponds and move into different regions following a farm crash, because state owned land could be purchased and privatised by shrimp farm owners. Geographically, shrimp farming activities shifted from the Upper Gulf of Thailand region, to the Eastern and Southern coastal regions (Szuster 2006), and several large corporate farms were established in Southern parts of Thailand during the 1990s (Vandergeest et al. 1999). Through this model of growth, management and the institutions at the time neglected the importance of maintaining a flow of coastal ecosystem services. Widespread exploitation of coastal habitat provided relatively high and quick returns on investment. However, this was at the expense of the long-term benefits provided by healthy ecosystems and social conditions (Pritchard et al. 2000).

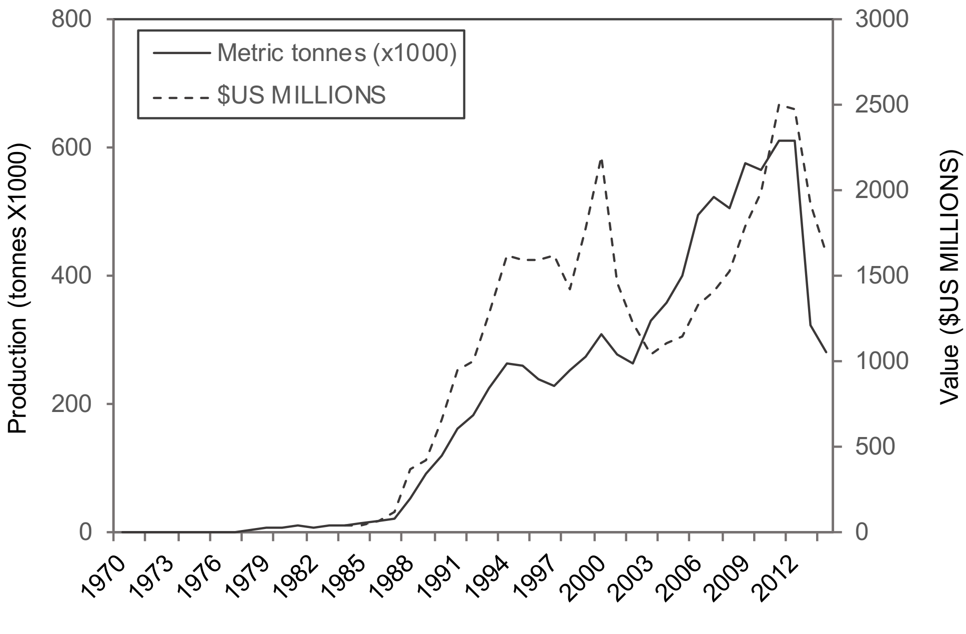


Figure 2.7. Growth of the shrimp farming industry in Thailand from 1970 – 2014. Value data is from 1984 – 2014, and are nominal values, rather than inflation adjusted values. Data source: FAO FishStatJ, 2016.

Periodic shrimp disease outbreaks continued to occur in Thailand through the 1990s causing crashes in production (Department of Fisheries 2002). The average lifespan of a shrimp farm was around 5–10 years (Claridge 1996; Huitric et al. 2002) and, although the situation changed rapidly from month to month, in some areas, it was estimated that approximately 70-80 percent of ponds had been abandoned (Stevenson 1997; Jenkins 1999). Soils within abandoned shrimp ponds were contaminated by salt and chemical residues and were characterized by high salinity levels and low oxygen diffuse rates. Adverse physical and chemical soil conditions have impeded the establishment of vegetation within some abandoned ponds (Tanavud et al. 2010).

Concern over mangrove destruction, soil salinization, water pollution, the spread of shrimp disease and the overall sustainability of the shrimp farming sector, grew within stakeholder groups and international NGO's in the 1990s (Huitric et al. 2002). Researchers began focusing on environmental degradation and the associated social-ecological issues surrounding shrimp farming (Naylor et al. 1998; Lebel et al. 2002; Primavera 1997; Briggs and Funge-Smith 1994; Huitric et al. 2002), leading to debates over the sustainability of the industry. This led to the development of national and international aquaculture regulations and frameworks, such as the FAO's Code of Conduct for Responsible Fisheries, introduced in 1995 (FAO 2016b), and the Fisheries Act and Ministerial Regulations, established by the Thai Department of Fisheries in 1991, and updated in 1998 (Beresnev and Phung 2016). Despite concerns over environmental sustainability and loss of mangrove habitat, decisions by the Ministry of Agriculture and Cooperatives at this time continued to appear contradictory. For example, the Royal Forestry Department introduced a national ban on mangrove logging in 1996 and, in 1997, declared it would invest in the replanting of degraded mangroves. However, 80 percent of mangroves in Thailand remained under concessions and, in 1997, the Department of Fisheries stated that it would promote continued development of shrimp farming into 'Development' mangrove areas (Beresnev and Phung 2016).

2.4.3 Shrimp farming and sustainability

Major declines in the production of giant tiger shrimp occurred in the early 2000s (Figure 2.8), caused by diseases such as white spot disease (WSD) and Monodon Slow Growth Syndrome (MSGS) (Thitamadee et al. 2016). Thus, shrimp farmers began to shift to cultivation of the specific pathogen free (SPF) *P. (Litopenaeus) vannamei* or whiteleg shrimp (Thitamadee et al. 2016), which is a species native to Latin America (Figure 2.8; NACA 2003). *L. vannamei* quickly became the dominant farmed species worldwide, increasing from 10 to 74 percent of global shrimp production between 2000 and 2012 (Cock et al. 2015). Cultivation of *L. vannamei* grew very rapidly in Thailand between 2002 and 2012 due to market preference, high yields, and because the species showed resistance to major native diseases, and tolerance to high stocking densities and low temperature and salinities (Cock et al. 2015). Shrimp production in Thailand reached an all-time high in 2011 of around 610, 000 t (Department of Fisheries 2016; Figure 2.8).

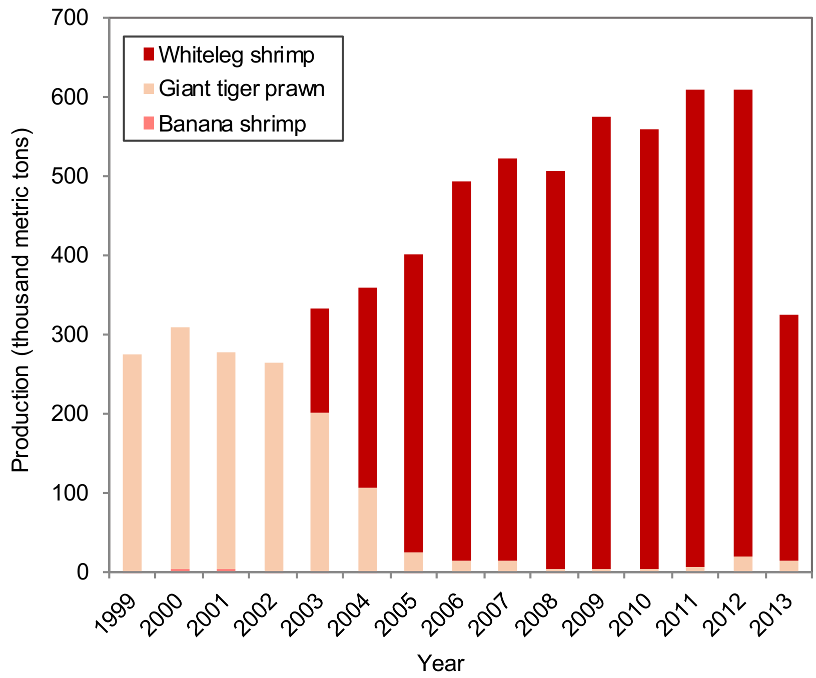


Figure 2.8. Shrimp production by species in Thailand from 1999 to 2013. Data source: FAO FishStatJ, 2016.

2.4.4 Present state of shrimp farming in Thailand

Thailand has experienced a substantial decline in aquaculture production and exports since 2012. In 2014, the country dropped down to the fourth largest exporter of aquaculture products, after China, Norway, and Vietnam. This decline is largely linked to a fall in total shrimp production, which dropped from over 600, 000 t in 2012 to 325, 000 t in 2013 (FAO 2016b). Recent decline in output has been attributed to problems with disease within the industry, coupled with a year-on-year drop in market price for shrimp. Further issues of supply and demand in the USA, EU, and Japanese markets has had a significant effect on profit margins for producers (FAO 2016a). Drops in production have been caused by a combination of shrimp mortality and a reduction in pond stocking density due to farmer concerns over economic losses (Thitamadee et al. 2016). Shrimp mortality has been linked to the disease termed acute hepatopancreatic necrosis disease (AHPND) or Early Mortality Syndrome (EMS), which affects *L. vannamei*, and was first reported in Thailand in 2012 (Tran et al. 2013). Cases of EMS have been reported to be due to reduced biosecurity within the industry (Thitamadee et al. 2016) and facilitated by poor environmental conditions related to salinity and pH, and exposure to high concentrations of nitrite and ammonia (Lin and Chen 2003; Cock et al. 2015). These conditions can inhibit the immune response of *L. vannamei* and increase its susceptibility to EMS (Hong et al. 2016). Poor environmental and pond management continues to threaten Thailand's shrimp farming industry, and sustainable alternatives to current aquaculture management systems are needed (Little et al. 2012; FAO 2016).

2.4.5 Present state of mangroves in Thailand

A study of Thailand's mangroves using satellite images in 2007 estimated total forest cover of 229, 620 ha (MFF 2011), indicating that there has been some recovery since the earlier estimate of 167, 584 ha in 1996. Currently, around 42,778 ha of mangrove lie within mangrove 'Conservation' zones where they are managed to preserve their ecological values. Technically, within these zones human settlement and forest utilization is prohibited (Sudtongkong and Webb 2008), except where a person has a license or permission to do so from the MoNRE. However, human settlement existed in these areas before the 'Conservation' zones were established, and therefore many people have existing claims to parts of this land (Beresnev and Phung 2016). Thailand has increased enforcement of regulations restricting new shrimp farm developments in mangrove areas in recent years, and some mangroves in Thailand have partially recovered through natural recruitment and planting in degraded areas.

Under Thailand's National Economic and Social Development Plan (2017-2021), the government encourages local communities to participate in forest management though creating participatory networks of forest restoration and protection. The government has encouraged local communities to participate in the management and rehabilitation of mangrove areas since 1997 (RTG 1997, 2007). However, community forest management and rights over mangrove forest have no legal recognition (Lakanavichian 2006; Sudtongkong and Webb 2008). Despite this, it is estimated that around 1 percent of total forested area in Thailand, which includes some mangrove forest, are currently managed locally (RECOFTC 2014). Types of locally managed forest areas include protected forests, important breeding and nursery areas for valuable aquatic species, areas managed for timber, and forest with religious or cultural significance (Beresnev and Phung 2016).

2.5 Wider issues relating to social-ecological resilience

2.5.1 Decline of shrimp farming and disused aquaculture ponds

Due to problems with disease in the industry, many shrimp producers have either temporarily or permanently abandoned their farms, leaving large areas of disused or abandoned shrimp ponds in Thailand. These ponds, which are in land formerly occupied by mangroves, could potentially be reforested (Barbier 2006). Most abandoned shrimp ponds are now controlled by the DMRC, who have already begun replanting mangroves in some areas (Beresnev and Phung 2016; Interview in 2017). Other abandoned shrimp farms are either privately owned or illegally occupied by shrimp farmers or outsiders. The DMRC has stated that they plan to reclaim these areas, and around 17, 000 ha of former mangrove will be assigned to state Provinces for local use, and a further 33, 000 ha will be restored back into mangroves (Beresnev and Phung 2016). Reclaiming abandoned pond areas may be difficult however because they are widely dispersed geographically and occupied by many people with different types of land tenure. Furthermore, restoring mangrove areas can be expensive and challenging (Lewis et al. 2016), and some former mangrove areas in Thailand have already been reclaimed for oil palm production.

2.5.2 What happens to carbon in abandoned shrimp ponds?

Research documenting mangrove C stock changes due to land-use change has been steadily growing over the past half-decade (Pendleton et al. 2012; Kauffman et al. 2014, 2014b,2016, 2017, 2018; Murdiyarso et al. 2015; Castillo et al. 2017; Bournazel et al. 2015). However, little attention has been paid to understanding the fate and stability of the remaining C pools (previously sequestered and stored C) when aquaculture ponds (in former mangrove area) are abandoned. When aquaculture ponds are abandoned and drain or are no longer being flooded, the C that was once buried under saturated and anoxic conditions may be released to the atmosphere (in the form of CO_2) due to accelerated oxidation and erosion of soil organic matter (Donato et al. 2011; Pendleton et al. 2012). Carbon emissions from shrimp ponds and cleared mangrove soils have been reported in earlier studies by Sidik and Lovelock (2013) and Lovelock et al. (2011). The oxidation and subsequent degradation of soil C following clearing and draining of peat soils has also been documented in terrestrial tropical peatlands in Southeast Asia (Couwenberg et al. 2010). Following wetland disturbance, it is believed that the rate of C release is most rapid during the immediate years and diminishes with time (Lovelock et al. 2011; Crooks et al. 2011). Lovelock et al. (2011), for instance, reported high short-term CO_2 emissions from disturbed mangrove soils which decline logarithmically over a 20-year period. Stabilisation of C loss around 20 years after conversion has also been reported for marshland soils in northeast China (Huang et al. 2010). However, in mangroves, this process is still poorly understood.

Slowing or reversing ongoing loss of C sequestration capacity in disturbed wetlands may take years to decades (Matsui et al. 2010; Putz and Chan 1986; Jimenez et al. 1985; Ward et al. 2006), and depends on the duration and intensity of the disturbance, along with geomorphic position, soil hydrological conditions, duration of tidal inundation, and the level of intervention (Alongi 2014; Lewis et al. 2019; McKee and Faulkner 2000). Based on empirical observations (McKee and Faulkner, 2000; Osland et al. 2012) of recovery time frames of major ecosystems, Lewis et al. (2016) hypothesised that mangrove recovery to normal C sequestration rates following chronic disturbance (such as conversion for aquaculture) depends on the alleviation of stress on the ecosystem, such as the breaching of pond walls. Lewis et al. (2016) predict scenarios from zero C recovery without removal of stress, to recovery of normal C storage rates within 15-25 years with intervention.

One suggested approach of removing stress in abandoned ponds is through ‘Ecological Mangrove Restoration’ (EMR, Lewis and Marshall 1998), whereby hydrological modification is carried out to assist natural recruitment of mangroves in to the ponds. This process includes strategic breaching of ponds walls, manual construction of tidal channels, and assisted dispersal of mangrove propagules (Lewis et al. 2005). The EMR approach has been implemented at several sites worldwide (Lewis and Brown 2014). Some studies suggest that surface soil C pools may recover due to increased tidal flooding after pond modification. For example, Matsui et al. (2010)

reported a twofold increase in the surface 5 cm soil C stocks 10 years following hydrological restoration of abandoned shrimp ponds. Furthermore, in created mangrove wetlands, Osland et al. (2012) reported an age-related trajectory for soil C pools in the upper 10 cm, and equivalent C pools to natural mangrove sites 20 years following wetland creation. Yet these estimates are not sufficiently refined, particularly for C pools stored belowground, and how these stocks are affected by land use change (Donato et al. 2011). In particular, more data is needed to assess how C stocks change over time as forests regenerate naturally in abandoned pond areas.

2.5.3 Shrimp disease, pond management and sustainability

Mangrove forests are often characterised by a network of tidal creeks that exchange water between the forest and the open sea. This shared water body is the main water source for shrimp farms. The productivity of the shrimp aquaculture system is therefore heavily dependent on functioning surrounding mangrove forests for regulating water quality and natural food inputs (Rönnbäck 1999). Farm operations therefore rely on good quality water in the surrounding forest. In land-integrated (semi-intensive) shrimp farming systems, untreated wastewater rich in nutrients, organic matter, and antibiotics, is often discharged directly into the surrounding waters (Primavera 2006). Waters surrounding shrimp farms become oxygen depleted and highly turbid (Boyd and Massault 1999). These impacts may spread over several kilometres causing significant damage to the ecological function of the forest (Burford et al. 2003). The subsequent increase in suspended sediment concentrations (Beveridge et al. 1991; Pruder 1992; Boyd and Tucker 1998) results in degradation of water quality, contributing to the spread of disease within the farm system (Chanratchakool et al. 1995).

The conversion of mangroves into shrimp ponds has a huge impact on biodiversity and the delivery of ecosystem goods and services, and creates damaging social-ecological trade-offs, particularly for fishing communities (Hall 2004; Vandergeest 2007; Hatje et al. 2016; Flaherty and Karnjanakesorn 1995; Hoque et al. 2017, 2018). Because mangroves provide important habitat for a wide range of species, their removal is known to directly reduce coastal biodiversity, resulting in significant declines in wild capture fisheries yield (Valiela et al. 2001; Alongi 2002; Cattermoul and Devendra 2002). Destruction of critical nursery grounds when mangroves are removed can affect the recruitment success of local fish populations (Lebel et al. 2002; Naylor et al. 1998). As a result, a return to traditional fishing may not be feasible, and declines in local fisheries also adversely affects the local supply of food (Lebel et al. 2002). Mangrove decline also results in decreased availability of timber and firewood, and greater vulnerability to tsunamis and extreme climate events through reduced coastal protection (Alongi 2002; Satyanarayana et al. 2013). Because of the wealth of ecosystem services provided by mangroves, it is estimated that intact forests in Thailand have a 70% higher economic value than those converted into shrimp ponds (Primavera 2006).

Achieving sustainability in coastal social-ecological systems requires the generation and integration of diverse knowledge types on ecosystem health (Glaser et al. 2012, Leslie et al. 2015). Knowledge systems include the local ecological knowledge (LEK) held by resource-dependent individuals and communities, or scientific knowledge derived and used by formal institutions for resource-based decision making (Berkes 2017). In recent decades there has been greater engagement with LEK by scientists to study ecosystems and their health and management (Drew 2005; Berkes 2010). Local and scientific knowledge development following disturbance, such as natural resource depletion, is thought to facilitate self-organisation, so increasing the resilience of SES to cope with future environmental perturbations (Berkes and Turner 2006). Chapter 6 of this thesis recognizes the role of LEK in informing sustainability measures for the coastal environment. This introduction to LEK is continued in Chapter 6.

Chapter 3 Methodology

3.1 Study sites

A multiple case study approach was adopted for this research. The case studies included two coastal areas of Thailand: Chanthaburi Province on the eastern coast of the Gulf of Thailand, and Koh Klang, an island located in Krabi Province on the Andaman Sea coast (Figure 3.1). These areas were selected as suitable locations to study social and ecological dimensions of shrimp farming in mangrove areas and drivers of resilient social-ecological systems due to the history of shrimp farming and mangrove degradation in these regions, and the presence of multiple interacting drivers of rapid social and environmental change.

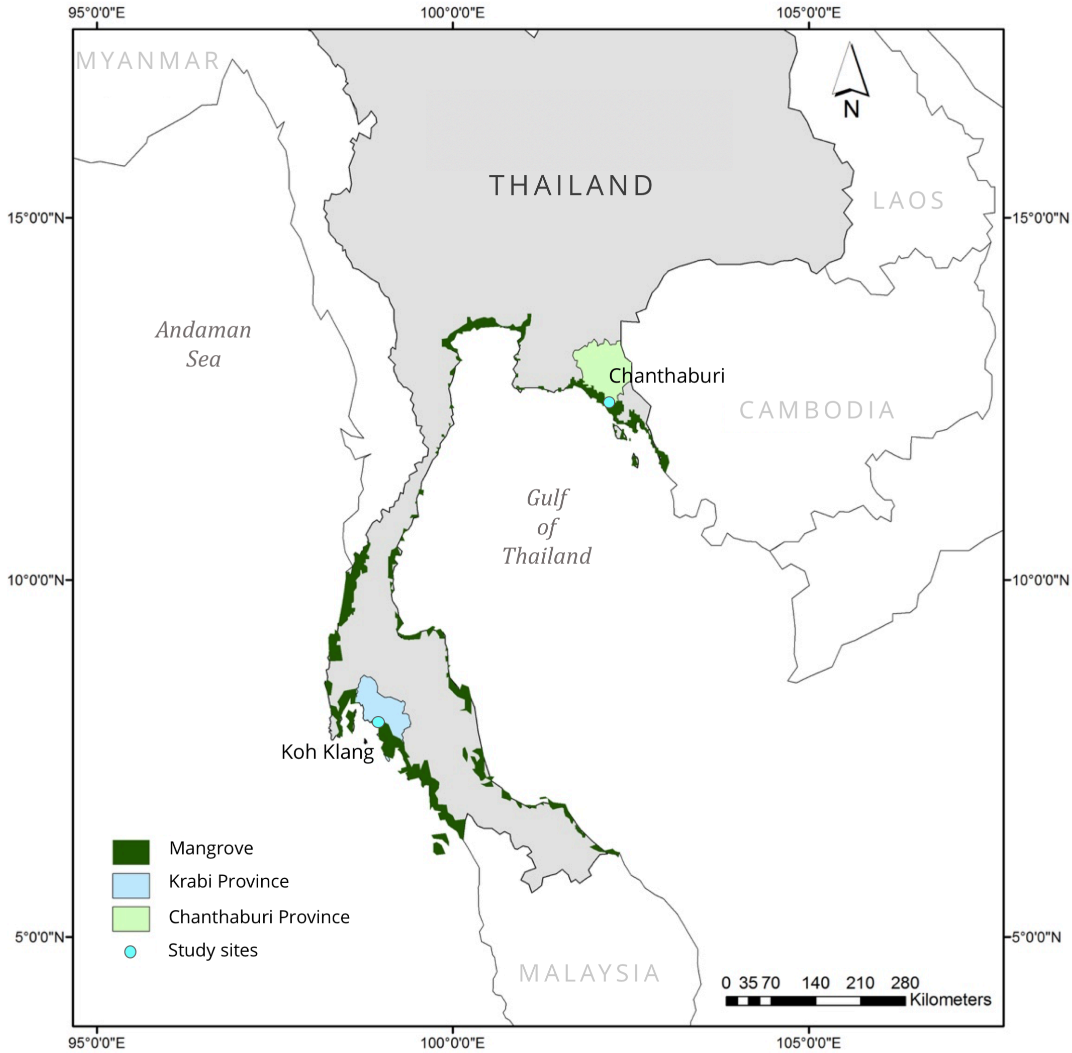


Figure 3.1. Map showing the location of two study sites along the coast in Thailand. Mangrove distribution data source: Giri et al. 2011. See http://data.unep-wcmc.org.

3.1.1 Selection of study sites

Potential study sites were identified from the literature and through discussions with academics at Kasetsart University and government officials from the Department of Marine and Coastal Resources (DMCR) working on coastal management in relation to mangrove forests and shrimp culture in Thailand. Appropriate sites were initially selected based on the following criteria:

- Local mangrove forest coverage
- Local shrimp aquaculture development
- Level of shrimp farm abandonment

- Local activities involving mangrove restoration
- Existing data available
- Contacts in the area

Visits to potential study sites were arranged with the help of Kasetsart University, the DMCR, and the NGO, Mangrove Action Project (located in Trang on the Southern Andaman sea coast), who assisted with obtaining permission from village heads and local Mangrove Management Units to visit the study areas. The two study site locations were selected for case studies because they offer an interesting contrast in relation to i) how shrimp farming developed in these regions and the types of people involved, ii) the current shrimp farming situation in these regions, and iii) differences in ecological conditions and efforts to restore degraded mangrove forests.

The coastal shrimp farming landscape of Chanthaburi was selected as the first case study location. Chanthaburi was one of the first regions of Thailand where intensive shrimp farming developed in the 1980s. At this time, many of the shrimp farms in Chanthaburi were family-run operations, and shrimp farmers were typically former fisher-folk and agriculturalists, with very little prior experience in aquaculture (Flaherty et al. 2000). Despite this, the industry expanded rapidly in this region through the 1980s and 1990s, aided by and promoted by the Thai government (section 2.4). For decades, Chanthaburi has been one of the largest shrimp-producing provinces in Thailand (Hazarika et al. 2000; Department of Fisheries, 2018). However, the region has been hit by severe social-ecological fluctuations since 2013 driven by disease epidemics in cultured shrimp and negative environmental change (Piamsomboon et al. 2015). Consequently, many shrimp farmers have temporarily reduced or abandoned their production in recent years, and there is currently a diversity of farms of different sizes that operate in the landscape at different production intensities side-by-side. Chanthaburi was therefore identified as an appropriate case study to explore current shrimp farming practices under rapid social-ecological change and to better understand the socio-economic landscape of shrimp production systems in this region.

Koh Klang, an island situated in the Krabi river estuary on the southern Andaman sea coast, was chosen as the second case study location. Compared to Chanthaburi in the Gulf of Thailand region, intensive shrimp farming began later in Southern coastal regions of Thailand, including on Koh Klang. Geographically, shrimp farming activities shifted from the Gulf of Thailand region to the Southern coastal regions in the 1990s

(Szuster 2006). The shrimp industry had developed substantially by the 1990s, and thus when shrimp farming began in Southern coastal regions was very much dominated by large corporate farms (Vandergeest et al. 1999). On Koh Klang, around half of the intensive shrimp farms that appeared on the island in the 1990s were owned by outside business people and large corporate businesses such as Charoen Pokphand (CP) (Interview in 2016), a company that dominates the shrimp industry in Thailand, also supplying shrimp food, chemicals and shrimp fry to producers. The rest of the shrimp farms on Koh Klang were operated and managed by small-scale landowners and former fisher-folk who were allured by the promise of high and quick returns on investment (Interview in 2016). Families would work together to run the shrimp farms on Koh Klang, with the men typically taking on more manual roles, such as harvesting stock, while the women engaged in tasks such as shrimp feeding and record keeping (Interview in 2016). For many islanders on Koh Klang, shrimp farming was initially perceived as a safer and less strenuous occupation compared to sea fishing, which can be unpredictable and dangerous, particularly during the monsoon period (Interview in 2016).

Intensive shrimp farming was relatively short lived on Koh Klang, due to the rapid spread of disease, rising costs, and escalating problems associated with mangrove destruction, soil salinization, and water pollution. The average lifespan of a shrimp farm was only around 5–10 years (Interview in 2016). For local small-scale farmers, a few years of good profits spiralled into large debts because of the need for additional chemicals to manage poor pond conditions, coupled with loss of profit due to disease (Interview in 2016). By the mid 2000s, large corporate farms began to disappear from the island, and many of the people of Koh Klang were left with unproductive ponds and huge debts from shrimp farming (Interview in 2016).

Currently, all shrimp ponds on Koh Klang either lie disused or are used for crab culture or traditional polyculture (personal observation in 2017). Many former shrimp farmers have converted back to fishing in recent years. The community, along with NGOs and the government, have been working to restore degraded mangrove forest on Koh Klang since the end of shrimp farming, an ecosystem which local people rely so heavily on for their livelihoods. This provided an opportunity to analyse the impact of shrimp farming and shrimp pond abandonment on mangrove ecosystems and local livelihoods on Koh Klang, and how the community has responded to social and environmental change.

3.2 Chanthaburi Province, Gulf of Thailand

The research presented in Chapter 5 of this thesis was conducted in Chanthaburi Province, on the eastern coast of the Gulf of Thailand (12.61° N, 102.10° E). The Gulf of Thailand is a semi-enclosed sea with an average depth of 58 m (Khongchai et al. 2003). Because of the relatively shallow depth and high nutrient inputs from five major rivers, including the Chao Phraya River, the waters of the Gulf of Thailand are highly productive, supporting abundant populations of commercial fish species (Supongpan 1996; Green and Short 2003). The climate of Chanthaburi is monsoonal with three dominant seasons; rainy season from mid-May to mid-October; cool season, from mid-October to mid-February; and warm season, from mid-February to mid-May. Annual precipitation is around 2800 mm and temperature ranges from around 21 to 33°C. The mean temperature is about 27.8°C. Tides are diurnal with a tidal range of 1.4 m (Aungsakul et al. 2011).

Chanthaburi's coastline stretches 68 km across four coastal districts; Na Yai Am, Tha Mai, Laem Sing, and Khlung. Chanthaburi is one of the largest shrimp-producing provinces in Thailand (Hazarika et al. 2000; Department of Fisheries, 2018). The social-ecological system which forms the basis for the analysis in Chanthaburi province is shrimp farming communities in the coastal sub-districts of Khlung and Laem Sing. The ecological system in this region is characterized by coastal habitats, including extensive seagrass beds, tidal mudflats, and mangrove forests (Janetkitkosol et al. 2003). However, large areas of mangrove forest have been cleared and converted, with remaining mangroves only occurring in narrow fringes. Behind the mangrove fringe, there are many shrimp farms, rice fields, and fruit orchards. In some districts of Chanthaburi, such as Laem Sing, the low-lying geographical conditions make these areas vulnerable to sea level rise (Doydee and Panpeng 2015).

3.2.1 Background to shrimp farming and farmers in Chanthaburi

Shrimp farming in Chanthaburi has played an important role for the local and national economy over the past few decades. Intensive shrimp farming along Chanthaburi's coastline began in the 1980s and expanded at a remarkable rate through the 1990s and 2000s. In 2012, Chanthaburi represented one of the largest shrimp aquaculture regions in Thailand, with around 2120 shrimp farms, covering 6758.72 ha in area and producing over 60 000 t of shrimp (Department of Fisheries 2018).

Many of the shrimp farms in Chanthaburi are small to medium size family-run operations, traditionally jointly owned by husband and wife (Arlene et al. 2016). Shrimp farmers are typically former agriculture farmers, fisherfolk and local business people who entered the aquaculture industry during the 'boom' years in the 1980's, often with little prior knowledge or expertise in shrimp farming (Boromthanarat and Nissapa 2000). In the late 1980s, small commercial investors and larger national companies bought coastal land in mangrove forests and low-lying paddy fields, or entered into agreements with local farmers in Chanthaburi to develop shrimp farms along the coast (Boromthanarat and Nissapa 2000). The Thai government and provincial governors promoted development of the industry. However, a lack of control over expansion and effective enforcement of land and water uses, led to environmental degradation and the emergence of diseases in shrimp in the late 1990s, forcing many shrimp farmers to leave the industry, while other farmers and private companies tried to find solutions by reducing stocking density and constructing water treatment facilities (Boromthanarat and Nissapa 2000).

Institutional support for the industry grew around the year 2000 with a focus on developing participatory shrimp farming management for sustainability at the community level in Chanthaburi (Boromthanarat and Nissapa 2000). A multi-stakeholder approach, using the sub-district Khlung as a case study, aimed at developing strategies to improve shrimp production and placed local community groups as key stakeholders (Boromthanarat and Nissapa 2000). A steering committee comprising government agencies, such as the Department of Fisheries, and community groups, such as the newly established Shrimp Farmer Group, small scale fishers, and local residences, was set up at the provincial level for shrimp production and waste development planning.

Sustainability objectives of the steering committee focused primarily on water quality, shrimp disease, and seedstock quality. Small-holding farmers were provided with technical advice from the Kung Krabaen Royal Development Study Centre (KKRDC) of the Department of Fisheries on ecologically friendly approaches to shrimp farming, such as the use of mangrove buffers for water quality management. The integrated management plan created programs for: i) mangrove rehabilitation and environmental improvement; ii) shrimp production and wastewater improvement; iii) recognition and handling of conflicts among user groups; iiii) involvement of major stakeholder groups in the preparation of the plan; and v) clear specification of institutional responsibility and jurisdiction for implementation (Boromthanarat and Nissapa 2000).

Despite efforts towards more sustainable shrimp production in Chanthaburi in the early 2000s, the region has experienced multiple interacting drivers of rapid social-ecological change in the past decade. Following a recovery of the industry, shrimp production in Chanthaburi has declined sharply in recent years, and many aquaculture ponds have recently been abandoned (Piamsomboon et al. 2015). In late 2012, shrimp farms in this region suffered from widespread disease problems and mass crop mortality. Shrimp production dropped from around 60 000 t in 2012 to 30 000 t in 2013 (Department of Fisheries 2016), largely due to outbreaks of Early Mortality Syndrome (EMS). A recent study of intensive shrimp farms in Chanthaburi province (Piamsomboon et al. 2015) identified disease risks to be associated with many independent small- to medium-scale farms in the region sharing common water sources. The use of communal waterways for pond intake and outflow is thought to increase the chance of ponds receiving hypertrophic or eutrophic water, which can facilitate the spread of disease (Lyle-Fritch et al. 2006; Piamsomboon et al. 2015).

Changes to water resources and shrimp farm effluent loading, and salinization of rice fields as a result of aquaculture expansion, has created conflicts among agricultural farmers and shrimp farmers in Chanthaburi (Vandergeest 2007). The Department of Fisheries is now encouraging shrimp farmers in Chanthaburi to become certified under the Good Agricultural Practices (GAP) standard, to improve environmental conditions and enhance prevention of disease. Some of the old abandoned farms in Chanthaburi are presently under extensive management by local farmers using ecologically friendly approaches (Interview in 2017).

In terms of gender dimensions today, men often have most responsibility in the operation and management of shrimp farms in Chanthaburi, although both men and women are involved in the daily tasks (Interview in 2016). Women more commonly have an alternative income or have other household responsibilities, so their duties are limited to less timely tasks such as feeding and record keeping (Arlene et al. 2016; Interview in 2016). A study by Arlene et al. (2016) found that men generally have more knowledge of shrimp farming than women because historically women were excluded from attending government training programmes. Women also have roles in local shrimp farming markets buying locally produced shrimp and crabs (personal observation in 2016; Figure 3.2). On larger intensive farms in Chanthaburi, migrant labour, both male and female, are employed to carry out daily tasks such as feeding the shrimp and checking the stock (personal observation in 2016).

Figure 3.2. Shrimp farming and shrimp markets in Chanthaburi Province.

3.2.2 Status of mangrove forests in Chanthaburi

A large proportion of mangrove area has been deforested for the development of shrimp aquaculture in Chanthaburi. Some estimates state that up to 80 percent of shrimp farms are located in previous mangrove forests (Stevenson 1997). Mangrove area cover in

Chanthaburi declined from approximately 28, 188 ha in 1961 to its lowest area of 2, 663 ha in 1991 (Figure 3.3; DMCR 2018).

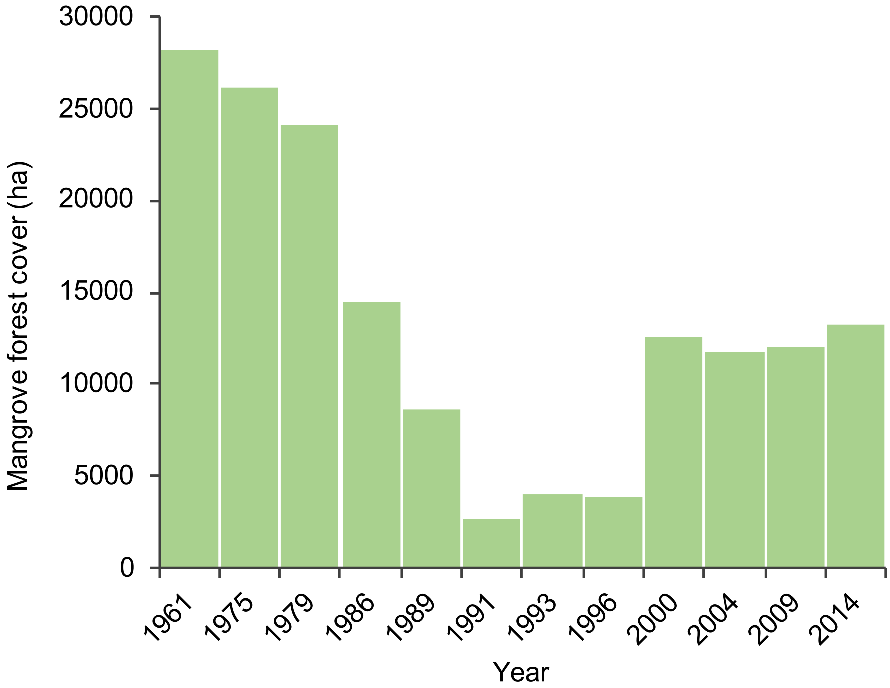


Figure 3.3. Changes in mangrove area cover 1961 – 2014 in Chanthaburi. Data source DMCR, MoNRE, 2018 URL http://www.dmcr.go.th/detailLib/3769.

There has been some recovery of mangroves in Chanthaburi over the past 15 years (DMCR, MoNRE, 2018; Figure 3.2) due to natural regeneration and reforestation projects initiated by the KKRDC and the DMCR. For example, the KKRDC has been actively restoring mangroves in areas located behind shrimp farms and in the inner part of Kung Krabaen Bay, Chanthaburi Province (KKRDC 2019). Mangrove trees have been planted by volunteers, including local shrimp farmers, as part of an ongoing programme to integrate shrimp culture with environmental conservation. By restoring mangroves in areas degraded by shrimp farming, the aim is to improve the quality of water discharged from shrimp farms, while at the same time restore important breeding and nursery grounds for marine life (KKRDC 2019). A mangrove forest nature trail has also been constructed in the Kung Krabaen Bay area which serves to educate tourists on the mangrove ecosystem and integrated mangrove-shrimp culture management (KKRDC 2019).

3.3 Koh Klang, Andaman Sea coast

The empirical research presented in Chapters 4 and 6 of this thesis was conducted on Koh Klang (7.78° N, 99.08° E), an island situated in the Krabi River Estuary Ramsar site, Krabi Province, on Thailand's southern Andaman Sea coast. The Andaman Sea coastline is an area of high biodiversity and ecological importance, with rich marine life and natural resources, and many embayments and offshore islands (True and Plathong, 2010). The intertidal and sub-tidal tropical ecosystem of Krabi River estuary is dominated by two vegetation assemblages: mangrove forest and seagrass beds (Janetkitkosol et al. 2003). In 2007, mangrove forest in Krabi covered 35, 593 ha, representing 15.5 percent of total mangrove cover in Thailand (DMCR 2018). The climate is tropical and under monsoon influence, with two distinct seasons; a rainy season from June to December, and dry season, from January to May. Tides are semi-diurnal with a tidal range of 2.5 m. Average annual precipitation is about 4 015 mm, and the mean annual temperature is 27.5°C.

3.3.1 Local livelihoods on Koh Klang

Koh Klang has a total area of around 26 km^2 and is situated administratively in the sub-district of Klong Prasong. Klong Prasong has four villages (or *Moo* in Thai), one is located on the mainland (*Moo 4* Ban Bang Kanoon) and the other three on Koh Klang island (*Moo 1* Baan Koh Klang, *Moo 2* Baan Klong Prasong, and *Moo 3* Baan Kong Kam). In 2016, there were around 1000 households on Koh Klang, the majority of which (~98%) are Muslim families. Total population in 2016 was approximately 4,700. Table 3.1 shows a breakdown of the population of Koh Klang in terms of age and gender.

Table 3.1. Population of Klong Prasong, Krabi, by village (*Moo* in Thai), age group, and gender (M and F). Source: Tambon Administrative Organisation, 2016.

	Moo 1		Moo 2		Moo 3		Total	
Age group (years)	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
< 18	374	351	101	83	340	281	815	715
18-60	677	694	235	229	440	457	1352	1380
>60	95	128	40	46	43	56	178	230
Total	**1146**	**1173**	**376**	**358**	**823**	**794**	**2345**	**2325**

The ecological system of Koh Klang is characterized by mangrove forests, which cover around 80 percent of the island (2, 440 ha) and are predominantly found in eastern, northern and central parts (DMCR 2018). Villagers are highly dependent on the intertidal estuary and mangrove ecosystem for provision of food and fuelwood, and for supporting critical spawning and nursery grounds for numerous commercially valuable species, such as the giant mud crab, red snapper, grouper, banana shrimp, and giant tiger prawn (Beresnev and Phung 2016). Artisanal fishing, aquaculture, and organic Sang Yod rice culture are the main activities of local people living on the island, and the oil palm industry is also steadily growing (Interview in 2016). The local artisanal fishery is based on gear such as crab traps, squid traps, cast nets, and bamboo stake traps. To the west of the island, the expansive coastal zone and beach area is also a particular focus for traditional fishing practices and collecting of shrimp, fish and shellfish.

Both men and women are involved in occupations related to the mangrove forests and fisheries on Koh Klang. Men predominantly engage in sea fishing, traditional artisanal fishing in the inshore region, and collecting marine resources, such as mud crab, from mangrove canals when the seas are rough (Interview in 2016). While women traditionally collect shellfish, fish, squid, and shrimp from the beach and fishing traps and nets daily at low tide. Women are also usually responsible for preparing fish and other aquatic products for food and fishing bait. With help from the local government and NGOs, some people on the island are also involved in eco-tourism, including providing mangrove tours and homestays. Other businesses on the island include a hotel, shops, passenger boats and motorcycle taxis.

Several local community groups operate on the island related to fisheries, mangrove forests, and aquaculture. These include the Aquaculture in Abandoned Shrimp Ponds Group, the Seafood Processing Group, Andaman Salty Fish Group, Aquaculture for Life Group, and the Fish Cage Culture Group. Other groups related to natural resource livelihoods and the conservation of natural resources include the Natural Resources Conservation Group, Eco-tourism and Community Livelihood Group, the Mangrove Conservation Group, and the Payment for Ecosystem Service Community Enterprise Group (Tambon Administrative Organization, 2016).

3.3.2 Governance of natural resources on Koh Klang

Natural resources are managed by both informal and formal institutions on Koh Klang. Management of mangroves is overseen by the Mangrove Management Unit 26 (MMU26), a local unit of the DMCR (DMCR 2019). The MMU26 has a formal linkage with the community through governing the use of and access to the mangroves and enforcing the national ban on commercial logging (Shafwaty Sa'at and Lin 2018; Lin 2015). The MMU26 encourage the community to "manage the forests themselves", in accordance with Thailand's national agenda of promoting Community Based Natural Resource Management (CBNRM) (Shafwaty Sa'at and Lin 2018). Thailand's government has set a legal framework for empowering local communities to engage in CBNRM to manage natural resources through policies including Thailand's Constitution, the Environmental Quality Act of 1992, and the Community Forestry Bill of 2007.

Each village on Koh Klang is led by a village headman (Phu Yai Ban), who is elected by the community to serve for a five-year term (Interview in 2016). The villages also have advisor bodies or Village Committees, composed of members elected by the community. Village heads play a critical role in governing the environmental system on Koh Klang. They are responsible for taking care of the mangroves and assisting with forest restoration activities conducted by different external actors such as NGOs. Mangrove Action Project and Raks Thai Foundation, for example, have been working on different socioeconomic and environmental issues on Koh Klang for several years, particularly since the tsunami in 2004 (Interview in 2016).

Informal regulations regarding mangrove use are widely adopted by the community on Koh Klang. Informal regulations state that mangroves can only be accessed by the local community for household purposes (such as collecting shellfish and building materials). Fishers are also required to report illegal logging in the mangroves to the village head. An informal rule also states that ten mangrove seedlings should be planted for every tree cut down for household purposes (Lin 2015). Informal mangrove management is linked with formal institutions. For example, the MMU26 supplies free seedlings to the local community for restoration projects (Lin 2015).

Three main factors have been identified as driving community management of natural resources on Koh Klang (Lin 2015). First is the livelihood dependency, particularly in relation to the provision of mangrove ecosystem services, such as nursery grounds and feeding areas for juvenile marine animals, which are a main source of income for many local people. The recent expansion of ecotourism related to mangroves on the island (Khanal and Babar 2007) is a second factor. Finally, local community interaction with external actors, such as NGOs, has encouraged more sustainable management of the mangroves.

The development of new biodiversity-based markets are also influencing livelihoods in Koh Klang (Srang-iam 2017). The Biodiversity-based Economy Development Office (BEDO), for example, is a public organisation interested in using Payments for Ecosystem Services (PES) as a tool for conservation of biodiversity while at the same time providing an income source for communities. In 2012, the BEDO launched a PES scheme related to eco-tourism on Koh Klang, whereby eco-tourism-related businesses pay a monthly fee for environmental services. The fees are managed by the Mangrove Forest Conservation Group and can be used locally for conservation projects, such as those related to mangrove restoration (Srang-iam 2017).

3.3.3 Shrimp farming and social-ecological pressures on Koh Klang

Krabi province and Koh Klang have suffered enormous pressures over the past few decades due to natural and anthropogenic causes (Bennett et al. 2015). The area is prone to coastal flooding during high tides and is vulnerable to storms and coastal erosion due to its exposure to the Andaman Sea. The area also experienced ecosystem degradation due to the natural effects of the 2004 Indian Ocean tsunami, and human activities, such as destructive fishing, pollution, and habitat degradation, have threatened the ecological health of the area (Bennett et al. 2015). Shrimp farming expanded rapidly on Koh Klang in the 1990s, and encroachment and conversion of mangroves for aquaculture ponds resulted in around a 25 percent loss of mangrove cover between 1985 and 2002 (Upanoi and Tripathi 2003).

Since the Indian Ocean tsunami in 2004 and the end of shrimp farming on the island in the mid 2000s, efforts have been made to restore mangroves and rebuild areas that have been destroyed over generations. NGO's such as MAP, Wetlands International, and Global Nature Fund, in collaboration with IUCN and the DMCR, aim to restore mangrove in abandoned shrimp ponds in this region, for Disaster Risk Reduction and climate change adaptation, and to support alternative livelihoods on the island. MAP has been working on mangrove restoration sites in Thailand since 2009, and currently have 3 sites on Koh Klang under 2 different projects. Projects such as these have brought positive changes to both ecosystems and the local community (Bennet et al. 2014).

3.4 Data collection

The fieldwork for this research was conducted in two phases. The first phase was a scoping study conducted from September to October 2016. This initial scoping visit to Thailand involved liaising with key government and non-government organisations and research institutes who provided logistical support. The scoping visit helped to develop research aims, objectives and methodology, and to identify study sites and become familiar with the study areas and communities. The visit also enabled development of a network of contacts from government and non-government organisations and research institutions which played a vital role in ensuring support for carrying out the main fieldwork phase. Key collaborators established during the visit included the mangrove research division of the DMCR, the NGO MAP, and the Department for Forest Management, Kasetsart University, Bangkok. The DMCR are responsible for management of the mangrove forests in Thailand and assisted in gaining formal permission to conduct research in the selected study sites. Through in-depth interviews with officials from the DMCR and the Mangrove Management Units, a deeper understanding was also gained about the current issues of shrimp farming and the scale of shrimp pond abandonment in Thailand. MAP provided detailed descriptions of the study site on Koh Klang and assisted with identifying key contacts for the second phase of the fieldwork.

Several key informant interviews were conducted during the scoping visit to Thailand in October 2016. Interviewees included government officials at the DMCR in Bangkok, officials from the Mangrove Management Unit in Khlung, Chanthaburi province, local government representatives in Krabi Province, village heads and community members on Koh Klang, and shrimp framers in Chanthaburi province. Interviews were conducted in Thai, with the assistance of a translator, and were recorded with the participants' permission. For the community interviews on Koh Klang and the shrimp farmer interviews in Chanthaburi province, participants were initially selected based on their role in the community (e.g. village heads and leaders of environmental groups) and further interviewees were identified through 'snowball sampling' (Bryman 2016). Each informant was interviewed following a semi-structured conversation and the conversations were freely conducted, giving opportunity for the exploration of the informant's knowledge content. An informal interview process also offered opportunity to observe and gain insight into the local setting and every-day life activities in the villages. Informal conversations and semi-structured interviews with shrimp farmers, local communities, village heads, and NGOs also helped gain familiarisation with the local context (Dunn 2005).

The final phase involved the main fieldwork which was conducted from January to May 2017. Mixed methods were implemented during this fieldwork phase covering both the ecological and social sciences. Methods included biophysical surveys of mangrove ecosystem change, ecosystem C stock assessments, survey questionnaires, workshops, and participant observation. An overview of the methods employed in this thesis is shown in Table 3.2 and Figure 3.4. Specific details of the methods are described in the research Chapters 4, 5 and 6.

Table 3.2. Overview of the mixed methods applied in the research.

Method	Unit of analysis/Target group	Data type	Description
Inventories of forest structure, biomass, and ecosystem carbon stocks in mangrove forests and abandoned shrimp ponds and statistical analysis.	Plots (154 m^2) were established along 125 m long transects (4-5 plots per transect) in the mangrove forest (7 transects) and abandoned shrimp ponds (12 transects) on Koh Klang island. Abandoned ponds were categorised by time since abandoned (chrono-sequence of 10, 15, 22 years).	Quantitative data: Mangrove tree density, species composition, tree decay status, tree diameter and height. Soil cores taken from each plot down to 2 m and measurement of total soil depth.	Calculation of aboveground and belowground biomass using allometric equations. Conversion of biomass into carbon density. Laboratory analysis of soil carbon concentration and bulk density to determine soil carbon density. The total soil carbon pool was determined by partitioning the soil horizon into depth intervals of 0–15 cm, 15–30 cm, 30–50 cm, 50– 100 cm and 100–200 cm, and taking measurements of bulk density and carbon concentration at each layer. The soil carbon mass per sampled depth interval was calculated as: Soil carbon (Mg ha^{-1}) = bulk density (g cm^{-3}) * soil depth interval (cm) *%C. The total soil carbon pool was then determined by summing the carbon mass of each of the sampled soil depths. The total ecosystem carbon stock was estimated by adding all of the component pools (trees, roots, soil). Differences in ecosystem carbon stock between forest and abandoned pond sites, and along the chrono-sequence of pond sites were analysed using the Kruskal-Wallis H test and Dunn's post-hoc test. Statistical analysis was computed in R Program Statistical software
Workshops	Groups of 7-9 participants were selected during house visits and based on pre-defined criteria. Participants were from two villages on Koh Klang. In each village, 4 workshops were conducted with community members who differed based on their occupation (ecosystem based/non-ecosystem based) and age (>35/<35).	Qualitative data: Group narratives, participatory mapping, historical timelines.	The questions discussed at the workshops related to the definition of ecosystem health, how ecosystem health has changed over a lifetime and drivers of change in ecosystem health on Koh Klang. Participatory mapping of ecosystem features, and historical timelines of ecosystem change were tools used to facilitate discussion around the questions. Discussions were recorded in Thai and translated and transcribed into English. Transcripts were coded and analysed using NVivo 11.
Key informant interviews	Semi-structured interviews were conducted with stakeholders from the local to national scale. In Chanthaburi, interviewees included 12 shrimp farmers, a local shrimp farming cooperative official, 2 village heads, 2 Provincial representatives from the local government Mangrove Management Unit, and 6 representatives from the government	Qualitative data: Individual and group responses	The interviews lasted for approximately 60 minutes and were conducted in Thai with the aid of an interpreter. In Chanthaburi, the interviews helped gain background information on current and historical shrimp farming patterns, and the scale of shrimp farming in Chanthaburi Province. On Koh Klang, informants were questioned about how they interact with the coastal ecosystem, their views on coastal ecosystem health, and the causes of ecosystem change over their lifetime.

	Department of Marine and Coastal Resources in Bangkok. On Koh Klang, interviews were conducted with authorities and community members (21 interviews). Interviewees were recruited using the snowball sampling method and included the local government head of Klong Prasong, 2 village heads, 6 inshore fishers, 2 local leaders of environmental groups, 11 fishers and mangrove resource collectors.		Written notes were taken during the interviews which were used to gain background information and to compliment the survey responses and workshop discussions.
Survey questionnaires	102 shrimp farmers and farm workers were surveyed in Laem Sing and Khlung, Chanthaburi province. Respondents were selected to provide a wide geographical cover across the survey area, and a relevant sample of the shrimp farmers in the area. Respondents were sought systematically by visiting farms and houses along the coastal Province area, and through snowball sampling.	Qualitative and semi quantitative data: Individual responses	The integrative agent-centred framework (IAC) was used as a theoretical framework for designing a structured survey to collect data for a range of explanatory variables that potentially drive shrimp farmers' decision-making processes in Chanthaburi Province. Surveys were conducted in Thai and translated into English. Survey respondents (farmers) were classified into farm intensity type based on production intensity (high, medium, low). Survey responses which related to the drivers of behaviour were statistically compared between farm intensity types. Differences in the response strategies adopted by farmers over the previous two years were statistically compared between groups in relation to the drivers of behaviour. Statistical differences were analysed using the Kruskal-Wallis H test, followed by the Dunn post hoc multiple comparisons test. All statistical analysis was performed using the software R.
Field observation of coastal natural resource use.	Observation of inshore fishers and mangrove natural resource collectors was conducted during a 4 week visit to Koh Klang.	Qualitative data: Photographs and written notes	Several days were spent with inshore fishers and mangrove users to observe how they interact and use the coastal ecosystem. Written notes and photographs were taken and were used to provide a deeper understanding of local ecosystem use and to compliment discussions and key informant interviews.

Figure 3.4. Mixed methods used in the research in Koh Klang and Chanthaburi.

3.4.1 Selecting participants

It was important to secure the participation of stakeholders in the research planning and implementation phases of the fieldwork. The following sections outline the selection criteria of participants who took part in the research and how they were recruited at each of the two study sites.

3.4.1.1 Participants in Chanthaburi

A series of semi-structured interviews were conducted with stakeholders from the local to national scale during the research planning phase in Chanthaburi province in October 2016. The aim of the interviews was to gain background information on current and historical shrimp farming activities, and the scale of shrimp farming in Chanthaburi province. This information helped to shape the research questions addressed in Chapter 5 of this thesis. The selection of participants to interview was based on them having knowledge of the study area due to their occupation and/or place of residence. At the national scale, six representatives from the DMCR in Bangkok were interviewed in a group setting. The interview was conducted during a meeting to discuss the scope of the research project, which was necessary to obtain permission to conduct research in coastal areas of Thailand. At the local scale, interviewees included private individual shrimp farmers (n = 12), a local shrimp farming cooperative official, village heads (n = 2), and Provincial representatives from the local government Mangrove Management Unit (n = 2). During this initial planning stage, shrimp farmers were recruited for interviewing by snowball sampling (Goodman, 1961), whereby initial interviews were conducted with village heads in the subdistricts of Khlung and Laem Sing. Village heads were then asked to identify other potential participants.

The main fieldwork phase of the research in Chanthaburi was conducted between February and May 2017. A total of 102 shrimp farmers and farm workers were interviewed using a structured survey. Participants were selected to provide a wide geographical cover across the survey area of Khlung and Laem Sing, and a relevant sample of the shrimp farmers in the area. Initially, several shrimp farmers were first recruited for the survey through snowball sampling and by visiting key places where shrimp farmers were known to frequent, such as shops supplying shrimp feed and chemicals. This approach helped to build trust between the research team and local community. Further participants were then sought systematically by visiting shrimp farms and houses along the coastal Province area. A systematic approach ensured that potential biases associated with particular locations and shrimp farm sizes was avoided.

3.4.1.2 Participants on Koh Klang

A preliminary 2-week-long visit to Koh Klang took place in October 2016 during the research planning stage of the project. The aim of the visit was to gain background information on the communities in the three villages on the island, specifically how local people interact with the mangrove forests and wider coastal environment, and the history of shrimp farming activities. A total of 21 interviews were conducted with key informants during this initial planning stage. The selection of informants was based on occupation, role in the community, and potential knowledge base. For example, the local government head of Klong Prasong, local leaders of environmental groups (n = 2) and village heads (n = 2) were initially interviewed to gather information related to current and historical mangrove use, forest degradation and restoration activities on the island, current and past shrimp farming activities, and information on how institutions have shaped livelihoods on the island. Following this, further interviews were conducted with inshore fishers (n = 6) and mangrove resource collectors (n = 11) to gain a deeper understanding of these livelihood activities. Informants were recruited by snowball sampling with the criteria that participants should have lived on the island for over 20 years. This criteria ensured that historical viewpoints and in-depth local knowledge could be captured. The semi-structured interview questions related to how people interact with the coastal ecosystem, and views on current and past coastal ecosystem health. Interviewees were also asked questions related to shrimp farming and how it has impact ecosystems and livelihoods on the island. In addition, to provide a deeper understanding of local ecosystem use and local livelihoods, several days were spent with inshore fishers and mangrove users to observe how they interact and use the local coastal ecosystems. The information gathered during the planning stage of the research on Koh Klang helped to shape the research questions addressed in Chapter 6 of this thesis and the research design adopted in Chapters 4 and 6.

Following the preliminary visit to Koh Klang in October 2016, 8 workshops were conducted with local residents over a three-week period in April 2017. The workshops focused on two of the three villages on the island: Village 1 (Ban Ko Klang) and Village 3 (Ban Klongkam). Selection of the two villages was based on the information gathered during the scoping visit in October 2016 and related to the following criteria: (i) differences between the villages in respect to proximity to and ease of access to mangrove and coastal resources, and (ii) differences in the type of primary livelihood activities people were engage in. Village 3 is located in close proximity to the mangrove forests and main beach area, and these resources are the primary source of income for many villagers. Whereas, village 1 is located further from the beach and main mangrove area on the island, and local people are involved in a wider range of livelihood activities, such as rice culture and the tourism industry.

A total of 72 individuals from the 2 villages participated in the workshops. The selection of participants for the workshops was based on the following criteria: age, occupation, and place of residence. As both men and women are engaged in occupations related to the mangrove forests and fisheries on the island, it was decided that gender would not be part of the selection criteria. Thus, groups were formed of a mixture of both male and female participants at differing male:female ratios.

An initial set of 10 participants were invited to participate in the workshops with the help of local participants from the scoping visits who identified key individuals that used the coastal ecosystem within their livelihoods. Following this, visits were made systematically to each household in the selected villages to recruit further participants. A record was made of all individuals who showed interest in participating in the workshops including details of their age, primary occupation, second occupation, previous occupation, place of residence and contact phone number. Individuals on the record list were then split into 8 groups of people. For this, individuals were first grouped by place of residence (village 1 and village 3). The two groups were then split into four groups representing different ages (<35 years and >35 years) and occupations (individuals primarily engaged in work related to the use of local natural resources (e.g. fisher, farmer) and individuals primarily engaged in activities not related to the use of local natural resources natural (e.g. taxi boatman, market seller)). The selected individuals were then contacted by telephone to confirm their attendance at the workshops.

3.5 Ethics and research approval

The research conducted in this study was approved by the University of Reading Research Ethics Committee. The necessary risk assessment procedures were cleared by the School of Archaeology, Geography and Environmental Science prior to fieldwork commencing in September 2016 to ensure safety in the fieldwork and overseas travel. All participants in the study were provided with an information sheet in Thai to introduce the project. Before data was collected, either verbal or written consent was granted by each participant involved in interviews, surveys or workshops. Participants were assured that their names would always be kept anonymous, and that they are free to withdraw from the interview at any time should they feel uncomfortable or unwilling to participate. Participants were informed that all information will be stored securely at the University of Reading, and that the data provided would be used in academic publications and the research thesis.

Chapter 4 Preservation and recovery of mangrove ecosystem carbon stocks in abandoned shrimp ponds

4.1 Introduction

Mangrove forests are highly productive ecosystems (Komiyama et al. 2008; Alongi 2014; Bouillon et al. 2008) that are increasingly recognised as major hotspots for global carbon (C) sequestration and burial (Alongi 2014, Siikamäki et al. 2012). On average, mangroves have a mean whole-ecosystem C stock of ~950 t C ha^{-1} (Alongi 2014), which is around 2.5 – 5 times higher than the mean ecosystem C stock found in temperate, boreal and upland tropical forests (200-400 t C ha^{-1}; Pan et al. 2011).

Ecosystem C storage in mangroves worldwide is very much dominated by belowground soil C pools (Donato et al. 2011; Kauffman et al. 2011; Kristensen et al. 2008), the variability of which is driven mainly by tidal amplitude and minimum temperature (Rovai et al. 2018). Organic-rich deposits can form up to several meters deep and can be stored below-ground for centuries if left undisturbed (Fujimoto et al. 1999; Macintyre et al. 1995). Globally, the C stored by mangroves (4.0-20 Pg C; Donato et al. 2011) is equivalent to over twice the annual global anthropogenic CO_2 emissions (Pachauri et al. 2014), highlighting the potential role of mangrove conservation for climate change mitigation (Murdiyarso et al. 2015).

Mangrove forests are also one of the world's most threatened ecosystems (Duke et al. 2007; Polidoro et al. 2010). Approximately 30-50% of global mangrove cover has been lost over the last 50 years due to urbanisation and the demand for alternative land uses (Giri et al. 2011; Valiela et al. 2001). Aquaculture is one such land-use change substantially driving global mangrove loss (Richards and Friess 2016; Valiela et al. 2001; Hamilton 2013). This problem has been particularly acute in Thailand where extensive areas of mangrove were replaced with aquaculture ponds during the 1980s-2000s (Barbier and Sathirathai 2004). Mangrove cover was reduced from 370,000 ha in 1961 to 167,500 ha in 1996, around half of this because of aquaculture (Hamilton 2013).

Conversion of mangroves into shrimp ponds has the potential to reverse the C sink function of the forests (Pendleton et al. 2012) because pond construction changes the topography of the land therefore altering key biophysical variables controlling CO_2 flux from the soils, such as soil temperature, soil moisture content, and the duration of tidal inundation (Lovelock et al. 2011; Fuentes and Barr 2015; Cameron et al. 2019). The construction of shrimp ponds results in the removal of trees and around a 1.5 m of soil, resulting in loss of significant amounts of C stored in the vegetation (trees aboveground and belowground roots), in the litter, and part of the soil. The excavated soil is usually piled up under aerobic conditions to form dykes, thus increasing oxidation of the soil C stock (Lovelock et al. 2011; Sidik and Lovelock 2013). Some studies suggest that mangrove conversion results in the loss of over 50% of soil C and up to 90% of total ecosystem C (Kauffman et al. 2014, 2017; Murdiyarso et al. 2015; Bhomia et al. 2016; Castillo et al. 2017). Yet large uncertainties exist regarding the magnitude of C loss, and the implications for natural CO_2 sinks and C reservoirs globally.

Many of the shrimp ponds created in Thailand during the 1980s-2000s have proved unsustainable due to disease outbreaks (Thitamadee et al. 2016; Flegel 2012). Up to 70% are now thought to be abandoned (Hossain et al. 2001; Stevenson 1997). While research documenting mangrove C stock losses due to land-use change has been steadily growing over the past half-decade (Pendleton et al. 2012; Kauffman et al. 2014, 2016, 2017, 2018; Murdiyarso et al. 2015; Castillo et al. 2017), little attention has been paid to understanding the fate and stability of the remaining C pools (previously sequestered and stored C) following pond abandonment (but see Cameron et al. 2019).

When ponds are abandoned and are no longer being flooded, the C that was once buried under saturated and anoxic conditions may be released to the atmosphere (in the form of CO_2) due to accelerated oxidation and erosion of soil organic matter (Donato et al. 2011; Pendleton et al. 2012). C emissions from shrimp ponds and cleared mangrove soils have been reported in earlier studies by Sidik and Lovelock (2013) and Lovelock et al. (2011). The oxidation and subsequent degradation of soil C following clearing and draining of peat soils has also been documented in terrestrial tropical peatlands in Southeast Asia (Couwenberg et al. 2010). Following wetland disturbance, it is believed that the rate of C release is most rapid during the immediate years and diminishes with time (Lovelock et al. 2011; Crooks et al. 2011). However, in mangroves, this process is poorly understood.

Accurate quantification of C losses or gains due to land-use change is critically important in the context of climate change, and for the inclusion of mangroves in climate change mitigation projects that require estimation of ecosystem value, such as under the United Nations Framework Convention on Climate Change program (UNFCCC 2011).

4.2 Materials and methods

Ecosystem C stocks of mangrove forest sites (n = 7) and abandoned shrimp pond sites (n = 12) were quantified on an island situated within the Krabi River Estuary (Koh Klang; 7.78° N, 99.08° E; Figure 4.1), on Thailand's southern Andaman Sea coast. Mangrove forests are an important intertidal habitat in this region (True and Plathong 2010). In 2015, mangrove forests in Krabi province covered 32,360 ha, representing 15 percent of total mangrove cover in Thailand (DMCR 2018).

Ecosystem C stocks were assessed using biometric and soil coring methods along transects to determine aboveground (tree) and belowground (root + soil) C pools. Using a 22-year chrono-sequence approach, it was also assessed whether, and at what rate, C stocks were recovering after ponds had been abandoned. Abandoned ponds of different ages (10–22 years) were compared with natural reference mangrove sites. Sampled ponds had been abandoned for 10 (n = 3), 15 (n = 3), and 22 years (n = 3). In addition, three abandoned ponds under Ecological Mangrove Restoration (EMR) projects (Lewis 2005, 2009) ('EMR'; $n = 3$) were sampled, in order to examine the impact of rehabilitation of abandoned shrimp ponds on ecosystem C stocks.

The sampled EMR ponds were designated as Community Based Ecological Mangrove Restoration (CBEMR) sites. These sites had undergone hydrological modification to assist natural recruitment of mangroves in to the ponds. At the time of sampling, all EMR sites were in their third year following the completion of ecological-hydrological intervention. The ponds had been abandoned for 12-18 years before the restoration activities started.

All of the sampled abandoned shrimp ponds were formerly mangroves until they were converted in the late 1980s -1990s (see Appendix). The abandoned ponds had retained their basic structure at the time of sampling in April 2017, but due to removal or erosion of the old sluice gates, they were open to tidal flushing at varying levels. The pond sites were assumed not to be propagule-limited due to evidence of regrowth and their proximity to the surrounding mangroves.

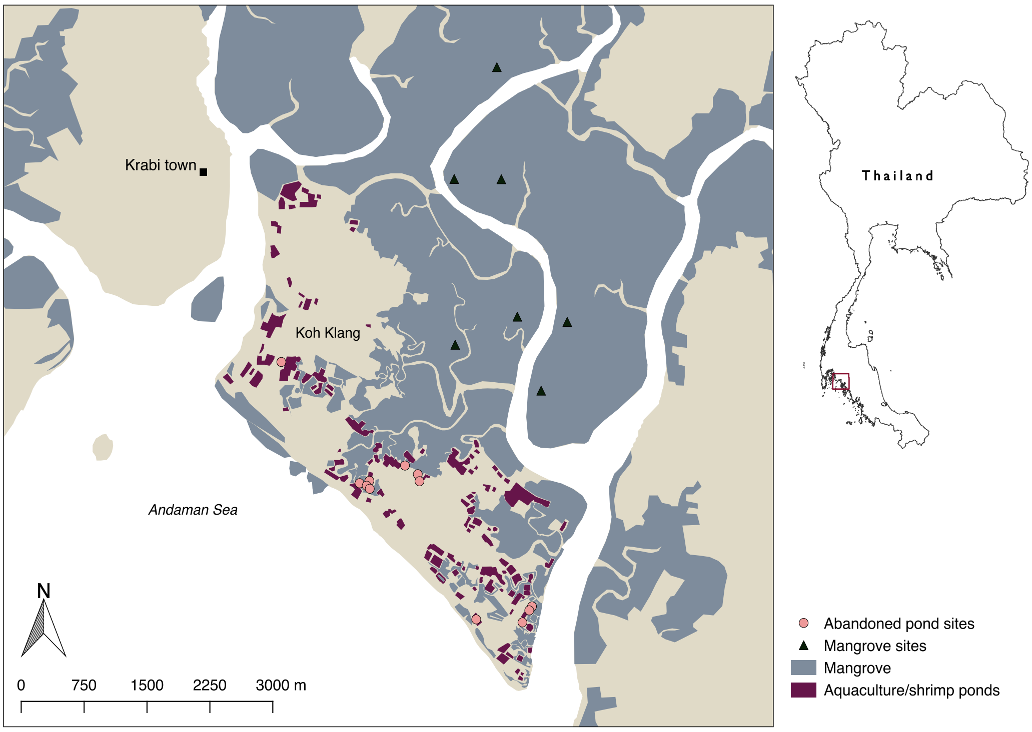


Figure 4.1. Map of the study area, Koh Klang (Krabi Province). Displayed are the location of the mangrove sites (black triangle) and abandoned shrimp pond sites (pink circles).

4.2.1 Study design and data collection

Forest structure, biomass, and ecosystem C stocks were determined at nineteen sites on Koh Klang, including seven secondary mangrove sites and twelve abandoned pond sites. For the mangrove forest sites, forest structure, biomass, and soil sampling was conducted in April-May 2015 (Bukoski et al. 2017), and additional soil sampling was conducted in May 2017. Research permission for sampling at mangrove sites was obtained from the Thai Department for Marine and Coastal Resources. Mangrove forests in the sample area have diverse species compositions, dominated by *Rhizophora, Xylocarpus*, and *Avicennia* species. *Avicennia* was also a dominant species present inside or around most of the abandoned ponds. Other species in or around the ponds included *Sonneratia alba, Rhizophora apiculata*, and *Excoecaria agallocha.* Field sampling in abandoned ponds took place in May 2017 with permissions from private owners.

At each of the nineteen study sites, field methods for sampling forest structure, biomass, and ecosystem C stocks outlined by Kauffman and Donato (2012) were followed. For intact mangrove sites, seven transects were located randomly within the forest area, orientated perpendicular to, and between 23 and 360 m from, the coastline. Each transect consisted of five 7 m radius (154 m^2) subplots, spaced at 25 m intervals, with the first subplot of each transect positioned at the point closest to the shoreline (Figure 4.7). A similar transect design was used to sample the abandoned pond sites to generate a comparable data set. Transects were positioned diagonally across each pond and each transect consisted of three to five 154 m^2 subplots, depending on the size of the pond. Data was collected at each subplot for calculation of stand density, tree biomass, and total ecosystem C stocks, including aboveground C in the form of live and dead trees, downed wood, and soil C up to 3 m depth. From the C stock data collected, emissions arising from mangrove to shrimp pond conversion could be estimated using a C stock change approach.

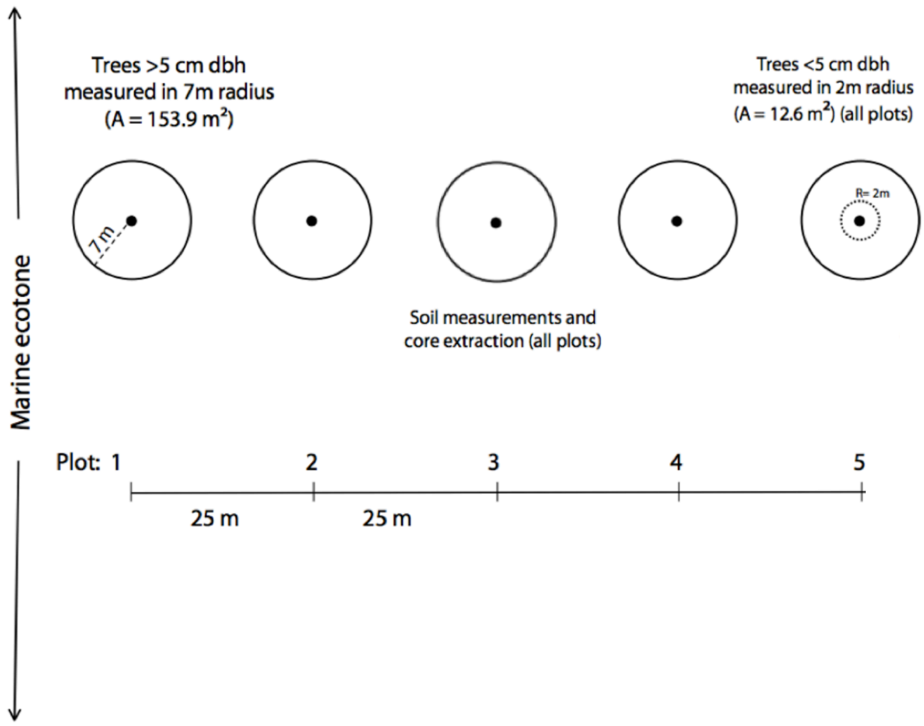


Figure 4.2. Schematic of plot layout for mangrove sampling (adapted from Donato et al. 2011). A = area, dbh = diameter at breast height.

Aboveground forest structure and species composition was recorded at each subplot and all tree stem diameters (standing and downed) greater than 5 cm at 1.3 m tree height, or 0.3 m above the highest prop root for *Rhizophora species* (dbh), were measured. The diameter of all saplings was recorded within nested 2 m radius (12.57 m^2) subplots. All stems within the 2 m nested plot with a dbh less than 5 cm and less than 1.37 m in height were classified as saplings (Bukoski et al. 2017). In abandoned ponds that had only a sparse cover of vegetation, the diameter of all mature trees and saplings was recorded throughout the 7 m radius subplot. All seedlings were counted within nested subplots. For dead trees, the decay status was also recorded following Kauffman and Donato (2012), where Status 1 = dead trees without leaves; Status 2 = dead trees without secondary branches; and Status 3 = dead trees without primary or secondary branches.

Additionally, soil cores up to 2 m depth were taken from the centre of every subplot at each abandoned pond site, and at four of the five subplots for each of the mangrove sites. In total, this included 28 soil cores from mangrove sites and 48 soil cores from pond sites. Soil cores were obtained using an open-face peat auger with a 1 m length and 5 cm diameter. Initially, a 1 m soil core was extracted, and sub-samples of 5 cm were taken from the centre of each of the following four depth intervals (in cm): 0–15, 15–30, 30–50, 50–100. A further 5 cm sub-sample was obtained from a second core extracted from the 1 - 2 m layer where possible. At some abandoned pond sites, soils were < 1 m depth and therefore soil samples were only taken from the first 4 depth intervals. Absolute depth of soil to parent material was measured at 5 points within each subplot using a marked 3 m length probe. Depth estimates were limited to 3 m, but where depths were thought to exceed the probe length this was recorded as >3 m.

4.2.2 Measuring Ecosystem Carbon Stocks

4.2.2.1 Above and belowground tree carbon

Tree diameters were converted to kg of dry weight of aboveground via allometric equations developed for mangrove species in close proximity to the study area (Table 4.1). Where no species-specific allometric equation was available, a general allometric equation was used to estimate biomass via species-specific wood-densities (Komiyama et al. 2005). Belowground biomass estimates were calculated using a generic allometric equation for all species, developed by Komiyama et al. (2005). This equation was used for all tree species with the exception of *Rhizophora sp.,* where a species-specific allometric equation was applied (Ong et al. 2004).

Estimates of above and belowground biomass were subsequently multiplied by 0.48 for aboveground and 0.39 for belowground, to convert kg of biomass to kg of C (Kauffman and Donato 2012). Biomass of saplings was calculated as an average value using the relationship between biomass and height of stems, based on the average sapling height. Total sapling biomass for each subplot was then calculated by multiplying the average biomass value by the number of saplings recorded in each subplot (Bukoski et al. 2017).

Table 4.1. Allometric equations used to calculate tree and root biomass.

Species	AGB/tree (kg)	BGB / root (kg)	References
Avicennia marina; Avicenna alba	$AGB=0.308*D^{2.11}$	$BGB=1.28*D^{1.17}$	Comley and Mcguinness, 2005
Bruguiera gymnorrhiza; Bruguiera cylindrica	$WV= 0.0000754*D^{2.5}$ $LB=10^{(-1.1679+(1.4914*(LOG(D))))}$ $WB=WV*WD*1000$ $AGB=LB+WB$	$BGB=0.0188*D^{2}*(D/(0.025 D+0.583))^{0.909}$	Kauffman and Cole, 2010; Tamai et al. 1986.
Nypa fructians	$Log\ AGB=0.85*LogD^{2}L+1.54$	$BGB=0.199*WD^{0.899}*D^{2.22}$	Matsui et al. 2014; Komiyama et al. 2005
Rhizophora spp.	$WV= 0.0000695*D^{2.64}$ $LB=10^{(-1.8571+(2.1072*(log(D))))}$ $WB=WV*WD*1000$ PRB= D>5cm PRB=WB*0.101 D>5.0<10cm PRB=WB*0.204 D>10>15cm PRB=WB*0.356 D>15>20cm PRB=WB*0.273 D>20cm PRB=WB*0.210 $AGB=LB+WB+PRB$	$BGB=0.00698*D^{2.61}$	Kauffman and Cole, 2010; Ong et al. 2004
Sonneratia alba	$WV=0.0003841*D^{2.10}$ $LB=10^{(-1.1679+(1.4914*(LOG(D))))}$ $WB=WV*WD*1000$ $AGB=LB+WB$	$BGB=0.199*WD^{0.899}*D^{2.22}$	Kauffman and Cole, 2010; Komiyama et al. 2005
Other species	$AGB=0.251*WD*D^{2.46}$	$BGB=0.199*WD^{0.899}*D^{2.22}$	Komiyama et al. 2005

AGB=Aboveground biomass; BGB=Belowground biomass D=dbh; L=Frond length; WV=Wood volume; PRB=Prop root biomass; LB=leaf biomass; WD=Wood density.

4.2.2.2 Soil Carbon

All soil samples were analysed for bulk density and percent organic matter at the Faculty of Forestry, Kasetsart University, Bangkok. Bulk density was determined as dry weight per unit volume, whereas organic matter (%OM) was determined via the combustion method (Loss on Ignition (LOI)). Weight loss of soil samples was measured after heating subsamples for 12-24 hrs at 105ºC to remove water, and at 550ºC for four hours to remove organic matter. The percentage of organic matter in the subsample was then calculated using the following equation:

$$LOI_{550} = ((DW_{105} – DW_{550})/DW_{105})*100$$

where LOI_{550} represents LOI at 550 °C (as a percentage), DW_{105} represents the dry weight of the sample before combustion and DW_{550} the dry weight of the sample after heating to 550 °C (both in g) (Dean 1974).

Soil organic carbon (%OC) was subsequently estimated for each sample by dividing organic matter values by a factor of 2.06 (Kauffman and Donato 2012). Soil OC density was then determined as the product of percent organic C and bulk density values. Carbon density values were combined with plot mean soil depth measurements to estimate soil C stocks for each site.

It should be noted that as soil subsamples were only taken from soil cores down to 2 m (at five depth intervals (in cm): 0–15, 15–30, 30–50, 50–100, 100-200), this meant that the deepest soil sample was taken from the 1-2 m soil layer (described in section 4.2.1). The C stock values for the deepest layer was then calculated as the C density from the soil sample obtained from layer 100-200 cm multiplied by the maximum soil depth for a given site. The mean soil depth of 6 of the 7 mangrove sites and 4 of the 12 abandoned pond sites was over 2 m. As a result, where soil depth was greater than 2 m, the soil C stock was extrapolated from the 100-200 m layer down to the maximum soil depth, thus making the assumption that there is no change in the soil C stock with depth from 2 m. Consequently, soil C stocks may have been underestimated or overestimated at sites where soil depth exceeded 2 m.

4.2.3 Data analysis

Statistical differences in mean C pools among mangrove forest and abandoned shrimp pond sites were tested using a Kruskal-Wallis rank sum test followed by a Dunn multiple comparison test to determine the differences between groups. Soil samples (n = 3-5) taken from the same pond and same soil layer were pooled and subsamples were taken for laboratory analyses. The mean C stock of a specific layer for a specific pond category was derived from averaging the mean of the layer subsamples across the ponds within the specific pond category. Therefore, when statistically comparing soil C stocks across soil layers within one pond category, the soil samples of any specific depth were not assumed to be closely linked to its upper/lower samples and were thus considered to be independent samples.

Relationships between response variables (such as, C pools) and fixed and random factors influencing the response (such as site type (fixed), time since pond was abandoned, soil depth, distance to major waterway, and above ground C stores (random)) were tested using regression models. All statistical analysis was computed in R Program Statistical software. Differences were considered to be significant if $p \leq 0.05$.

4.3 Results and discussion

4.3.1 Ecosystem carbon storage

The mean ecosystem C stock in the undisturbed mangrove forests was 1,029.5 ± 100.96 t C ha^{-1} (mean ± 1 standard error (s.e.m.)). This value is similar to ecosystem C stocks reported for estuarine mangroves in the Indo-pacific region (1,074 t C ha^{-1}; Donato et al. 2011), but slightly higher than the average for mangroves worldwide (965 t C ha^{-1}; Alongi 2014). The soil C stock was the largest component, representing 91.8% of the total ecosystem C.

Whole ecosystem C stores of the abandoned pond sites (541.65 ± 79.08 t C ha^{-1}) were on average 52% lower than the mangrove forests. However, the estimates were highly variable (Figure 4.3). The most significant loss in ecosystem C stock was recorded for ponds sampled 10 years after abandonment (mean: 304 ± 61.3 t C ha^{-1}; $p = 0.002$). Ecosystem C stocks were 70% lower in these ponds compared to the undisturbed mangrove sites. This is similar to the C losses reported for mangrove conversion to shrimp ponds by Kauffmann et al. (2017). By contrast, ponds sampled 15 years after abandonment had whole ecosystem C stocks (mean: 865.80 ± 146.7 t C ha^{-1}) that were not significantly different to the mangrove forest sites ($p = 0.81$).

Carbon stored in the living biomass, including tree and root biomass (mean: 84.76 ± 5.16 t C ha^{-1}), of the mangrove forests was much greater than tree and root C pools for the abandoned pond sites (mean: 17.22 ± 4.55 t C ha^{-1}; Appendix). The most recently abandoned ponds had the lowest C biomass (trace), and the ponds abandoned for 15 years (mean: 30.61 ± 3.45 t C ha^{-1}) had the highest, except for the EMR project ponds which were undergoing active restoration (mean: 34.31 ± 2.68 t C ha^{-1}).

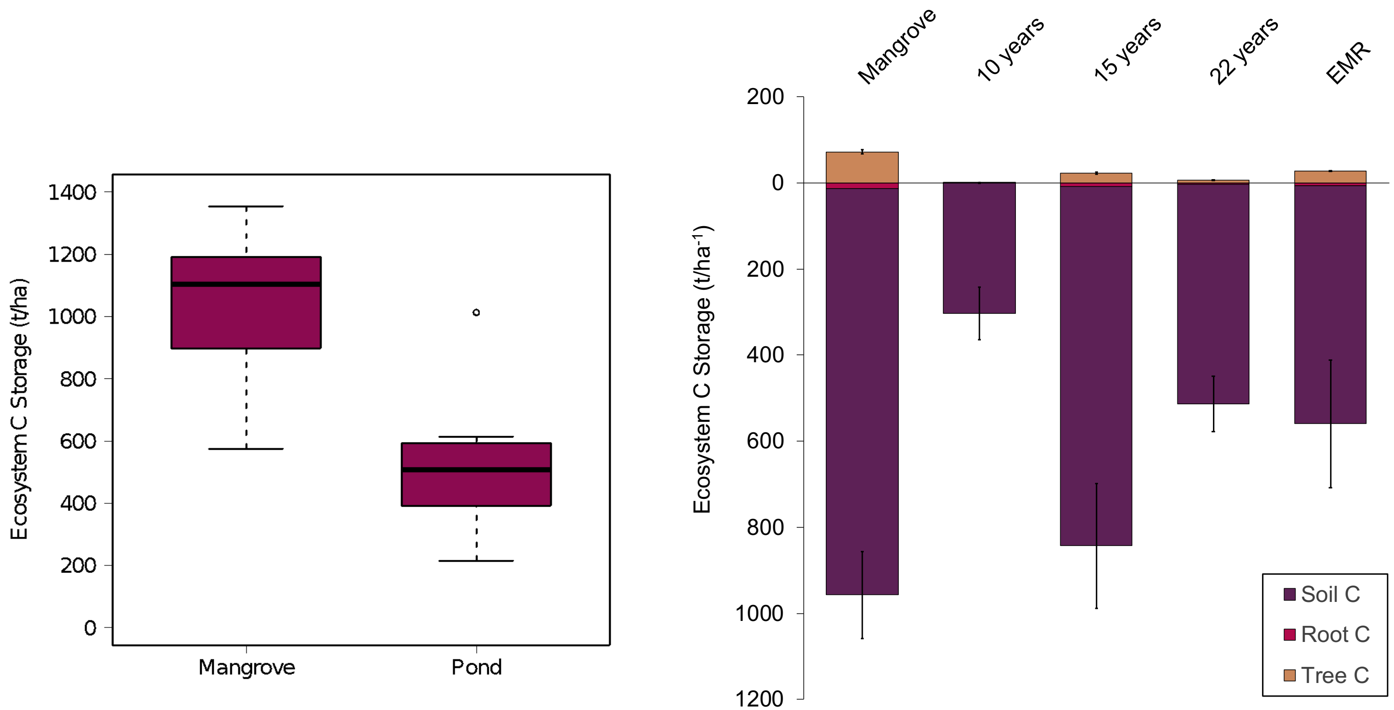


Figure 4.3. Whole Ecosystem C storage of mangrove forests and abandoned shrimp ponds. Data shows (a) the mean value for all mangrove forest sites compared to the mean of all pond sites, and (b) ecosystem C storage separated into aboveground and belowground C pools for the mangrove sites and sites of each pond category. Mangrove ecosystems contained on average 1,029.5 t C ha^{-1} and ponds contained on average 541.65 t C ha^{-1}. Mean ecosystem C stocks of the pond sites was significantly lower than the mangrove sites ($p = 0.0015$).

4.3.2 Soil carbon storage

Soil depth in the undisturbed mangrove forest sites often exceeded 3 m (mean depth: 267 ± 12.53 cm). Soil depth was more variable across pond sites, ranging from 129-249 cm (mean: 180.83 ± 16.90 cm). Soil depth was a strong driver of the variations in ecosystem C stores across sites ($R^2 = 0.82$, $p < 0.001$) because belowground C pools dominated at all sites, accounting for over 90% of total C stored. This finding is similar to other mangroves worldwide (Donato et al. 2011; Kauffman et al. 2011; Stringer et al. 2015).

Mangroves were found to be storing substantial C pools in the soils belowground, with a mean of 944.72 ± 101.5 t C ha^{-1}. This estimate of soil C storage is marginally lower than values reported for mangroves found in the Dominican Republic (1,136 t C ha^{-1}; Kauffman et al. 2014) but similar to the higher range soil C pools reported for Indonesian mangrove forests (572-1,059 t C ha^{-1}; Murdiyarso et al. 2015). However, because only C stocks in the uppermost 3 m was estimated, the absolute ecosystem C stocks may have been underestimated (Arifanti et al. 2019).

On average, the abandoned shrimp ponds contained 550.78 ± 74.62 t C ha^{-1} within the soils, which was around 40% lower than the undisturbed mangrove forests. However, soil C stocks in the most recently abandoned ponds (mean: 303.99 ± 61.24 t C ha^{-1}) were over 65% lower than the mangroves. The estimates of soil C stored in abandoned ponds are higher than values in other studies (mean: 95 t C ha^{-1} (Kauffman et al. 2014); mean: 352 t C ha^{-1} (Kauffman et al. 2017)). Although, Kauffman et al. (2017) report a 54% loss of belowground C pools upon conversion of mangroves to shrimp ponds, which is a similar magnitude of loss recorded for ponds sampled 10 years after abandonment in the present study. By contrast, high soil C stocks were found in ponds abandoned for 15 years (835 ± 144.72 t C ha^{-1}) because of their greater soil depth.

Relatively high soil C stocks in the abandoned ponds are likely driven by soil depth as some of the ponds had C-rich soils greater than 2.5 m deep, and soil C storage was found to be highly correlated to soil depth ($R^2 = 0.82$, p < 0.0001). Whereas, soil depth of abandoned shrimp ponds was markedly lower in other studies (~70 cm (Bhomia et al. 2016; Kauffman et al. 2014)). Furthermore, mangrove trees had colonised in some of the ponds, and seedlings had established in all of the ponds. Across all sites, soil C storage through the profile and in the top 15 cm soil layer was positively correlated to C storage in the vegetation (trees + roots) ($R^2 = 0.46$, $p = 0.005$; $R^2 = 0.59$, $p < 0.002$, respectively; Figure 4.4).

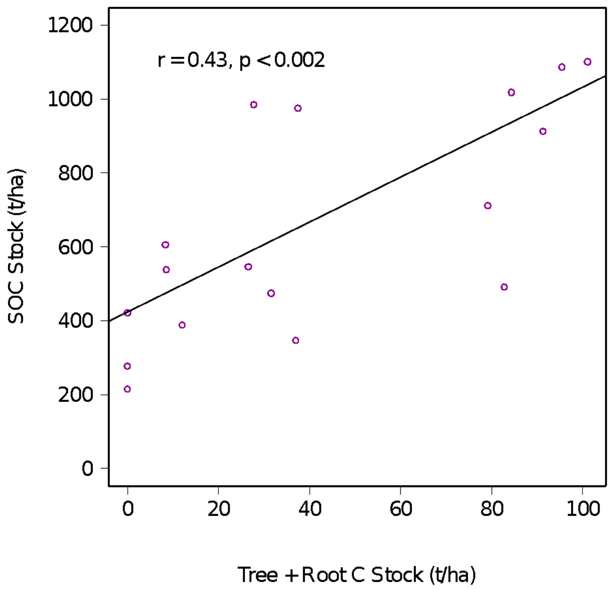


Figure 4.4. Relationship between soil C stocks and C stored in the above and below ground vegetation (tree + root).

In terms of soil C stores, the shallower soil depth in some of the pond sites was counteracted by higher soil bulk density (mean: 1.34 g cm^{-3}) compared to the mangrove sites (mean: 0.91 g cm^3). Bulk density did not differ much through the mangrove soil depth profile, ranging from 0.86 to 0.94 g cm^3, but was greatest in the surface soil layers of the ponds and showed a decreasing trend with depth (Figure 4.5). Standing water and the use of machinery in the ponds during pond construction and use may have affected bulk density in the surface soils through compaction. Furthermore, absence of vegetation in the ponds reduces biological activity and water permeability and can lead to collapsing of the soils and greater soil compaction. Relatively high soil bulk density is also reported for abandoned ponds in the Dominican Republic (>1.27 g cm^3; Kauffman et al. 2014), and India (>1.0 g cm^3; Bhomia et al. 2016).

Soil C loss from the abandoned shrimp ponds may have been underestimated due to the method used for sampling the ponds. When ponds are constructed, around 1.5 m of soil is normally removed during construction. Therefore, when comparing, for example, C stocks in the top 0-15 cm of mangrove soil with C stocks of the 0-15 cm of pond soil, the top 0-15 cm layer of the pond soils most likely correspond to the 150-165 cm depth layer of the mangrove soil profile (accounting for the top 1.5 m of soil that was removed from the ponds).

Differences in soil C stock recovery in the ponds may also be influenced by other confounding factors which are not controlled in natural observational studies, such as this study. Other confounding factors may explain the observed higher soil C stock in the 15-year-old abandoned ponds compared to the 22-year-old ponds. For example, local differences in environmental setting and conditions, such as dominant hydrodynamic processes, landforms and vegetation conditions can influence local variations of C stocks (Hinrichs et al. 2009; Holtermann et al. 2009; Jennerjahn et al. 2009; Woodroffe 1992). Soil C stocks can vary geographically because of site difference in allochthonous inputs (originating at a distance from the site) and autochthonous production of organic matter (e.g. production of litter and dead wood). For example, in Indonesia, higher mean total C stocks have been observed in river-delta mangroves compared to those found in an oceanic setting (Murdiyarso et al. 2009). Similarly, estuarine mangroves have been shown to contain higher soil C stocks compared to oceanic mangroves in SE Asia (Donato et al. 2011). Lower soil C stocks have also been observed in settings receiving high allochthonous inorganic sediment input (Rovai et al. 2018).

Other local factors such as tidal amplitude, wave action and elevation can also influence the distribution and deposition of organic C in intertidal mangroves. For example, where wave action is high, this can increase the removal of autochthonous organic matter. In addition, increased exposure time of soils promotes aerobic decomposition of organic matter (Bouillon et al. 2008; Ranjan et al. 2011). Plant community composition can also influence variations in soil C on a local scale because accumulation and decomposition rates of autochthonous organic matter are in part controlled by mangrove species type. For example, Rhizophoraceae leaves decompose relatively slowly due to their higher concentrations of phenolic compounds such as tannins (Alongi 2009; Cundell et al. 1979; Robertson 1988), which can inhibit microbial efficiency, compared to species such as *Avicennia*.

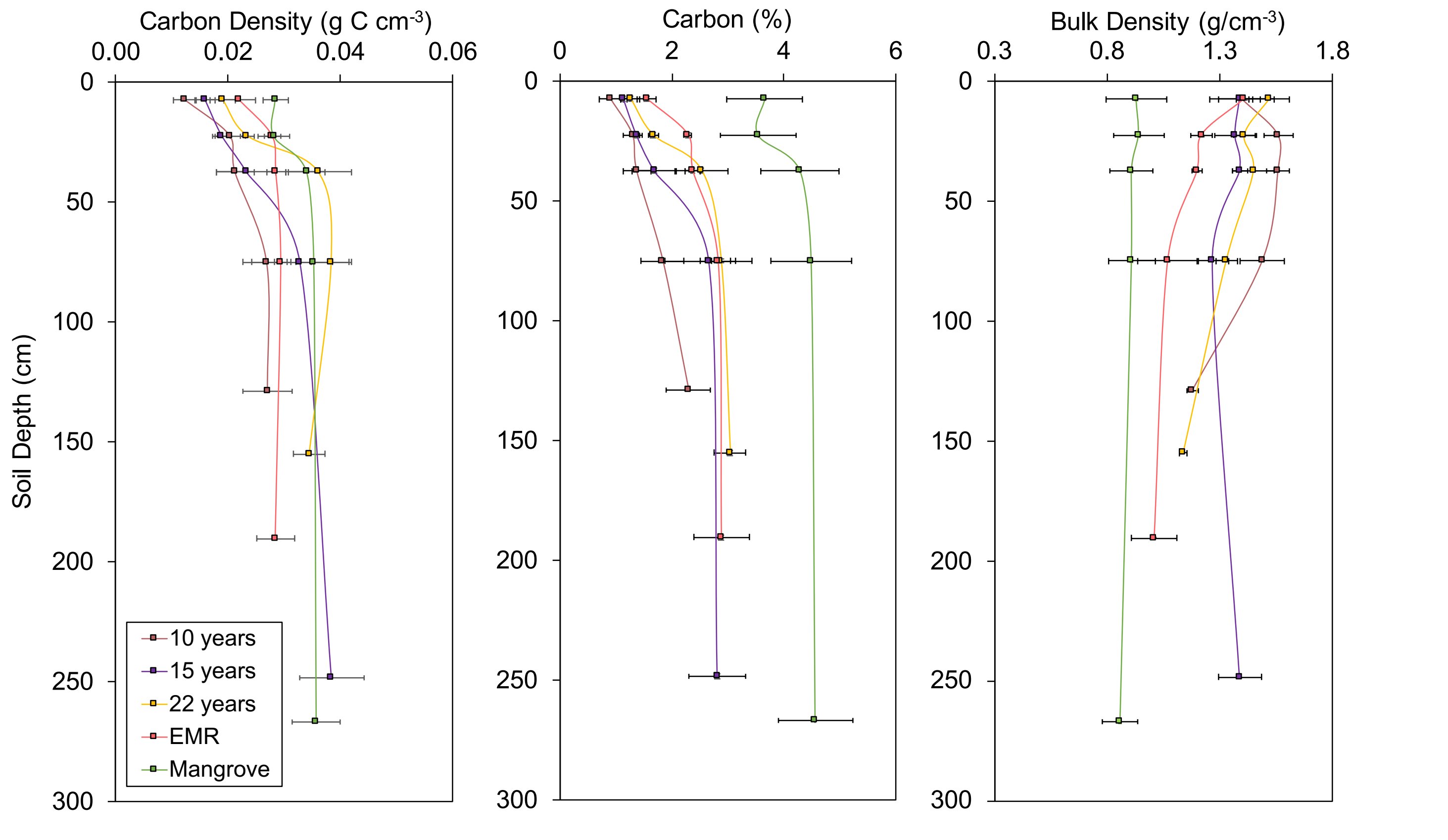


Figure 4.5. Changes in the soil properties (mean ± 1 standard error (SE)) of the mangrove forests and the four pond categories with depth: a) soil C density, b) soil C concentration (%), c) soil bulk density.

In addition, tidal inundation gradients can influence vegetation type and microbial processes by creating varying soil redox conditions within mangrove forests (Marchand et al. 2012). This can affect the amount of C exchanged with adjacent waterways. *Rhizophora spp*., for example, typically grow lower in the intertidal zone, in soils that are sub-oxic to anoxic (Leopold et al. 2013), and anoxic soil conditions can act to reduce efficiency rates of *in situ* microbial decomposition of organic matter, potentially favouring export of C. Higher in the intertidal zone there may be greater *in situ* C mineralization due to oxic to sub-oxic soil conditions (Alongi et al. 2000; Marchand et al. 2004). In general, frequent tidal inundation promotes litterfall and favours C export (Twilley 1985), rather than *in situ* decomposition (Lee 1989).

4.3.3 Stabilisation of carbon in the sub-surface soil layers

The soil C stocks in the subsurface soil layer (15 - 100 cm depth) of ponds abandoned for 10 and 15 years were not significantly different to the mangrove forests (see Appendix). This indicates that near surface C pools are most susceptible to land-use change, and the stability of organic C in the soils may be maintained below 15 cm depth. This finding is similar to that reported for land-use change in upland forests (Tanabe and Wagner 2003) and marshlands (Huang et al. 2010). For example, in marshland soils of northeast China, Huang et al. (2010) reported a 60% loss of near surface (0-20 cm depth) C stocks within the first 15 years after conversion to cropland, but only 37% C loss in the soils between 20-40 cm depth.

4.3.4 Mangrove regrowth and recovery of surface soil carbon stocks

Along the studied chrono-sequence of abandoned pond sites, the effect of land-use change on C pools was most substantial in the near surface soil horizon (0-15 cm depth), and the data supports a positive developmental trajectory for C pools in the upper soil layer. In ponds most recently abandoned, C stored in the 0-15 cm soil layer (mean: 18.34 ± 2.97 t C ha^{-1}) was 55% lower compared to the mangrove forest sites (mean: 42.49 ± 3.44 t C ha^{-1}; $p = 0.003$). However, in ponds abandoned for 15 and 22 years, C storage in the same soil layer was 45% (mean: 23.74 ± 2.64 t C ha^{-1}; $p = 0.018$) and 33% (mean: 28.46 ± 3.34 t C ha^{-1}; $p = 0.097$) lower than the mangroves, respectively (Figure 4.6). There was a positive linear relationship between C storage in the 0-15 cm soil horizon of ponds not under restoration and time since pond abandonment (R^2 =0.40, p = 0.039). As the most recent abandoned pond sites were sampled 10 years after abandonment, the observed pattern suggests that C loss soon after pond abandonment (i.e. in the period 0-10 years) may have been even greater than 55%.

Standardization of the soil profile to 1 m sediment depth allows for a better comparison of C stocks among sites because it removes the effect of soil depth on the observed variability in soil C stocks (section 4.3.2). When standardised to 1 m depth, a positive recovery trajectory for C stocks in the top 1 m soil profile is also observed with age of abandoned pond, as shown in Figure 4.6a. Moreover, 22 years after pond abandonment, the mean soil C stock in the top 1 m of pond soil (327.6 ± 8.64 t C ha^{-1}) was very similar to that of the mean soil C stock found in the top 1 m of mangrove soil (329 ± 7.55 t C ha^{-1}).

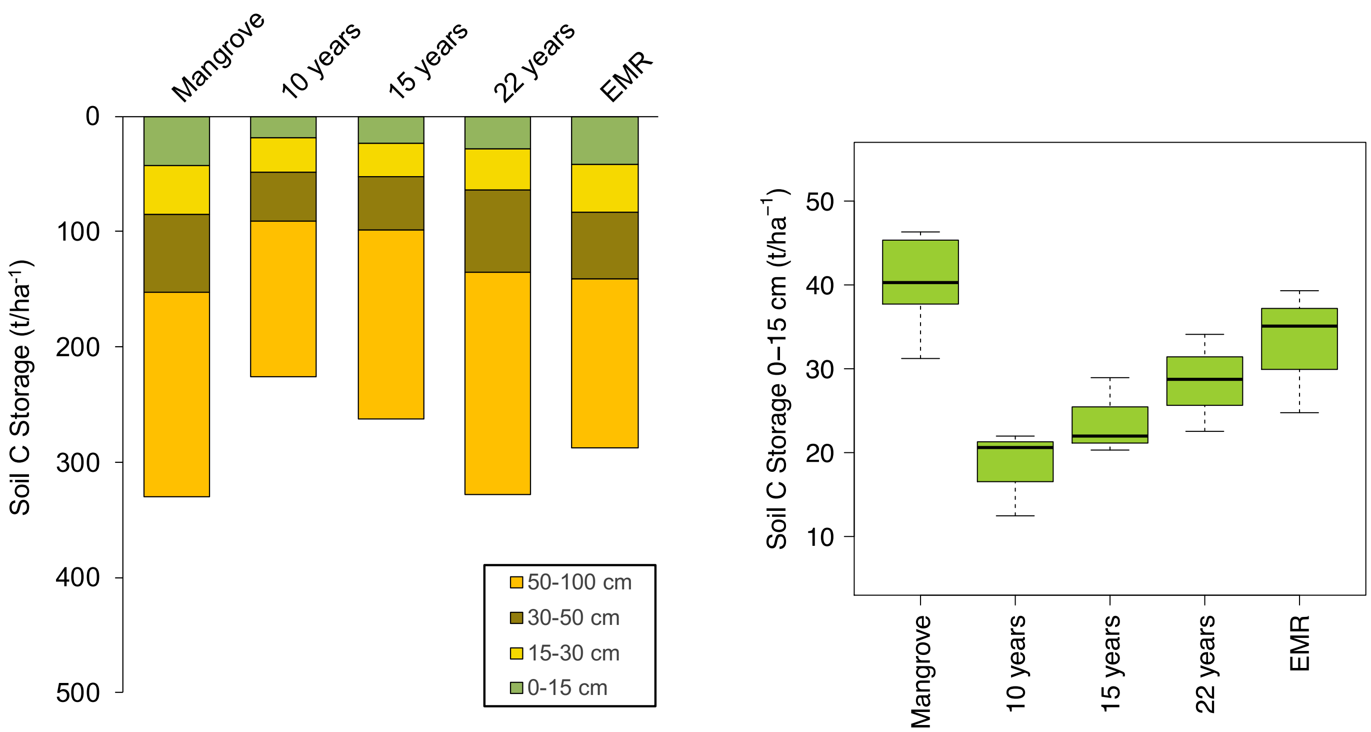


Figure 4.6. a) Soil C stores (t C ha^{-1}) within each depth interval down to 1m; and b) soil C stores (t C ha^{-1}) in the 15-cm soil layer. Data shows means for the mangrove sites and the four pond categories.

In addition, C concentration in the surface soil horizon (0-15 cm) of the abandoned ponds was significantly lower in ponds most recently abandoned (mean: 0.92 ± 0.21 %C; $p = 0.033$) and ponds abandoned for 15 years (mean: 1.14 ± 0.05 %C; $p = 0.04$), compared to the mangrove forest sites (mean: 3.66 ± 0.68 %C). However, C concentration in the surface layer of ponds abandoned for 22 years, and ponds under EMR projects was not significantly different to the mangrove soils ($p = 0.07$ and $p = 0.13$, respectively). Thus, the upper soil layer (0-15 cm) of ponds under restoration and those abandoned for 22 years resembled that of the natural mangrove sites.

All of the abandoned ponds had some evidence of natural mangrove regrowth but at differing degrees. Seedling and sapling density were both highest in the ponds abandoned for 22 years (seedling density: 5,643 ± 3,817 stems/ha^{-1}; sapling density: 1,085 ± 706 stems/ha^{-1}) and lowest in the ponds most recently abandoned (seedling density: 597.67 ± 220 stems/ha^{-1}; sapling density: 33 ± 33 stems/ha^{-1}; Figure 4.7). As soil C stocks are known to increase with forest age (Alongi et al. 1998; Osland et al. 2012), the data indicates that as mangrove trees colonise abandoned ponds, they contribute to the soil C building process. This is notable because other studies of C stock changes in abandoned ponds (Kauffman et al. 2014) report no aboveground C biomass in the sampled ponds.

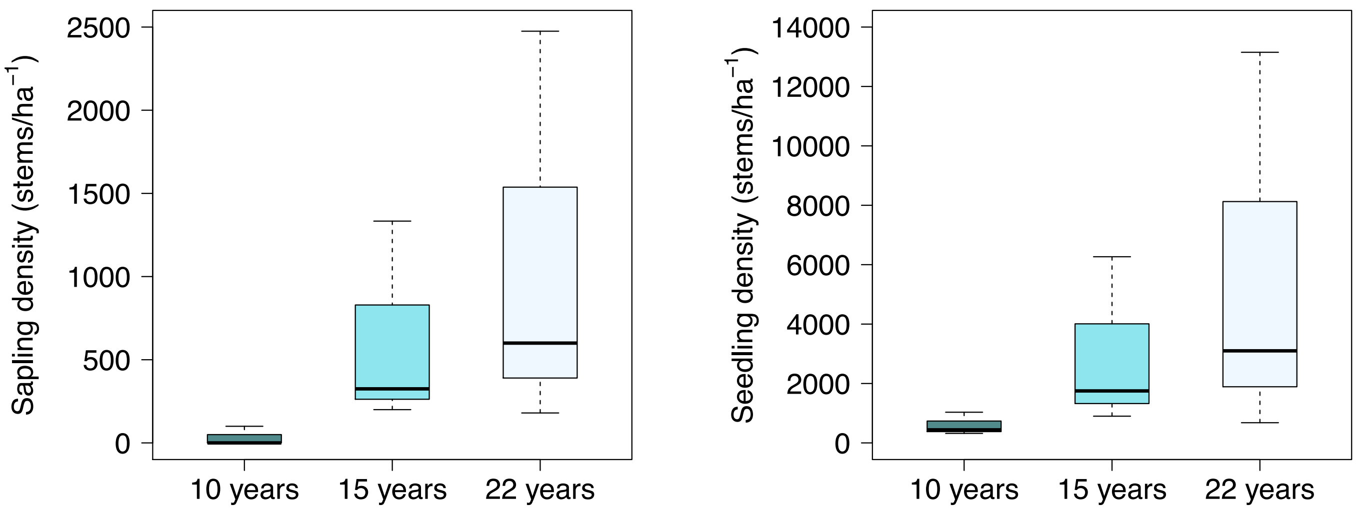


Figure 4.7. Density of a) saplings, and b) seedlings recorded at three of the pond categories (abandoned 10 years, 15 years, 22 years). Although both seedling and sapling density increased with time after pond abandonment, sapling and seedling density was not significantly different among pond categories (seedling density: $p = 0.193$, sapling density: $p = 0.065$).

The findings suggest that C accumulates in soils of the abandoned ponds over time, and these ponds may eventually attain a similar level of C storage as mangrove forests. These results imply that abandoned pond areas can develop as C sinks without active restoration efforts. This could either be related to increased C burial in the pond sediments as primary production and deposition of organic matter increases with age of the regenerating mangroves (Alongi 2014; Alongi et al. 1998), or stabilisation of the rate of C released due to oxidation of soil organic matter with time. Lovelock et al. (2011) report high short-term CO_2 emissions from disturbed mangrove soils which decline logarithmically over a 20-year period, and stabilisation of C loss around 20 years after conversion has also been reported for marshland soils in northeastern China (Huang et al. 2010).

Carbon stored in the surface layer (0-15 cm) of ponds under active restoration (33.05 ± 4.32 t C ha^{-1}) was not significantly different to that of the mangrove forest sites ($p = 0.44$) and ponds abandoned for 22 years ($p = 0.57$). Pond alterations during the EMR process include breaching of ponds walls, manual construction of tidal channels, and assisted dispersal of mangrove propagules (Lewis 2005). Relatively high surface soil C pools in these ponds may be explained as C stock development due to increased tidal flooding after pond modification. Other studies support this finding. For example, Matsui et al. (2010) reported a twofold increase in the surface 5 cm soil C stocks 10 years following hydrological restoration of abandoned shrimp ponds. Furthermore, in created mangrove wetlands, Osland et al. (2012) reported an age-related trajectory for soil C pools in the upper 10 cm, and equivalent C pools to natural mangrove sites 20 years following wetland creation. Physical disturbance of the pond soils during ecological-hydrological restoration may also stimulate nutrient release from the soil organic matter, encouraging plant growth (and hence soil C deposition). This may be particularly true where nutrients are added to ponds during pond use, and so residues (especially if additions include P) could be stimulating later tree growth. The results may then suggest that ecological-hydrological modification of abandoned ponds can provide important C storage functions as early as 3 years after restoration. Spatial differences in C stocks in the abandoned ponds may also be influenced by environmental conditions and other local variations such as species assemblages, sediment supply, elevation, drainage, tidal flooding, and time when tidal inundation resumed in the ponds (Alongi 2014; Chmura et al. 2003; IPCC 2003; Cameron et al. 2018; see section 4.3.2).

4.4 Conclusions

This study adds to the growing literature on the role of mangroves as highly significant global C sinks and improves understanding of C dynamics associated with land-use change in mangroves. Substantial C losses are shown to be associated with mangrove conversion for shrimp farming. However, this study demonstrates that C is preserved in deeper soil layers of some abandoned ponds, and that C accumulates fairly rapidly in the surface soil layer after pond abandonment. This suggests that C sequestration capacity of the ecosystem may improve in abandoned shrimp ponds over time as mangroves re-establish, and that the C stored in the surface soils of ponds may be comparable to natural mangrove forests 22 years after ponds are abandoned.

Chapter 5 Characterizing shrimp-farm production intensity in Thailand: beyond technical indices

5.1 Introduction

5.1.1 Shrimp farming sustainability

With the continued downward trend in the overall state of the world's marine fish stocks (Pauly and Zeller 2016), the aquaculture sector increasingly plays a major role in meeting the ever-growing human demand for fish and other aquatic products (FAO 2018; Belton et al. 2014; Hall et al. 2011a). Total worldwide aquaculture production reached about 80 million tonnes in 2016, estimated to be worth USD 232 billion (FAO 2018). Globally, aquaculture supports livelihoods and contributes to food and economic security by delivering sources of animal protein, nutrients, and income (Belhabib et al. 2015; Smith et al. 2010; Godfray et al. 2010).

However, aquaculture is often associated with environmental sustainability issues. Major environmental issues have been documented since the 1990s. These include widespread destruction and conversion of coastal ecosystems (Alongi 2002; Richards and Friess 2016; Valiela et al. 2001), direct loss of fisheries and coastal biodiversity (Naylor et al. 1998, 2000, 2009; Diana 2009; Polidoro et al. 2010), salinization of groundwater and transformation of agricultural land (Cardoso-Mohedano et al. 2018), high rates of natural resource consumption (Boyd and McNevin 2015), eutrophication of coastal waters and disease outbreaks (Naylor et al. 1998, 2000; Herbeck et al. 2013), and large fish meal and fish oil requirements which has put direct pressure on wild fish stocks (Tacon and Metian 2008). Environmental changes have also led to negative consequences for coastal communities, including displacement and loss of local livelihood, increased vulnerability to flooding, and loss of many essential services provided by intact ecosystems (Primavera 1997, 2006; Neiland et al. 2001; Paul and Vogl 2011). In response, there have been calls for more sustainable aquaculture production (FAO 2016a).

Thailand first developed national certification standards for aquaculture production in the late 1990s, and currently, three state-initiated certification standards exist, including the Good Aquaculture Practice (GAP), Code of Conduct (CoC) and, most recently, the GAP-7401 (Samerwong et al. 2018). These standards set requirements for shrimp producers aimed at improving farming practices, environmental integrity and social responsibility, and mitigating problems of disease, which presents a significant risk to producers across farm intensity types, from the small-scale family operations to the highly intensive corporate-run farms (Cock et al. 2015).

While Thai state-initiated standards attempt to be inclusive across producers of varying intensity and capability, two crucial issues can be identified as challenges for the promotion of sustainable aquaculture. First, policy-makers have had difficulties in tailoring sustainability policies and strategies to match the diversity of aquaculture farming systems. For example, on the rise of sustainability certification and quality standards, Bush et al. (2013) argue that while such schemes contribute towards the development of more sustainable production, they have significant limitations due to the complex, context-dependent social issues concerning aquaculture production, which are often overlooked. As a result, many small-scale producers are excluded from these strategies due to, for example, the costs or resources needed to follow the standards (Kusumawati et al. 2013), and so they are often pushed out of global value chains (Bush et al. 2013). Second, there are important gaps in understanding of behaviour among aquaculture producers at the farm-level regarding their production intensity (Bush et al. 2010). Actions taken by producers affect social, economic, and ecological conditions and can thus influence the overall sustainability of aquaculture production. A better understanding of farmer behaviour in relation to their production intensity is therefore central for designing measures that can effectively promote more sustainable aquaculture (Bush et al. 2010).

In policies such as the above-mentioned sustainability standards, as well as in research, shrimp aquaculture production intensity is often approached as a technical issue. Yet, shrimp farms are shown to be embedded within a socio-economic landscape (Vandergeest et al. 2015; Bush et al. 2010; Joffre et al. 2015, Bottema et al. 2018). Thus, levels of production intensity are hypothesized to also correspond to different farm socio-economic profiles that are not captured by technical indexes alone. Production intensity should be considered in terms of a combination of technical indices of production embedded within a broader socio-economic context. To reiterate: consideration of the complexity of shrimp farmer behaviour and the wider socio-economic perspective of aquaculture production matters when thinking about promoting sustainability through certification standards or other measures: standards may fail because they only take the technical aspects into account and fail to appreciate the socio-economic context in which those technical aspects are embedded (Kusumawati et al. 2013; Bush et al. 2013; also see Bottema et al. 2018).

This study builds on earlier literature on farmer behaviour related to shrimp farming. It applies the integrative agent-centred framework (Feola and Binder 2010) to examine drivers influencing shrimp farmer behaviour in relation to production intensity along the eastern coast of the Gulf of Thailand, and its embeddedness in the wider socio-economic context of shrimp farming households. The study was guided by the following two questions: i) which socio-economic factors are related to distinct levels of shrimp farming intensity?, and specifically, ii) which socio-economic factors matter in the decision to adopt a certain level of production intensity?

Chanthaburi, on the eastern coast of the Gulf of Thailand, is a relevant area for such a study because for decades it has been one of the largest shrimp-producing provinces in Thailand (Hazarika et al. 2000; Department of Fisheries 2018), yet the region has been hit by severe social-ecological fluctuations since 2013 driven by disease epidemics in shrimp and negative environmental change (Piamsomboon et al. 2015). Consequently, many farmers have temporarily reduced or abandoned their production. While shrimp farming in Thailand has previously been characterised as being very intensive compared to other Southeast and South Asian countries (Lebel et al. 2002; Kumar and Engle 2016), aquaculture practices have been changing rapidly (Henriksson et al. 2015), and currently in Chanthaburi there is a diversity of farms of different sizes that operate in the landscape at different production intensities side-by-side. This present research therefore captures current shrimp farming diversity in the face of this rapid change and aims to better understand the socio-economic landscape of shrimp production systems. This study contributes to the literature on shrimp farming and aquaculture sustainability by showing that levels of shrimp farming intensity are in fact an indicator of a diversity of socio-economic conditions and behavioural choices, which need to be targeted by sustainability policies differentially and beyond the technical sphere.

The Chapter continues with an overview of shrimp farming in Thailand and its relevance in relation to the above research gaps, and a brief overview of the study site. Literature on the characterisation of shrimp farming intensity types and farmer behaviour is then brought together. This is followed by an overview of the research methodology and presentation of the results from the case study. Finally, the key findings are discussed in relation to the wider aims of the study.

5.1.2 Shrimp aquaculture in Thailand

Shrimp farming has been a traditional livelihood practice on coastal landscapes in Thailand for centuries, but the character of coastal shrimp culture has changed dramatically over the past half century. Production of Penaeid shrimps, which account for around 80% of total shrimp production, has increased rapidly, from less than 24, 000 t in 1950 to over 600, 000 t in 2012 (FAO 2016b; Figure 5.1), with production from around 23, 800 shrimp farms along the coast (Department of Fisheries 2018). However, total shrimp production dropped from over 600, 000 t in 2012 to 325, 000 t in 2013 (FAO 2016b). This was the latest of many abrupt social-ecological dynamics: boom and bust periods driven by disease epidemics in cultured shrimp (Flegel 2012; Leaño and Mohan 2012), coupled with negative biophysical changes and ecological feedbacks, and a year-on-year drop in market price for shrimp (Lebel et al. 2002; Hall 2011b; Huitric et al. 2002; Barbier and Cox 2004; Piamsomboon et al. 2015).

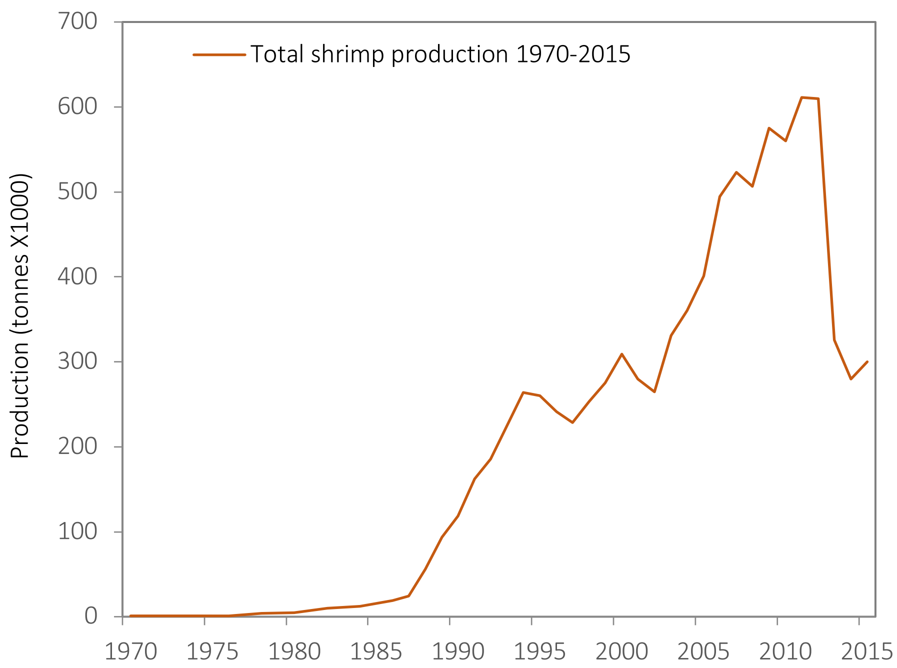


Figure 5.1. Production of cultured brackish water shrimp in Thailand from 1970 – 2015. Source: FAO FishStatJ.

Rapid expansion and intensification of shrimp production in Thailand over the last 40 years has caused widespread ecosystem conversion and degradation; in many coastal areas of Thailand, shrimp farming expansion has contributed to over 30% of the total mangrove loss since the 1970s (Hamilton 2013; Barbier and Sathirathai 2004). Extensive clearance of mangrove forest has led to negative social-ecological feedbacks, such as loss of natural livelihood resources (such as timber provision and fisheries production), coastal pollution, fishery declines, changes to water resources and effluent loading, and salinization of rice fields, which has created conflicts among agricultural farmers and shrimp farmers and loss of coastal livelihoods (Vandergeest et al. 1999; Vandergeest 2007; Valiela et al. 2001; Flaherty and Karnjanakesorn 1995).

This study was conducted in the sub-districts of Khlung and Laem Sing, Chanthaburi Province, on the eastern coast of the Gulf of Thailand (12.61° N, 102.10° E; Figure 5.2). The coastline of Chanthaburi stretches 68 km across four coastal districts; Na Yai Am, Tha Mai, Laem Sing, and Khlung. The region is characterized by its diversity of coastal habitats, including extensive seagrass beds, tidal mudflats, and mangrove forests (Janetkitkosol et al. 2003). However, large areas of mangrove forest were cleared and converted in Chanthaburi during the 1980s and 1990s to make space for aquaculture, with remaining mangroves only occurring in narrow fringes. Behind the mangrove fringe, there are many shrimp farms, rice fields, and fruit orchards.

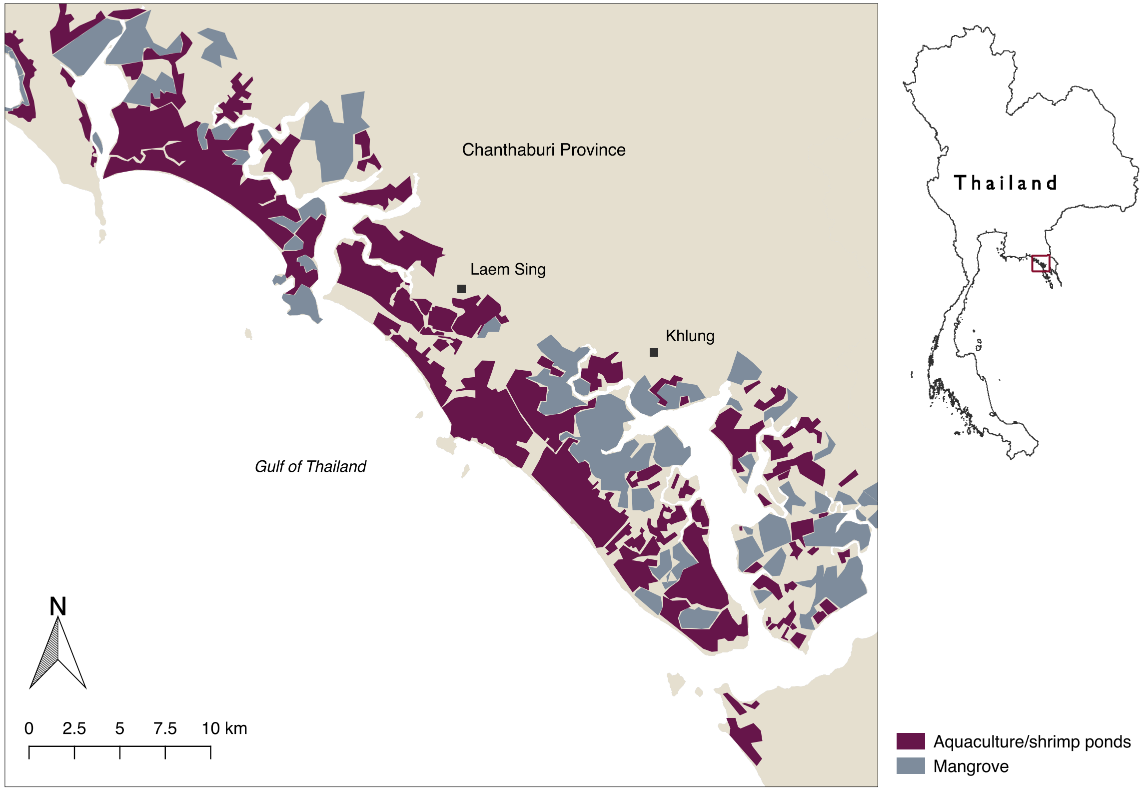


Figure 5.2. Map showing the study area location in the Districts of Laem Sing and Khlung, Chanthaburi Province, on the Gulf of Thailand coast.

Intensive shrimp culture along Chanthaburi's coastline began in the 1980s and expanded at a dramatic rate through the 1990s and 2000s (Hazarika et al. 2000). In 2012, Chanthaburi represented one of the largest shrimp aquaculture regions in Thailand, with around 2120 shrimp farms, covering 6758.72 ha in area and producing over 60 000 t of shrimp (Department of Fisheries 2018). Two Penaeid shrimps (*Litopenaeus vannamei* (Whiteleg shrimp) and *Penaeus monodon* (Black tiger shrimp)) are the main cultured shrimp species in the region, with *L. vannamei* accounting for over 80% of total shrimp production (FAO 2016b). Shrimp production in Chanthaburi has declined sharply in recent years, mainly due to widespread viral outbreaks in shrimp, such as acute hepatopancreatic necrosis disease (AHPND) and hepatopancreatic microsporidiosis (HPM) (Putth and Polchana 2016), and subsequent global shrimp price volatility has permitted increased production and export from other countries such as China, Indonesia, and Vietnam (Wanasuk and Siribur ananoon 2017). In Chanthaburi, shrimp production dropped from around 61 500 t in 2012 to 33 900 t in 2013. Production of shrimp remained at 33 700 t in 2015, indicating that the industry has not recovered in this region (Department of Fisheries 2018), and many aquaculture ponds have recently been abandoned (Piamsomboon et al. 2015).

What is left from these ecological, social and economic changes is a landscape with persisting environmental issues and a diversity of farming intensities and corresponding livelihood strategies, including large-scale intensive shrimp farms designed to maximise production, and many independent small- to medium-scale farms. Given that shrimp production is highly important for economic development in Thailand, and the demand for shrimp from international markets is projected to increase (FAO 2016c), policy makers are now confronted with the challenge of directing shrimp farmers away from environmental destruction, and towards more sustainable production systems (Bush et al. 2010; Bush and Marschke 2014; Joffre et al. 2015). Following the most recent crash of the shrimp industry in Thailand in 2013, the government updated their national certification standards in an attempt to improve environmental conditions and regain credibility in the global market. However, the uptake of these new standards has been limited due to their demanding requirements, leading scholars such as Samerwong et al. (2018) to question their inclusiveness and effectiveness.

In sum, the case of Thailand is illustrative of a situation in which (i) there is diversity of farming intensities, (ii) policy has had difficulties to promote sustainable aquaculture, also because (iii) there is a knowledge gap in understanding farmer behaviour in relation to production intensity.

5.1.3 Characterization of shrimp farming diversity

Different shrimp culture systems can be classified based on how similar or dissimilar they are to one another with regards to one or more variables related to technical, economical, ecological, geographical, or social aspects of production (Shang 1981). In terms of culture production intensity, global shrimp aquaculture has been characterized as either (i) extensive, (ii) semi-intensive, or (iii) intensive, reflecting a scale from low to high intensity (Tidwell 2012). However, these classes can vary between countries and regions (Primavera 1993, 1998; Dierberg and Kiattisimkul, 1996).

Farm intensity types are most commonly defined using technical variables related to farm size, stocking density, feed rate, or rate of fertilizer application, or economic performance indicators, such as yield and income (FAO 2018; Deb 1998; Dierberg and Kiattisimkul 1996; Islam et al. 2005; Stevenson et al. 2007; Joffre and Bosma 2009). To date, there has been a wealth of literature on technical aspects of different shrimp aquaculture systems, in terms of quantitative descriptions of farm size, pond management methods, resource use, production outputs, and economic analysis (for example, Stevenson et al. 2007; Kongkeo 1997; Boyd et al. 2016, 2017, 2018; Boyd and Engle 2017; Engle et al. 2017; Thakur et al. 2018; Islam et al. 2005). Technical analysis at the farm-level is important because it derives data which can be used to assess and reduce negative impacts of aquaculture and to guide more sustainable management practices (Boyd et al. 2017). In a farm-level survey from Thailand and Vietnam, for example, Boyd et al. (2017) concluded that, per ton of shrimp produced, intensive shrimp production systems are more efficient, use fewer resources, and result in less impact on the environment compared to more extensive shrimp production systems.

On the other hand, however, classifying culture systems using technical variables alone has its limitations. Firstly, it is difficult to classify polyculture systems based on production indices such as yield and feed rate because different species have different growth rates and feeding behaviour. In addition, farm size, which is sometimes used in classification criteria, does not consistently relate to production intensity because small farms and large farms can be managed at a similar level of intensity (Vandergeest et al. 1999; Engle et al. 2017). Furthermore, while the social-ecological costs of aquaculture have been well documented (Primavera 1993, 1997), typologies based on technical variables do not account for the social and ecological factors influencing production intensity. Technical indices of production should therefore be complemented with information on the socio-economic context of production, including on farmer decisions to adopt a certain level of intensity (Bush et al. 2103).

5.1.4 Shrimp farmer behaviour

To be able to attempt to steer the sector towards environmentally, economically and socially sustainable configurations, it is important to understand the decisions behind the diversity of farm intensities (Bush and Marschke 2014). Shrimp farmers are key actors within the system, therefore a comprehensive understanding of shrimp farmer behaviour[1] is crucial for guiding pathways towards sustainability (Bush et al. 2010).

A series of social, ecological, epidemiological, and regulatory factors have been shown to influence the behaviour of aquaculture producers regarding their production system and farm management (Joffre et al. 2015; Ahsan and Roth 2010; Bush and Marschke 2014; Ha 2012a, 2012b; Kusumawati et al. 2013; Tendencia et al. 2013). At the macro-scale, Hall (2004) discusses the social processes that have influenced farmer behaviour at the regional level across countries in Southeast Asia, namely; 1) government programs and State support for shrimp farming expansion in Thailand and Indonesia, 2) corporate involvement in training, research and the building of farm infrastructure (such as Charoen Pokphand Group (C.P.) in Thailand), 3) the role of collective farmer action to reduce problems, such as regulating water systems in Thailand and Indonesia, and 4) the influx of new shrimp producers in Java which destabilized traditional farm systems.

At the farm-level, much of the research on aquaculture farmer behaviour to date has focused on risk perception and management, for example in relation to disease or climate-related risks (Chitmanat et al. 2016; Lebel et al. 2016; Lebel 2016; Lebel and

[1]The term “behaviour” refers in this chapter to an action or a series of actions. An “action”, or “social action”, refers to a series of acts enacted by a social actor, selected among possible alternatives, on the basis of a plan which can evolve in the course of the action itself. The social action aims at a goal, given a situation or context shared also by other actors who can react, and by norms, values, means, and physical objects, which the actor considers, to the extent he/she disposes of information and knowledge (adapted from Gallino, 1993). “Social action” and “behaviour” are distinguished from “decision-making”, which refers to the cognitive ”process of making a selective intellectual judgment when presented with several complex alternatives consisting of several variables, and usually defining a course of action or an idea“ (from the Online Medical Dictionary: http://www.mondofacto.com/dictionary/).

Lebel 2018). In Denmark, for example, Ahsan and Roth (2010) identify that mussel farmers perceive and manage risks based on a combination of market factors (future price and demand for mussels), regulatory drivers (changes in government regulations), and bio-physical factors (weather and water conditions). Lebel et al. (2016) show that fish farmers in northern Thailand adopt short-term and medium-term adjustments to production to manage climate-related risk, such as seeking new information, and altering aeration, feeding rate, and stocking.

Other studies of farm-level behaviour explore how aquaculture producers collaborate in relation to risk perception, attitude and farm management (Ahsan 2011; Joffre et al. 2018; Le Bihan et al. 2013). Some studies (Bush et al. 2010; Joffre et al. 2015; Bottema et al. 2018) explore shrimp farmer social structures in relation to the embeddedness of farms within a landscape, and how the extent to which farms are integrated into the landscape depends on both physical and social factors. Bush et al. (2010) for example, suggest that aquaculture farmers operating intensive 'closed' systems are less likely to adopt collective strategies for risk management compared to farmers operating extensive 'open' systems, who are more likely to self-organise. In contrast, Bottema et al. (2018) compare stocking behaviours and risk management strategies across two shrimp farm intensity types ('closed' intensive shrimp and grouper farmers in Thailand and 'open' integrated mangrove shrimp (IMS) and extensive shrimp farmers in Vietnam), and explore how individual aquaculture farmers interpret and manage environmental risks and how their ability to deal with risk relates to farmer-farmer social relations. Bottema et al. (2018) show that collective action between farmers to mitigate risks depends on shared social experiences.

Other literature explores the influence of policy and risk perception on the adoption of certain farming practices, such as those aimed at conservation or climate change mitigation (Greiner et al. 2009; Niles et al. 2016; Joffre et al. 2018). For example, studies on shrimp producers have looked at factors influencing the adoption of more 'mangrove-friendly' integrated mangrove-shrimp systems (IMS). In Vietnam, Joffre et al. (2015) identified that farmers shift from extensive production systems to IMS systems based on a combination of drivers which influence farm profitability and disease risk, such as bio-physical drivers (the role of mangroves in pond management) and those related to the value chain and regulatory framework. Nguyen et al. (2018) explored factors influencing the adoption of IMS systems among shrimp farmers in Vietnam, which they relate to social dynamics such as learning through various media.

While this literature has contributed importantly to the understanding of aquaculture and aquaculture producers, questions still remain as to how individual decisions are made on the micro-scale, across different shrimp farming intensities in Thailand (Bush et al. 2010). This study therefore builds on findings from other contexts and countries by analysing shrimp farming diversity along the coast of Thailand with the aim to understand the factors involved in farmer behaviour in relation to production intensity, including technical, social, and ecological drivers.

5.2 Materials and methods

5.2.1 Data collection and theoretical framework

Exploratory field work was first implemented in October 2016, where a series of semi-structured interviews were conducted with stakeholders from the local to national scale. These interviews helped gain background information on current and historical shrimp farming patterns, and the scale of shrimp farming in Chanthaburi Province. Each of the interviewees had knowledge of the study area due to their occupation and/or place of residence. Interviewees included private individual shrimp farmers (n = 12), a local shrimp farming cooperative official, village heads (n = 2), Provincial representatives from the local government Mangrove Management Unit (n = 2), and representatives from the government Department of Marine and Coastal Resources in Bangkok (n = 6).

A semi-structured interview approach was adopted for the exploratory phase, where prompt questions were used to facilitate discussion around particular topics. Specifically, interviewees were asked questions related to the history of shrimp farm development in Chanthaburi and associated mangrove conversion, the types of shrimp farms in the present and past, and approaches to improve environmental sustainability across different governance scales.

5.2.2 Understanding farmer behaviour

Studies on farmer behaviour have commonly applied the Theory of Planned Behaviour (Ajzen 1991) and the Theory of Reasoned Action (Ajzen 1991) from the social and behavioural sciences (Rose et al. 2018). These two theories are similar in nature and state that behavioural intention is associated with attitudes (beliefs, world views, and opinions on a particular behaviour), subjective norms (perceptions of particular behaviour compared to what others are doing) and perceived behavioural control (ease of implementing a particular behaviour or feelings of control over decision-making). However, studies have shown action does not always follow intention (e.g. Viira et al. 2014). The ‘Diffusion of Innovations’ theory has also been widely applied in the agriculture literature (Rose et al. 2018). Briefly, the Diffusion of Innovations theory is temporal in nature and suggests that different individuals adopt innovations in behaviour on various timescales. If innovations in behaviour are successful, other peers may then adopt the behaviour. In other literature on farmer behaviour, the ‘health belief model’, has been used to explain environmental management decision-making (e.g. Morris et al. 2012), whereby an individual is believed to take action if: i) a negative outcome can be avoided, ii) there is a positive expectation about a particular behaviour, or iii) belief that an action can be implemented successfully (Rosenstock 1974).

5.2.3 The integrative agent-centred framework

In this study, the integrative agent-centred (IAC) framework (Feola and Binder, 2010) was used as a basis for designing a structured survey to collect semi-quantitative data for a range of explanatory variables that potentially drive shrimp farmer behaviour in Chanthaburi Province. The IAC framework is agent-centred and supports the understanding of farmers' behaviour consistently with the perspective of agricultural systems as complex social–ecological systems. It combines different behavioural drivers, bridges between micro and macro levels, and depicts a potentially varied model of human agency (Feola and Binder 2010). The IAC framework has previously been used to study farmer behaviour in relation to production intensity in agricultural systems (Feola and Binder 2010, 2010b) and was thus deemed suitable for supporting the research design for this study. The IAC framework is based on: (i) an explicit and well-motivated behavioural theory; (ii) an integrative approach; and (iii) feedback processes between agents’ behaviour and system’s dynamics.

The components of the IAC framework are based on the integration of the Structuration Theory (Giddens 1984) and the Theory of Interpersonal Behaviour (Triandis 1980). In combination, these two theories permit an improved approach to the investigation of farmer behaviour because they frame the feedback processes occurring between the farmer and the system and are thus well suited to investigating dynamic processes in the context of SES (Galt 2008).

The Structuration Theory (ST) states that actors influence and are influenced by social structures. The Theory of Interpersonal Behaviour (TIB) is a psychological theoretical framework developed to explain individuals' 'interpersonal' behaviour. The TIB states that intentions, habit, physiological arousal and contextual factors influence an agent's behaviour. The TIB is believed to be more comprehensive compared to other behavioural theories (Jackson 2004) because it includes a wide array of potentially relevant drivers of behaviour, thus making it appropriate for studying decision making in complex systems such as in agriculture (Scoones et al. 2007).

The IAC framework guides selection of potential explanatory factors to be considered in the analysis of farmer behaviour and the identification of the relationships among them. The questions in the survey corresponded to different classes of behavioural drivers outlined in the IAC framework (Figure 3). These included: Contextual factors (i.e. facilitating conditions or barriers), Habit (the frequency of past behaviour), Expectations (beliefs about the outcomes, their probability and their value), Subjective culture (social norms, roles, values), and Affect (the feelings associated with the act). Each of the behavioural drivers were measured through one or more questions in the survey (see Appendix for full survey). Each survey employed the same structured set of questions and no prompt questions were used during the surveys.

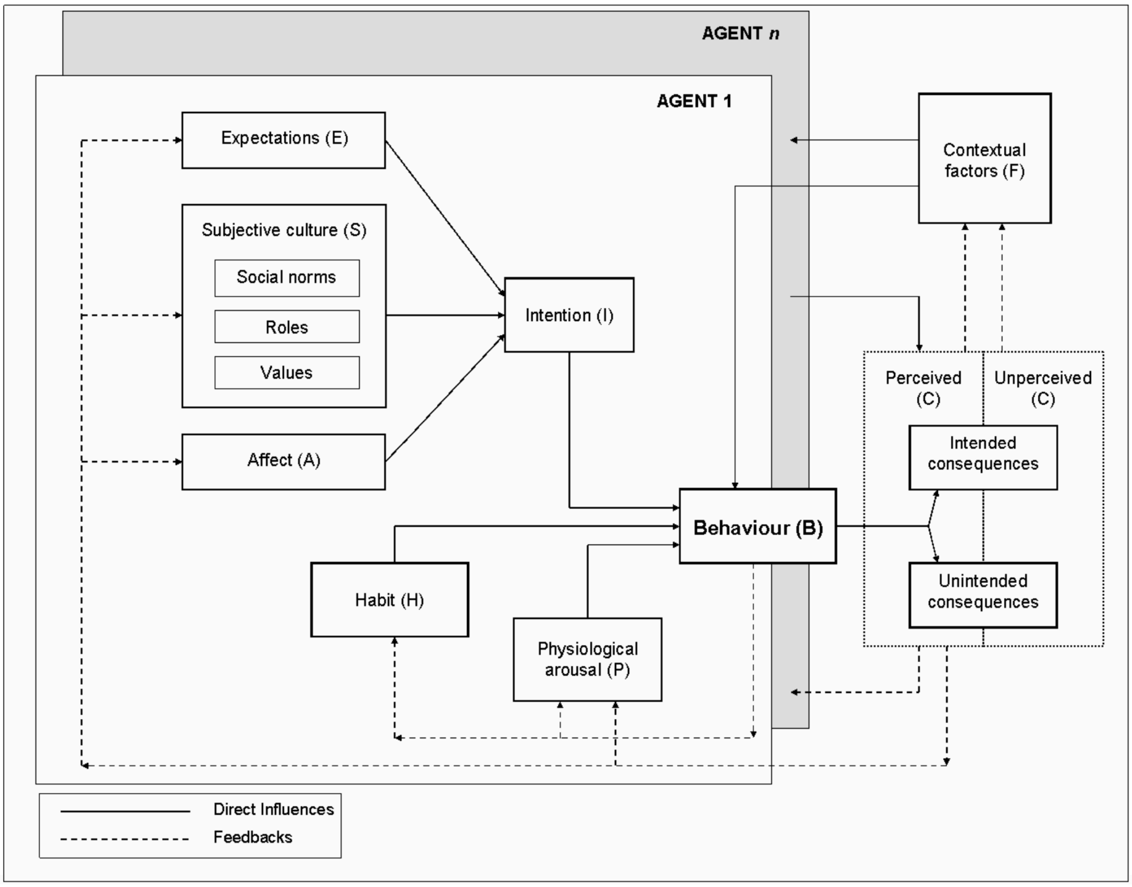


Figure 5.3. The IAC Framework (Feola and Binder 2010).

To enable consistency in the data across study sites of Khlung and Laem Sing, and to make the timeframe as close as possible to the survey time, the questions referred to specific timeframes of either one production cycle, one year, or two years, as relevant depending on the question. The survey design aimed to generate data from shrimp farmers working across a range of shrimp farm intensity types, from low-intensity traditional polyculture systems to more technologically advanced intensive shrimp monoculture, so that data could be compared across farm management intensity categories.

Fieldwork was conducted between February and May 2017. A total of 102 shrimp farmers and farm workers were surveyed. Respondents were selected to provide a wide geographical cover across the survey area, and a relevant sample of the shrimp farmers in the area, avoiding biases associated with particular locations and shrimp farm sizes. Respondents were sought systematically by visiting farms and houses along the coastal Province area, and through snowball sampling (Goodman 1961). All surveys were conducted on an individual shrimp farmer basis to ensure that the responses reflected personal information. In 6 of the 102 cases, the owner of the shrimp farm did not live on the farm, or was only present occasionally, and therefore the farm operator was interviewed instead. These surveys were subsequently removed from the sample.

5.2.4 Data analysis

In order to characterize the socio-economic context of farmers farming at different levels of intensity and to be able to then compare the behaviour of shrimp farmers across farm intensity types, survey respondents were first classified into farm intensity types based on technical similarity within groups with regard to production intensity. Survey data were used to characterize the socio-economic (including demographic and market related) factors associated with each level of farming intensity (Table 1). Three production intensity proxy variables were used to define farm intensity type: 'shrimp yield (kg ha crop)', 'shrimp stocking density (PL m^2)', and 'number of shrimp crops produced per year'. The grouping of farms under each of the three key variables was based on FAO farm type classifications (extensive 'low intensity', semi-intensive 'medium intensity', and intensive 'high intensity') for the two principal brackish water shrimp species cultured in the study region, *P. monodon* (Black tiger shrimp; FAO 2018c) and *L. vannamei* (White shrimp; FAO 2018b).

For the three production intensity proxy variables, the minimum and maximum values for each species were first calculated separately for each individual pond. Minimum and maximum values were then assigned to one of the three production intensity classifications ('low', 'medium', or 'high' intensity). Where minimum and maximum values fell between two intensity categories (for example, minimum = 'medium intensity' and maximum = 'high intensity'), then the mean of the variable was used. If ponds of a farm fell in more than one of the intensity categories (for example, 5 ponds for 'high intensity' and 1 pond for 'medium intensity'), then the farm was allocated to the modal farm type (i.e. 'high intensity' in the example).

The survey was designed to produce either quantitative responses (e.g. farm size, number of employed labour), or semi-quantitative data whereby all of the answers to qualitative questions were placed on a either a 3- or 5-point scale. For example, when asked *"approximately what proportion of your shrimp survived on your last harvest?",* the interviewee was given a choice of 5 answers ranging from 1= none to 5= all. As a result, all of the data generated from the survey was numerical and therefore no thematic analysis was conducted.

Following identification of the three farm intensity types, survey responses which related to the internal and external behavioural drivers (Figure 3) were compared between farm intensity types. Where differences in responses were found between farm intensity types, the significance level of the difference was statistically tested using the non-parametric Kruskal-Wallis (K-W) H test, followed by the Dunn post hoc multiple comparisons test, where appropriate. Drivers that were found to be statistically different were treated as the determinants of adopting a particular shrimp farming production intensity. All statistical analysis was performed using the software R. Differences at the 0.05 level were considered significant.

5.3 Results

5.3.1 Shrimp farm intensity types

This study shows that three distinct farmer profiles /socio-economic configurations and livelihood structures correspond to each distinct production intensity level (low, medium, and high). Descriptive statistics on the different socio-economic-technical variables of farm intensity types are presented in Table 5.1.

Table 5.1. Descriptive statistics on different socio-economic-technical variables of farm intensity types, including shrimp farmer demographic variables, technical (production related) variables, labour/farm organisation variables, and disease occurrence across the three sampled farm intensity types (low, medium, and high). Values are mean±1SD and range in parenthesis. Yield is measured in kg/ha/crop, Value is measured in THB/kg, Farm production costs and revenue is presented in 1,000THB per crop. SD = Stocking density.

		Farm intensity type		
Type of factors	**Variable**	**Low**	**Medium**	**High**
Demographic	Number of farmers	50	27	19
	Gender (% of farmers):			
	Male	64	78	100
	Female	36	22	0
	Age	55 ± 10 (29-78)	50 ± 10 (28-72)	49 ±12 (31-70)
	Highest education level (% of farmers):			
	None	18.0	0.0	0.0
	Primary	54.0	67.0	68.4
	Secondary	20.0	19.0	10.5
	College/university	8.0	15.4	21.1
Socio-economic	Farm ownership status (% of farmers):			
	Owner	76.0	78.0	63.2
	Leased	6.0	22.0	36.8
	Government entitlement (tenure)	18.0	0.0	0.0
	Farm operating years	32 ± 17 (6-100)***	17 ± 9 (1-40)	17 ± 12 (3-50)
	Farm helpers (persons/ha)	0.3 ± 0.3 (0-1.3)**	1.4 ± 2.2 (0-10.9)	2 ± 2.5 (0-10.4)
Technical (farm and ponds)	Farm area (ha)	11.2 ± 7.8 (1.6-38.4)	2.9 ± 3.6 (0.2-16.0)	3.8 ± 4.8 (0.4-16)
	Total pond area (ha)	10.9 ± 8.0 (1.0-38.4)***	2.2 ± 2.8 (0.2-12.8)	2.6 ± 2.7 (0.4-9.4)
	Number of ponds	1.2 ± 0.9**	4 ± 7 (1-40)	5 ± 5 (1-16)
	Average pond size (ha)	10.3 ± 7.1 (0.5-32)***	0.56 ± 0.23 (0.24-1.12)	0.56 ± 0.17 (0.32-0.86)
	Species cultured (No.)	4 ± 1 (1-5)***	1.1 ± 0.5 (1-3)	1 ± 0.2 (1-2)
Technical indices (production)	*L. vannamei* yield (mean)	28 ± 33 – 36 ± 41***	2288 ± 2144 – 2587 ± 2256***	6119 ± 3793 – 6767 ± 3928***
	L. vannamei yield (range)	0.3 - 188	0 - 9375	0 - 12500
	P. monodon yield (mean)	33 ± 59 – 37 ± 62	157 ± 65 -185 ± 104	4337 ± 2789 – 4716 ± 2139***

	P. monodon yield (range)	0.3 - 260	84.4 – 291.7	5625 – 2272.7
	L. vannamei SD (PL/m^2)	0.3 ± 1.3 (0-8)***	38 ± 20, 6-94***	63 ± 17 (31-94)***
	P. monodon SD (PL/m^2)	1.4 ± 2.5 (0-13)***	12 ± 10 (1-20)***	45 ± 12 (31-54)***
	L. vannamei crops/yr.	1 ± 0.1 (1-2)***	2.3 ± 1 (1-4)	2.5 ± 0.5 (2-3)
	P. monodon crops/yr.	1.1 ± 0.2 (1-2)***	2.3 ± 1 (2-3)	2.5 ± 0.5 (2-3)
	Fish and crustacean yield†	95.2 ± 200.2***	27.2 ± 118.8	0.0
	Feed rate (kg/ha/crop)	0.8 ± 4.3 (0-30)***	314 ± 251 (0-960)***	714 ± 464 (184-2,138)***
	Feed added (% farms)	6	96.3	100
Economic /market indices	*L. vannamei* selling price (mean)	127 ± 43 – 141 ± 52	136 ± 38 – 159 ± 40	164 ± 42 – 189 ± 51***
	L. vannamei selling price (range)	60-300	60-255	90-300
	L. vannamei sold (%)	75.3±35 – 83.6±37	87.6±27.7 - 92±28	89.1±25 – 93.4±25.5
	P. monodon selling price (mean)	434±164 - 598±111***	310±269 - 310±269	277±197 - 280±193
	P. monodon selling price (range)	150-700	120-500	130-500
	P. monodon sold (%)	80.4±34 – 86.4±35	85.7±0 - 100±0	91.7±14 - 100±0
	Farm production cost (mean)	31.8±38.6***	535±1022**	790.9±1131.6
	Farm production cost (range)	1 – 201.5	9.5 - 4800	65 - 4800
	Farm revenue	20±46 - 45±140	752±1140 - 872±1335***	1,955±2,525 – 2,263±2,739***
Disease indices	Disease outbreaks (no./2 yrs.)	2.3 ± 1.6 (0-7)	3.8 ± 4.4 (0-24)	3.5 ± 3.6 (0-16)
	Disease free farms (% /2 yrs.)	12	7.4	5.3

Significant difference between farm intensity types: ***0.001, **0.01 (Kruskal-Wallis test with the Dunn post hoc test).
†including fish sp., crab sp., and shrimp species other than *P. monodon* and *L. vannamei.*

Farm intensity type 1: '*low intensity*'. *Low intensity* farms comprised the largest sampled group (52% of the sample). These farms have been operating for on average 32 ± 17 years, which is significantly longer than *medium* and *high intensity* farm types (K-W test, $p < 0.05$). Although the majority of farms within this group were privately owned (76% of sample), around one fifth of the farms are on government owned land which was allocated to the farmer for use under the government's 'Entitlement' policy. Under this policy, abandoned or reclaimed intensive shrimp farms built in areas previously occupied by mangrove forest are allocated to local people for aquaculture use. These farms are located within government conservation areas where restrictions are made on the use of machinery for pond maintenance. Without maintenance, the old pond dikes can gradually erode, resulting in one large aquaculture area, rather than a number of individual ponds. As a result, mean pond size (10.3 ha ± 7.1) on *low intensity* farms is far larger than *medium* and *high* intensity ponds (~0.56 ha), and the mean total pond area (10.9 ha ± 8.0) is significantly larger by around 4-5 times compared to both *medium* and *high intensity* farms (K-W test, $p < 0.001$). The number of ponds on these farms is significantly lower than on all other farm intensity types (K-W test, $p < 0.05$), and there is little heterogeneity within the sample for this variable (1.23 ± 0.9). Although significantly larger in area, family members normally assist with day to day running of *low intensity* farms, and additional labour is hired only for less frequent work, such as pond harvesting. As a result, the labour input per hectare of *low intensity* farms (0.3 ± 0.3 persons per ha) is significantly lower than other farm intensity types (Table 5.1, K-W test, $p < 0.001$).

Aquaculture production of low *intensity farms* is diverse with no specialisation in a particular species. Almost 100% of the low intensity farm types are polyculture systems. The mean number of aquaculture species cultured (4 ± 1) is significantly higher than on other farm intensity types (K-W test, $p < 0.001$). All of the farms raise at least one of the principal species of shrimp cultured in the region (*P. monodon* and *L. vannamei*), however around 60% (95.2 ± 200.2 kg/ha/crop) of mean total aquaculture yield is from culturing species of fish, crab, and other less commercial important shrimp species (Table 5.1). Mean production of *L. vannamei* and *P. monodon* is relatively low for these farms, and significantly lower than other farm intensity types (K-W test, $p < 0.05$). The wide range in the yield of both of these species (*L. vannamei* = 0.3 – 188 and

P. monodon = 0.3 – 260 kg/ha/crop) suggests that there is high heterogeneity in the production specialisation within this farm intensity type.

Many of the *low intensity* farm types do not stock shrimp species. Instead, they produce shrimp on the basis of natural productivity in the pond. This is particularly evident for the species L. *vannamei*. Stocking of this species ranges from 0-8 PL m^2, and the mean value (0.3 ± 1.3 PL m^2) is significantly lower than on other farm intensity types (K-W test, $p < 0.001$). Stocking density is slightly higher for the higher-value P. *monodon* species (1.4 ± 2.5 PL m^2), however this is also at a rate significantly lower than other farm intensity types (K-W test, $p < 0.001$). The methods practiced on *low intensity* farms are typical of extensive polyculture production, whereby shrimp, along with fish and mud crab (*Scylla serrata*) species, enter the ponds through natural tidal inflow to the ponds. Wild species trapped in the ponds are raised with little to none commercial feed inputs, and the produce is harvested frequently throughout the year when they have attained a marketable size. The mean number of crops added to *low intensity* ponds is around 1 per year for both *P. monodon* and *L. vannamei,* which is significantly lower than on *medium* and *high intensity* farms (K-W test, $p < 0.001$). The addition of one crop of shrimp per year possibly enhances productivity and natural recruitment into the ponds.

On average, production costs on *low intensity* farms are around 31, 000 Thai baht (THB) per crop, which is significantly lower than other farm intensity types (K-W test, $p < 0.001$). These are low-input farms, where farmers rely on natural pond productivity. Only 6% of farmers reported using commercial feed, and this is at rates significantly lower than other farm intensity types (0.8 ± 4.3 kg ha crop, K-W test, $p < 0.001$). Approximately 75-85% of shrimp yield is sold, which is around average across farm intensity types. Of particular note however, is that the mean selling price of *P. monodon* (~430 – 600 THB/kg) is significantly higher compared to *medium* and *high intensity* farms (Table 5.1; K-W test, $p < 0.001$). This might be because the shrimp are growing in larger, less densely stocked ponds, thus enabling them to grow to a larger size, or that *low intensity* farmers are selecting larger, more valuable shrimp to sell. The mean selling price of *L. vannamei* (~130 – 140 THB/kg) produced on these farms, however, was not significantly different to other farms intensity types (K-W test, $p > 0.05$).

Some of the *low intensity* farmers reported being constrained by environmental change and environmental quality. For example, due to longer term problems, such as pond dike erosion and increasing costs of pond maintenance. Because one fifth of these farms were located within government conservation areas, farmers are faced with production constraints and fluctuations in the productive areas. Around 75% of *low intensity* farmers reported that they had observed erosion to the dykes of over 50% of ponds on their farm. In some cases, as the ponds gradually fill in with sediment, the total surface area of the farm is reducing.

Around 73% of the *low intensity* farmers reported that they had reduced the amount of shrimp produced in the past two years, 12% have increased the amount, and 16% have not changed the amount produced. 49% of farmers stated that they had reduced the number of species produced and 8% have increased the number of species. Shrimp farming is not the primary income source for the majority of *low intensity* farmers. Only 40% of low intensity farmers stated that all or most of their income is from shrimp farming, and 48% stated that very little or none of their income is from shrimp farming. Some of these farmers operate on a part-time or casual basis, sometimes for subsistence use only, or to provide food for running small scale homestays, for example. Some ponds are run to provide supplementary income i.e. farmers have primary employment elsewhere but keep a small number of ponds active but on a less intensive scale.

Farm intensity type 2: *'medium intensity'*. *Medium intensity* farms comprised 28% of the total sample. These farms have been operating for on average 17 ± 9 years, which is significantly less time than *low intensity* farms (K-W test, $p < 0.001$), but not different to *high intensity* farm types (K-W test, $p > 0.05$). Mean pond size (0.56 ha ± 0.23) is around 18 times smaller than *low intensity* farms, but not significantly different to *high intensity* farms (K-W test, $p > 0.05$). The farms have on average 4 ± 7 ponds, ranging from 1 to 40, and the labour input (1.4 ± 2.2 persons per ha) is significantly higher than *low intensity* farms. Labour input is also lower than on *high intensity* farms, however this difference is not significant (K-W test, $p > 0.05$).

Production of *P. monodon* is relatively low on *medium intensity* farms (~157 -185 kg ha crop), and significantly lower than on *high intensity* farms (K-W test, $p < 0.001$). Aquaculture diversity is generally low, and the majority of farms specialise in the production of *L. vannamei*. Of note is that the minimum yield of *L. vannamei* is close to zero, reflecting the impact from disease outbreaks over the past 2 years. These farms produce on average 1.1 ± 0.5 species, and although the number of species cultured ranges from 1 – 3, the total yield from species other than *P. monodon* and *L. vannamei* accounts for less than 1% of the total production. Mud crabs and fish species are sometimes cultured as secondary species, but they are not of primary importance on the farms. On some polyculture farms, farmers reported that they stock higher-value shrimp and crab species, but fish that are raised are recruited from the natural tidal waters. Production of fish and crustacean species is on average 27.2 ± 118.8 kg/ha/crop, which is significantly lower than that produced on *low intensity* farms (K-W test, $p < 0.001$). Pond stocking densities of both L. *vannamei* and *P. monodon* are significantly higher than on *low intensity* farms but significantly lower than on *high intensity* farms (K-W test, $p < 0.001$).

Production costs on *medium intensity* farms are considerably variable, possibly reflecting the heterogeneity in management within this farm intensity type. 96% of medium intensity farmers reported using commercial feed in their ponds, and this is at rates significantly higher (314 ± 251 kg ha crop) than *low intensity* farms (K-W test, $p < 0.001$), but significantly lower than on *high intensity* farms (K-W test, $p < 0.01$).

Around 46% of *medium intensity* farmers reported that they had reduced the amount of shrimp produced in the past two years, 30% had not changed the amount, and 23% had increased the amount. 27% have increased the number of species produced, 11% have reduced the number of species, and 61% have not changed the number of species produced. Around 70% of farmers stated that all or most of their income is from shrimp farming, and 20% stated that very little is from shrimp farming. *Medium intensity* farmers sell around 88 - 92% of *L. vannamei* yield, and up to 100% of *P. monodon* yield (85 – 100%). The mean price of *L. vannamei* produced on *medium intensity* farms (~135 – 160 THB/kg) is not significantly different to other farm types (K-W test, $p > 0.05$). The mean price of *P. monodon* ranges from ~120 – 500, is similar to that of *high intensity* farms, but significantly lower than the value of *P. monodon* produced on *low intensity* farms (K-W test, $p < 0.001$). Farm return on *medium intensity* farms (752000 - 872000 THB/crop) is significantly lower than *high intensity* farms (K-W test, $p < 0.001$), but not significantly different to *low intensity* farms (K-W test, $p > 0.05$).

Medium intensity farms have had the highest number of disease outbreaks over the past 2 years (3.8 ± 4.4 times), and over 90% of the *medium* and *high* intensity farms reported at least one disease outbreak over this period. Disease outbreak frequency was the lowest on *low intensity* farms (2.3 ± 1.6 times), however over 85% of farmers recalled at least one outbreak in the past 2 years, and disease occurrence was not significantly different across all farm intensity types (K-W test, $p = 0.09$).

Farm intensity type 3: *'high intensity'*. *High intensity* farms comprised the smallest sampled group (20% of sample). Farm area is on average 3.8 ± 4.8 ha, which is slightly larger than *medium intensity* farms but significantly smaller than *low intensity* farms (K-W test, $p < 0.05$). Total area of ponds in use makes up around 68% (2.6 ha) of total farm area. The further 30% may either comprise ponds that are currently left unused, or are used for water management, which is common practice in highly intensive shrimp farming systems. For example, separate ponds are used for preparing water, which is treated for a week before shrimp post-larvae (PL) are added. Chemicals and treatment ponds are used to control water quality, and predators are removed from the water before PL are stocked. *High intensity* farms contain the highest average number of ponds (5 ± 5), but of the smallest average size (0.56 ± 0.17 ha); maximum pond size did not exceed 1 ha across farms.

Aquaculture production on *high intensity* farms is specialised towards the production of *L. vannamei*. The number of species cultured ranges from 1-2, with an average of 1 ± 0.2 species. Almost 100% of the farms sampled are monoculture systems specialising in *L. vannamei* production, with *P. monodon* being the only other secondary species. Mean production of around 6100-6700 kg/ha/crop of *L. vannamei* on *high intensity* farms is significantly higher compared to all other farm intensity types (K-W test, $p < 0.001$). This species is stocked in high densities significantly higher than on *medium* and *low intensity* farms (K-W test, $p < 0.001$). Minimum yields of near zero for *L. vannamei* may reflect the high disease occurrence on these farms. *High intensity* farms have suffered among the highest number of disease outbreaks over the past two years (3.5 ± 3.6), and only 5% of these farms reported to have been disease free over this period. One of the farmers surveyed had suffered massive crop loss on the previous harvest.

Where *P. monodon* is cultured, mean production of this species (~4300 – 4700 kg/ha/crop) is also significantly higher than both *medium* and *low intensity* farms (K-W test, $p < 0.001$). *P. monodon* are stocked in densities lower than the smaller, faster growing *L. vannamei* species, however the stocking density of *P. monodon* ranges from

31 – 45 PL/m^2 (mean = 45 ± 12 PL/m^2), which is significantly greater than on *medium* and *low intensity* farms (K-W test, $p < 0.001$). *High intensity* farms stock 2-3 crops of *L. vannamei* and *P. monodon* per year, averaging 2.5 ± 0.5 crops per year. This is significantly greater than *low intensity* farms (K-W test, $p < 0.001$), but similar to *medium intensity* farms.

High intensity farms are characterised by the use of commercial feeds. Feed is added to ponds at rates (714 ± 464 kg/ha/crop) significantly higher than other farm intensity types (K-W test, $p < 0.001$). The intensive shrimp farms are often linked to large shrimp feed producing companies, such as C.P. (Charoen Pokphand) Group, which is one of the world's leading producers of shrimp and shrimp feed. They are a major supplier of shrimp feed and shrimp post larvae (PL) to intensive shrimp farmers in the study area. On *high intensity* shrimp farms, the ponds are managed in a very controlled way. For example, a cycle of a specific number of days (usually 90) following feed tables to attain shrimp of a certain size and weight at the end of the crop cycle.

Production costs are highly variable on *high intensity* farms (range = 65 – 4800, mean = 790 ± 1100 THB (x1000) per crop). The high variation around the mean value for this variable suggests that management practices across these farms varies greatly. Although production costs on average are not significantly higher than on *medium intensity* farms (K-W test, $p > 0.05$), *high intensity* farms generate significantly greater return than any other farm intensity type (1950000 – 2250000 THB/crop, K-W test, $p < 0.001$).

The average selling price for *L. vannamei* is higher than on other farm intensity types (~165 – 190 THB/kg). *P. monodon* produced on *high intensity* farms sells for a relatively low price, however (mean = ~280THB/kg), particularly compared to that produced on *low intensity* farms (mean = ~ 435 – 600THB/kg). A relatively low selling price for *P. monodon* may reflect differences in either the quality or size of shrimp sold, or who the shrimp are sold to.

Around 44% of the *high intensity* farmers reported that they had reduced the amount of shrimp produced in the past two years, whereas 27% said they had increased the amount of shrimp produced. 83% of high intensity farmers stated that they had not changed the number of species produced over the same period, the rest (16%) had decreased the number of species. Nearly three quarters of high intensity farmers (72%)

stated that all or most of their income is from shrimp farming, with only 17% stating that shrimp farming contributes very little to their total income.

5.3.2 Shrimp farmer behaviour (production intensity)

Based on the IAC framework, farmer behaviour (here: production intensity) is understood to be as the result of decisions that are influenced by a set of internal and external, symbolic and material, individual and social factors (Figure 5.3). All variables considered in the IAC framework (see Appendix) were tested for significance in driving behaviour, but only the significant ones are reported here. This analysis helps to distinguish which factors influence the decision to adopt a certain level of production intensity.

Shrimp farmers of the three farm intensity types differed significantly in relation to eight key variables considered by the IAC framework. This included **contextual** (external socio-economic and production) factors (such as training received on farming practices, access to the technical equipment needed to farm shrimp intensively, proportion of total income from shrimp farming, and season-specific changes to their production), as well as internal factors related to **subjective culture** (social norms and roles) (such as perception of how shrimp farmer is perceived by other farmers, how often shrimp farmer follows advice from other farmers, pond stocking considerations, level of care for the environment, and perception of a 'good shrimp farmer'), and **expectations** (perceived risks associated with intensive shrimp farming). A summary of the key findings in relation to these interactions is presented below.

Contextual factors (socio-economic). Shrimp farmers who operated *low intensity* farms were less likely to have received training from private and/or government agencies, compared to *high* (p = 0.017) and *medium intensity* (p = 0.0083) farmers. A significant difference was also observed in terms of technical equipment access, with a higher proportion of *high* and *medium intensity* farmers having access to equipment, compared to *low intensity* farmers (p < 0.0001). *Low intensity* farmers were also found to have more diverse income sources and a significantly lower proportion of these farmers relied solely on income from shrimp farming (p = 0.012). Whereas, farmers whose income depended 100% on shrimp farming were significantly more likely to operate *high intensive* farm systems (p = 0.012).

Contextual factors (production). *Medium* and *high intensity* farmers were more likely to engage in season-specific changes to their production, such as modifying shrimp stocking during the monsoon onset. A significantly higher proportion of these farmers stated *season* is a primary factor considered before stocking shrimp, compared to *low intensity* farmers (high: $p = 0.020$, medium: $p = 0.025$; Figure 5.4a). Whereas economic factors, such as *production costs* and *money available and potential loss of money* were shown to be important stocking considerations among *low intensity* farmers.

Subjective culture (social norms). Social dynamics, such as information networks and conformity with the descriptive norm, also played a role in defining farming intensity levels. For example, *medium intensity* farmers were significantly more likely to have received advice from other shrimp farmers regarding their production ($p = 0.0001$), suggesting that other farmers are a source of information to base production decisions on. On the contrary, *low intensity* farmers appeared to have weaker social networks, that is they were significantly less likely to have received advice from the government ($p = 0.0001$) or other farmers ($p = 0.008$) on their farming practices. In addition, when asked how other farmers perceive their production intensity, *low intensity* farmers were significantly more likely to give a neutral response (i.e. not negative or positive), compared to *medium* ($p = 0.046$) and *high* ($p = 0.006$) intensity farmers. These findings indicate that *low intensity* farmers' decisions on production are made on a more individual basis and are less influenced by external actors.

Subjective culture (roles). A sense of care for the environment among *low intensity* farmers was reflected in the way these farmers perceived the status of a "good shrimp farmer". For example, 22% of *low intensity* farmers considered *care for the environment* as a main trait, and a significantly higher proportion of *low intensity* farmers believed that *no chemical use* ($p = 0.0009$) and *farming on the basis of nature* ($p = 0.044$) were important characteristics (Figure 5.4b). These findings illustrate that production decisions of *low intensity* farmers are in part rooted in perceptions of how farming affects the natural environment. Whereas, decision-making based on learning from experience was more important to *high intensity* farmers, who were significantly more likely to regard this as characteristic of a "good shrimp farmer" ($p = 0.013$). There was a sense that shrimp farmers are influenced by a wider ideological culture, specifically the kings 'sufficiency economy' ideology which states that rural Thais should focus on satisfying their basic needs through moderate production and consumption of local natural resources and encourages farmers to learn new modes of natural resource management. In this study, when asked from whom advice is taken, around 10% of shrimp farmers stated that they use the king's advice and ideology.

Expectations. Farmer intensity types were also differentiated with respect to their perception of the consequences of intensive farming, illustrated by differences in risk perception. Although 62% of all farmers across intensity types believed *disease outbreak* to be a primary risk factor, *medium* and *high intensity* farmers were significantly more likely to perceive *low quality shrimp post-larvae (PL)* as a main risk (high: $p = 0.012$, medium: $p = 0.023$). However, this perceived risk was not apparent among low intensity farmers. Instead, a higher proportion of *low intensity* farmers considered *high production cost* to be a main risk factor, indicating that their production choices could be in part based on limiting potential cost to the household. The risk *losing money* through intensive shrimp farming was regarded highly across all farmer intensity types (>75% of farmers; Figure 5.4c).

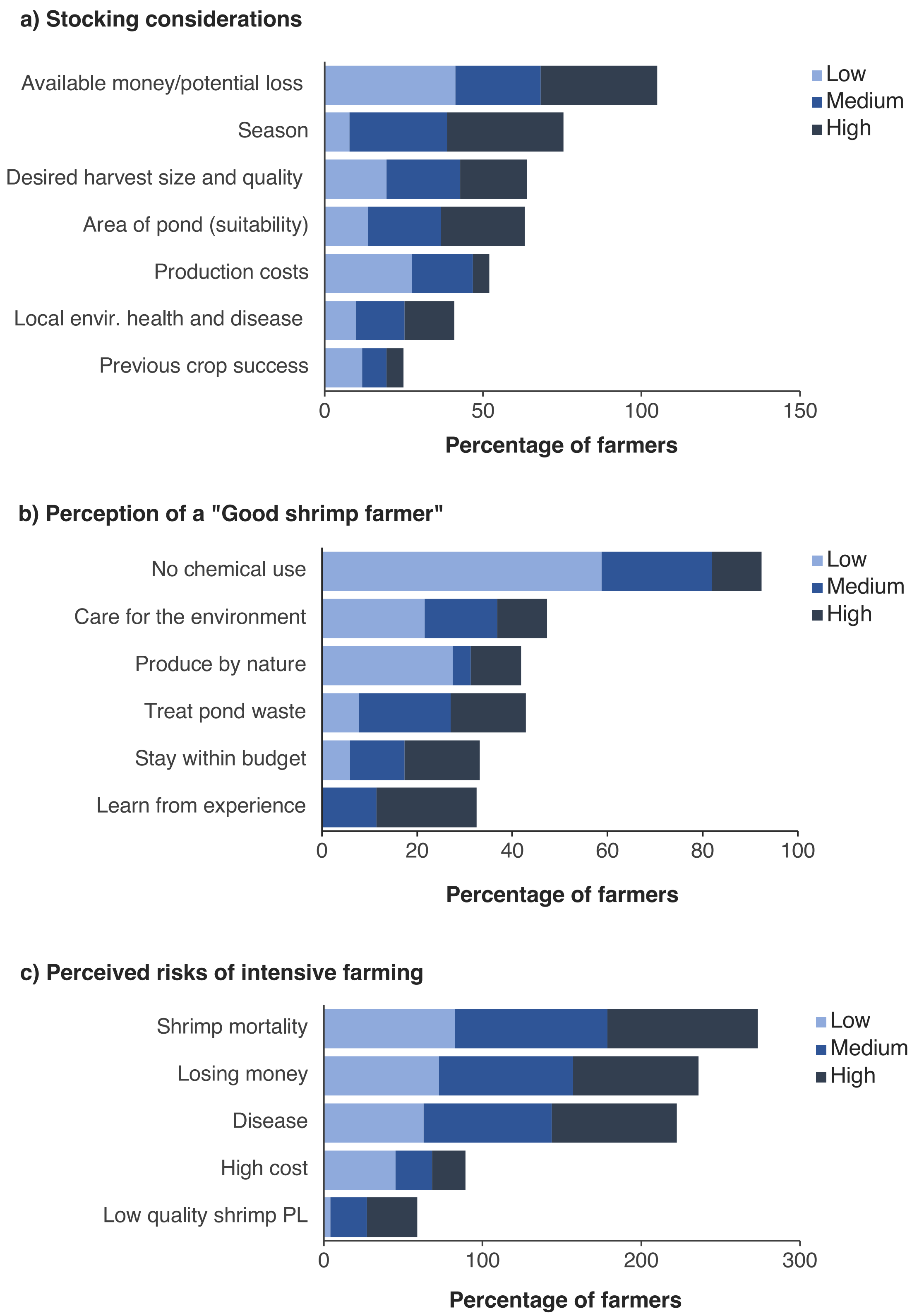


Figure 5.4. Shrimp farmer a) pond stocking considerations, b) perceptions of a "good shrimp farmer", and c) perceived risks of intensive farming, and. Data shows the percentage of farmers of low (n = 50), medium (n = 27) and high (n = 19) intensity type.

5.4 Discussion and conclusions

This study investigated shrimp farming diversity and farmer behaviour in two coastal districts of Chanthaburi Province, Thailand. The study aimed to answer two research questions: i) which socio-economic factors are related to distinct levels of shrimp farming intensity?, and specifically, ii) which socio-economic factors matter in the decision to adopt a certain level of production intensity? Here the study's findings are discussed in relation to these two questions and a reflection is made on the implications of these findings for the promotion of sustainable shrimp farming in Thailand.

Three types of shrimp farms were identified in the study area, defined by their production intensity (low, medium, and high), and socio-economic factors. While different in their technical dimensions, this study shows that farm intensity types also differ in terms of socio-economic factors: shrimp farming intensity is associated with a combination of technical (e.g. farm area, pond size, stocking density and production), economic (shrimp selling price, production costs and farm revenue), social (e.g. farm operating years, the use of family labour, engagement in shrimp farming and with other shrimp farmers), and ecological factors (e.g. farmer reliance on natural pond productivity, and constraints brought about by environmental change and fluctuations in productive areas). This study therefore illustrates that farming at a certain production intensity is much more than a technical decision, but instead farms and farmers are embedded within a broader socio-economic context. This supports earlier work by scholars such as Bush et al. (2010), Joffre et al. (2015), and Bottema et al. (2018), who have explored shrimp farmer social structures in relation to the embeddedness of farms within a landscape. Bush et al. (2010) and Vandergeest et al. (2015), for example, argue that a farms' socio-economic embeddedness relates to its level of physical interaction with the surrounding environment, which influences farm management decisions (Waite et al. 2014).

Shrimp farming in Thailand has previously been presented as being very high-intensive production orientated (Lebel et al. 2002; Kumar and Engle 2016), with considerably less diversity, compared to other Southeast and South Asian countries like Vietnam, Bangladesh or Indonesia, where there is greater dependence on varying degrees of lower-intensity extensive production systems (Belton and Azad 2012; Jespersen et al. 2014; Joffre et al. 2015; Nguyen et al. 2017). In 2002, for instance, Lebel et al. (2002) described Thailand's shrimp farming industry as being dominated by high intensity farming systems. Yet, this study found that a large proportion of shrimp farms in Chanthaburi were low intensity farms, indicating that shrimp farming in this area has evolved over the past 15 years towards more lower intensity production. The findings may support a recent study by Engle et al. (2017), who report that shrimp farming in Thailand lacks long-term profitability due to economic losses resulting from disease epidemics coupled with increasing land and capital costs.

This study also enabled identification of a number of external and internal socio-economic factors related to the decision to adopt a certain level of production intensity. External contextual factors included; training received on farming practices, access to technical equipment, proportion of total income from shrimp farming, and season-specific changes in production. Relevant internal factors related to expectations, such as risk perception, and subjective culture (social norms and roles), such as perception of how a shrimp farmer is perceived by other farmers, how often shrimp farmers follow advice from other farmers, level of care for the environment, and perceived traits of a ‘good shrimp farmer’. Two of these factors warrant further discussion.

5.4.1 Social networks and risk management

First, high intensity farmers were not likely to engage in farmer-farmer interactions. This supports previous work by Bush et al. (2010) who suggest that aquaculture farmers operating intensive ‘closed’ systems are less likely to adopt collective strategies for risk management compared to farmers operating extensive ‘open’ systems, who are more likely to self-organise. In contrast, social networks and farmer to farmer interactions were more frequent among medium intensity farmers. Collaboration among medium intensity farmers appeared to be important for risk management and building trust, as the following statement from one farmer shows, “*it’s good to have a good relationship with surrounding farmers because sometimes they can contaminate ponds*”. While another farmer explained that, “*neighbouring farmers consult with each other to solve problems together*”. Similarly, other studies have shown that farmer to farmer interactions can influence decisions on production and risk management (Adger 2003; Bottema et al. 2018; Hoque et al. 2018; Ahsan 2011; Joffre et al. 2018; Le Bihan et al. 2013), and can lead to the development of trust and the exchange of knowledge (Berkes and Folke 2002). Bottema et al. (2018), for example, found that communication and information sharing about disease and other environmental risks among neighbouring aquaculture farmers in Thailand and Vietnam, was perceived by the farmers to be an important component of risk management.

5.4.2 Economic and cultural factors

Second, this study also illustrates that a combination of economic and cultural factors matter in the decision to adopt a certain level of production intensity. For instance, among low intensity farmers, there was a sense of pride in being recognized as producers who care for the environment, and these farmers were more likely to perceive caring for the environment as a trait of a 'good shrimp farmer'. This suggests that subjective culture plays a role in the adoption of low intensity farming. Greater care for the environment among low intensity farmers, compared to high or medium intensity farmers, could be a reflection of higher dependency on a healthy natural environment, given that low intensity farming relies on natural pond productivity. It could also be argued that these farmers have more time to care for the environment, given that they allocate less time to shrimp farming, compared to high and medium intensity farmers. On the other hand, high intensity farmers were more likely to perceive a 'good shrimp farmer' as being one who uses their own experience in farm management decisions.

Regarding economic factors, production costs and potential loss of money were shown to be particularly important stocking considerations among low intensity farmers, indicating that financial capital was a factor driving the decision to adopt low intensity production. The results conform with another study of shrimp producers in Thailand by Engle et al. (2017), who show that the ability of farmers to shift to more intensive production practices depends on the farm's access to sufficient capital, experience, and knowledge. Similarly, in Bangladesh (Bunting et al. 2017), rising costs of shrimp production and greater exposure to debt cycles has driven farmers away from adopting technology for intensive production.

5.4.3 Policy implications

Finally, in emphasizing the heterogeneity that exists among shrimp farms and shrimp farmer behaviours in Thailand, this analysis challenges the effectiveness and accessibility of the most recent national certification standards for aquaculture in this country (GAP-7401). Whilst these standards aim to improve the sustainability of shrimp production, through reducing production risks, and improving social and environmental conditions, they fail to recognise the diversity of the sector and the different socio-economic contexts for different levels of farming intensity, as highlighted in the present study.

In 2014, 1, 925 farms in Chanthaburi were registered with the Department of Fisheries. However, in 2017, only 25% (570) of farms were certified to Thai GAP standards (DoF 2018), meaning that they are eligible to supply shrimp for export purposes (Nietes-Satapornvanit 2014). For many farmers, the adoption of GAP-7401 standards involves high costs and labour requirements (Samerwong et al. 2018) that do not correspond to the family-based labour model adopted by many low and medium intensity farmers, nor their socio-economic context. Even high intensity farmers, they often stated that government guidance on production was too general or difficult to follow and did not account for the variability among farming practices, and so if taken on board it was done so and adapted to their own individual context. One farmer, for example, stated that, "*there are many government regulations and they're not always realistic, so farmers have to modify them*". This confirms key findings in the same region (Samerwong et al. 2018), where Thai shrimp farmers were shown to value their own experience and methods for tackling disease problems, rather than external advice, which has constrained their willingness to adhere to Good Aquaculture Practice (GAP) standards. Thus, national standards should be designed to reflect the diversity needed to support such a diverse sector: to achieve sustainability in shrimp farming, policies and certification standards should be adjusted (or adjustable) to different socio-economic contexts.

Chapter 6 Local perceptions and ecological knowledge in relation to ecosystem health and ecosystem service delivery in coastal Thailand

6.1 Introduction

Tropical coastlines encompass a range of complex ecosystems influenced by connectivity to land, including mangrove forests, seagrass meadows, and coral reefs (Spalding et al. 2010). These ecosystems are not only highly dependent on each other (Duke and Wolanski 2001; Berkström et al. 2013), but they support the livelihoods and well-being of hundreds of millions of people because of the wide range of ecosystem services they provide (Costanza et al. 2014; MA 2005). Benefits to people include provision of habitat and nursery grounds for species of fish and invertebrates, supply of protein and building materials, erosion control and coastal protection against storms and ocean waves, water quality regulation, recreation and ecotourism (Huxham et al. 2017; McIvor et al. 2012; Barbier et al. 2011).

Yet, although humans depend on coastal ecosystems in so many ways, these ecosystems are proving to be highly vulnerable under increased human pressures (Duke et al. 2007; Myers and Worm 2003; Halpern et al. 2008). The expansion of human use and activity over the centuries has transformed coastal landscapes and put great pressure on marine ecosystems, provoking rapid alterations to their productivity and functioning (Worm et al. 2006; Waycott et al. 2009; Cloern et al. 2016) and pressure on vital ecosystem services (Rodriguez et al. 2006). Half of the world's coastal ecosystems are now in decline or lost completely (Duarte et al. 2008).

Ecosystem disturbance is particularly acute along the Andaman Sea coast of Thailand (World Bank 2006; Panjarat 2008). Population growth and the need for alternative land uses has meant that large areas of coastal habitats, including mangrove forests, have been removed, or damaged, leading to environmental degradation and fisheries decline (Bennett et al. 2015). In recent decades, this region has also been exposed to the effects of climate change, involving shifting seasons, coastal erosion and coral bleaching events (Tanzil et al. 2009; Phongsuwan 2011). Human populations in this region are particularly sensitive to these changes due to their high dependence on fisheries and coastal resources for their livelihoods and well-being (Bennett et al. 2015).

Here, a case study of a coastal fishing community on the Andaman sea coast of Thailand, is used to examine local definitions and perspectives of changing ecosystem health and ecosystem service delivery. The focus is particularly on differences among user groups that vary by their occupation, age and environmental setting. The study was guided by the following research questions: (i) how do different user groups define coastal ecosystem health and the associated ecosystem services?, (ii) how do different user groups perceive ecosystem health and ecosystem service delivery to have changed at different points over their lifetime in relation to social and ecological change?, and (iii) to what extent does ecosystem management affect local perspectives of ecosystem health and ecosystem service delivery?

Engaging with communities to study perspectives of ecosystem health can generate important insights into the spatial distribution of local ecological knowledge, patterns of ecosystem use, and the dependencies and relevance of different ecosystem services at the local level (Martín-López et al. 2012). This type of knowledge, which would otherwise be missed from larger-scale scientific assessments (Kovacs 2000), is important for decision makers in order to better understand how to manage ecosystems in a way that maintains specific benefits to communities (Nielsen and Müller 2009). Furthermore, studying local perception of ecosystem change in relation to ecosystem-related management can inform on rates of change in ecosystem service supply following policy introductions, allowing decision makers to understand if and how policy aims are met, and helping to reduce the potential risk of policy failure due to ecosystem service trade-offs (McShane et al. 2011; Hauck et al. 2013).

Defining and valuing ecosystem services is a rapidly growing research field, that contributes to the identification of potential trade-offs arising from the management of natural resources (Costanza et al. 2017). Consideration of ecosystem service trade-offs is particularly relevant in the field of mangrove forest use and management (Orchard et al. 2016) given the wide range of goods and services they provide (Brander et al. 2012; Lee et al. 2014). Researchers have attempted to classify mangrove ecosystem services at the global scale using macroecological approaches (Rivera-Monroy et al. 2017). However, global scale assessments do not account for the local scale dynamics of ecosystem service delivery and dependencies. Furthermore, economic tools used to allocate quantitative values to ecosystem services (Costanza and Folke 1997; Daily et al. 1997) often lead to undervaluing of the local scale benefits which may not have a market value (Alongi 2002). Finally, ecosystem services are spatially and temporally dynamic (Fisher 2009), and differences in cultures and livelihoods of stakeholders may affect the way ecosystems are valued locally and different ecosystem service preferences (Biggs et al. 2012; Robards et al. 2011). There is therefore a need for more context-dependent understanding of ecosystem service delivery which accounts for small scale differences influenced by different social and ecological contexts (Hedden-Dunkhorst et al. 2015; Vo et al. 2012). Whilst the social and ecological importance of mangrove forests is well recognised in the literature (Uddin et al. 2013; Huxham et al. 2017), few studies have attempted to understand local perspectives of the benefit of this ecosystem (but see de Souza Queiroz et al. 2017; Rönnbäck et al. 2007).

6.1.1 Ecosystem health, ecosystem services and local ecological knowledge

The concept of ecosystem health is a measure of the resilience, organisation, and vigour of an ecosystem, and its overall ability to maintain structure and function when faced with stress over time (Costanza 1992). Healthy ecosystems provide a diverse range of benefits to support human well-being – ecosystem services (MA 2005). Examples of ecosystem services include provisioning (the production of resources such as food, wood, and fresh water), regulating (e.g. regulation of climate, disease, and water quality), supporting (e.g. nutrient cycling and soil formation), and cultural (e.g. the supply of spiritual, aesthetic and recreational benefits). Ecosystem health is critical for the maintenance of these vital ecosystem services: as ecosystem health declines, so do the benefits that nature provides (Rockström et al. 2009; Barnosky et al. 2012).

A growing body of researchers suggest that knowledge held by local people about species patterns, local habitats, and how they have changed over time, is potentially a powerful mechanism for the building of ecosystem health (Folke 2004; Gómez-Baggethun et al. 2012), and for safeguarding biodiversity and ecosystems services (e.g. Hickey and Johannes 2002; Nandeesha et al. 2013). In recent decades there has been greater engagement with local ecological knowledge (LEK) by scientists to study ecosystems and their health and management (Drew 2005; Berkes 2010). In this study, LEK is defined as knowledge held by a specific group of people about their local ecosystem (Olsson and Folke 2001). Communities who interact closely with their natural environment build dynamic relationships with the biophysical entities in their landscape (such as, flora, fauna, soils, and waterways) (Goldman 2003; Fairhead and Scoones 2005). This interaction is the basis for developing knowledge on different ecological processes, feedbacks, and surprises, and a deep understanding of the health of the ecosystem around them.

Current research on LEK relating to coastal ecosystems is largely focused on species-specific information that is important for traditional users of marine resources, such as fishers. Fishers have been shown to have information on fish ecology and biology, for example (Grant and Berkes 2007; Correia Madeiros et al. 2018). Studies have also shown that coastal resource users are likely to know specific information about patterns of animal migrations and aggregations (Crona and Bodin 2006; Palsson 1998), species population trends (Johannes 2000; Pitcher 2001) and biodiversity hotspots (Huntington 2000; Haggan et al. 2007). This type of information is important for fisheries research (Ames et al. 2000), and marine conservation planning (Power and Mercer 2003; Shepert 2008).

A major process in social-ecological interactions is perception (Gobster et al. 2007), and a large body of research has been dedicated to the study of how ecosystems are perceived by local people (Scholte et al. 2015). Perceptions of ecosystems and their associated ecosystem services may vary between individuals and groups (Lamb and Purcell 1990; Ode et al. 2009) because of the way people interact with the natural environment, or due to socio-cultural values or personal factors such as gender, age, locality, occupation, or environmental awareness (Rönnbäck et al. 2007; Nassauer 1992). When the perception of change in an ecosystem has been investigated, this is often through the use of oral history as a tool to collate environmental and ecological knowledge (Berkes et al. 2000). For instance, Robertson and McGee (2003) studied LEK on past flooding, ecology and the environment in the Kanyapella Basin, Australia, and perception of how the regime has changed over time. Local people interviewed were found to have detailed descriptions of how flood management had changed the water regime and flood events. Although some inaccuracies in local recollections were identified in this study, local information still proved effective in assisting a wetland restoration project. Although this study and others (such as Calheiros et al. 2000; Olsson and Folke 2001) demonstrate the potential for integrating LEK with scientific knowledge in developing ecosystem management strategies, few studies have looked at perspectives of change in the coastal ecosystem as a whole (but see Johannes 1981; Olsson and Folke 2001). Some studies focus on specific components of an ecosystem, such as changes in fish catch and biomass (Daw et al. 2011), biodiversity (Gadgil et al. 1993; Haggan et al. 2007) or seasonal fish abundance (Hallwass et al. 2013).

Studies of local perceptions of ecosystem health can also generate important insights into the contributions and relevance of ecosystem services to human well-being (Martín-López et al. 2012). However, current research has left some important knowledge gaps. Firstly, many studies of local perceptions of ecosystem services either focus on specific ecosystems, such as forests (e.g. Abram et al. 2014; Sherrouse et al. 2011), or wetlands (e.g. Dobbie and Green 2013; Badola et al. 2012), or do not differentiate between different ecosystems in a landscape (e.g. Allendorf and Yang 2013; Aretano et al. 2013). Other studies focus only on specific types of ecosystem services, in particular socio-cultural services (e.g. Tengberg et al. 2012; Klain and Chan 2012). Finally, there are few studies of how ecosystem service-based policies and conservation instruments influence local perception of ecosystem health and ecosystem service supply (Pascual et al. 2014).

6.2 Materials and methods

6.2.1 Study area

The research was conducted on Koh Klang, an island situated in the Krabi River Estuary Ramsar site, on Thailand's southern Andaman Sea coast (7.78° N, 99.08° E; Figure 6.1). Koh Klang has a total area of around 26 km^2 and is located administratively in the sub-district of Klong Prasong, Krabi Province. The people of Klong Prasong are distributed in four villages; one is located on the mainland of the province (Ban Bang Kanoon) and the other three on Klang island (Ban Klong Prasong, Ban Ko Klang, Ban Klongkam). Total population on the island in 2010 was approximately 4,700. The island's economy is largely centred around local natural resource use. Most people are involved in coastal fishing, aquaculture, or traditional rice agriculture, and the oil palm and rubber industry are also steadily growing.

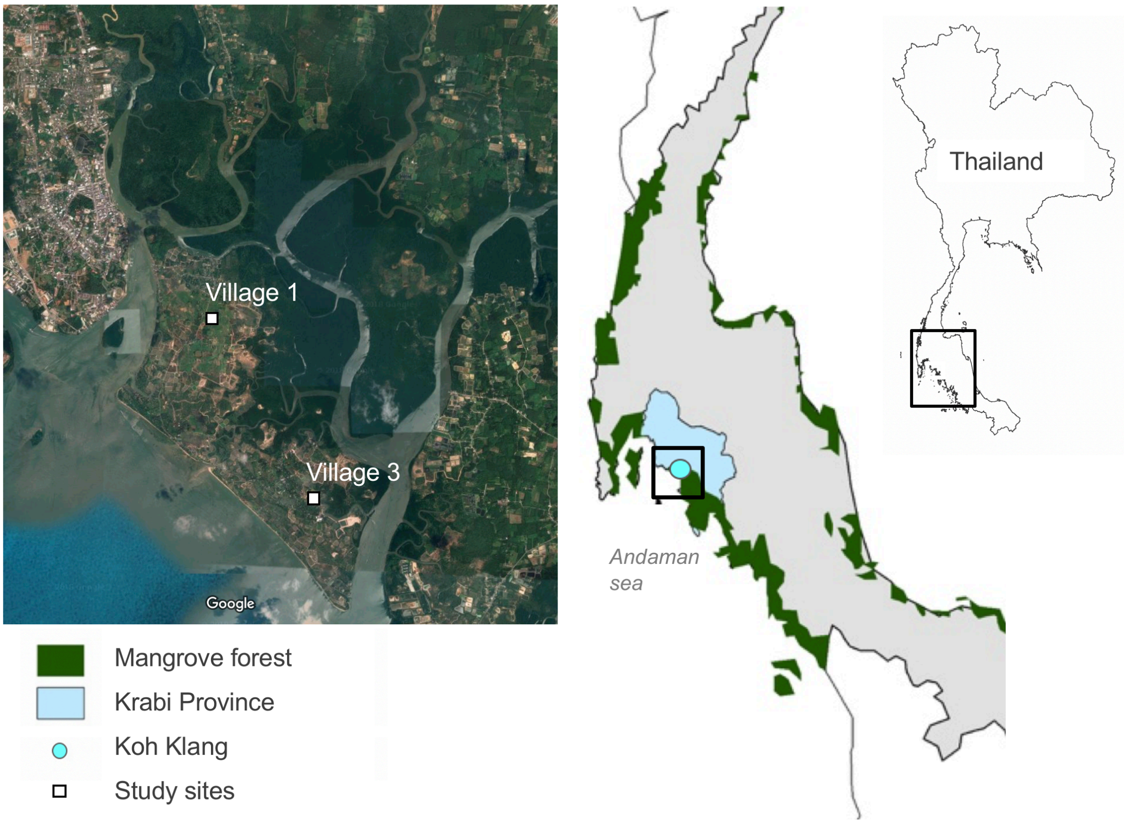


Figure 6.1. Map of study area on the island Koh Klang, Krabi Province. Mangrove distribution data source*:* Giri et al. 2011. See http://data.unep-wcmc.org. Satellite image of Koh Klang: Google Maps 2018).

Koh Klang is a fitting location to study perception of ecosystem health and social-ecological interactions because of its distinct ecological and cultural histories involving many changes to the land and ecology. The island is covered by 2,440 ha of mangrove forest, predominantly found in eastern, northern and central parts (MMU26 2014). These forests are one of the most important coastal ecosystems on the island because the ecosystem services provided by them relates significantly with the local economy; villagers are highly dependent on the intertidal estuary and mangrove ecosystem for provision of food and fuelwood, and for supporting critical spawning and nursery grounds for numerous commercially valuable species, such as the giant mud crab, red snapper, grouper, banana shrimp, and giant tiger prawn (Beresnev and Phung 2016). To the west of the island, the expansive coastal zone and beach area is also a particular focus for traditional fishing practices and shellfish collecting. The local artisanal fishery is based on gear such as crab traps, squid traps, cast nets, and bamboo stake traps.

Krabi province and Koh Klang have suffered huge pressure over the past few decades due to natural and anthropogenic causes (Bennett et al. 2015). The area is prone to coastal flooding during high tides and is vulnerable to storms and coastal erosion due to its exposure to the Andaman Sea. The area also experienced ecosystem degradation due to the natural effects of the 2004 Indian Ocean tsunami, and human activities, such as destructive fishing, pollution, and habitat degradation, have threatened the ecological health of the area (Bennett et al. 2015). In the 1990s, shrimp farming began on the island and grew rapidly over a decade. Conversion of mangroves for aquaculture ponds resulted in around a 25 percent loss of mangrove cover (Upanoi and Tripathi 2003). Due to problems with disease, poor environmental quality, and low market price for shrimp, there is currently no active shrimp ponds on the island, and many shrimp ponds are now either abandoned or are being used for traditional aquaculture.

Since the tsunami in 2004, efforts have been made to restore mangroves and rebuild areas that have been destroyed or degraded. The Thai government and non-government organisations, such as MAP, Wetlands International, and Global Nature Fund, in collaboration with The International Union for the Conservation of Nature (IUCN), have also begun to restore some mangroves in abandoned shrimp ponds areas on Koh Klang. Between 2012 and 2015, MAP and IUCN worked on restoring mangroves in abandoned shrimp ponds using Community Based Ecological Mangrove Restoration (CBEMR) methods (MAP 2018). CBEMR methods promote the natural regeneration of mangroves through restoring the hydrology and topography of the sites to provide a habitat for natural seedling recruitment. The projects also have a strong socio-economic focus; they aim to build community capacity and awareness of mangroves through community involvement and education, as a way of reducing further forest destruction (King and Cordero 2015).

6.2.2 Data collection

6.2.2.1 Interviews

To gather background information, preliminary visits and structured interviews were conducted in the three villages on Koh Klang in October 2016. During this period, a total of 21 interviews with key informants were performed. Interviewees were recruited using the snowball technique (Bryman 2016), and included the local government head of Klong Prasong, village heads ($n = 2$), inshore fishers ($n = 6$), local leaders of environmental groups ($n = 2$), fishers and mangrove resource collectors ($n = 11$). The interviews lasted for approximately 60 minutes and were conducted in Thai with the aid of an interpreter. Informants were questioned about how they interact with the coastal ecosystem, their views on coastal ecosystem health, and the causes of ecosystem change over their lifetime. Each interview was conducted either in an individual's home or in a community building. In addition, to provide a deeper understanding of local ecosystem use, several days were spent with inshore fishers and mangrove users to observe how they interact and use the local coastal ecosystems.

6.2.2.2 Workshops

Following the preliminary visit to the study site in October 2016, 8 workshops were conducted with residents living on Koh Klang over a three-week period in April 2017. The workshops focused on two of the three villages on the island: Village 1 (Ban Ko Klang) and Village 3 (Ban Klongkam). Selection of the two villages was based on the following criteria: (i) differences in the proximity to and ease of access to mangrove and coastal resources, and (ii) differences in the type of primary livelihood activities people were engage in. Village 3 is located in close proximity to the mangrove forests and main beach area, and these resources are the primary source of income for many villagers. Whereas, village 1 is located further from the beach and main mangrove area on the island, and local people are involved in a wider range of livelihood activities, such as rice culture and the tourism industry.

A total of 72 individuals from the 2 villages participated in the workshops. The participants from each village were split into four groups representing different ages and occupations. The total sample was divided first into age groups segmenting the population into two generations: <35 years and >35 years. The two groups in each village were then split by occupation, representing groups of people who were primarily engaged in work related to the use of local natural resources (e.g. fisher, farmer), and groups of people who were primarily engaged in activities not related to the use of local natural resources natural (e.g. taxi boatman, market seller). Thus, comparisons could be made between different groups of people. Comparisons were based on the variables; (i) age (experience of ecosystems), (ii) occupation (engagement with ecosystems for livelihood), (iii) space (distance to physical features), and place (village of residence). Across all workshops, the age of participants ranged from 17 to 77 years old. Groups were formed of a mixture of both male and female participants at differing male:female ratios. All participants had resided in the study area all their life. A description of the workshop participants is shown in the Appendix.

Various participatory activities were conducted during the workshops to elicit local ecological knowledge about (1) ecosystem features, (2) the status of the ecosystem features over time, (3) drivers of ecosystem change, and (4) definitions of ecosystem health. Participatory map drawing (McCall and Minang 2005) of ecological features on the island and participatory timeline building of trends in the status of the ecosystem were used during the workshops to aid discussions.

All workshops were conducted in Thai, with the assistance of a translator, and were recorded with the participants' permission. To enable comparisons to be made across each group, each workshop followed the same structure (Morgan et al. 1998), however the conversations were freely conducted, giving opportunity for the exploration of the participants' knowledge. An informal setting also offered the opportunity to observe and gain insight into the local setting and every-day life activities in the villages.

6.2.3 Data analysis

6.2.3.1 Definitions and drivers of ecosystem health

The workshops were recorded and transcribed with the assistance of a translator. Data from the transcripts, maps and graphs were coded (Saldana 2015) using NVivo 12 software and explored using comparative analysis. Initially, the data was examined to identify common themes and patterns of words used, and their frequency. Pre-defined codes were then applied to the data to explore emerging patterns, ideas and notions of ecosystem health. The pre-defined codes and sub-codes used in the analysis are presented in Table. The codes were based on characteristics of the definition and description of ecosystem health from the literature. Costanza (1992) states that definitions of ecosystem health should account for scales of space and time and combine; (i) a description of the system, (ii) measures of system resilience, balance, organisation (diversity, connectivity), and vigour (metabolism, productivity), and (iii) weighted factors to compare the system components in terms of function and sustainability. Following this, comparative analysis of the themes of discussion and the types of words used (Ragin 2014) was conducted across study sites, age groups, occupation groups, and groups that vary by their distance to physical features. In the results section presented below, codes are used when displaying quotations in order to identify the individual by age (Younger (<35)/ Older (>35)), occupation (ecosystem related (ER)/ Non-ecosystem related (NER)) and place of residence (Village 1(V1)/ Village 3(V3).

Table 6.1. List of codes and sub-codes used in the analysis of data on the perception of ecosystem health among workshop participants on Koh Klang. Designed following Costanza (1992) definitions of ecosystem health.

Codes	Sub-codes
System Components	Species, physical features (forest, beach, sea), seasons
Measures of Resilience	Overall system performance, ecological status, influences/stress on health, environmental change, human impacts
Measures of Balance	Stability of seasons, species abundance, diversity and distribution
Measures of Organisation	Diversity of species, structure, connectivity, predictability
Measures of Vigour	Fertility, productivity
Ecosystem function and sustainability	Function and sustainability to humans, and to other components of the system

6.2.3.2 Perception of coastal ecosystem services

Further coding of the transcripts was conducted using NVivo 12 software to explore how local people value the ecosystem in relation to the ecosystem services provided. The transcripts were coded based on four ecosystem service types: Provisioning, Cultural, Regulating, and Supporting, as they are categorised by the Millennium Ecosystem Assessment report (MA 2005). The Millennium Ecosystem Assessment report defines Provisioning services as '*Products obtained from ecosystems (e.g. food and water)*', Cultural services as '*Non-material benefits obtained from ecosystems (e.g. cultural heritage)*', Regulating services as '*Benefits obtained from regulation of ecosystems (e.g. climate regulation and water purification)*', and Supporting services as '*Services needed for the production of all other ecosystem services (e.g. nutrient cycling)*'. To analyse the relative importance of different ecosystem services to each workshop group, the number of times a given ecosystem service (such as nursery habitat or wood provision) was mentioned was summed for each group. Differences in the mean frequency of mentions of each ecosystem service type were then statistically compared across the different groups (defined by age, occupation, and place of residence) using Welch's independent t-test. All statistical tests were computed in the R statistical program.

6.3 Results

6.3.1 Defining ecosystem health

Across groups, ecosystem health was most commonly defined in terms of the rich abundance of marine life needed to support the provision of food for people. Mangrove forests, mangrove channels, and the beach area in particular were emphasised as being the community's main food source. Discussions about marine biodiversity and food provision were often intricately linked with the same four types of harvestable species: shrimp, shellfish, crab, and fish. Mangrove forests, the beach, and the sea were the components of the ecosystem most frequently cited as the places where these species are found. For example, a young fisher from village 1 said, "[Ecosystem health is] *fertile mangrove forests full of animals. The sea is rich in shrimp, shellfish, crab and fish, both in numbers and species. A large beach where we can go collecting shellfish for our food, and abundant marine animals on the beach so we don't have to go far to collect them*" (V1, ER, <35).

Figure 6.2. Coastal livelihood activities on Koh Klang. Top row: inshore fishers and beach harvesters showing use of traditional bamboo stake traps the beach; bottom row: mangrove forests and mangrove shellfish collectors.

Whilst the general theme across all user groups was similar, there were some differences in the way people defined ecosystem health between groups. For example, many younger participants from village 3 also referred to the wider diversity of plants and animals, both food and non-food species, "[Ecosystem health means] a *mangrove forest that is habitat for many crabs, shellfish, shrimp, and fish, a productive beach for squid, shellfish, crabs, and fish. More shellfish and crabs in the sea to provide food for people, and natural diversity of trees, birds, and flowers in the mangrove forest*" (V3, ER, <35). A fertile and biodiverse mangrove forest was central to many of the discussions around ecosystem health. A diversity of mangrove tree species, including *Nypa fruticans* and *Avicennia officinalis*, was important because of their various uses, such as providing material for building, and for making tobacco paper and dessert wrappers. Discussions about the material use of mangrove species were more frequent among younger participants involved in non-ecosystem related work. For example, one young non-fisher said, "[Ecosystem health is] *more fertile forest and big trees, more green forest area. Diversity of fertile forest, a diversity of tree species in the forest, such as jak tree* (*Nypa fruticans) and samae tree (Avicennia officinalis)*" (V3, NER <35).

6.3.2 Measuring ecosystem health

Across user groups, ecosystem health was generally measured by the productivity of the marine environment, with a focus on the size, diversity, and abundance of marine animals, and the ease of harvesting them. Older fishers and mangrove collectors in particular referred to the relative average size of fish and abundance of animals when describing changing ecosystem health over time. They often reflected on how, when they were young, they did not have to try hard to catch fish. An elder fisher from village 1 said, "*40 years ago, the average size of pla krabok (mullet) was around 2 kg. Nowadays, I do not see that big size anymore. The average size of that king of fish is only around half a kg now found in the sea. We could collect more black crabs 40 years ago too. We would put only one crab fishing gear and we got over 10 crabs at a time. And it took less time to catch them. Now it is different, the ecosystem is different*". Younger participants discussed other indicators of mangrove forest health, such as the size and density of trees, or the abundance of monkeys, "*the number of monkeys in a forest can indicate the forest's fertility. It means there is enough food in that forest for monkeys, so they do not invade our community*" (V1, NER, <35).

6.3.3 Local ecological knowledge

6.3.3.1 Knowledge of coastal biological processes

Ecosystem health indicators were linked to knowledge about the wider function of mangrove forests in coastal biological processes. For example, both younger and older generations recognised that mangrove forests provide nursery habitat for juvenile marine animals that reside part of their life outside of the mangroves, as the following statement shows, "*you can find some marine animals in the forests, crabs, fish, shellfish, and shrimps, but the sizes are smaller than the ones you catch from the sea. The mangrove forests are like their shelters to hide themselves before they are strong enough to go into the sea. It's not safe for them to go out in the sea if they are not strong enough. Every mangrove forest is like a safe home to all marine animals"* (V1, ER, <35). Elder fishers from village 3 also show an understanding of ecosystem functioning. They understand that the coral reefs are habitat for marine animals. For example, when discussing changes arising from the 2004 Indian Ocean tsunami, one participant stated, "*underwater the seabed was destroyed and there was less smaller fish. The coral was turned upside down. That used to be fish habitat. 60-70% of the coral was destroyed*" (V3, ER, >35).

6.3.3.2 Knowledge of spatial and temporal trends in species

Table 6.2 summarises the local ecological knowledge of the 8 different user groups. All groups held knowledge of relatively simple information, such as knowledge of different species and their habitats. Whereas, knowledge of more complex ecological processes, such as knowledge about the wider function of mangrove forests in coastal biological processes and understanding of how ecosystems change on temporal scales (daily, seasonally, or in response to disturbance), was less evenly distributed across groups.

Table 6.2. Summary of the local ecological knowledge among groups of different age (>35 years/<35 years), occupation (ecosystem related (ER)/ non-ecosystem related (NER)), and from different villages (village 1 (V1)/ village 3 (V3)) on the island of Koh Klang, Krabi. The 'number of observations' shown in parenthesis refers to the number of times the type of knowledge was discussed by each group.

Type of knowledge	Example of local ecological knowledge among groups	Group	Number of observations in group
Knowledge of species and their habitats	Understanding that mangroves are habitat for marine animals, birds, reptiles etc.	V3 Younger ER V1 Younger NER V1 Older NER V1 Younger ER V3 Younger NER V3 Older NER V1 Older ER V3 Older ER	8 7 5 5 4 3 3 2
	Understanding that coral reefs are habitat for marine animals.	V3 Older ER	1
	Understanding that the beach/sea is habitat for marine animals and birds.	V1 Younger ER V1 Older ER V3 Younger NER V3 Older ER V3 Older NER V3 Younger ER V1 Older NER V1 Younger NER	8 6 3 2 2 2 2 1
Knowledge about the wider function of mangrove forests in coastal biological processes. Holistic perception of the seascape and their ecological processes.	Understanding that mangrove forests support nursery habitat for juvenile marine animals that spend part of their life outside of the mangroves.	V1 Younger ER V3 Older ER V3 Younger ER V3 Younger NER V1 Younger NER	5 4 3 3 1

Understanding that ecosystems change over time	Notions that different tidal stages provide a different diversity of shellfish species in the mangrove forests.	V1 Younger ER	1
	Understanding of seasonal shifts in species abundance (related to the monsoon onset)	V3 Younger NER V1 Older ER V1 Younger NER	1 1 1
Disturbance - knowledge that historic land use change changes the abundance of marine animals, and ecosystem functions.	Knowledge that species of fish and shrimp that had once disappeared have started to come back (related to improved environmental health).	V3 Older ER	3
	Loss of mangrove forests affects fisheries productivity/species abundance.	V1 Younger ER V1 Older ER V1 Older NER	3 2 1
	The tsunami negatively affected fisheries productivity in the sea and mangrove forests.	V3 Younger ER V3 Older ER V3 Older NER V1 Older ER V1 Younger ER V1 Younger NER V3 Younger NER	4 3 2 2 2 2 1
	Water contamination caused by shrimp farming resulted in coral bleaching.	V3 Older ER	2
	Changes in water quality affects fisheries productivity.	V3 Older ER V1 Older NER	1 1
Disturbance - Notion that changes in climate have occurred recently resulting in a negative effect on fisheries.	Recent changes in seasonal temperature and precipitation - the seasons have been ‘unstable’ (cooler weather in summer, shifts in the timing of the monsoon onset, rain in summer and hardly in the rainy season).	V3 Older ER V3 Older NER V1 Older NER	3 3 2

Many participants held ecological knowledge useful for finding and harvesting marine resources, such as detailed knowledge about the location of important species. While the four key groups of animals (shrimp, shellfish, crab and fish) were clearly important across user groups, participants from village 3 held greater knowledge about the location and abundance of fish species, whereas participants from village 1 were mostly concerned with shellfish productivity and harvesting. An elder from village 1 said, "*Polymesoda proxima (clam), horn shell, and cone shell are dominant shell species. Cockles are found at village 1, and this is where the greatest number of shells are found. Babylonia areolate and cone shell are at village 3, and root clam are at village 2*" (V1, NER, >35). Similarly, younger groups from village 1 were specific when describing species of importance and their location, and also described how different tidal stages provide a different diversity of shellfish species in the mangrove forests, "*Periwinkles, babylonia, tegillarca grasosa, and mangrove snail are found in the mangrove forest. Root clams and horse mussels are from the beach. In the mangroves, people go collecting periwinkles at high tide and babylonia at low tide*" (V1, ER, <35).

Some elder fishers predicted short-term changes in fish productivity based on the colour and turbidity of the seawater, a type of 'folk oceanography', "*If the water is clear, we can collect more fish but if the water is unclear we collect less fish. When the water is unclear we don't catch enough to cover the cost of the fuel*" (W1, V3, >35). Other participants held specific knowledge about the seasonal shifts in species abundance. For instance, one younger group from village 3 associated changing species diversity with changing seasons, and stated that a healthy ecosystem is one that functions in a way so to provide a variety of marine resources for each season, "*there are abundant marine resources for each season, stable seasons for animals, stable seasonal productivity in the sea. For example, jellyfish can be found in its own season, which is November-February. If in November the ecosystem is healthy, we can find these species*". This suggests greater local knowledge of biodiversity and temporal patterns in productivity.

6.3.4 Ecosystem service delivery

43 different ecosystem services were mentioned at least once across user groups (Figure 6.3), of which 37% were cultural services, 35% were provisioning services, 16% were regulating services, and 12% were supporting services. Of the four ecosystem service types, provisioning and supporting services were mentioned most frequently by the

community as a whole (68 and 42 times, respectfully), followed by cultural services (33 times) and regulating services (20 times).

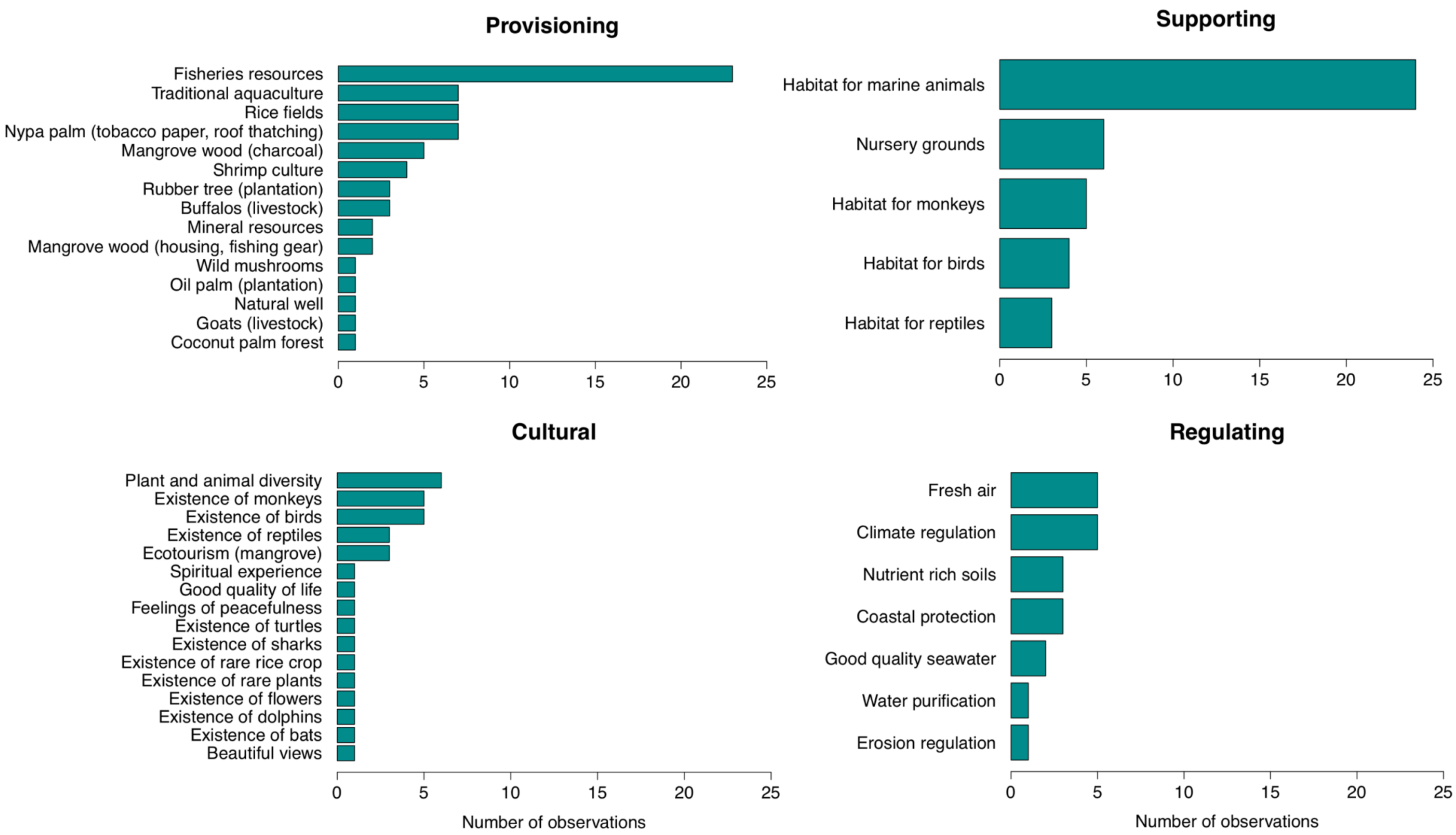


Figure 6.3. Ecosystem service delivery. Data shows the types of a) provisioning, b) supporting, c) cultural, and d) regulating services mentioned on the y-axis, and the number of observations on the x-axis. Observations are combined across all of the 8 workshops. Characterisation of ecosystem services was based on the Millennium Ecosystem Assessment report (as described in section 6.2.3.2).

6.3.4.1 Ecosystem services in relation to socio-demographic determinants

No significant difference was observed in how frequently provisioning services, regulating services, and supporting services were mentioned across the different user groups (Figure 6.4). However, mentions of cultural services were significantly more frequent among groups in village 1 compared to groups in village 3 ($p = 0.042$). The two most frequently mentioned services were the same for all user groups: habitat for marine animals and fisheries resources. Although, fisheries resources were mentioned significantly more frequently among groups in ecosystem related occupations compared to groups in non-ecosystem related occupations ($p = 0.034$).

Although not significantly different, there were some other slight differences between groups in terms of the types of ecosystem services most frequently mentioned. Firstly, when comparing groups involved in ecosystem-related work with those not involved in ecosystem related work, provisioning services (such as *Nypa* palm and its use for making tobacco paper and roof thatching) were mention 30% more frequently for those involved in non-ecosystem related work, whereas supporting services (such as nursery grounds) were mentioned 20% higher among groups of participants primarily involved in ecosystem-related work. Furthermore, when comparing responses from the two villages, supporting services (such as habitat for marine animals and nursery grounds) were mentioned 20% more frequently in village 3. Finally, cultural services were mentioned around 30% more frequently among younger generations compared to older generations.

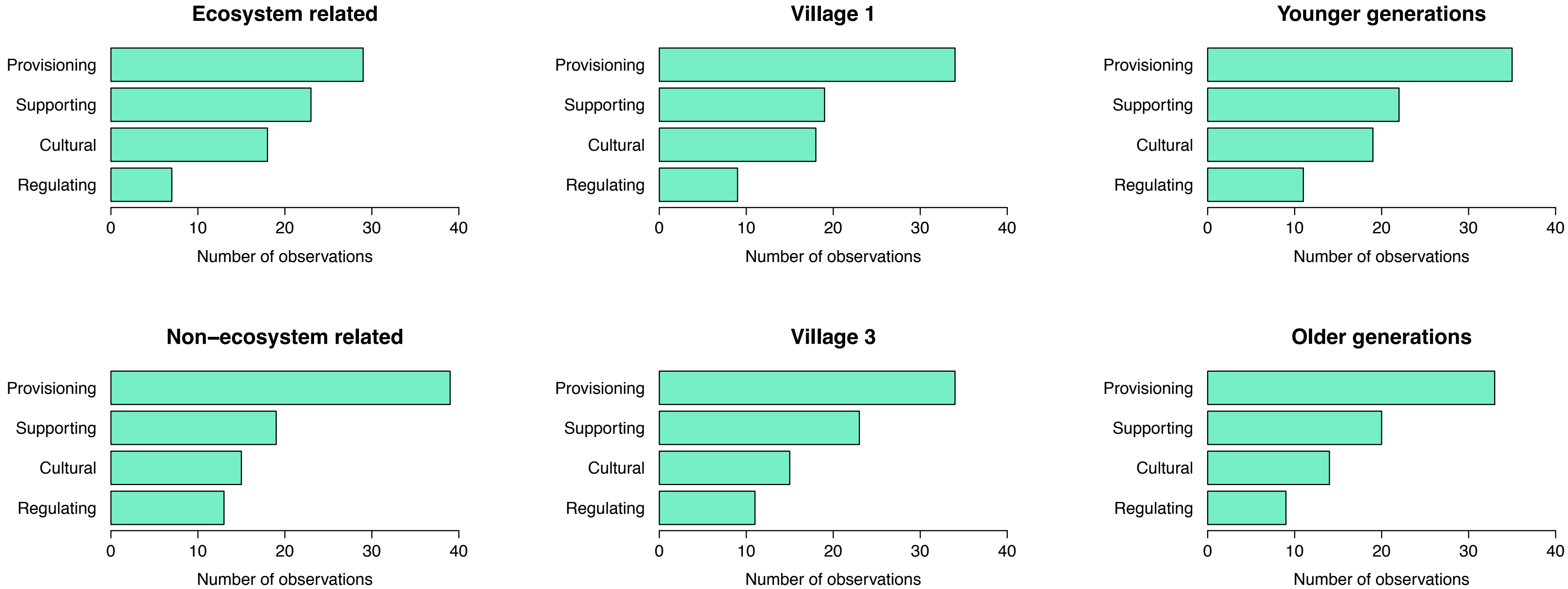


Figure 6.4. Perceptions of ecosystem services in relation to socio-demographic determinants. Data shows the number of provisioning, supporting, cultural, and regulating services mentioned (number of observations). Comparisons are made between groups based on a) occupation (ecosystem related, and non-ecosystem related) b) place of residence (village 1 and village 3), and c) age (older generations >35 years and younger generations <35 years old.

6.3.4.2 Mangrove ecosystem services

The participants associated several components of the coastal ecosystem with ecosystem service delivery. These included the beach, sea, mangrove forests, mangrove channels, coral reefs, and agricultural land. However, mangrove forests were by far the most frequently mentioned component, accounting for almost 60% of total ecosystem service discussions (Figure 6.5).

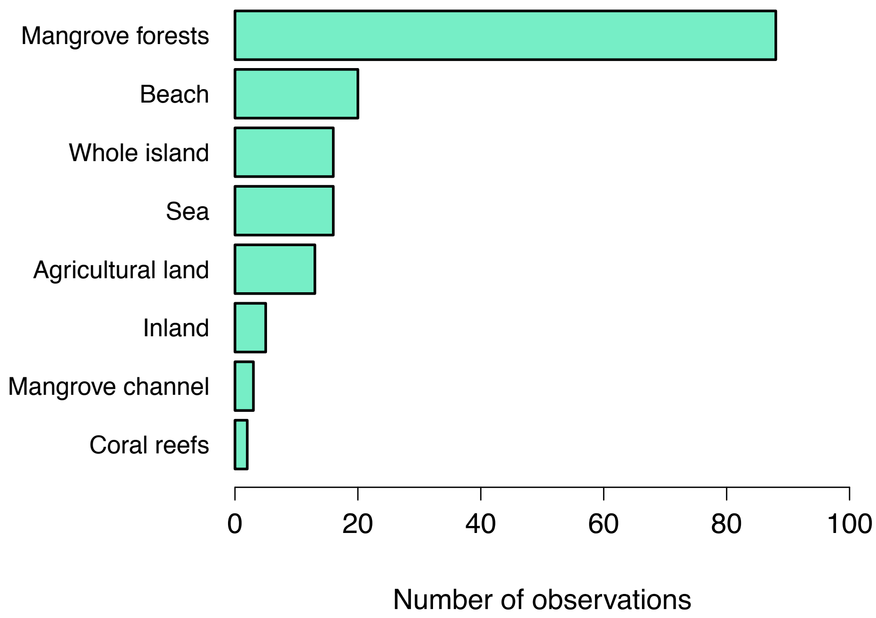


Figure 6.5. Perception of the components of the ecosystem important for the provision of ecosystem services in the community. Data shows the relative importance of each component of the ecosystem on the island, determined by the number of times each component is mentioned in relation to the ecosystem service provision. Observations are combined across all of the 8 workshops.

Mangroves were most frequently mentioned in relation to provisioning services (e.g. resources for building, making fishing traps, tobacco paper and roofing material) and supporting services (e.g. habitat and nursery grounds). These two types of services accounted for 40% and 25% of discussions, respectively. Cultural services (e.g. ecotourism) and regulating services (e.g. erosion control) accounted for 16% and 19% of the discussions, respectively. Across groups, the participants mentioned 24 different mangrove ecosystem services. The most frequently mentioned mangrove services included marine fisheries resources, habitat for marine animals, traditional aquaculture and materials for making tobacco paper and roof thatching (see Appendix).

6.3.4.2.1 Mangrove provisioning services

Fisheries resources, traditional aquaculture, and materials derived from the *Nypa* palm were the most frequently mentioned mangrove provisioning services across groups. However, older groups focused largely on the fisheries resources provided by mangroves, whereas younger groups discussed wider uses of mangroves, and uses in relation to a wider range of tree species. For example, a younger group from village 3 describe how dead *Excoecaria* trees provide conditions for the growth of wild mushrooms, a food source for the community, "*schizophyllum (mushroom) grows from the tree when it dies. It grows from the mutar trees (Excoecaria) that have fallen down. If it grows from this tree then it's tastier. The mushroom is quite expensive, 250 baht per kg*" (V3, NER, <35). They also emphasise the multiple uses of the *Nypa* palm and refer to it as the new 'cash crop' on the island since the end of shrimp farming, "*The cigarette is more expensive now and that's why people have turned to tobacco. Jak (Nypa) leaves are used for making tobacco paper. Jak has now become a cash crop. It's used for tobacco paper, also for dessert wrapper and for the roof thatching as well. Those trees now grow inside the ponds. The shrimp ponds have now turned into a plantation of jak trees*" (V3, NER, <35).

6.3.4.2.2 Mangrove supporting services

The role of mangroves in supporting nursery grounds and habitat for marine animals was widely discussed across groups. One elder fisher from village 3 stated, "*a good ecosystem is a forest which is habitat for small marine animals, a nursery ground for smaller fish. More trees are a sign of a good ecosystem because it's a bigger nursey ground for shrimp, shellfish, fish, and crab, so their survival increases*". Young fishers from village 1 also identify that marine life has returned because of an increase in forest area, "*because we replanted more trees back to the forests, marine animals have started to come back. It's better. We're building new houses for them. It's like if we lose our house in a big fire and someone builds a new house for us, we feel happy and secure. Soon, we start to have more babies*".

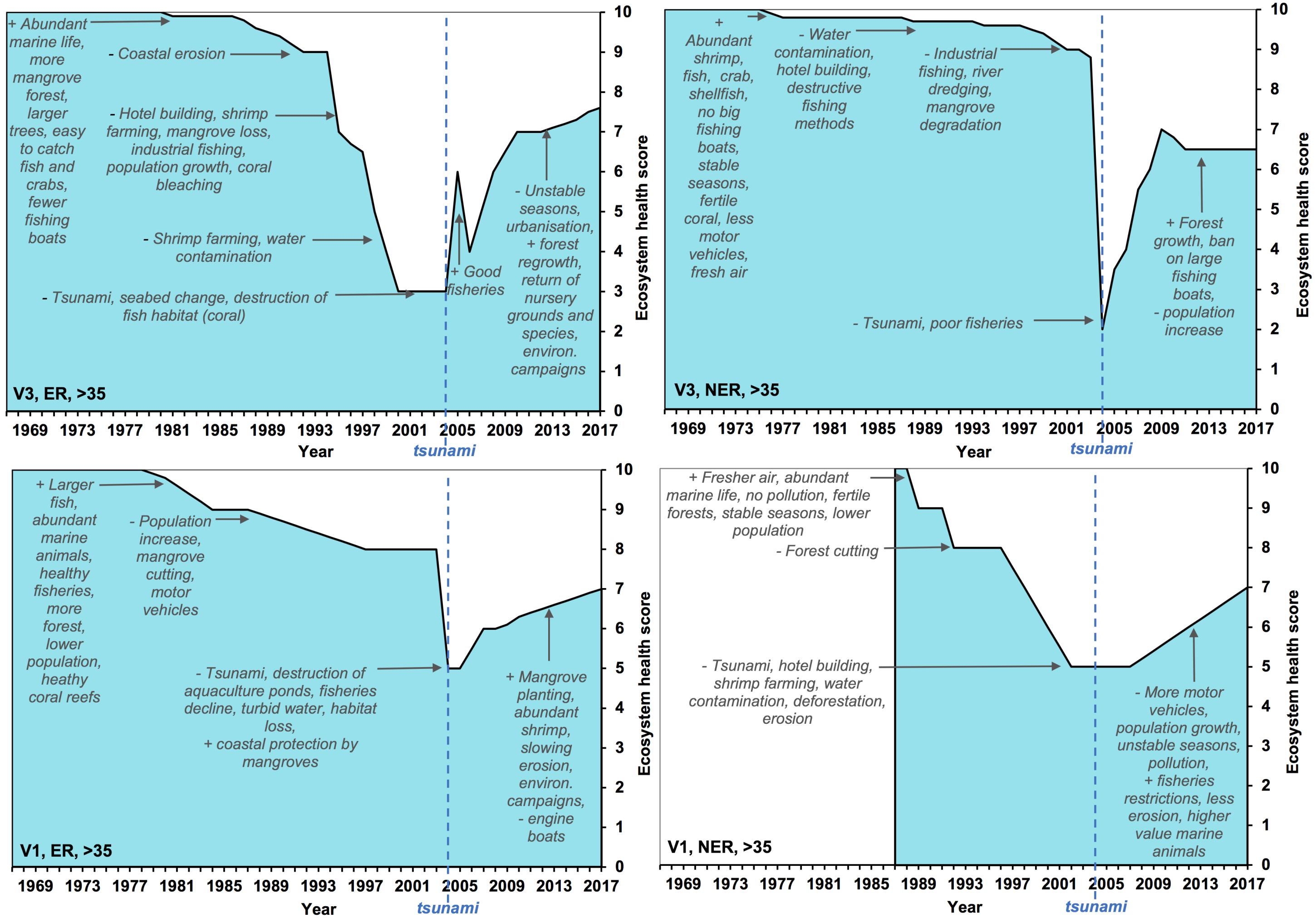
6.3.4.2.3 Mangrove regulating services

Climate regulation, fresh air, and coastal protection were among the most frequently mentioned mangrove regulating services across groups. However, some differences were observed between villages in the types of regulating services they discussed. For example, soil fertility and nutrient cycling was only discussed among groups from village 1, who regarded this service as important for rice production on the island. According to an elder from village 1, "*The soil is still very fertile, and we gain more crops. Foreign researchers studied the rice fields and they said that the soil is rich in nutrient supply. A mixture of fresh water and sea water makes our rice tasty. Normally, the price of rice is around 30-40 baht per kg, but we sell our rice at a better rate, 100 baht per kg, because it's tastier. Our rice fields are very productive*" (V1, NER, >35).

In addition, only two groups discussed the protective function of mangrove forests: young and older groups from village 1. Both groups use the 2004 Indian Ocean tsunami as an example of how the forest protected the island from the waves, as the following statement shows, "*The mangrove forests around the island reduced the impact of the tsunami, so our Koh Klang wasn't damaged too much. The mangrove forests helped lessening the big waves that hit the island. There are many mangrove channels protecting village 1 from the big waves. The tsunami only affected the island partially, so the overall ecosystem was still in good condition*" (V1, NER, <35).

6.3.5 Perceptions of ecosystem health over time

Figure 6.6 presents the group timelines of perception of change in ecosystem health over time. A number of human and environmental drivers were identified as contributing to change in ecosystem health. Different sets of drivers were generally associated with different time periods, as discussed below.


+ Abundant marine life, more mangrove forest, larger trees, easy to catch fish and crabs, fewer fishing boats
- Coastal erosion
- Hotel building, shrimp farming, mangrove loss, industrial fishing, population growth, coral bleaching
- Shrimp farming, water contamination
- Tsunami, seabed change, destruction of fish habitat (coral)
+ Good fisheries
- Unstable seasons, urbanisation, + forest regrowth, return of nursery grounds and species, environ. campaigns
V3, ER, >35
Ecosystem health score
Year
tsunami
+ Abundant shrimp, fish, crab, shellfish, no big fishing boats, stable seasons, fertile coral, less motor vehicles, fresh air
- Water contamination, hotel building, destructive fishing methods
- Industrial fishing, river dredging, mangrove degradation
- Tsunami, poor fisheries
+ Forest growth, ban on large fishing boats, - population increase
V3, NER, >35
Ecosystem health score
Year
tsunami
+ Larger fish, abundant marine animals, healthy fisheries, more forest, lower population, heathy coral reefs
- Population increase, mangrove cutting, motor vehicles
- Tsunami, destruction of aquaculture ponds, fisheries decline, turbid water, habitat loss, + coastal protection by mangroves
+ Mangrove planting, abundant shrimp, slowing erosion, environ. campaigns, - engine boats
V1, ER, >35
Ecosystem health score
Year
tsunami
+ Fresher air, abundant marine life, no pollution, fertile forests, stable seasons, lower population
- Forest cutting
- Tsunami, hotel building, shrimp farming, water contamination, deforestation, erosion
- More motor vehicles, population growth, unstable seasons, pollution, + fisheries restrictions, less erosion, higher value marine animals
V1, NER, >35
Ecosystem health score
Year
tsunami

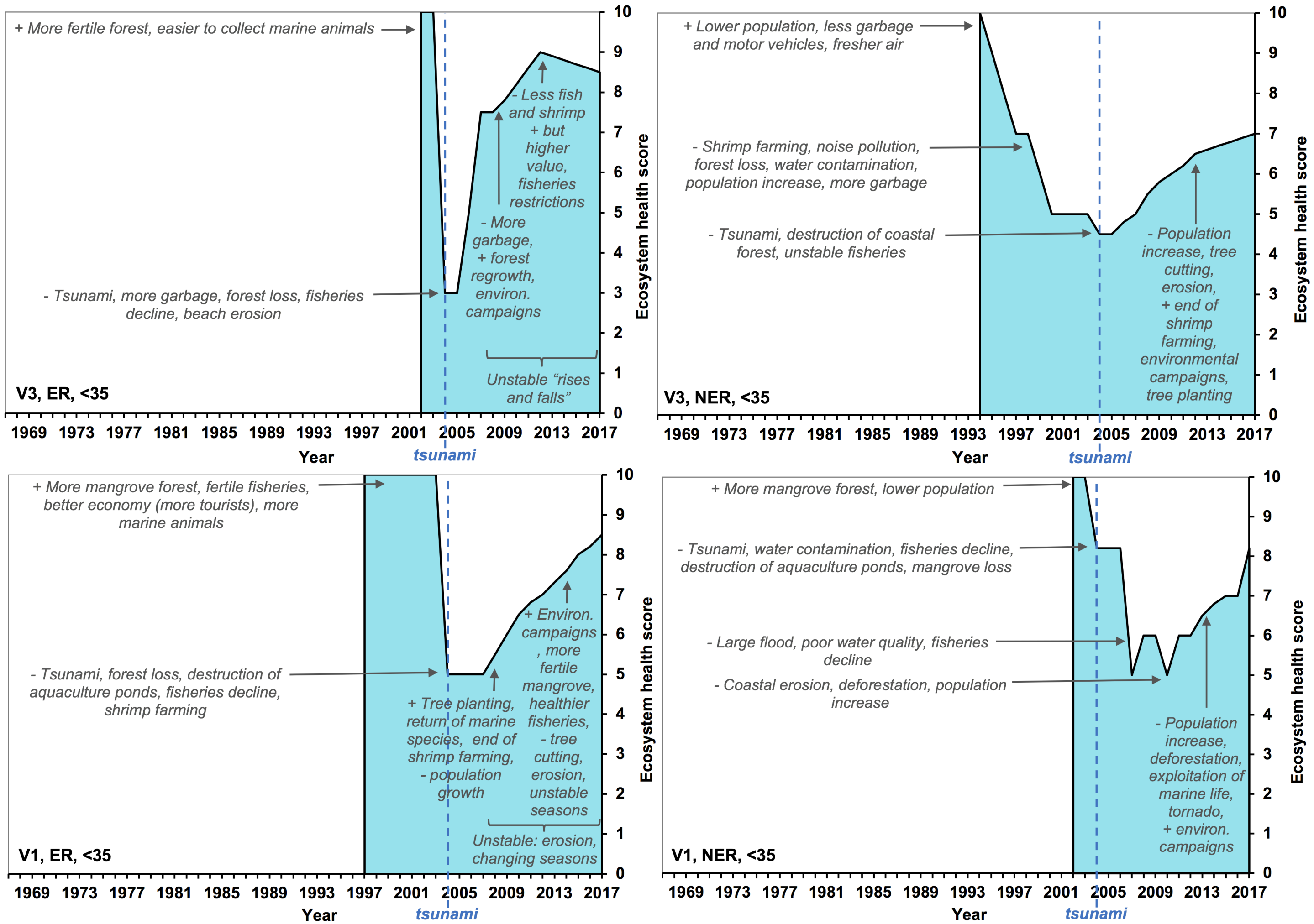


Figure 6.6. Ecosystem health scores. Graphs show the perceived relative health of the ecosystem (scored from 0-10) over a lifetime, as stated by each workshop group. The groups varied by occupation (ER = ecosystem related, NER = Non-ecosystem related), age group (>35 = older generation, <35 = younger generation), and place of residence (V = village (1 or 3)). Also shown is the perceived social and ecological drivers of change in the ecosystem state, both positive (+) and negative (-).

6.3.5.1 Pre-tsunami: age related differences

All groups of participants perceived the ecosystem to be perfectly healthy at the start of their lifetime (score of 10), and all saw a decline in ecosystem health within the first 5-10 years of their life. For the majority of the oldest participants, the decline in ecosystem health began in the mid to late 1970s. Whereas, for the youngest groups of participants, the ecosystem was seen to decline from the 1990s to early 2000s. The perceived rate of decline in ecosystem health prior to the early 2000s varied between groups. This was most apparent among older groups from village 3. For instance, elders involved in ecosystem related work perceived a dramatic decline in ecosystem health, from a score of 10 in 1980 to 3 in 2001. Whereas, for elders not involved in ecosystem related work, they perceived the ecosystem to decline by only 0.8 points over the same period, from 9.8 in 1980 to 9 in 2001.

Across groups, a number of drivers of change in ecosystem health during the 1980s and 1990s were discussed. All were negative and included coastal erosion, shrimp farming expansion, urban development, population growth, forest cutting, and the rise of destructive fishing methods. Participants felt that the main indicators of ecosystem decline during this period were water contamination, mangrove loss, fisheries decline, and coral bleaching.

Some elders recognised that the perception of health is only as good as your memory and experience and illustrated knowledge transmission among generations. For example, an elder fisher from village 3 said, "*to our generation, we think it was so good then, but in our parents' generation, it was much better 50 years ago. Although it was not in my days, I was told by my parents. They said that at that time they could catch black crab with their hands. They didn't need fishing gear. Fishermen would go fishing in the sea and see many shrimp jumping in the water because there were so many of them. At that time, many green turtles were found breeding on the beach. Also, you could see stingrays in the pools, as well as sharks. Vultures were found in the area too, but not anymore*".

6.3.5.2 Tsunami

Across groups, the mean ecosystem health score for 2004, the year of the tsunami event, was 4.5. For 7 of the 8 groups, this was the lowest ecosystem health score given for any year over their lifetime. Between groups in the categories age and occupation, there were no significant differences in the ecosystem health scores given for 2004. However, there was a significant difference between villages, with participants from village 3 scoring the ecosystem health in 2004 (mean = 3.1) significantly lower than village 1 (mean = 5.8; $p = 0.037$). The participants associated the tsunami with a number of negative ecosystem changes, including alterations to the seabed, destruction of fish habitat (coral reefs), a decline in fisheries production and stability, water turbidity, water contamination (garbage), beach erosion, destruction of coastal forest (such as pine and coconut palm), and destruction of aquaculture cages in the mangrove channels.

Two years prior to the tsunami, in 2002, the mean ecosystem health score across groups was 7.5, meaning that the participants perceived a decline in the health of the ecosystem by 3 points between 2002 and 2004. Three groups felt that significant negative changes in ecosystem health had already occurred prior to the tsunami due to shrimp farming expansion on the island, which began in the late 1980s. Participants associated shrimp farming expansion with deforestation and water contamination, which they stated had negative impacts on coral reefs and marine species abundance. The period between 2000 and 2002 was cited as the 'peak time' for ecosystem decline due to shrimp farming and tourism development. An elder from village 3, who previously owned shrimp ponds, said, "*Since I started to do shrimp farming until now it* [the ecosystem state] *has been bad. There are many factors that have contributed to the decline in ecosystem health. Wastewater from the hotel together with the shrimp farms ruined the ecosystem. It was very bad, especially in the year 2000 because all the area was full of shrimp ponds instead of mangrove forest. Chemicals used by the shrimp farmers, together with the contaminated water released from the hotel, caused coral bleaching and some species of fish disappeared*" (V3, ER, >35).

Two other groups from village 1 perceived a relatively small decline in ecosystem health (-1.8 to -3 points) between 2002 and 2004. These groups felt that the tsunami did not have a great impact on ecosystem health because the island was protected by its surrounding mangrove forests, as highlighted in the previous section.

6.3.5.3 Post-tsunami recovery

For the year 2009, four years after the tsunami, the mean ecosystem health score across groups was 6.3, indicating that participants perceived the ecosystem heath to have increased by an average of 2.4 points relative to 2004. Across groups, all ecosystem health scores were higher for 2009 than 2004. The mean relative change in ecosystem health score between 2004 and 2009 was similar among groups of different age and occupation (range = +2.2 to +2.6). However, there was a difference in the perceived magnitude of change between the two villages: participants from village 3 perceived a greater increase in ecosystem heath over this period (+3.7) than participants from village 1 (+1.2). Furthermore, although all groups felt that the ecosystem health had increased relative to 2004, the magnitude of increase varied across individual groups (ranging from +0.4 to +5 points). Two older groups perceived the greatest increase in ecosystem health in the two years after the tsunami. Older fishers in village 1 stated that the ecosystem was relatively resilient to the effects of the tsunami, "*In the two-year period straight after the tsunami, it was very bad, but a few years after the tsunami, it began to get better. The tsunami affected some shellfish habitat, the amount of shellfish was less, but only for around 2 years. After that, the amount of shellfish increased".* Some related the observed resilience of shellfish populations to their natural environmental conditions, stating that there are natural seasonal fluctuations in the abundance of marine animals caused by the monsoon. Younger participants from village 3 also felt that the tsunami only caused short term perturbations to the ecosystem and that recovery after the tsunami was aided by the end of shrimp farming coupled with mangrove forest regeneration, "*The wave ruined the beach but only moderately. The mangrove forest wasn't destroyed much. It's a tough forest. A few years after the tsunami, there was natural improvement, it was quite stable. The forest started to regenerate and there were no more shrimp farms. That's why the environment gradually recovered* (V1, ER, <35).

6.3.5.4 2009 – present

For the present-day, ecosystem health was scored similar across groups, ranging from 7 to 8 points. However, many participants also felt that the ecosystem state was currently unstable, stating that the relative health fluctuated year by year. They related the apparent instability to both positive and negative drivers of change. A young fisher from village 3 stated, "*A few years after the tsunami it was better. But lately it has been declining. It's pretty unstable. It rises and falls*". Negative drivers of change included urbanisation, population growth, pollution (garbage), tree cutting, floods, coastal erosion, and 'unstable seasons'. Many participants across groups complained about the shifts in the timing of the rainy season in recent years, stating for example that it had rained in April this year, although the typical rainy season falls from June to December. Some related climate instability with changing productivity of the marine environment, as the following statements show, "*it was easier to collect fish in the sea, and the season was more stable 10 years ago. That was the main factor. The rain use to come on time. The seasons were more stable before the tsunami*" (V3, NER, >35). "*Nowadays, we can say that the ecosystem condition is gradually better, but it's not stable. Things recovered after the tsunami, fish stocks, but they are not stable*" (V1, ER, <35).

On the other hand, positive drivers of change included environmental campaigns, mangrove tree planting, and fisheries restrictions. For example, many participants discussed how the overall state of the ecosystem is getting better due to an increase in forest area, which they associated with larger nursery grounds and more productive fisheries. Some of the older participants related changes in mangrove forest health with the disappearance and reappearance of marine species. For example, an older participant from village 3 referred to the disappearance and re-emergence of the jinga shrimp, "*It's getting better. If we look at the forest, there's more area and there's more marine species. Species that had once disappeared have started to come back. Jinga shrimp disappeared but now it has started to come back. Because there's more fertile forest, that species has started to come back*" (V3, ER, >35).

6.3.6 Impact of ecosystem related policies on perceptions of ecosystem health

Figure 6.7 presents some of the major measures and policies for management of natural resources in Thailand from 1966 to present, with a focus on mangrove forests and coastal fisheries. Some of these measures may have shaped local perceptions of ecosystem health, as discussed below.

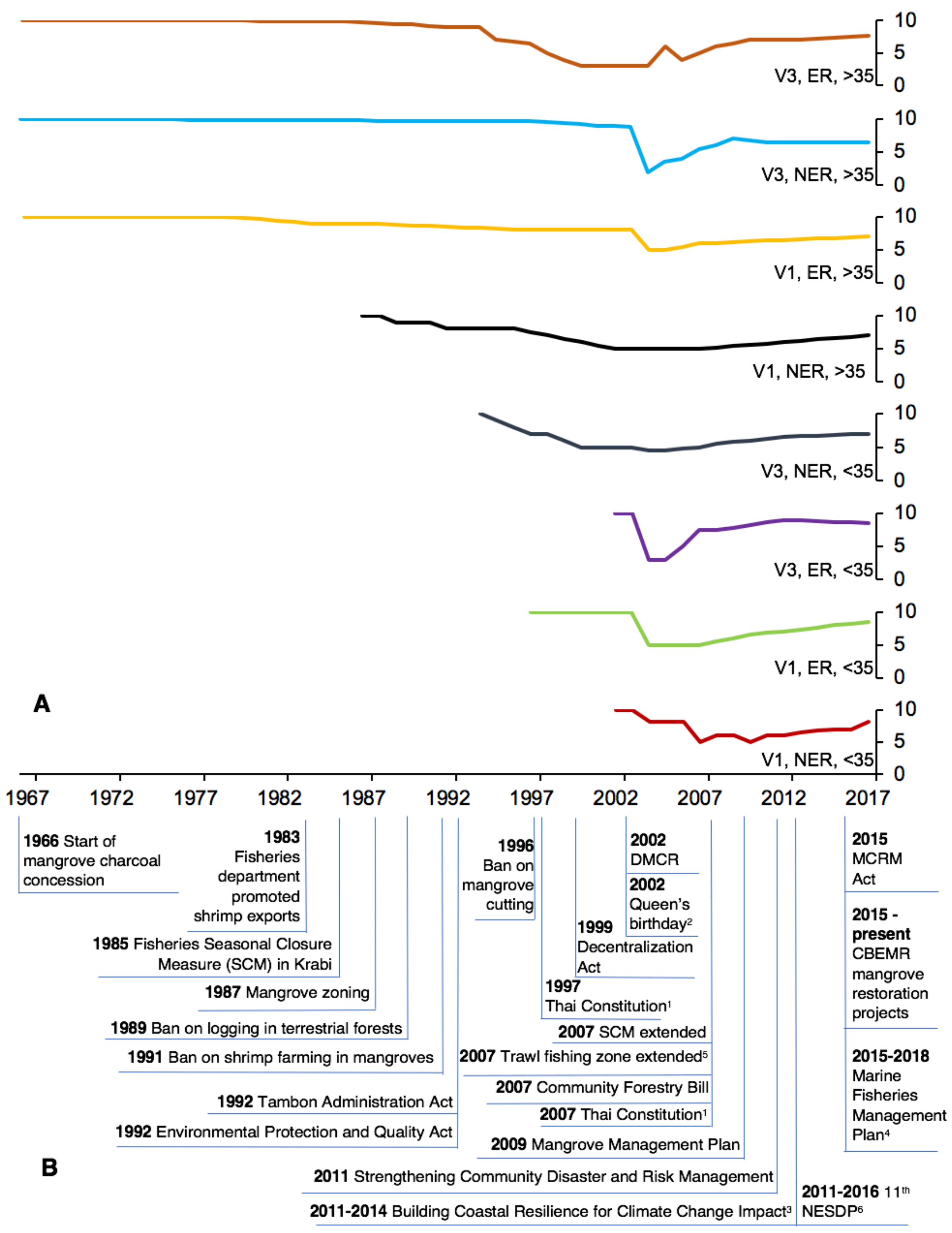


Figure 6.7. A) Ecosystem health scores for 8 groups which differed by age (>35/<35 years), occupation (ecosystem related (ER)/non-ecosystem related (NER)), and village (village 1(V1)/village 3(V3)). B) Some of the major measures and policies for natural resource management in Thailand (1966-present) that may have shaped the ecosystem health perceptions, with a focus on mangroves and coastal fisheries. [1]*Communities must participate in natural resource management;* [2] Mangrove rehabilitation and sustainable conversation project; [3]Bamboo fence built 2012; [4]Trawl mesh size increased from 2.5 cm to 4 cm 2015, 640 ha of mangrove area increased 2015 – 2019, 4% of coral reef and 4% of seagrass under management 2015 – 2019; [5]from 3.4km to 5 km from shoreline; [6]*Mangrove restoration.*

6.3.6.1 Fisheries livelihood strategies

Across all groups, some of the recent changes in fisheries policy created both positive and negative discussions around livelihood and ecosystem health. Some of the positive discussions were centred around the recent government ban on commercial fishing vessels in the nearshore (5km) zone. The government restrictions aim to improve spawning and nursery grounds for marine species, while at the same time reduce conflicts between commercial and artisanal fishers. Several older participants discussed the negative impacts of larger fishing boats on past ecosystem health, "*At that time* [10 years ago] *there were many big fishing boats in this area. Big fishing boats are now banned in this area. They would use the gas capsule to coerce the fish into the net"* (V3, NER, >35). "*Trawlers are not allowed to enter the beach anymore. They are not now allowed to anchor near the beach. Big trawlers make big waves hit the shore"* (V1, NER, >35). The 5 km restriction zone was perceived to be a positive driver of ecosystem health over the past 10 years, and some elder fishers from village 3 felt that the positive impact of this measure would continue in the future, "*By law big fishing boats cannot come into this area anymore. I can't tell if this will be beneficial to the ecosystem because it has not been long. Let's see in the next two years. I think it will be better".*

On the other hand, perceptions of participants on the effectiveness of other fisheries management measures were quite critical. For example, the government measures to enforce restrictions on the type of fishing gear used in the area as part of the Marine Fisheries Management Plan (FMP) 2015-2019 (Department of Fisheries 2015). This includes small artisanal fishing gear of the type used by the community over many generations. Government restrictions on the use of this gear was more of a concern in village 3 where traditional inshore fishing has been a primary livelihood for many of the households for centuries. The new restrictions had impacted their livelihood, and some fishers felt that it had turned them into criminals, "*These days, we haven't gone out fishing for a while because the government won't allow us to do so"* (V3, ER, >35). "*Most of the bamboo stake traps were demolished by the Department of Fisheries. But if I had the choice, then I would prefer to be a thief"* (V3, ER, <35). The Department of Fisheries have also recently enlarged the minimum fishing gear mesh size from 2.5 cm to 4 cm as a measure to reduce the amount of juvenile fish caught. According to younger fishers from village 3, the changes to mesh size had negatively impacted their fish catch.

The new fishing gear restrictions were also discussed widely in village 1, although the attitude and issues raised were different. Some participants in village 1 felt that the use of traditional fishing gear had negatively impacted the mangrove forests because of the requirement for mangrove wood, "*At village 1 and village 3, most of the fishing traps were destroyed. To build the traps, you need lots of wood. This is why they* [the government] *do not allow people to make it anymore. People renew the poles twice a year and each family needs around 200 trees each time. It causes deforestation. They use the samae wood (Avicennia) in the mangrove forests. Only small sized wood though, small tree trunks"* (V1, NER, >35).

6.3.6.2 Ecosystem rehabilitation projects and local capacity building

In response to the tsunami in 2004, the Thai government and non-government organisations established a number of local projects on Koh Klang which aimed at long term rehabilitation of the environment and local livelihoods. For example, a capacity building project 'Building Coastal Resilience for Climate Change Impact' was set up in 2011 by the local Mangrove Management Unit (MMU26) and the NGO, Raks Thai. The project aimed to provide the community with training and education and encouraged them towards management of their natural resources. Participants felt that these projects have had a positive impact on ecosystem health, and education of the youth was seen to be key to this, as the following statements show, *"The young generation have been educated to care for the ecosystem. Some campaigns are supported by the government and by the school"* (V3, ER, >35).

Community involvement in natural resource management has been promoted by the Thai government since 1997 (Thai Constitution) and is a key objective in the current National Environment and Social Development Plan (NESDP). The government's Mangrove Rehabilitation and Sustainable Conversation project, for example, encourages the community to assist with mangrove planting on Koh Klang. Participants felt that environmental awareness had increased in the community and the tsunami disaster brought people together for information sharing and resilience building. Participants discussed how the community planted trees in degraded mangrove areas which aided recovery of the ecosystem post-tsunami, "*For 2-3 years after the tsunami, the environment had not recovered. The mangrove forests were destroyed. We solved this problem by planting more trees back to the forest. Students from all schools on Koh Klang also came to help plant mangrove trees. We replanted more trees back to the* *forests and marine animals have started to come back"* (V1, ER, <35). Others referred to the positive impact of government projects to restore the coral reefs after the tsunami, "*Nowadays the condition of the coral has gradually recovered by the support of the government to restore it. Around 80% has now recovered*" (V3, ER, >35).

6.4 Discussion and conclusions

6.4.1 Local ecological knowledge distribution

The results from this study reveal cross-scale local ecological knowledge among the communities on Koh Klang, ranging from an understanding of individual species and their habitats, knowledge of biodiversity and seasonal patterns in productivity, to wider ecosystem functions, dynamics and interactions. Overwhelmingly, there is a sense that the coastal area is very much part of the community's culture and identity.

The community as a whole were shown to hold a good understanding of more simple ecological knowledge, such as on specific species and their habitats. Knowledge of more complex ecological process ranged from an understanding that mangrove forests support nursery habitat for juvenile marine animals that spend part of their life outside of the mangroves, to knowledge of seasonal shifts in species abundance. Whilst more simple ecological knowledge was distributed relatively uniformly across groups, understanding of more complex ecosystem processes was heterogeneously distributed and more variable across and within user groups of different occupation, age or place of residence. Other studies elsewhere have identified more group-specific patterns of complex knowledge development (Crona and Bodin 2006; Ferguson and Messier 1997, Ghimire et al. 2004). Crona and Bodin (2006) for example, observed distinct group-specific ecological knowledge among fishermen in Kenya who were operating in distinct subsystems related to gear types (such as deep-sea, speargun and gillnet).

The fact that there was no obvious group-specific knowledge among user groups on Koh Klang suggests either that there is more social homogeneity across groups of different age, occupation and place of residence, or that the social ties within user groups are weaker thus resulting in a lower level of group-specific complex knowledge development (Reagans and McEvily 2003). These findings could be explained by a number of factors. Firstly, Koh Klang participants share strong cultural and religious links that may facilitate greater communication and social cohesion (Reagans and McEvily 2003). Second, it was difficult to recruit individuals who had no previous direct or indirect experience related to coastal resource extraction. In many cases, participants who were not directly involved in ecosystem related work, had either previous experience of marine resource extraction or had family members who were directly involved (see Appendix). As a result, the occupation groups represented level of experience in work related to the marine environment, rather than truly distinct groups. As Koh Klang has sustained livelihoods based around the coastal environment for many generations, the villagers share a common background and life experiences, which was an unavoidable limitation to the study design.

6.4.2 Locally perceived ecosystem services

The results also show that the community of Koh Klang benefit in numerous different ways from coastal ecosystem service delivery, particularly in relation to the mangrove forests which surround the island. These findings conform with other studies which illustrate the importance of mangroves in sustaining livelihoods in coastal communities in the tropics (Rönnbäck et al. 2007; Glaser 2003).

The provision of marine fisheries resources and the supportive function of mangroves in providing nursery grounds was well understood across user groups. This demonstrates that the community not only understand the 'final' service (Fisher 2009), such as fish and shellfish production, but they understand how the supporting services of the mangroves (habitat and nursery ground provision) contribute to fisheries production. The findings concur with other studies which show that coastal fishing communities depend on and understand well the function of mangroves in supporting important nursery grounds for fish and crustaceans (Huxham et al. 2017; Barbier 2006).

The study also demonstrates that different user groups perceive different benefits from the coastal ecosystem, confirming findings from other studies which show patterns among resource users with respect to dependencies on different ecosystem goods and services (Rönnbäck et al. 2007). Variation in the apparent importance of different goods and services across user groups may reflect differences in economic dependency, or the value that comes from knowledge and proximity. For example, younger user groups on Koh Klang identified that the *Nypa* palm had become the new 'cash crop' on the island because of a growing market for using the fronds for making tobacco paper because the price of cigarettes had increased in recent years. Hence this was a new and growing livelihood on the island which had gained traction among the younger resource users. Whereas, traditional fishing practices have been a livelihood practice on the island for many generations, and the importance of the fisheries resources to older generations in particular would explain their strong focus on this provisioning service. In addition, a greater focus on cultural services was observed among younger generations compared to older generations. Again, because tourism is a growing industry on the island, especially compared to fishing, this was something the younger groups were more engaged in.

These findings contribute to a better understanding of local level needs and perspectives on ecosystem service delivery, and illustrate that, even on the local scale, different social and ecological contexts may result in different ecosystem service dependencies (Vo et al. 2012). This knowledge is crucial for dealing with ecosystem management measures with potential trade-offs among stakeholders (McShane et al. 2011; Hauck et al. 2013; Howe et al. 2014).

6.4.3 Community perception of ecosystem change

The results also revealed that both young and old generations perceived the ecosystem to be perfectly healthy at the start of their lifetime, suggesting that perception may be influenced by age-related differences. These findings concur with other studies (Alessa et al. 2008; Fernandez-Llamazares et al. 2015). This observed pattern could relate to the ‘shifting baseline syndrome’ defined by Pauly (1995). That is, new generations base their perception of the level of change in ecosystem state on the level they observed at the start of their lifetime. On the other hand, the observed pattern may suggest that some generations misperceive the past ecosystem state, thinking that it was better than it actually was, or inaccurately account past ecosystem state because of a desire to please. Similar findings have been observed in previous studies (Yasue et al. 2010), and these issues are well known limitations of research on perceptions (Christie 2005; Leleu et al. 2012).

This study also emphasises that perceived changes in ecological conditions are very much dependent on how individuals are affected on a personal level (consistent with Schwarz et al. 2011; O’Brien and Wolf 2010). For example, the impact of the tsunami on ecosystem state was perceived to be greater among resource users in village 3, reflecting how this village was personally affected. For example, some of the major impacts of the tsunami were cited as seabed alterations and loss of fisheries productivity, which relate more directly to the main livelihood activities in village 3. Whereas, the tsunami had less of a personal impact on the main ecosystem-based livelihoods in village 1, which are centred around livestock and rice production in inland areas.

The results also suggest that the way people perceive ecosystem changes over time may reflect differences in knowledge of the historical ecosystem state. For example, several negative drivers of change were occurring before the tsunami in 2004, related to the expansion of shrimp farming on the island and associated deforestation. Yet, the study shows that only some user groups had knowledge of the pre-tsunami ecosystem decline. These findings have important implications for the sustainability of ecosystem service supply in areas affected by ecosystem degradation. That is, if a community perceives no change in ecosystem state during periods of gradual ecosystem decline, the erosion of important benefits may go unnoticed because their importance is not appreciated until a disaster occurs (Adger et al. 2005). This indicates that local groups could benefit from the support of higher-level authorities for combining scientific information with local ecological knowledge, in order to avoid future unnoticed declines in ecosystem health.

6.4.4 Implications for future mangrove management

Both positive and negative views about ecosystem management strategies were observed among the community on Koh Klang, highlighting the need to balance negative social costs of management with ecosystem benefits through specific attention to livelihoods (Pomeroy et al. 2004). Of particular note was that efforts from the government, NGO's, and the local community to help restore degraded mangroves resulted in a perceived recovery of mangrove ecological functions by the community, and the interviews in this study revealed positive attitudes towards future mangrove restoration on the island.

The findings help to frame the future management of mangroves and the challenge to address ecosystem degradation in Thailand. For example, the ability of the forest to cope with environmental change depends on numerous social and ecological feedbacks: mangroves require both a suitable environmental setting and ecological conditions, and local awareness of conservation through organised mangrove restoration (Brown 2007; Alongi 2008). Incorporating local ecological knowledge into community-based management strategies has been shown to improve the development of more sustainable natural resource policies that benefit the ecosystem and the mangrove-dependant community (Gutiérrez et al. 2011). For example, other studies show how communities most dependent on the fisheries production of mangrove forests are most likely to invest time in their restoration (Barbier 2006). Enhancing participation in mangrove management, through coordinated efforts involving multiple stakeholders, has been shown to work more effectively, offering different complimentary scales of knowledge that would be otherwise missed in a government led top top-down approach (Moller et al. 2004). Furthermore, community engagement in natural resource governance also connects people with nature, so giving social and cultural benefits and a sense of ownership to the people who depend most on mangroves for their livelihood (Biswas et al. 2009). Strategies to ensure sustained community participation, and the integration of traditional and scientific knowledge in mangrove management, could include community cooperation in restoration planning and monitoring, environmental stewardship, or involvement in local government advisory councils (Berkes et al. 2006). Approaches which aim to improve human well-being while at the same time promote ecosystem conservation also responds to the United Nations Sustainable Development Goals (United Nations 2015).

Chapter 7 Discussion

7.1 Key insights

This research uses a social-ecological systems lens to analyse features of resilience of shrimp farming in coastal mangroves areas in Thailand. The case study approach focuses on the local scale dynamics affecting shrimp farmers and mangrove dependent communities, which have been challenged by rapid social and ecological change in recent decades (Chapter 2). Underpinning this research is the recognition that people are part of dynamic coastal ecosystems and are dependent on natural resources for wellbeing and development (Chapter 1). The overarching aim was to use multi- and inter-disciplinary approaches to understand how studying shrimp farming in mangrove areas as a social-ecological system can advance understanding of some selected drivers of resilient social-ecological systems, which is at the forefront of the challenge to address degradation in coastal ecosystems (Walker and Salt 2012). This aim was addressed through three studies at two coastal sites in Thailand on: (i) the impact of shrimp farming on mangrove ecosystem C stocks; (ii) patterns of shrimp farming diversity along the Gulf of Thailand coast in relation to farmers' behaviour and social-ecological conditions; and (iii) local perceptions and ecological knowledge in relation to ecosystem health and ecosystem service delivery.

Using a social-ecological lens has offered a means of holistically studying shrimp farming in mangrove areas in Thailand. Multiple themes and findings emerged from this study which have the potential to advance environmental and shrimp farming sustainability. For resilience scholars, the research helps to build a more holistic understanding of factors influencing resilience of different social-ecological systems and builds on research from other contexts. The main objective of this final chapter is to discuss the key findings of the research chapters (Chapters 4, 5 and 6) in relation to the wider aim of this thesis. The key findings arising from this research are summarised below:

1. Mangroves have exceptionally high whole ecosystem C stocks but shrimp production results in a large land-use C footprint and a substantial loss in the ecosystem service of C sequestration and storage by mangroves (Chapter 4).

2. The effect of shrimp farming disturbance on mangrove soil C pools is shown to be most substantial in the near surface soil horizons, but this study demonstrates that C is preserved in deeper soil layers of some abandoned ponds, and that C accumulates fairly rapidly in the surface soil layer after pond abandonment. This suggests that C sequestration capacity of the ecosystem may improve in abandoned shrimp ponds over time as mangroves re-establish, and that the C stored in the surface soils of ponds may be comparable to natural mangrove forests 22 years after ponds are abandoned (Chapter 4).

3. Mangroves not only contain high ecosystem C stocks but also provide a multitude of other non-carbon goods and services to coastal communities in Thailand. Variation in the importance of different mangrove goods and services to community user-groups reflects differences in economic dependency, and the value that comes from knowledge and proximity (Chapter 6).

4. Along the Gulf of Thailand coast, shrimp farming intensity is associated with a combination of technical (e.g. farm area, pond size, stocking density and production), economic (shrimp selling price, production costs and farm revenue), social (e.g. farm operating years, the use of family labour, engagement in shrimp farming and with other shrimp farmers), and ecological factors (e.g. farmer reliance on natural pond productivity, and constraints brought about by environmental change and fluctuations in productive areas) (Chapter 5).

5. A number of external and internal socio-economic factors are related to the decision to adopt a certain level of shrimp production intensity along the Gulf of Thailand coast, including training received on farming practices, access to technical equipment, proportion of total income from shrimp farming, season-specific changes in production, risk perception, and subjective culture (social norms and roles) (Chapter 5).

6. Levels of shrimp farming intensity in coastal Thailand are an indicator of a diversity of socio-economic conditions and behavioural choices, which need to be targeted by sustainability policies differentially and beyond the technical sphere (Chapter 5).

7. Coastal communities in Thailand hold a wealth of local ecological knowledge, but knowledge of complex ecosystem processes is heterogeneously distributed across and within user-groups of different occupation, age and place of residence. Strong cultural and religious links among coastal user-groups may facilitate greater communication and social cohesion and this could have a positive effect on community resilience by enabling collective synthesis and use of their ecological knowledge, in order to respond to environmental challenges in a way that produces more sustainable management of their coastal resources (Chapter 6).

8. Differences in the way coastal communities perceive ecosystem changes over time may be influenced by age-related differences and differences in knowledge of the historical ecosystem state (Chapter 6).

9. Periods of abrupt environmental change, such as following the 2004 Indian ocean tsunami, can bring organisations and coastal communities together, creating opportunity for self-organisation, environmental education, and capacity building, which plays a significant role in the sustainability of natural resources, livelihoods and social resilience (Chapter 6).

7.2 Wider implications

7.2.1 Mangrove ecosystem services and resilience

The future persistence of mangroves as important ecosystems for both people and nature requires an understanding of ecosystem resilience and suitable management measures that help maintain this resilience (Brown 2007). As demonstrated in Chapter 4 and 6 of this research, disturbances, such as land use change, are events that alter the characteristic of ecosystem processes, shaping ecosystem structure (habitat fragmentation), function (delivery of services to people and nature) and resource availability (White and Jentsch 2001). In order to recover from disturbance, mangrove forests require resistant properties and resilience capacity (Alongi 2008; Barr et al.

2012). The ability of the forest to cope with environmental change depends on numerous social and ecological feedbacks: mangroves require both a suitable environmental setting and ecological conditions, such as adequate hydrology and tidal dispersal of propagules, and local awareness of conservation through organised mangrove restoration efforts for social resilience (Brown 2007; Alongi 2008).

The findings in Chapter 4 of this research are important because they tackle the challenge to address mangrove degradation and have implications for the restoration, conservation and management of mangroves in the future. The structural and functional properties of mangroves in abandoned shrimp ponds reflects the level of recovery to pre-disturbance state and thus ecosystem resilience (Gunderson 2000; Alongi 2008). Indications of mangrove resilience is shown in this study through patterns of ecosystem recovery in abandoned shrimp ponds over time. Knowledge on recovery trajectories of mangrove forests is incredibly important for a range of people and organisations who are working to restore mangrove forests in abandoned shrimp pond areas in Thailand, including local communities, local Mangrove Management Units, ecologists, and local conservation NGOs such as MAP.

The findings of Chapter 4 are also useful beyond the case study explored in this research because of the extent of mangrove conversion, not only in Thailand, but throughout their range (Richards and Friess 2016; Thomas et al. 2017). In showing that mangroves store vast amounts of C, but these stores are highly vulnerable to loss through land-use change for shrimp farming, the results are significant in terms of macro-level policy decisions because they highlight the importance of including mangroves in climate-change mitigation activities. Globally, the rate of mangrove deforestation is among the highest of all forest ecosystems (Hamilton and Casey 2016; Richards and Friess 2016; Thomas et al. 2017). Conservation of the remaining mangroves would not only maintain vital C stocks but would also protect the multitude of other non-carbon goods and service that mangroves provide to coastal communities, as illustrated in Chapter 6 of this thesis.

7.2.2 Local ecological knowledge for managing ecosystem degradation

Studying resilience of mangrove-dependent communities has offered a means to understand how human systems cope with environmental degradation and highlights the importance of integrating social and ecological values for natural resource management (Berkes et al. 2000). Ecological knowledge and learning, social memory, historical experience, and social capital are some of the primary sources of social resilience highlighted in Chapters 5 and 6 of this thesis. Chapter 6, for example, demonstrates how environmental education is effective when communities affected by a major environmental disaster or disturbance come together for information sharing (Wilson 2013).

On Koh Klang, the 2004 tsunami presented an opportunity for such building of social capital through linking the community and organisations for self-organisation and environmental education. Efforts from the government, NGO's, and the local community to help restore degraded mangroves resulted in a perceived recovery of mangrove ecological functions by the community, and the interviews in this study revealed positive attitudes towards future mangrove restoration on the island. This research therefore not only helps local natural resource management bodies and NGO's, such as MAP and Raks Thai Foundation, by advancing understanding of how they can be involved in local resilience building and the outcome of their work, but also helps to frame the future management of mangroves and the challenge to address degradation, given that there is much more to do in Thailand. In broader terms, resilience scholars will benefit from this research because the engagement of local people in environmental activities post-disaster and degradation, and their recognition of the benefits, has shown that communities can learn to recognise and act upon feedbacks, which can in turn foster greater resilience of the social-ecological system (Berkes et al. 2013).

Resilience among social groups relies on shared understanding of environmental issues (Adger 2003; Crona and Bodin 2006). Environmental education strategies for managing degradation and building resilience include consideration of different forms of knowledge and the incorporation of knowledge from social and ecological components of the system (Krasny and Roth 2010). Chapter 6 of this study demonstrated how mangrove-dependent communities interact with their environment and how they maintain strong ties with the mangroves through daily contact and observation. The community were shown to hold a wealth of ecological knowledge on mangrove processes and how they have changed over time. These findings open up a new line of investigation on how local and national decision makers can value and build on this LEK for management of these systems. Given that LEK is a key attribute of resilient social-ecological systems, it should be better utilised in natural resource governance (Rist and Dahadough-Guebas 2006; Biswas et al. 2009). For example, such local understanding and close relationships with mangroves can potentially provide vital inputs to the evaluation of forest rehabilitation success because local people are the ones who are continuously monitoring the ecosystem status over time (Walters 2004). Other research has shown that ecological knowledge held by local communities about species patterns, local habitats, and how they have changed over time, is shown to potentially be a powerful mechanism for the building of ecosystem health (Colding et al. 2003; Folke et al. 2004; Gómez-Baggethun et al. 2012), and for safeguarding biodiversity and ecosystems services (Gadgil et al. 1993; Johannes 1998; Hickey and Johannes 2002; Drew 2005; Barthel et al. 2013; Nandeesha et al. 2013).

The findings in Chapter 6 also suggest that the way people perceive ecosystem changes over time may reflect differences in knowledge of the historical ecosystem state and that perception may be influenced by age-related differences. These findings stand out because they raise questions about how knowledge is acquired, remembered, and shared among coastal communities, and if LEK is not passed on through generations, then how do we make sure it's not lost in the future? The historical lack of institutions for knowledge exchange and to communicate to local people the effects of shrimp farming may have contributed to the apparent lack of understanding of the impact of shrimp farming on ecosystem health. The study suggests that in times of ecosystem decline, local groups could benefit from the support of higher-level authorities for combining scientific information with local ecological knowledge.

Given their dependency on mangrove forests, coastal communities in Thailand should be given more responsibility and rights for mangrove management because ultimately they are a major determinant of the state of mangrove forests. Enhancing participation in mangrove management, through coordinated efforts involving multiple stakeholders, has been shown to work more effectively, offering different complimentary scales of knowledge that would be otherwise missed in a government led top top-down approach (Moller et al. 2004). Incorporating LEK into community-based management strategies has also been shown to improve the development of more sustainable natural resource policies that benefit both ecosystems and mangrove-dependent communities (Gutiérrez et al. 2011; Alexander et al. 2018). Community engagement in natural resource governance empowers local people and also offers the opportunity for sharing different forms of ecological knowledge within the community, thus helping to prevent the loss of LEK through generations. Furthermore, it connects people with nature, so giving social and cultural benefits and a sense of ownership to the people who depend most on mangroves for their livelihood (Biswas et al. 2009).

Strategies to ensure sustained community participation, and the integration of traditional and scientific knowledge in mangrove management, could include community cooperation in restoration planning and monitoring, environmental stewardship, or involvement in local government advisory councils (Berkes et al. 2006). Approaches which aim to improve human well-being while at the same time promote ecosystem conservation also responds to the United Nations Sustainable Development Goals (United Nations, 2015).

7.2.3 Potential for ecosystem service synergies

Conservation of mangroves is increasingly promoted as an opportunity to mitigate climate change and also as an adaptation measure in coastal areas, given both their carbon-rich nature along with their social, economic and ecological importance (Locatelli 2011; Murdiyarso et al. 2012; Kuwae and Hori 2019). On a global scale, knowledge of the land-use C footprint of shrimp production is important for policy makers. The C stock data provided in Chapter 4 of this research helps to refine current estimates of C losses due to land use change. This data can support international C stock assessments that aim to tackle mangrove degradation and the loss of vital ecosystem C stores, such as outlined in the guidelines of the Intergovernmental Panel on Climate Change (IPCC 2007).

It is important to note that the ecosystem service of C sequestration and storage was not perceived as locally important in Chapter 6 of this study. However, knowledge that the local community perceive greater benefits from an intact or regenerating forest, in particular because of the enhancement of habitat and nursery grounds, has implications for the potential for ecosystem service synergies across local and global scales. On a global scale, scientists and international organisations interested in climate change mitigation increasingly place value on mangrove forests in terms of their 'blue carbon' sequestration and storage function (Donato et al. 2011; Siikamäki et al. 2012). While C sequestration and habitat provision are different benefits from the same ecosystem, the results from this study suggest that measures to restore the C sequestration capacity of the forests will compliment or enhance the wide range of vital services needed at a local level for human wellbeing (Howe et al. 2014). Carbon forestry mechanisms (CFMs) are examples of schemes that can be effective in mitigating atmospheric CO_2 levels while at the same time enhancing non-carbon ecosystem services (Siikamäki et al. 2012; Murdiyarso et al. 2013; Locatelli et al. 2014). One example is a Payments for

Ecosystem Services (PES) type scheme, whereby local stakeholders are incentivised to manage mangroves in a way that maintains or enhances ecosystem service provision (Wunder 2015). Whilst mangrove forests are increasingly considered suitable for such schemes (Locatelli et al. 2014), a number of ecological, economic, social and governance challenges (Friess et al. 2016; Thompson 2018) has so far meant that only a small number of PES schemes have been implemented in mangroves worldwide (e.g. Plan Vivo 2018; Jones et al. 2014). The C stock assessments presented in Chapter 4 of this research can help operationalise mangrove conservation projects that require C stock estimation in mangroves.

7.2.4 Shrimp farming sustainability

For much of the 2000s, Thailand has been one of the world's largest producers and exporters of shrimp (FAO 2018b). In recent years however, disease problems and poor environmental conditions have been an ongoing challenge for shrimp producers in Thailand (FAO 2018a), which has led to major declines in shrimp production since 2012 (Chapter 2 and 5). Shrimp farming sustainability is often presented as a technical problem which can be addressed by farmers adopting best practices and Codes of Conducts (Lebel 2016). However, the social issues surrounding the adoption of best practices have largely been neglected by government officials and industry leaders concerned with shrimp farming sustainability (Lebel 2016; Bush et al. 2010, 2013).

Chapter 5 of this thesis focused on shrimp farmers as resource users in the wider social-ecological system, and the connections between farmer behaviour, social dynamics, and ecological change from a social resilience perspective. This study has shown that there are great local-scale differences in shrimp farming livelihoods in Thailand, not only in terms of technical production but also the entire social and ecological characteristics of different shrimp farming types are different. This is an important and unexpected finding, given that shrimp farming in Thailand is often presented as being very high-intensive production orientated (Kumar and Engle 2016), with considerably less diversity, compared to other Southeast and South Asian countries like Vietnam, Bangladesh or Indonesia, where there is an overall dependence on varying degrees of lower-intensity extensive production systems (Belton and Azad 2012; Jespersen et al. 2014; Joffre et al. 2015).

The information presented in Chapter 5 advances current understanding of shrimp farming diversity in Thailand. This information is vital for experts, government officials, and industry leaders concerned about the sustainability of shrimp aquaculture. For example, the findings have important implications for future improvements to policies and certification standards, such as the Good Aquaculture Practices (GAP-7041) standards in Thailand. Given such diversity in shrimp farming livelihoods in Thailand, there is need for new codes of conduct, standards, and regulations which better engage with, support and embrace this diversity, and the multiple social-technical-ecological challenges faced by shrimp farmers. Attention should be given to ascertain the type of livelihood support needed and to better engage farmers in training and communication to increase social resilience. In particular, this study indicates that more support should be given to low intensity farmers who are shown to be most dependent on natural resources while at the same time less resilient to environmental change due to lower access to technical resources and weaker social networks.

This study also highlighted a lack of collective action and social cohesion across different farmer groups. For example, farmer-farmer networks and social norms were particularly important for medium intensity farmers. Whereas, high and low intensity farmers exhibited fewer social ties. High intensity farmers instead had opted to manage change using their own experiences over external advice, and through technology use.

A lack of common understanding of environmental issues and lower collective action to respond to disturbances across intensity types may act to reduce resilience in the social-ecological system as a whole because of the shared dependency on natural resources and ecosystem services. A recent study of shrimp farmers in Thailand by Bottema et al. (2018) also found a lack of cooperation and communication between farmers operating different production systems within the same landscape. They show, for example, that extensive farmers do not effectively communicate with intensive shrimp farmers because of their belief that they are responsible for water pollution. While research suggests that greater social cohesion facilitates better care for the environment (Mix 2011), effective social cohesion may be a challenge in shrimp farming landscapes because a diversity of farm types have evolved in distinct social-economic-technical configurations. This raises the question of how knowledge exchange and social learning can be better linked across individuals and different farm intensity types to foster greater social cohesion and resilience?

One approach could be for fisheries practitioners and decision makers to focus on increasing spaces for learning and knowledge generation and exchange among farmers and stakeholders. Practitioners could also focus on understanding how LEK within the social-ecological system is generated and used among shrimp farmers. This was an interesting part of the research in Chapter 6 and would be particularly useful for exploring what farmers know about the mangrove ecosystem, how they use this knowledge, how is it disseminated across farmer groups, and how it can be better incorporated into frameworks aimed at achieving sustainability.

7.2.5 Linking aquaculture sustainability to carbon sequestration

Integrated mangrove-shrimp cultivation has recently emerged as a ‘mangrove-friendly’ way of mitigating environmental issues surrounding shrimp aquaculture (such as biodiversity loss, pollution and eutrophication) (Ha et al. 2012; Primavera 2000; Bosma et al. 2016). Integrated mangrove-shrimp culture involves planting and restoration of mangroves around water canals and in sections of aquaculture ponds (Bosma et al. 2016). This type of aquaculture is amenable to small-scale farmers (Primavera 2006) and thus could potentially be promoted among low and medium intensity farmers in Thailand to help ameliorate the sustainability issues highlighted in Chapter 2 and 5 of this thesis. The development of more mangrove-friendly aquaculture in Thailand could potentially be a way of simultaneously conserving and restoring mangrove forest, enhancing C and non-C based ecosystem services, and improving the resilience of shrimp farming livelihoods (Ahmed et al. 2017; Primavera 2000). This type of aquaculture has already been established at a small number of farms in Chanthaburi (IUCN 2018). Increased participation of shrimp farmers in mangrove restoration and more mangrove-friendly culture practices could be enhanced through increasing awareness of the multiple benefits of healthy mangroves through environmental education, training programs, and technical support (Ahmed et al. 2017).

Chapter 8 Reflections on the research methodology

8.1 Identified issues and adaptation of fieldwork methodology

This section begins by reflecting on the fieldwork methodology described in Chapter 3 and how this was adapted through the study, identifying the problems that were encountered and the actions taken to minimise them. The final section reflects on the use of the SES framework and interdisciplinary research.

8.1.1 Potential issues with the fieldwork approach:

- The risk that the current situation and context of the study sites is misinterpreted.
- The risk that words or phrases used in the surveys and workshops would be unfamiliar or misinterpreted by the participants.
- The risk that shrimp farmers and community members would distrust the researcher.
- The risk that there would be conflict between government officials and shrimp farmers in Chanthaburi (Chapter 5).
- The risk that the use of translators would result in the loss or distortion of the local narrative.
- The risk that workshop prompts and questions used in Koh Klang (Chapter 6) would be structured in a way that reinforces the researcher's assumptions about natural resource use and value.
- The risk of inaccuracies in the information gathered on the sampled abandoned shrimp ponds, specifically related to how long they had been abandoned (Chapter 4).
- The risk that the surveyed shrimp farmers in Chanthaburi would not be representative of the shrimp farming landscape (Chapter 5).
- The risk of gender bias in the recruitment of individuals for workshop groups on Koh Klang (Chapter 6).
- Difficulties in grouping livelihoods on Koh Klang (Chapter 6).

- The risk that data is unreliable when people are discussing the past status of ecosystems (Chapter 6).

8.1.2 Actions taken to reduce or eliminate fieldwork issues:

- A pilot study was conducted prior to the main fieldwork phase (section 3.4) which was informative and robust. Initial visits to the study areas enabled development of a network of contacts from government and non-government organisations and research institutions which played a vital role in ensuring support for carrying out the main fieldwork phase of the study. The pilot study also helped with designing the scope of the study and the fieldwork sampling approach, which was adjusted as a result of the visit to the study areas. For example, the initial survey design in Chanthaburi included sampling inside shrimp ponds of a range of farm intensity types with the aim to model shrimp pond health with shrimp farmer behaviour. The pilot study however identified that high intensity ponds were biologically sensitive areas because of ongoing problems with disease in shrimp. It was therefore impossible to recruit high intensity farmers who were willing to have their ponds sampled. The research questions and sample design were therefore adjusted to focus on social-ecological dynamics without pond sampling.

- The exploratory phase of the fieldwork also presented the opportunity to engage with local communities and gather information to see which approaches work best. On Koh Klang this proved to be particularly useful in shaping the research approach. The research questions initially focused on understanding shrimp farmers' perception of ecosystem health and how shrimp farmers have adopted strategies to cope with recent social-ecological change. However, through the preliminary visit, it was identified that all shrimp farming had recently stopped on the island. The research approach was therefore subsequently adapted to focus on community perspectives of ecosystem health, comparing different user groups on the island, rather than shrimp farmers.

- The pilot study also offered a chance to test a set of questions that could be used in the surveys and workshops in Chanthaburi and Koh Klang (Chapters 5 and 6). Several days were spent consulting with academics at Kasetsart University, Bangkok, and with representatives from the NGO MAP, regarding the wording of the surveys, interview scripts and workshop facilitation notes. This was to ensure that the words and phrases used would be understood locally. For example, there was concern that shrimp farmers would respond to survey questions by saying what they believe people would want to hear. Survey questions used in the study presented in Chapter 5 were therefore adjusted to account for this. For example, questions such as '*I believe that the health of the coastal environment is important. To what extent do you agree?*' was rephrased to *'A healthy coastal ecosystem is important. To what extent do you agree with that statement?'*. The risk of the interviewee simply agreeing with the interviewer was reduced as a result. A further example is regarding the use of the phrase 'ecosystem health' to describe ecosystem condition during the workshops conducted on Koh Klang (Chapter 6). Local translators questioned how well this term would be understood in the community. To avoid providing too much information which could influence the workshop discussions, it was decided that human health would be used to explain the meaning of 'ecosystem health', using examples of how insights into the diagnosis of human health is similar to that of ecosystem health.

- During the pilot visit, and through discussions with representatives from the government DMCR, it became apparent that there was some conflict between government officials and shrimp farmers in Chanthaburi due to recent issues with land tenure and the government policy to reclaim illegally occupied shrimp farm land to restore mangrove forest. To overcome problems with trust, surveys were only conducted with the assistance of independent translators rather than government officials, and interviewees were made aware of my role as a researcher. Having the assistance of MSc students from Kasetsart University to help with survey translation also reinforced that the study was for educational purposes, and thus suspicion within the shrimp farming community was removed.

- Care was taken when selecting translators to assist with the research. The primary translator used to facilitate interviews and the workshops on Koh Klang was recommended by a local NGO. She had previously worked on international research projects and on marine conservation initiatives in Thailand and so understood well the objectives of the study. She was very popular within the community and was able to identify local cultures and values. This increased engagement of the community: they showed great interest in the project as a result local people were very keen to share their knowledge.

- The prompts and questions used in the workshops on Koh Klang (Chapter 6) served only as a guide for discussion around particular research themes. Only 'open' questions were used so that the participants were free to discuss and debate their own thoughts and opinions. Participatory mapping was also used as a way to prompt discussions in a free and open way. Semi-structured questions were used only for gathering information during the pilot stage of the study on Koh Klang. In addition, an open-minded approach was adopted during discussions with participants when observing their everyday livelihood activities, which helped with framing prompts for the workshops to reflect topics which were relevant to the community.

- Gathering of unreliable data on the age of abandoned shrimp ponds (Chapter 4) was minimised through a detailed verification process. Information on the age of ponds was cross check using a number of information sources. Landowners were initially interviewed at least twice to gather information. For these interviews, representatives from local NGOs including Raks Thai Foundation and MAP, assisted with translation. Information from the landowners was cross checked with other local residents and information from MAP, who had been working on abandoned shrimp ponds on the island for a few years and so were knowledgeable about shrimp farming dynamics. Historical satellite imagery was also consulted to check the status of the sampled ponds over the past 20 to 30 years. Using translators who were familiar with the community helped to build trust to ensure greater robustness of the information. Repeatedly discussing the information in different ways and comparing responses also helped to ensure accurate data was collected.

- Systematically visiting all households and shrimp farms along the study area in Chanthaburi (Chapter 5) ensured that the sampled farmers would be a representative reflection of the shrimp farming landscape, ensuring that there were no biases associated with gender, geographical location, or farm intensity type. Although an uneven number of shrimp farmers were sampled across different farm intensity types, with around half of the shrimp farmers operating low intensity farms, it is believed to be a good reflection of the ratio of farm intensity types in the area as the largest proportion of farmers were observed to be small-scale low intensity farmers. Furthermore, the unbalanced male: female ratio was a fair reflection of the male dominance within the shrimp farming industry in Chanthaburi.

- Prior to the pilot visit to Koh Klang, the original workshop design separated groups by gender and involvement in ecosystems for their livelihood (Chapter 6). However, the pilot visit revealed that there is little gender difference in the involvement of people working in natural resource related occupations, instead both males and females are engaged in this type of work. The differences are in the type of work related to the environment. For example, males are typically involved in sea fishing whereas females normally engage in collecting shellfish and fish in inshore areas on the island. It was therefore decided that the participants in the workshop would be mixed by gender and grouped by occupation (level of involvement in ecosystem related work).

- Individuals who participated in the workshops on Koh Klang (Chapter 6) were recruited through systematic household visits. The aim was to recruit participants who would reflect groups of people working in ecosystem related livelihoods (such as fishers) and groups working in non-ecosystem related occupations (e.g. market sellers). However, during the recruitment of participants, it was identified that it was difficult to find participants who had no prior experience of work related to the natural environment. Occupation groups were therefore defined by their level of involvement in ecosystems, rather than whether they were or were not involved.

- The perceptions of ecosystem health and change in ecosystem state documented in Chapter 6 were not verified with scientific measurements. Therefore, the accuracy of local knowledge and perceptions was not assessed. It was acknowledged that accuracy of information could be a potential limitation when using local narratives about the past ecosystem state. Therefore, detailed cross checking of information was done to ensure the information would be reliable, this included repeatedly discussing the information in different ways and comparing responses.

8.2 On the use of the SES framework and interdisciplinary research

Integrating methods across natural and social science disciplines proved to be essential for this research because it provided a more holistic understanding of the social-ecological system, which would otherwise not be captured in mono-disciplinary research. The application of the SES concept commenced in the exploratory project phase to help unpack the components of the research problem. The Social-Ecological Systems framework (SESF) was a well-suited approach to help operationalise the interdisciplinary research because it provided a guide to link observed social and ecological processes. The SESF emphasises reciprocity between social and ecological systems, including feedback loops and learning processes in the social system in response to changes in the ecological system. Having a structured overview of the different important components and features of the SES helped with the development of research questions to explore how these components interact, and the relationships between the various components in the empirically observed cases of Chanthaburi and Koh Klang. The SESF was particularly useful because it removed the focus on more common explanatory variables (such as economics), and instead provided a broad range of possible influential variables. As a result, analysis of the research problem took a more open-minded approach.

The SESF also proved important in helping to organise the research information into scalar dimensions that other lenses do not always capture. For example, the multi-tier hierarchy of variables gave a structure to analysis of scales of ecosystem services provided by mangroves, which were explored on a local (such as fisheries production, habitat provision; Chapter 6) and global scale (C sequestration and storage; Chapter 4).

The SESF also helped illustrate the micro-scale social dynamics which have shaped mangrove management on Koh Klang (Chapter 6), including the interplay between the governance system and ecosystem users. The study presented in Chapter 6, for example, illustrates how local knowledge and government agency showcase the polycentric governance and scalar dimensions of mangrove management in coastal Thailand. Informal governance of mangroves on Koh Klang, through local rules, shows how local actors are part of and help to shape the natural resource governance system on the island. Chapter 6 also demonstrates how local knowledge and government and non-government agency can drive changes in environmental awareness and learning process at different hierarchical levels of the social system and recognises the role of religious and culture links for social cohesion needed to operationalise environmental management. Other frameworks, such as the Ecosystem Services framework, do not account for such micro-scale social dynamics (Binder et al. 2013).

In Chapter 4, mangrove ecosystem functioning is analysed beyond its local scale utility for humans. However, one of the main limitations of using the SESF is that it conceptualises the ecological feedbacks and dynamics from an anthropocentric perspective and is better at capturing the complexity of social variables compared to ecological complexity. Another limitation of the SESF is that it doesn't adequately account for the strength of the interaction between ecosystem services and local livelihoods. This research therefore benefitted from integrating other closely linked concepts to SES, such as ecosystem services (Chapter 6). The ecosystem services concept recognises the functions, services and values of natural systems to people and nature. Ecosystem services have a fundamental role in mangrove dependent communities, such as on Koh Klang, and have implications for natural resource governance and collective action. However, the role of ecosystem services in driving feedbacks and dynamics in the SES is understated in the SESF. Therefore, integrating concepts of ecosystem services with SES allowed for conceptualising ecosystem benefits to society and revealed some underlying structures and processes that drive how ecosystems are valued locally.

8.3 Incorporating temporal dynamics into the analysis

Resilience thinking assumes that complex adaptive systems, such as SES, are in an ever-changing state (Walker and Salt 2012; Gunderson and Holling 2002). Resilience is a process linked to dynamic changes over time associated with changing ecosystem state, community learning as they respond to feedbacks in the system, and the willingness of actors to take responsibility and control over their natural resources (Wilson 2010, 2012).

This study captured how different variables in the mangrove social-ecological system interact under changing conditions, but it only incorporated the spatial dimension in an explicit way while some of the temporal dynamics were captured implicitly. Appling a social-ecological systems lens to analyse mangrove shrimp-farming systems has derived interesting results and a snapshot into factors driving resilience. This study has shown so much variation and fluctuation in social-ecological conditions and resilience on spatial scales. This leads to further questions about how this resilience changes over time. That is, how do factors such as ecosystem services, ecosystem conditions, LEK, local perceptions, and farmer decision making come together over time, and do they change?

Investigating these questions through adding a temporal dimension to this study would present an interesting way to explore and build on this research. Adding a temporal dimension using a longitudinal approach that cuts across the themes explored in this study would generate longer term insights into the resilience of shrimp farming in mangrove areas under changing social-ecological conditions. Further investigations could, for example, focus on the resilience of other ecological processes in abandoned shrimp ponds, such as macrofaunal recovery and the development of nursery grounds. Furthermore, to investigate the temporal dynamics of perceptions of ecosystem health, LEK, and ecosystem service delivery, and if or how LEK changes over time in relation to environmental education and participation in natural resource management. A longitudinal study could also capture how shrimp farmer decision making and livelihood strategies change over time in relation to disease and environmental conditions, and how particular livelihood strategies affect the sustainability of shrimp farms (e.g. productivity) in the long term. Implementing a longitudinal study of ecological and social changes and interactions would complement the more cross-sectional approach taken this study.

Chapter 9 Concluding remarks

The rapid development and intensification of shrimp farming along Thailand's coast since the 1980s has come with high social and ecological costs, including livelihood uncertainty, the loss of tens of thousands of hectares of mangrove forest and associated ecosystem services, and the erosion of social-ecological resilience of the coastal ecosystem. This research has highlighted the importance of understanding shrimp farming in mangrove areas as a coupled social–ecological system in order to address pathways for social and ecological resilience. Ultimately, this study is an important contribution to the understanding of increasingly complex problems in the coastal environment. The study has dealt with important questions of how communities and shrimp farmers live with social-ecological change and how they have the ability to turn environmental crisis into opportunities to move forward to promote environmental sustainability. The findings of this study are timely to inform implementation of Thailand's National Economic and Social Development Plan (2017-2021), which calls for developing environmentally-friendly coastal aquaculture and shrimp-farming, encouraging community forest management though creating participatory networks of forest restoration and protection, and the promotion of re-forestation and forest restoration by following King Rama IX's initiative: "growing forest, cultivating mind".

Finally, this research is important to the general public and consumers of shrimp. In emphasising the message of a 'jumbo carbon footprint', as termed by Kauffman et al. (2017), the research provides information about the sustainability of shrimp aquaculture and potential trade-offs between consuming shrimp from unsustainable sources at the cost of lost ecosystem services at the local level due to mangrove conversion. In highlighting the issues around shrimp farming sustainability, this research will help consumers to make better informed decisions regarding how their food choices affect ecosystems, livelihoods and climate change.

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Appendix

Table 1. Qualitative description of the 12 abandoned ponds sampled at Koh Klang, Krabi Province (Chapter 4).

Pond category	Estimated time since abandoned (years)	History of pond use
EMR	18	Shrimp farming then no activity from 1999 onwards. 2013 EPIC CBEMR hydrological restoration
EMR	13	1984 mangrove converted; 1998-2001 pond used for shrimp farming; 2004 pond used for raising fish. 2013 EPIC CBEMR hydrological restoration
EMR	12	2000-2005 Shrimp farming then no activity. 2015 GNF CBEMR hydrological restoration
A10	10	Intensive shrimp pond. No use after pond was abandoned
A15	15	Intensive shrimp pond. No use after pond was abandoned
A22	22	Intensive shrimp pond. No use after pond was abandoned

Table 2. Soil properties and aboveground and belowground carbon stocks of the mangrove and abandoned shrimp pond sites at Koh Klang, Krabi Province (Chapter 4). Data are means.

		Soil Properties				C stocks ($t\ C\ ha^{-1}$)			
Category and Location	**Plot**	**Mean depth (cm)**	**C (%)**	**BD ($g\ cm^{-3}$)**	**C density ($g\ C\ cm^{-3}$)**	**Soil**	**Tree**	**Root**	**Total Ecosystem**
Mangrove	Mangrove J1	266	1.99	1.34	0.025	711.3	68.9	10.3	790.5
	Mangrove J2	281	4.71	0.65	0.031	1017.8	74.2	10.2	1102.1
	Mangrove J3	290	6.06	0.63	0.036	1100.9	85.7	15.4	1202.0
	Mangrove J4	199	2.39	1.08	0.025	490.9	70.4	12.5	573.8
	Mangrove J5	255	6.06	0.76	0.044	1086.3	79.5	16.0	1181.7
	Mangrove J6	283	2.57	1.13	0.028	912.3	77.7	13.6	1003.6
	Mangrove J7	296	4.97	0.79	0.038	1293.6	48.0	11.0	1352.6
	Mangrove mean	267	4.11	0.91	0.032	944.7	72.06	12.70	1029.5
A10	A10 P4	121	1.20	1.41	0.017	214.2	T	T	214.24
	A10 P5	149	1.84	1.39	0.025	421.1	T	T	421.10
	A10 P6	117	1.60	1.51	0.023	276.7	T	T	276.68
	A10 mean	129	1.55	1.43	0.022	304.0	T	T	304.01
A15	A15 P2	240	1.26	1.45	0.018	545.8	22.7	3.92	572.4
	A15 P3	265	2.28	1.25	0.028	974.8	25.5	11.97	1012.3
	A15 P3b	241	2.26	1.38	0.031	984.9	19.2	8.58	1012.7
	A15 mean	249	1.93	1.36	0.026	835.2	22.5	8.16	865.80
A22	A22 P7	158	2.36	1.36	0.031	537.8	5.89	2.66	546.34
	A22 P8	182	2.33	1.37	0.031	605.2	5.45	2.90	613.51
	A22 P9	126	2.14	1.37	0.028	388.0	7.59	4.46	400.04
	A22 mean	155	2.28	1.37	0.030	510.3	6.31	3.34	519.96

EMR	EMR P1	275	2.22	1.30	0.029	840.6	NS	NS	NS
	EMR P10	136	2.22	1.11	0.024	346.2	27.7	9.33	383.16
	EMR P11	160	2.70	1.14	0.029	474.1	28.7	2.94	505.71
	EMR mean	190	2.38	1.18	0.027	553.6	28.2	6.13	444.44
	Pond mean	180.8	2.03	1.34	0.026	550.9	12.97	4.25	541.65

NS denotes where trees were not sampled; T=trace.

Bulk density (g cm^{-3})

Category and Plot	Depth (cm) 0-15	15-30	30-50	50-100	>100cm	Overall Mean (± 1SE)
Mangrove J1	1.53	1.32	1.39	1.26	1.21	1.34 ± 0.06
Mangrove J2	0.57	0.57	0.7	0.68	0.75	0.65 ± 0.04
Mangrove J3	0.55	0.68	0.66	0.62	0.65	0.63 ± 0.02
Mangrove J4	1.09	1.27	0.97	1.1	0.95	1.08 ± 0.06
Mangrove J5	0.78	0.7	0.8	0.77	0.76	0.76 ± 0.02
Mangrove J6	1.19	1.07	1.06	1.23	1.08	1.13 ± 0.04
Mangrove J7	0.82	0.89	0.81	0.7	0.74	0.79 ± 0.03
Mangrove mean	0.93	0.94	0.91	0.91	0.86	0.91 ± 0.01
A10 P4	1.19	1.53	1.65	1.44	1.22	1.41 ± 0.09
A10 P5	1.33	1.68	1.47	1.35	1.14	1.39 ± 0.09
A10 P6	1.67	1.46	1.55	1.68	1.19	1.51 ± 0.09
A10 mean	1.40	1.56	1.56	1.49	1.18	1.44 ± 0.07
A15 P2	1.56	1.33	1.44	1.41	1.53	1.45 ± 0.04
A15 P3	1.24	1.24	1.4	1.18	1.21	1.25 ± 0.04
A15 P3b	1.36	1.55	1.33	1.23	1.44	1.38 ± 0.05
A15 mean	1.39	1.37	1.39	1.27	1.39	1.36 ± 0.02
A22 P7	1.62	1.33	1.44	1.31	1.12	1.36 ± 0.08
A22 P8	1.59	1.39	1.29	1.42	1.17	1.37 ± 0.07
A22 P9	1.34	1.5	1.61	1.26	1.12	1.37 ± 0.1
A22 mean	1.52	1.41	1.45	1.33	1.14	1.37 ± 0.07
EMR P1	1.42	1.28	1.25	1.34	1.19	1.30 ± 0.04
EMR P10	1.34	1.12	1.17	0.94	1.0	1.11 ± 0.07
EMR P11	1.47	1.26	1.19	0.93	0.84	1.14 ± 0.11
EMR mean	1.41	1.22	1.20	1.07	1.01	1.18 ± 0.07
Pond mean	1.42 ± 0.04	1.39 ± 0.05	1.4 ± 0.05	1.29 ± 0.06	1.18 ± 0.05	1.34 ± 0.05

C content (%)

Category and plot	Depth (cm) 0-15	15-30	30-50	50-100	>100	Overall Mean
Mangrove J1	1.60	1.51	1.91	2.56	2.37	1.99
Mangrove J2	4.98	4.04	4.42	4.77	5.35	4.71
Mangrove J3	5.77	5.60	6.52	6.22	6.20	6.06
Mangrove J4	1.95	1.90	2.96	2.41	2.71	2.39
Mangrove J5	5.53	5.96	6.57	6.58	5.66	6.06
Mangrove J6	2.14	2.10	2.77	2.72	3.13	2.57
Mangrove J7	3.68	3.66	4.87	6.16	6.49	4.97
Mangrove mean	3.66	3.54	4.29	4.49	4.56	4.11
A10 P4	1.15	0.98	0.88	1.43	1.54	1.20
A10 P5	1.10	1.41	1.59	2.60	2.52	1.84
A10 P6	0.50	1.53	1.65	1.48	2.82	1.60
A10 mean	0.92	1.30	1.38	1.84	2.29	1.55
A15 P2	1.24	1.28	0.88	1.11	1.82	1.26
A15 P3	1.09	1.41	2.09	3.44	3.34	2.28
A15 P3b	1.08	1.42	2.08	3.43	3.28	2.26
A15 mean	1.14	1.37	1.68	2.66	2.81	1.93
A22 P7	0.93	1.60	3.25	2.64	3.36	2.36
A22 P8	1.43	1.85	2.70	3.20	2.47	2.33
A22 P9	1.43	1.55	1.65	2.79	3.29	2.14
A22 mean	1.26	1.67	2.53	2.88	3.04	2.28
EMR P1	1.65	2.18	2.38	2.25	2.65	2.22
EMR P10	1.23	2.28	2.14	3.30	2.16	2.22
EMR P11	1.78	2.40	2.59	2.92	3.83	2.70
EMR mean	1.55	2.29	2.37	2.82	2.88	2.38
Pond mean	1.22	1.66	1.99	2.55	2.76	2.03

Table 3. Soil C stores (tC ha^{-1}) at depth intervals in the mangrove forest sites (n = 7) and the abandoned pond sites on Koh Klang, Krabi Province (Chapter 4). Pond sites are categorised as abandoned 10 years (n = 3), 15 years (n = 3), 22 years (n = 3), and EMR ponds (n = 3). C stores are in units of tC ha^{-1} ± 1s.e.m.

Soil Depth (cm)	Mangroves	10 years	15 years	22 years	EMR
0-15	42.49 ± 3.44	18.34 ± 2.97**	23.74 ± 2.64*	28.46 ± 3.34	41.84 ± 2.07
15-30	42.22 ± 3.97	30.42 ± 4.05	28.23 ± 2.40	35.09 ± 1.87	41.84 ± 4.3
30-50	68.17 ± 6.72	42.37 ± 6.72	46.43 ± 10.52	72.13 ± 11.74	57.12 ± 3.52
50-100	176.68 ± 16.05	134.3 ± 21.62	164.05 ± 43.09	191.92 ± 17.59	147.16 ± 5.78

The asterisks show Kruskal-Wallis level of significant difference between the pond and mangrove sites along rows representing soil depth intervals: *P < 0.05; **P < 0.01.

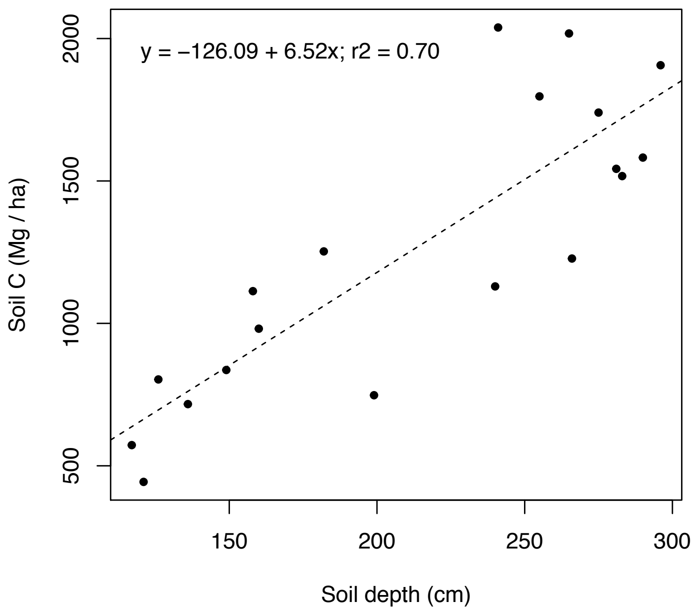

Figure 1. Relationship between soil C storage and soil depth (Chapter 4). For every 50 cm increase in soil depth, SOC stock increases by around 325 Mg C ha.

Table 4. List of the questions used in the survey conducted with shrimp farmers in Chanthaburi Province, and how the questions relate to specific components of the IAC Framework (Chapter 5).

Component of IAC Framework	Factor to measure	Survey question
Contextual factors (socio-economic)	Age	
Contextual factors (socio-economic)	Level of education	What is your highest educational level reached?

Contextual factors (socio-economic)	Member of a shrimp farmer group (frequency of attendance to meetings)	Are you a member of a Shrimp Farmers' Group?
Contextual factors (socio-economic)	Received training on farming practices from research group or shrimp farmer group	Have you received formal training and/or technical assistance in shrimp farming?
Contextual factors (socio-economic)		Do you have access to the technical equipment needed to farm shrimp intensively?
Contextual factors (socio-economic)	Size of shrimp farm (area)	What is the size of your farm (rai)? What was the land used for before the shrimp ponds were built?
Contextual factors (socio-economic)	Number of shrimp ponds	How many ponds are on the farm? How many of these ponds did you use in the last harvest? For how many years have the ponds been in use? Of the ponds used in the last harvest, please indicate for each pond: Area of pond (rai) What products were produced (e.g. shrimp, fish.) Pond stocking density (no. per pond)
Contextual factors (socio-economic)	Total annual production of shrimp	How many crops of shrimp did you produce in the past 12 months? The last time you harvested your ponds, what was the total weight of your harvest (kg)?
Contextual factors (socio-economic)	Average farm labour units (people/year)	In the past 12 months, did anyone help you with the running of the farm?
Contextual factors (socio-economic)	Land ownership status	Are you the owner of the shrimp ponds or are they leased?
Contextual factors (socio-economic)	Annual operating costs:	The last time you harvested your ponds, what was the cost of producing the harvest (baht)?
Contextual factors (socio-economic)	Access to credit/investment capital	Do you have access to credit to assist you with running the farm?
Contextual factors (socio-economic)	Level of outstanding debt	Do you currently have any debt from shrimp farming?
Contextual factors (socio-economic)	Annual income	What proportion of your total income normally comes from shrimp farming?
Contextual factors (production)	Location of shrimp farm	What is the location of your shrimp farm? (indicate on map)
Contextual factors (production)	Seasonal weather conditions	During the rainy season, do you change the amount of shrimp you stock in your ponds?
Contextual factors (production)	Disease frequency on shrimp farm	How many times did your shrimp farm experience disease outbreaks in the **last 2 years**?

Contextual factors (production)	Shrimp mortality due to disease outbreak	**The last time you harvested your ponds**, approximately what proportion of your shrimp survived?
Contextual factors (production)	Frequency of erosion of pond dykes	Have you observed erosion of the pond dykes on your farm?
Habit	Number of years as intensive/extensive shrimp farmer	How long have you been farming shrimp? Has the amount of shrimp that you produce changed over the **past 2 years**? Has the number of different products that you produce (e.g. shrimp, fish) changed over the **past 2 years**?
Expectations	Perceived risks	Are there any risks associated with intensive shrimp farming?
Expectations	Expected market demand	**At the start of the last production cycle**, did you expect the market demand for shrimp to:
Expectations	Perception of shrimp prices	**At the start of the last production cycle**, what price did you expect to sell your harvest for? (baht/kg)
Expectations	Perception of price of shrimp	**At the start of the last production cycle**, did you expect the market price for shrimp to:
Expectations	Perceived impact of shrimp farming on water quality	If you increased the amount of shrimp you produce in your ponds, how do you think this would impact on the water quality in the ponds?
Expectations	Perceived impact of shrimp farming on soil quality	If you increased the amount of shrimp you produce in your ponds, how do you think this would impact the soil quality in the ponds?
Expectations	Whether shrimp farmer expects a reduction in shrimp disease if shrimp farm intensity is reduced/increased	If you increased the amount of shrimp you produce in your ponds, how do you think this would affect the survival rate of shrimp?
Subjective culture - social norms	How shrimp farmer is perceived by others	Is the opinion of ______ about the amount of shrimp you produce per pond important to you? Your spouse/family Other shrimp farmers Your local Shrimp Farmer group Research groups/aquaculture experts The government Environmentalist groups What do you think_______ thinks about the amount of shrimp you produce per pond?
Subjective culture - social norms	Social conflict	What do you think_______ would think if you increased the amount of shrimp you produce per pond?
Subjective culture - social norms	How often shrimp farmer follows advice from others	How often do you follow advice from_______ regarding the amount of shrimp you stock in your ponds?

Subjective culture - social norms	Perception about production intensity of other shrimp farmers	At the start of a production cycle, what are the three most important things that you consider when deciding on how many shrimps to stock in your ponds?
Subjective culture - social norms	Perception about the intensity of other shrimp farms	Do most shrimp farmers in this area stock shrimp in their ponds at the same density as you? Do most shrimp farmers in this area produce the same number of crops per year as you?
Subjective culture - roles	Status of shrimp farmer	What are the 3 most important aspects to being a good shrimp farmer?
Subjective culture - roles	Care for the environment	"*The health of the coastal environment is important to me*". How much do you agree with this statement?
Subjective culture - values	Religion	What is your religion?
Physiological arousal	Feelings associated with shrimp farming	Do you enjoy farming shrimp at this level of intensity?

Table 5a. Perceptions of a "good shrimp farmer" (Chapter 5). Data shows the percentage of farmers stating factor as a main trait.

Good farmer trait	Farm intensity Low	Medium	High
Stay within budget	5.9	11.5	15.8
Care for the environment	21.6	19.2	10.5
Treat pond waste	7.8	19.2	15.8
Learn from experience	0	11.5	21.0
Good pond and shrimp management	53.8	29.4	31.6
No chemical use	58.8	23.1	10.5
Produce by nature	27.5	3.8	10.5

Table 5b. Perceived risks of intensive farming (Chapter 5). Data shows the percentage of farmers stating factor as a main risk of intensive shrimp farming.

Risk factor	Farm intensity Low	Medium	High
Disease	62.7	80.8	78.9
High cost	45.1	23.1	21.1
Low quality shrimp PL	4.0	23.1	31.6
Shrimp mortality	82.4	96.2	94.7
Losing money	72.5	84.6	78.9

Table 5c. Stocking considerations at the start of the production cycle (Chapter 5). Data shows the percentage of farmers stating factor as a main stocking consideration.

Stocking consideration factor	Farm intensity Low	Medium	High
Area of pond (suitability)	13.7	23.1	26.3
Production costs	27.5	19.2	5.3
Desired harvest size and quality of shrimp	19.6	23.1	21.1
Local environmental health and disease prevalence	9.8	15.4	15.8
Money available and potential loss of money	41.2	26.9	36.8
Previous crop success	11.8	7.7	5.3
Season	7.8	30.8	36.8

Table 6. Characteristics of the participants that took part in the workshops on Koh Klang (Chapter 6).

Workshop number	Village	Gender M:F	Age range	Primary occupation	Second occupation	Previous occupation
1	3	7:3	33-77	Sea Fishers, Oil palm farmer.	Freelance handyman, Homestay owner, Educator, Mechanic.	Navy soldier, Hotel worker, Fisherman, Rubber farmer.
2	3	0:7	45-80	Homestay owner, Cook, Market seller, Mother, Grandmother, Child carer.	Homestay owner, Mangrove and inshore fisher, Cigarette paper maker/seller.	Mangrove and inshore fisher, Shrimp farmer, Sea fisher, Hotel worker, market fish seller.
3	3	1:6	15-30	Student, Shop owner, Freelance laundrette, Tourist company officer, Shop assistant, Mother.		Shrimp market seller, Hotel worker, Freelance laundrette, Pharmacy worker.
4	3	1:6	19-30	Mother, Mangrove and inshore fisher, Sea Fisher.	Mangrove and inshore fisher, Mechanic.	Student, Freelance handyman, Sea Fisher, market fish seller.
5	1	0:8	36-85	Rice farmer, Chicken farmer, Sea Fisher, Turkey farmer, Fruit farmer, Inshore and mangrove shellfish collector and seller.		Sea Fisher, Rice farmer.
6	1	0:8	40-62	Mother, Mobile food seller, Shop owner, School cook.		Market worker.
7	1	4:3	18-29	Mother, Mangrove and inshore fisher, Sea Fisher, Fish seller, Sea shrimp fisher.	Student, Fish seller, Sea Fisher.	Sea fisher.
8	1	5:4	18-30	Mother, Student, Restaurant worker, Taxi boatman.	Baker and cake seller.	Student, Shop owner, food seller.

Table 7. Frequency of discussion about each type of ecosystem service (from workshops conducted on Koh Klang, Chapter 6). Comparisons are made between groups based on a) workshop number, b) employment type, c) age, and d) place of residence.

			Frequency of observations			
Age group	**Village**	**Employment type**	**Cultural**	**Provisioning**	**Regulating**	**Supporting**
Older	3	Ecosystem related	5	6	4	7
Older	3	Non-ecosystem related	4	8	1	6
Younger	3	Non-ecosystem related	2	12	5	3
Younger	3	Ecosystem related	4	8	1	7
Older	1	Ecosystem related	4	8	2	4
Older	1	Non-ecosystem related	1	11	2	3
Younger	1	Ecosystem related	5	7	0	5
Younger	1	Non-ecosystem related	8	8	5	7
		Total observations	**33**	**68**	**20**	**42**

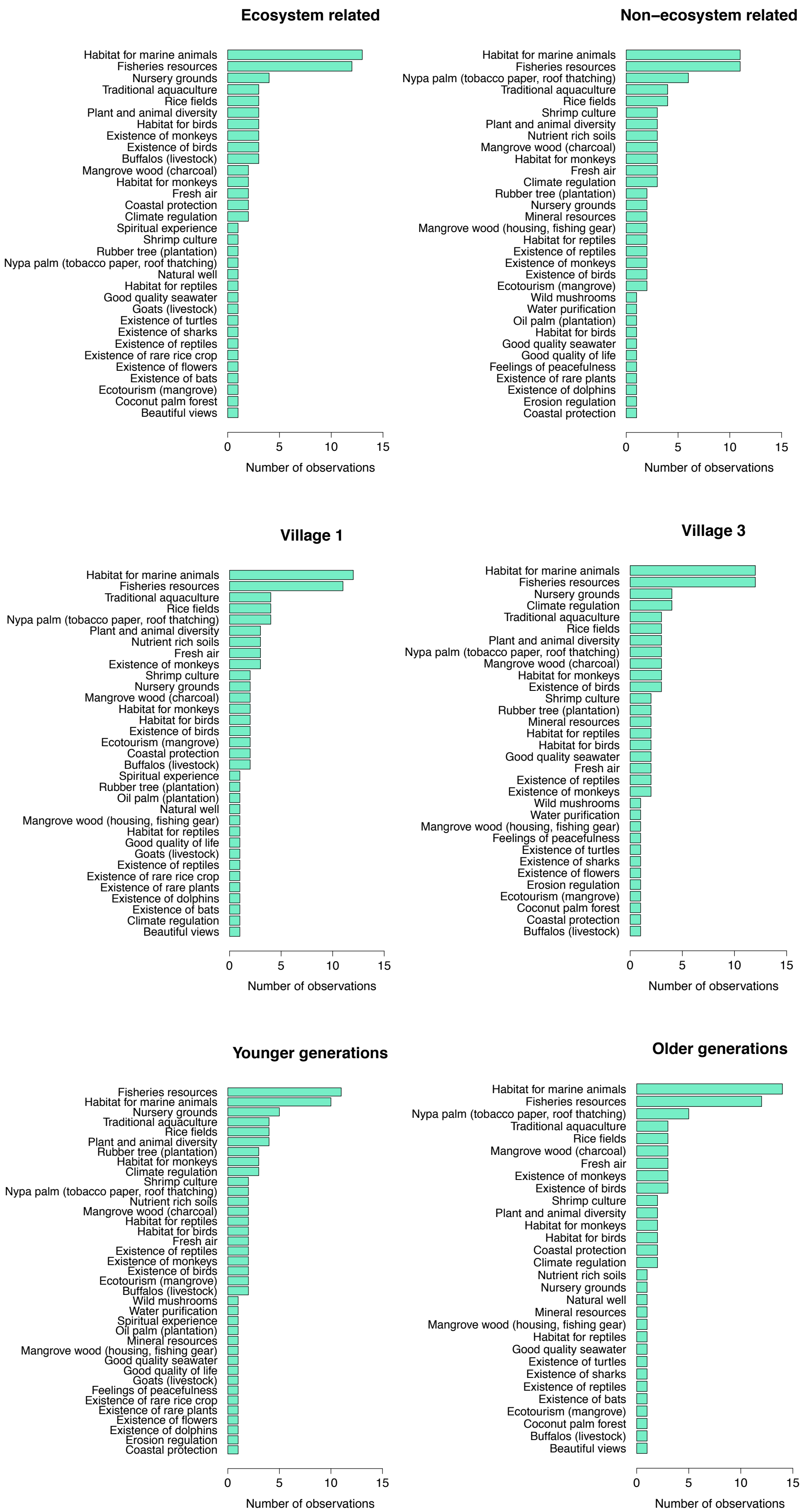
Ecosystem related
Habitat for marine animals
Fisheries resources
Nursery grounds
Traditional aquaculture
Rice fields
Plant and animal diversity
Habitat for birds
Existence of monkeys
Existence of birds
Buffalos (livestock)
Mangrove wood (charcoal)
Habitat for monkeys
Fresh air
Coastal protection
Climate regulation
Spiritual experience
Shrimp culture
Rubber tree (plantation)
Nypa palm (tobacco paper, roof thatching)
Natural well
Habitat for reptiles
Good quality seawater
Goats (livestock)
Existence of turtles
Existence of sharks
Existence of reptiles
Existence of rare rice crop
Existence of flowers
Existence of bats
Ecotourism (mangrove)
Coconut palm forest
Beautiful views
0 5 10 15
Number of observations
Non–ecosystem related
Habitat for marine animals
Fisheries resources
Nypa palm (tobacco paper, roof thatching)
Traditional aquaculture
Rice fields
Shrimp culture
Plant and animal diversity
Nutrient rich soils
Mangrove wood (charcoal)
Habitat for monkeys
Fresh air
Climate regulation
Rubber tree (plantation)
Nursery grounds
Mineral resources
Mangrove wood (housing, fishing gear)
Habitat for reptiles
Existence of reptiles
Existence of monkeys
Existence of birds
Ecotourism (mangrove)
Wild mushrooms
Water purification
Oil palm (plantation)
Habitat for birds
Good quality seawater
Good quality of life
Feelings of peacefulness
Existence of rare plants
Existence of dolphins
Erosion regulation
Coastal protection
0 5 10 15
Number of observations
Village 1
Habitat for marine animals
Fisheries resources
Traditional aquaculture
Rice fields
Nypa palm (tobacco paper, roof thatching)
Plant and animal diversity
Nutrient rich soils
Fresh air
Existence of monkeys
Shrimp culture
Nursery grounds
Mangrove wood (charcoal)
Habitat for monkeys
Habitat for birds
Existence of birds
Ecotourism (mangrove)
Coastal protection
Buffalos (livestock)
Spiritual experience
Rubber tree (plantation)
Oil palm (plantation)
Natural well
Mangrove wood (housing, fishing gear)
Habitat for reptiles
Good quality of life
Goats (livestock)
Existence of reptiles
Existence of rare rice crop
Existence of rare plants
Existence of dolphins
Existence of bats
Climate regulation
Beautiful views
0 5 10 15
Number of observations
Village 3
Habitat for marine animals
Fisheries resources
Nursery grounds
Climate regulation
Traditional aquaculture
Rice fields
Plant and animal diversity
Nypa palm (tobacco paper, roof thatching)
Mangrove wood (charcoal)
Habitat for monkeys
Existence of birds
Shrimp culture
Rubber tree (plantation)
Mineral resources
Habitat for reptiles
Habitat for birds
Good quality seawater
Fresh air
Existence of reptiles
Existence of monkeys
Wild mushrooms
Water purification
Mangrove wood (housing, fishing gear)
Feelings of peacefulness
Existence of turtles
Existence of sharks
Existence of flowers
Erosion regulation
Ecotourism (mangrove)
Coconut palm forest
Coastal protection
Buffalos (livestock)
0 5 10 15
Number of observations
Younger generations
Fisheries resources
Habitat for marine animals
Nursery grounds
Traditional aquaculture
Rice fields
Plant and animal diversity
Rubber tree (plantation)
Habitat for monkeys
Climate regulation
Shrimp culture
Nypa palm (tobacco paper, roof thatching)
Nutrient rich soils
Mangrove wood (charcoal)
Habitat for reptiles
Habitat for birds
Fresh air
Existence of reptiles
Existence of monkeys
Existence of birds
Ecotourism (mangrove)
Buffalos (livestock)
Wild mushrooms
Water purification
Spiritual experience
Oil palm (plantation)
Mineral resources
Mangrove wood (housing, fishing gear)
Good quality seawater
Good quality of life
Goats (livestock)
Feelings of peacefulness
Existence of rare rice crop
Existence of rare plants
Existence of flowers
Existence of dolphins
Erosion regulation
Coastal protection
0 5 10 15
Number of observations
Older generations
Habitat for marine animals
Fisheries resources
Nypa palm (tobacco paper, roof thatching)
Traditional aquaculture
Rice fields
Mangrove wood (charcoal)
Fresh air
Existence of monkeys
Existence of birds
Shrimp culture
Plant and animal diversity
Habitat for monkeys
Habitat for birds
Coastal protection
Climate regulation
Nutrient rich soils
Nursery grounds
Natural well
Mineral resources
Mangrove wood (housing, fishing gear)
Habitat for reptiles
Good quality seawater
Existence of turtles
Existence of sharks
Existence of reptiles
Existence of bats
Ecotourism (mangrove)
Coconut palm forest
Buffalos (livestock)
Beautiful views
0 5 10 15
Number of observations

Figure 2. Perceptions of ecosystem services in relation to socio-demographic determinants (Chapter 6). Data shows the types of services of each ecosystem service category mentioned by each group. Comparisons are made between groups based on a) occupation (ecosystem related, and non-ecosystem related) b) place of residence (village 1 and village 3), and c) age (older generations >35 years and younger generations <35 years old).

Table 8. Mangrove ecosystem service delivery. Data is from workshops conducted with community members on Koh Klang, Krabi Province (Chapter 6). 'Number of observations' refers to the number of mentions of a particular ecosystem service provided by mangroves.

Mangrove ecosystem service	Type of ecosystem service	Number of observations
Fisheries resources	Provisioning	8
Nypa palm (tobacco paper, roof thatching)	Provisioning	7
Traditional aquaculture	Provisioning	7
Habitat for marine animals	Supporting	7
Mangrove wood (charcoal production)	Provisioning	5
Climate regulation	Regulating	5
Fresh air	Regulating	5
Habitat for monkeys	Supporting	5
Nursery grounds	Supporting	5
Existence of birds	Cultural	5
Existence of monkeys	Cultural	5
Shrimp culture	Provisioning	4
Coastal protection	Regulating	3
Habitat for birds	Supporting	3
Habitat for reptiles	Supporting	3
Ecotourism	Cultural	3
Water quality regulation	Regulating	3
Mangrove wood (house building, fishing gear)	Provisioning	2
Mineral resources	Provisioning	2
Wild mushrooms	Provisioning	1
Erosion regulation	Regulating	1
Nutrient rich soils	Regulating	1
Existence of dolphins	Cultural	1
Existence of reptiles	Cultural	1