

Bangor University

DOCTOR OF PHILOSOPHY

Towards successful community mangrove management and rehabilitation

Wodehouse, Dominic

Award date:
2020

Awarding institution:
Bangor University

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 16. May. 2022

TOWARDS SUCCESSFUL COMMUNITY MANGROVE MANAGEMENT AND REHABILITATION

A Thesis for the Degree of Doctor of Philosophy

By D.C.J. Wodehouse, MSc, B. Comm (Hons.), Tech Cert.

School of Natural Sciences, Bangor University

College of Environmental Sciences and Engineering

Bangor, Gwynedd. LL57 2UW

January 2020



PRIFYSGOL
BANGOR
UNIVERSITY

Title	Towards successful community mangrove management and rehabilitation
Principle Supervisor	Dr Mark Rayment
Co-Supervisors	Prof. Morag McDonald
Finance	This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
Assessment Committee	<p>Prof. Dave Chadwick (Chair)</p> <p>Environment Centre Wales. School of Natural Sciences. Bangor University</p> <p>Prof. Julia P.G. Jones (Internal Examiner)</p> <p>School of Natural Sciences, Bangor University</p> <p>Prof. Mark Huxham, (External Examiner)</p> <p>School of Applied Sciences, Edinburgh Napier University.</p>
Date of Registration	1 st September 2011
Date of First Submission	30 st September 2019
Final Submission	21 st January 2020

SUMMARY

Mangroves are an assemblage of salt-tolerant trees and plants that exist in the intertidal coastal zones of countries in the tropics and sub-tropics. Healthy mangroves can greatly assist the sustainable existence of local coastal villagers because of the wealth of ecosystem goods and services they provide. However, a significant proportion of this ecosystem has been degraded or converted to other land uses. Many government mangrove agencies are realising that because of the diffuse nature of this ecosystem and limited government resources, they need to work with local communities that are based within or near these forests, encouraging some form of community management and involvement to counter mangrove losses.

The overall goal of this research was to explore some of the barriers that inhibit successful community mangrove management, across two countries in Southeast Asia in order to contribute to the discussion about how best to enable this process. The first objective was to assess whether communities were able to rehabilitate mangroves successfully and the role of government assistance within this. The second objective was to study in a more qualitative, detailed manner how villagers carried out this rehabilitation work and to identify the knowledge and understanding that underpinned their decisions, contrasting these with actual outcomes.

Environmental organisations typically encourage protection of existing mangroves over rehabilitation of degraded areas because rehabilitation projects have uncertain outcomes, and the full suite of ecosystem benefits are only provided by mature stands. Therefore, a third objective was to explore how communities preserve their own mangroves and inhibit cutting of mangrove through the development of their own management rules, or the use of national law. A final objective was to help independent organisations to assist mangrove communities by suggesting a simple method that would allow comparison and therefore ranking of the status of mangroves across a group of communities, to indicate which were most in need of, and likely to benefit from, outside assistance.

Outcomes from the first two objectives suggested that inappropriate targets, set centrally by mangrove agencies, together with gaps in villager and mangrove agency field office staff knowledge of mangrove ecosystems, have led to sub-optimal rehabilitation outcomes. Almost all rehabilitation projects relied on planting rather than assisting natural regeneration, and much of this planting proved either unnecessary or was conducted in inappropriate locations. There was confusion about the suitability of mudflats for planting, normally considered below an appropriate tidal elevation for mangrove establishment. Effective tidal flushing and drainage was demonstrated to have a significantly positive effect on planting results. Villagers were aware of the possibility of

rehabilitating some sites simply by improving the hydrology, but this appeared not to result in activities on site to improve site topography or hydrology.

Consideration of the community management rules of this sample of villages suggested that many of the principles suggested by terrestrial community forest researchers hold true in a mangrove environment, particularly the need for strong social capital and effective leadership, but as has been suggested previously, local context and parameters play such a significant role that the wider application of these conclusions should be done with caution.

Finally, to help external organisations that wish to assist mangrove communities, I have suggested a series of indicators for the development of mangrove quality and sustainability criteria, that when combined with other bio-physical measures, are easier to aggregate and assess than some of the existing terrestrial forest indicators. A suggested indicator weighting system is proposed, which with further testing in mangrove ecosystems other than river deltas, might provide a simple way to prioritise the location of mangrove management interventions.

School of Natural Sciences, Bangor University.

Thoday Building. Deiniol Rd. Bangor. Wales. LL57 2UW. UK

d.wodehouse@bangor.ac.uk

ACKNOWLEDGEMENTS

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

The sincerest thanks go to many people who assisted this research. In particular I am hugely grateful to my supervisor, Dr Mark Rayment for his patience, good humour and support. Thank you also to my PhD committee of Prof. Rob Brook (retired), Prof. Julia Jones, Prof. Dave Chadwick and Prof. Morag McDonald for their insightful comments and feedback.

Thank you to the translators and field assistants, Khun Phonsawan 'Gift' Jinowat, Khun Kamondham 'Tuan' Truatmakha and Khun Petchrung 'Aey' Sukpong in Thailand; Valiente Milan and Jevy Simion in Palawan and Agnes 'Ging' Faustino and Jerry Qutorio for their patience, stamina and discerning interpretation. Thank you also to Khun Dear, Yosuke Fukushima san and Khun Namtan 'Namy' Kunja for helping with the transects, and Jim Enright and Khun Jaruwan 'Ning' Kaewmahanin of NGO Mangrove Action Project for the use of the office, research advice and long-term support.

Thank you to Assoc. Prof. Boosya Bunnag and Dr Pavinee 'Jin' Patanachan of King Mongkut University for acting as Thai supervisors and helping with village selection; the National Research Council of Thailand; the directors and staff of the Royal Thai Government's Department Marine and Coastal Resources mangrove field offices for their generosity with their time and knowledge; Dr Antonio Dano and Dr Portia Lapitan from the Philippine Ecosystems Research and Development Bureau and John Pontillas of the Palawan Council for Sustainable Development and the members of the Malampaya Sound Protected Area Management Board for permission to conduct this research.

Thank you to Dr Isabel Rosa and Dr James Gibbons for providing a statistical light in my numerical darkness, Assoc. Prof. Dan Friess of the National University of Singapore for his GIS expertise, Dr Jean Yong of the Singapore University of Technology and Design for his mangrove species identification PDF and Charlotte Bubb for proof reading. Additionally, thank you to Prof. Rene Rollon of University of Philippines and Assit. Prof. Sev Salmo III of Ateneo University for their fieldwork advice. Finally, thank you to the excellent people in the mangrove villages studied for their generosity and willingness to share their lives.

AUTHORSHIP

The first chapter has been prepared for and published in the peer-review journal *Estuarine, Coastal and Shelf Science* (2019). I carried out the fieldwork, analysis, writing of the paper and all communication with the publication. My supervisor, Dr Mark Rayment helped developed the research questions, designed the research matrix, contributed several data capture techniques, added to the statistical analysis and edited the paper. Therefore, in Chapter 1, the pronoun 'we' is used to acknowledge the significant input of my co-author.

<https://doi.org/10.1016/j.ecss.2019.04.003>

In the other data chapters Dr Rayment developed the research questions with me, designed the research matrix, contributed several data capture techniques, added to the statistical analysis and edited the chapters. I designed the studies, developed the semi-structured questionnaires and the rehabilitation science test (Chapter 2), conducted all the fieldwork with the aid of translators, captured, coded and analysed the data, wrote and edited the thesis. While acknowledging this valuable input from my supervisor, PhD Committee and other staff at Bangor University described in the 'Acknowledgements' section, and the tremendous assistance of the translators, the pronoun 'I' is used where appropriate as I conducted all the fieldwork and my overall contribution is estimated to be 95%.

Dedicated to the late

Roy R. 'Robin' Lewis III. 1944-2018

whose training in India (2005) set me on this path.

What's needed is informed supervision,

between the scientists and the mangrove workers on the ground.

And to the memory of my parents,

Joyce and Charles Wodehouse

ACRONYMS

CBEMR /EMR	community-based ecological mangrove rehabilitation
CBNRM	community-based natural resource management
CENRO	centre of environment and natural resources office (DENR field offices in the Philippines)
CFM	community forest management
CG	conservation group (within a village)
CGL	conservation group leader
DBH ¹³⁰	Diameter at breast height (measured 1.30m above the ground)
DENR	Department of Environment and Natural Resources (host of the mangrove agency in the Philippines)
Df	degrees of freedom
DMCR	Department of Marine and Coastal Resources (Mangrove Agency, Thailand)
DNP	Department of National Parks (Thailand)
FSCI	forest structure complexity index
GLZM	generalised linear model
GPS	global positioning system/satellite
Ha	hectare
HMRA	hierarchical multiple regression analysis
Inv.	inverse
ISO	derived from the Greek isos (equal) a measure of photographic sensitivity
IUCN	International Union of Conservation Networks
KII	key informant interviews
KML	keyhole mark-up language (expressing geographic annotation)
LAI	leaf area index

MB	megabytes
NGO	non-governmental organisations
NGP	National Greening Program (a Philippine terrestrial and mangrove tree planting program)
NTFP	Non-timber forest products
PBC	perceived behavioural control
PCQM	point centre quarter method (for tree inventory)
PPT	parts per thousand (a measure of salinity)
SD	standard deviation
SSI	semi-structured interview
TPB	theory of planned behaviour
WW2	World War 2

TABLE OF CONTENTS

Declaration and Consent.....	3
Details of the Work	3
Summary	7
Acknowledgements.....	9
Authorship	10
Acronyms	12
Table of Contents.....	14
Introduction	19
Definition, Coverage and the Benefits that Come from Mangroves	19
Coverage and Factors Affecting Distribution	19
The Abundant Goods and Services Mangroves Provide Can Facilitate a Sustainable Existence for Local Coastal Communities	20
Pressures that have led to Deforestation & Degradation	21
Similar to Terrestrial Forests, Mangroves Continue to be Lost Globally	23
Historic Drivers of Mangrove Loss – Southeast Asian Examples	24
Mangrove Conversion to Aquaculture and Subsequent Pond Abandonment	24
Contemporary Drivers of Mangrove Losses	25
Reforestation Planting Efforts by the Governments and Villages 1920 - 2007	26
Examining Mangrove Management and Rehabilitation since 2007.....	27
Chapter 1. Mangrove Area and Propagule Number Planting Targets Produce Sub-Optimal Rehabilitation and Afforestation Outcomes.....	30
1.1 Abstract.....	30
1.2 Introduction	31
1.2.1 Mangroves are Particularly Beneficial to the Poorest Coastal Villagers	31
1.2.2 Mangrove Losses Declining, but Measurement is Challenging.....	31
1.2.3 Mangrove Rehabilitation Initiated for Many Reasons and by a Variety of Actors	31
1.2.4 ‘Restoration’ or ‘Rehabilitation’?	32
1.2.5 What is ‘Successful’ Rehabilitation?	32
1.2.6 Rehabilitation and Afforestation Successes and Failures	33
1.2.7 Technical Reasons for Previous Failures	33
1.3 Methods	35
1.3.1 Location of Study Sites.....	35
1.3.2 Assessment Method	37
1.3.3 Research Method Limitations	42
1.3.4 Statistical Tests	43
1.4 Results.....	44
1.4.1 Site Descriptors and Demographics for All 119 Attempts.....	44
1.4.2 Rehabilitation Successes and Failures.....	47
1.4.3 Interactions Between Variables	51

1.4.4	Was Planting Necessary?	53
1.5	Discussion.....	54
1.6	Conclusion.....	59
Chapter 2. Knowledge Gaps Continue to Affect Village and Government Mangrove Rehabilitation Techniques		60
2.1	Abstract.....	60
2.2	Introduction	62
2.2.1	Mangrove Restoration: We Know Enough (But Do Not Communicate It)	62
2.2.2	The Need for Evidence-Based (Mangrove) Conservation and Rehabilitation	63
2.2.3	Previous and Current Government Mangrove Rehabilitation Outcomes	64
2.2.4	The Impact of Village Needs and Objectives on Mangrove Silviculture and Management Remain Poorly Understood66	
2.3	Methods	68
2.3.1	Location of Study Sites and Village Selection Criteria	68
2.3.2	Semi-Structured Questionnaire Interviews.....	69
2.3.3	Semi-Structured Interviews Cross-Checked with Key Informant Interviews	71
2.3.4	Rehabilitation Science Test	72
2.3.5	Classification of Mangrove Zones	73
2.3.6	Research Issues and Limitations	74
2.4	Analysis	76
2.4.1	Statistical Tests	76
2.5	Results	77
2.5.1	Respondent Demographics.....	77
2.5.2	Site Choice: Mudflats when Planting Space Was Required, or Higher Mid and Back Mangrove for Combating (Perceived) Degradation	80
2.5.3	Limited Site Preparation or Physical Site Amendment Regardless of Elevation	82
2.5.4	Site-Species Matching and the Over-Application of Mid Mangrove Species	84
2.5.5	Planting Material Use Dominated by Direct Planting of Propagules.....	85
2.5.6	No Common Definition of Success, But Consistent Over-Estimation of Survivorship.....	86
2.5.7	Planting Timing was not an Ecological Consideration	88
2.5.8	After Planting – Less Activity than Expected.....	88
2.5.9	Did Village Planters Believe That Their Planting was Necessary?	91
2.5.10	Planting and Establishment Issues from the Rehabilitation Science Test	92
2.6	Discussion.....	94
2.6.1	Interpreting the Planting Process as the Villagers Understood It	94
2.6.2	Knowledge Gaps, Misunderstandings and Access to Information	101
2.7	Conclusions	105
Chapter 3. Community Mangrove Management: Laws, Rules, Context & Realities		107
3.1	Abstract.....	107
3.2	Introduction	109
3.2.1	Village Common-Resource Management Institutions	110
3.2.2	The Potential Advantages of Community Forest Management	112
3.2.3	Establishing Enduring, Effective Community Forest Management is Challenging	112

3.2.4	Brief Summary of the Relevant Mangrove Laws in Thailand & the Philippines	114
3.2.5	Tentative Steps Towards Community Management in Thailand	115
3.2.6	The Importance and Complexity of Village Context is often Under-Reported.....	116
3.3	Methods	119
3.3.1	Location of study sites and village selection criteria.....	119
3.3.2	Semi-Structured Questionnaire Interviews.....	119
3.3.3	Villager Interviews Supplemented by Key Informant Interviews.....	123
3.3.4	Research Method Limitations	123
3.4	Analysis	125
3.4.1	Statistical Tests	125
3.5	Results.....	126
3.5.1	Respondent Profiles.....	126
3.5.2	Summary of the Mangrove Management Rules by Village.....	127
3.5.3	Awareness of Mangrove Rules Was High and Attitudes Positive Despite Restricting Cutting.....	128
3.5.4	The Main Threat to Mangroves was Unsustainable Harvesting	131
3.5.5	An Effective Application of the Sanctions in a Village Bolstered Rules Credibility.....	134
3.5.6	The Issue was Enforcement and a Lack of Patrolling, not the Rules	135
3.5.7	Reporting Mangrove Cutters	137
3.6	Discussion.....	140
3.6.1	Interpreting the Semi-Structured Interview Results	140
3.6.2	Necessary Conditions for Effective Community Natural Resource Management.....	146
3.7	Conclusion	153
Chapter 4. Developing Simple Mangrove Forest Quality & Sustainability Indicators to Help Non-Specialists Mangrove Workers Prioritise External Assistance		154
4.1	Abstract.....	154
4.2	Introduction	156
4.2.1	Mangrove Cutting, Gap Recovery, Stressors and Resilience.....	157
4.2.2	The Value and Challenges of Indicators and Criteria	158
4.2.3	Defining Mangrove Quality and Possible Substitute Measures	159
4.2.4	Defining Mangrove Sustainability and Possible Substitutes	161
4.3	Methods	164
4.3.1	Country and Village Selection	164
4.3.2	Transect Location Selection	164
4.3.3	Point Centred Quarter Method to Gather Tree Demographics	165
4.3.4	Cutting Assessment Measurements	169
4.3.5	Additional Mangrove Quality and Sustainability Measures	170
4.3.6	Research Method Limitations	174
4.4	Analysis	175
4.4.1	Generalized Linear Model Analysis.....	175
4.4.2	Hierarchical Multiple Regression Analysis	175
4.4.3	Statistical Tests	175
4.5	Results.....	178
4.5.1	Overall Results	178

4.5.2	Mangrove Quality Indicators	178
4.5.3	Mangrove Sustainability Indicators	180
4.5.4	Mangrove Quality: Generalized Linear Model Analysis	181
4.5.5	Mangrove Sustainability: Generalized Linear Model Analysis	182
4.5.6	Hierarchical Multiple Regression Analysis	183
4.5.7	Measures and Their Influence on the Predictive Models	188
4.5.8	Suggested Indicator Weightings for Ranking Villages' Mangroves	190
4.6	Discussion.....	192
4.6.1	Interpreting Indicators for Mangrove Quality.....	192
4.6.2	Interpreting Predictive Indicators for Sustainability	195
4.6.3	Potential Interaction between Juvenile Density and Cutting.....	198
4.6.4	The Effect of Increased Salinity on Mangroves	198
4.7	Conclusion.....	200
Chapter 5. Implications & Recommendations		201
5.1.1	Rehabilitation: Poor Outcomes, Knowledge Gaps & Remedial Actions	201
5.1.2	Management Rules, Sanctions, Enforcement and Leadership.....	204
5.1.3	Mangrove Inventory, Quality & Sustainability	206
5.2	Recommendations: Local or Village management tasks.....	209
5.2.1	Village-Level Assistance for Villagers and Village Conservation Groups	209
5.2.2	District or Provincial Level Government Units	209
5.2.3	Government Mangrove Field Offices.....	209
5.2.4	National Mangrove Agencies	210
5.2.5	Mangrove Scientific Community, International NGOs, Relevant UN Organisations	211
References		212
Appendix A. Mangrove Ecosystem Goods and Services		243
Provisioning: A Range of Forest Products		243
A Strong Correlation between Mangrove and Fisheries but little Causality		243
Supporting.....		245
Net Primary Productivity Similar to Tropical Rain Forest		245
Carbon Sequestration and Storage		245
Regulating: Nutrients, Weather, Crabs and Biodiversity.....		245
Removal of Sediment and Nutrients from River Water		246
Protection from Waves, Storms, Wind and Tsunamis.....		246
Crabs' Varied Diet, Carbon Cycling and the Linkage with the Inshore		247
Mangroves are an Important Store of Microbial Diversity.....		247
Cultural services: Ecotourism, Recreation and Spiritual Beliefs		248
Appendix B. The Community-Based Ecological Mangrove Rehabilitation Process		249
Appendix C. Pre-Research Ethics Statements to Potential Respondents for Informed Consent.		
(English, Thai, Tagalog)		250
Appendix D. Species Identification Chart.....		253
Appendix E1. Rehabilitation Semi-Structured Questionnaire. Thai.....		256
Appendix E2. Rehabilitation Semi-Structured Questionnaire. Tagalog (Philippines)		258

Appendix F. Village Details and Notes	261
Appendix G. Rehabilitation Science Test. Combined. English, Thai, Tagalog.	262
Appendix H1. Community Mangrove Forestry Rules. Semi-Structured Questionnaire. Thai (Thailand)	267
Appendix H2. Community Mangrove Forestry Rules. Semi-Structured Questionnaire. Tagalog (Philippines)	270
Appendix I. Reflexivity Statement.....	273
Professional Context as a Mangrove Rehabilitation Educator	274
Choice of Translators.....	274
In the Village	275
Appendix J. Sample Set of Community Mangrove Management Rules, from Village T2A.....	277
Appendix K. Recommended State Community Forest Management Input from the Thai Government	279
Appendix L. Tree Condition Rating Photos	281
Appendix M. Transect Data Collection Sheet	285

INTRODUCTION

DEFINITION, COVERAGE AND THE BENEFITS THAT COME FROM MANGROVES

Mangroves consist of salt-tolerant woody plants, shrubs, palms, herbs and ferns which are principally found in inter-tidal areas of the tropics and sub-tropics. The word 'mangrove' can be used in two ways; either describing a group or assemblage of plants or an individual plant. In the former collective sense mangroves refers to a collection of halophyte plants combined with a dynamic bio-geo-physio-chemical environment (Dahdouh-Guebas and Koedam, 2008). Although mangroves are often referred to as 'mangrove forests', there tends to be little or no understory under a closed canopy (Alongi, 2009a, 2002). Mangroves favour sheltered, low wave energy, muddy inter-tidal coastal areas such as river deltas (Alongi, 2009a; Sakho et al., 2011). Mangrove species are able to live in inter-tidal areas and tolerate salinity, tidal inundation, anoxic soil and chemically challenging soil conditions due to a series of morphological and bio-chemical adaptations (Alongi, 2002), including the ability to disperse their propagules by water, a process known as hydrochory (Saenger, 2002).

An exact number of mangrove species is still debated because they are an ecological assemblage rather than a taxonomic group (Saenger, 2002). Tomlinson (2016) suggested that they divide into three sets: 35 major species, 15-19 minor elements of 'true' mangrove, and mangrove associates. True mangroves are defined as only existing in inter-tidal mangrove areas, potentially forming pure stands, having morphological adaptations such as pneumatophores to facilitate gas exchange to their roots, possessing mechanisms to deal with salt, hydrochory, and having split from their land-based relatives (Tomlinson, 2016). Minor elements are unlikely to form pure stands and as such are less ecologically significant. Mangrove associates are more difficult to define as some writers include many beach forest genera, such as *Pluchea* sp., *Sesuvium* sp. and *Ipomoea* sp. (Tomlinson, 2016).

Coverage and Factors Affecting Distribution

In a review Hamilton and Casey (2016) demonstrated how challenging it has proved to measure mangrove coverage by remote sensing with any sort of confidence. For example, mangrove coverage was reported to be 137,760km² in 2000 (Giri et al., 2011) but Hamilton and Casey (2016) estimated coverage in the same year at 83,495km². Mangrove ecosystems occur around the tropics and sub-tropics, within approximately 105 countries (Donato et al., 2011), normally existing within 30° north and south latitudes, with some exceptions. The majority is found between 5° north and 5° south (Alongi, 2002). Species are not evenly distributed around the planet, but form a macrofaunal

biodiversity gradient, with the Indo—West Pacific being the most biodiverse (Alongi, 2002), followed by nine or 10 species in eastern (Bosire et al., 2003) and western Africa (Dahdouh-Guebas et al., 2000; Sakho et al., 2011), down to only three species in the USA and west coast Latin America (Tomlinson, 2016).

Mangrove distribution is affected by several abiotic factors and some of these interact with each other, including:

- Tidal amplitude and local topography due to the depth, duration and frequency of inundation (Lewis, 2005; Saenger, 2002).
- Sea surface and air temperatures (Morrisey et al., 2010) approximately following the 16°C isotherm at their extreme range (Gilman et al., 2008; Saenger, 2002) but more generally within the 20°C isotherm (Alongi, 2009b).
- Fluctuations in rainfall patterns and salt levels (Alongi, 2002; Morrisey et al., 2010; Tomlinson, 2016). Although mangroves are sometimes described as halophyte, a better term would be halotolerant as most mangroves can grow in fresh water. Only a few species require a certain level of salt to fully develop, such as *Avicennia marina* (Saenger, 2002). For example, increasing aridity is currently changing the profile of Australia’s mangroves with a recent large-scale die-off of mangroves due to a lack of rainfall (N. Duke, pers. comm).
- Although mangroves prefer soft mud they can also grow on peat, sand and within coral debris (Ellison, 2000). Once established they affect and probably increase sediment deposition, although this process is not fully understood (R.R. Lewis, pers. comm., but see Ranasinghe, 2012).
- Wave energy can affect species distribution and destroy mangroves, but once established, mangroves often mitigate and reduce wave energy (Mazda et al., 2003).
- Appropriate currents and wind direction for propagule and seed dispersal, (Alongi, 2009b; van der Stocken et al., 2012).

The Abundant Goods and Services Mangroves Provide Can Facilitate a Sustainable Existence for Local Coastal Communities

If managed sustainably mangroves have the potential of forming the basis of sustainable living for coastal communities, and as such, are hugely valuable to them. The Millennium Ecosystem Assessment (2005) categorisation provides a useful way to classify and describe mangroves’ ecosystem services: provisioning, supporting, regulating, and cultural services. These goods and services have been described in detail in Appendix A, to illustrate the complexity of this ecosystem, how beneficial mangroves can be to coastal communities as well as other nearby ecosystems, and

how villagers might interact or use the resource. In brief, mangroves' provisioning services include providing wood for building, charcoal and cooking (Walters, 2005a) and other non-timber forest products such as *Phoenix* sp. palm fibres for weaving (Aung et al., 2011), honey (Nagelkerken et al., 2008), *Avicennia* sp. leaves for nitrogen-rich animal fodder (Dahdouh-Guebas et al., 2000) and a nursery for fish, crabs and shrimp (Lee, 2004). Mangroves ecosystems can be very productive, producing up to 64 tonnes/ha/year dry weight matter (Alongi, 2009a), and annually storing 168 ± 36 gCm⁻²yr⁻¹ of carbon (Taillardat et al., 2018). This productivity allows mangroves to support a very productive inshore fishery (Walters et al., 2008). Mangroves also help to regulate and reduce sediment in river water (Kuhlmann, 1988; Mazda et al., 2003) and reduce the nutrient load flowing into the inshore, minimising the risk of eutrophication (Moberg and Rönnbäck, 2003). Waves and wind are reduced by the roots, stems and crowns of the mangroves, thus protecting coastal villages (McIvor et al., 2012). Finally, mangroves provide cultural services, giving mangrove communities a sense of place, identity and character (Richards and Friess, 2015; Ronnback et al., 2007; Walters et al., 2008) and providing the opportunity for ecotourism (Badola et al., 2012).

PRESSURES THAT HAVE LED TO DEFORESTATION & DEGRADATION

Within a broader context of terrestrial deforestation, by which is meant the complete, long-term removal of tree cover, the debate continues about the drivers and causes of deforestation (Angelsen and Kaimowitz, 1999). Alternative land uses such as mining, urban development and farming can potentially offer greater private economic returns (Busch and Ferretti-Gallon, 2017), but in the process, forest clearers are unlikely to consider the loss of forest ecosystem services or the negative externalities caused by this deforestation (Grieg-Gran et al., 2005). Forest loss is likely to lead to a reduction in beneficial biodiversity and other negative impacts such as soil erosion, fragmentation of habitats, disturbed carbon cycles and flooding (Getahun et al., 2013). Globally, commercial agriculture is the biggest cause of deforestation followed by subsistence farming, while timber extraction, logging, charcoal production and grazing cause most forest degradation (Hosonuma et al., 2012; Kissinger et al., 2012; Tadesse et al., 2014). Within these forest losses, illegal logging remains a huge driver of forest loss (Global Witness, 2016). Mechanised agriculture, a key driver of deforestation, is often a function of good access to export markets, commodity prices and appropriate bio-physical conditions for farming, whereas small-scale agriculture is mostly constrained by access to local markets. Legal protection and establishment of protected areas has to a certain extent restricted larger-scale mechanised agriculture but not the expansion of subsistence farming or clearance for cattle grazing (Müller et al., 2012). In an in-depth study of the drivers of deforestation, Busch and Ferretti-Gallon, (2017) list several causes of site-specific

deforestation: the biophysical characteristics of a plot (suitable slope, wetness, access); market demand for commodities such as agricultural products and timber; built infrastructure and roads (supported by Angelsen and Kaimowitz, 1999; Damania et al., 2018); management rights and ownership (protected areas and better enforcement both helping to reduce deforestation) and population pressure (supported by Tadesse et al., 2014).

There are caveats and exceptions to all these drivers. For example, building roads into forests and remote areas can help social development, connect markets together, reduce transport costs and local prices and produce markets for local agricultural products. Improved infrastructure can also provide access to off-farm jobs away from natural resource exploitation. Getahun et al. (2013) found that remote rural areas of southern Ethiopia, far away from roads, were witnessing deforestation more quickly than areas nearer to roads. However, in general, new roads providing improved access to markets for natural resources from common-property forests have led to deforestation and forest degradation around these roads (e.g. Philippines, Lui et al., 1993; Congo, Agrawal, 2001; Wilkie et al., 2010; South America, Southworth et al., 2011; Ethiopia, Damania et al., 2018; Tadesse et al., 2014).

Population pressure is frequently mentioned as another driver of deforestation. In a re-examination of a seminal publication 'More people, less erosion' by Tiffen et al., (1994), Boyd and Slaymaker, (2000) suggest that population pressure in semi-arid areas might not necessarily lead to resource erosion, under certain conditions. From their six case studies, these conditions included the possibility of soil and water conservation measures facilitating the farming of high-value crops, a shortage of agricultural land and the central importance of agriculture to the local community. Deforestation can be beneficial if newly deforested farmland can support an increased population (Busch and Ferretti-Gallon, 2017). However, in a systematic review of 55 studies, Busch and Ferretti-Gallon (2017) found that population pressure was consistently associated with greater deforestation. For example, increasing population pressure and migration in southern Ethiopia led to forest conversion for small-scale agriculture (Tadesse et al., 2014).

Therefore, to avoid what some writers perceive as Hardin's (1968) 'tragedy of the commons'¹ (e.g. Barreto et al., 2006 in the Amazon; Wilkinson and Salvat 2012 in Nepal), where effective open-access to a resource resulted in significant depletion, many tools have been developed to grant protection to forests, such as protected area status, legal protection and gazettement of forests, national park

¹ The 'commons' which Hardin was referring to were open-access, common-pool fisheries where property rights had not been established, in a situation where it was impossible to exclude fishers (Cole and Ostrom, 2010).

status, restriction of exports or imports of illegally harvested timber, certification and payment for ecosystem services among various mechanisms (Busch and Ferretti-Gallon, 2017; Grieg-Gran et al., 2005; Müller et al., 2012 but see Rasolofoson et al., 2015). Other forms of governance and property systems might also effectively manage and protect natural resources such as private or government ownership, or forms of common property management and user-group control (Cole and Ostrom, 2010; Slaev and Collier, 2018).

SIMILAR TO TERRESTRIAL FORESTS, MANGROVES CONTINUE TO BE LOST GLOBALLY

Part of the reason for Hamilton and Casey's (2016) inconsistent measurements of mangrove area and loss was due to low resolution remote sensing imagery, the difficulty of classifying mangrove as opposed to other types of vegetation, and the lack of a definitive methodology for identifying and classifying 'mangrove' at different levels of degradation and canopy cover (Giri *et al.*, 2011; Hamilton and Casey, 2016). These difficulties notwithstanding, Chapman, (1975) estimated that 75% of the tropical coastline used to be covered in mangroves. In 1980 there were 198,000km² of mangroves (FAO, 2003), but by 2003 this had reduced to 154,000km² (FAO, 2007). For example, the extent of Bangladesh's Sundarbans has been reduced by more than 50% over the last 200 years (Islam and Wahab, 2005). Kenya's mangroves are under significant harvesting pressure (Kairo et al., 2008). Between 1924 – 1999, 83% of the mangroves in the Ayeyarwady delta in Myanmar were cleared (Ohn, n.d.). During the Vietnam war, 'Agent Orange' defoliant² spraying killed 1,000km² of mangroves (Hong and San, 1993).

Within the 21st century, as remote sensing techniques have improved, global losses have been reported to be 0.16% - 0.39% per year, indicating a slowing of the rate of loss from the 1980s (0.99%) and 1990s (0.7%) (Hamilton and Casey, 2016). Southeast Asia has historically seen some of the greatest losses. For example, the Philippines' mangrove stock has fallen from 4,500km² in 1900 to 1,200km² in 1995 but the rate of loss has slowed to 0.1% per year since 2000 (Long *et al.*, 2014; Primavera and Esteban, 2008). In Thailand, using 1961 as a baseline, less than half of all the mangroves remain (Aksornkoe, 2004). From 2000 - 2012 Thai losses were running at 0.69% per year (Hamilton and Casey, 2016). In contrast, Alongi (2002) points out that some countries, including Papua New Guinea, Australia and Belize have managed to maintain their mangrove cover, or even increase it (e.g. Cuba, between 1908-1995), and that much of the older data, on which the general assumption of 50% losses since WW2 were based, were supported by very little empirical

² 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) (Huong et al., 2007)

data due to inconsistent definitions of what constituted mangrove forest, (e.g. including or excluding related salt marshes and freshwater swamps).

HISTORIC DRIVERS OF MANGROVE LOSS – SOUTHEAST ASIAN EXAMPLES

Just as much of the world's primary terrestrial temperate forest has been replaced by secondary forests or plantations (Liira et al., 2007), few ancient primary mangrove forests survive. It should also be acknowledged that mangrove ecosystems are very dynamic over time scales of decades and centuries, making natural gains and losses (Field, 1998), but here I looked at only anthropogenic disturbance. Until the mid-1990s, mangroves were considered forests of limited value, to be leased out in commercial concessions for timber extraction (Aksornkoe, 2004). For example, between 1961 – 1996, 80% of Thailand's mangroves were allocated to concessions for charcoal production (Sudtongkong and Webb, 2008) which in combination with the development of the aquaculture industry within the mangrove region (see below), resulted in the conversion of 2,000km² of mangroves (RAP FAO, 2007). Despite the terms of the concession contracts requiring compartmentalisation, rotational felling and replanting (Sudtongkong and Webb, 2008), mangroves under concession were subject to clear-felling, encroachment, extraction from outside concession boundaries and inconsistent replanting (government mangrove agency official, village T1A). In 1996 a Royal Thai Government cabinet resolution let these concessions expire without renewal and banned further mangrove timber extraction (Aksornkoe, 2004). A comparable narrative comes from the Philippines, where mangrove wood was traditionally harvested not only for charcoal but also for bakery fuelwood (Walters, 2004), debarking for tannins (Melana et al., 2000) and extracted to meet the needs of an expanding population (Maliao and Polohan, 2008).

Mangrove Conversion to Aquaculture and Subsequent Pond Abandonment

A second driver of mangrove conversion has been aquaculture within the mangrove zone. Barbier and Sathirathai (2004) speculated whether the Thai aquaculture boom of the 1980s and 1990s, responsible for converting a significant proportion of the country's mangroves to shrimp farms, was in part driven by the development of the road network within southeast Thailand. Similarly, approximately half of the Philippines' mangrove was converted due to government policies encouraging aquaculture activity in mangrove areas (Primavera, 2000; Primavera and Esteban, 2008, but see the Global Aquaculture Alliance, 2012, who dispute this). Many ponds have been sited, excavated and operated poorly with little technical knowledge (Islam and Wahab, 2005). In Thailand mangroves have been cleared for ponds that have sometimes been managed with only a limited attempt at sustainability (Stevenson et al., 1999), and although rates vary, ponds are generally operated at high shrimp fry stocking densities, resulting in poor water quality (Gowing and Ocampo-

Thomason, 2007; Matsui et al., 2014). This has often led to significant productivity reductions after only three to seven years in many countries around South, Southeast Asia and the Far East (Moberg and Rönnbäck, 2003; Stevenson et al., 1999), due to disease outbreaks such as Early Mortality Syndrome (De Schryver et al., 2014), poor seed quality (Selvam et al., 2012b) and failure to acknowledge the life-supporting and water cleaning functions that mangroves provide (Jitthaisong et al., 2012; Moberg and Rönnbäck, 2003).

This pond failure syndrome has a significant social dimension (Primavera et al., 2007). Once the ponds have failed and are left abandoned and unproductive, the indebted shrimp pond owners are often compelled to sell off their ponds to outside businessmen or companies to pay off their debts (Stevenson et al., 1999). It is estimated that there are 4,000km² of abandoned ponds worldwide (R. R. Lewis, pers. comm.) Approximately 70% of ponds have been abandoned in Thailand and a great many in the Philippines (Primavera and Esteban, 2008; Stevenson et al., 1999). Similar issues are reported by Selvam et al. (2012) in India where aquaculture pond failure has encouraged migration to the cities. Furthermore, few local people benefit from shrimp farms (Stevenson et al., 1999) as they are more capital than labour intensive, employ fewer people than rice farming, and cheaper labour is often imported, e.g. Burmese workers on Thai farms (Datta et al., 2012; pers. obs. 2009; Primavera, 1995).

CONTEMPORARY DRIVERS OF MANGROVE LOSSES

Losses caused by anthropogenic pressures and events can be direct or indirect (Field 1998). Beyond conversion for aquaculture, direct pressure can include land use change for agriculture or (unsustainable) harvesting of timber (Ellison, 2000; Primavera and Esteban, 2008). Indirect pressures might be changes in hydrological connectivity or upstream water flows and fresh water input (e.g. water flows blocked by road building in Colombia, Twilley et al., 1999), sedimentation from activity upstream (e.g. the Indus River in Pakistan, Shah 2012), changes in policy to allow wood-burning bakeries (Walters, 2004), oil spills (Duke, 1996), cattle grazing (Rathnayake et al., 2012), destruction of natural regeneration or planted seedlings by boat impact damage and footfall (Hashim et al., 2010; pers. obs. Myanmar 2011).

Similar to terrestrial forests, researchers have suggested that many of these pressures on mangrove and the resulting degradation are a function of increased local population and immigration (Alongi, 2002; Datta et al., 2012; Field, 1998, 1996; Glaser and da Silva Oliveira, 2004; Marschke and Nong, 2003; Moberg and Rönnbäck, 2003; Ohn, n.d.; Springate-Baginski and Than, 2011). Myanmar has witnessed a significant population increase in the coastal regions, sometimes up to 183 people per

km². Historically, Kenyans have harvested mangrove timber for export to the Middle East. More recently the population increase on the coast has resulted in intensive mangrove timber extraction at unsustainable levels for local housing construction, partly because within each Muslim family every wife expects a house of their own and each son also builds a house (Dahdouh-Guebas et al., 2000). An extraction permit system to try to manage this increased level of mangrove harvesting had poor results due to limited enforcement (Dahdouh-Guebas et al., 2000). Senegal (Sakho et al., 2011), Bangladesh (Iftekhar and Islam, 2004) and the Philippines (Maliao and Polohan, 2008) have experienced similar challenges from population pressure. Despite government management for almost 140 years and being within a Protected Area, Bangladesh's mangroves at Chakaria in the Sundarbans have almost completely disappeared due to population pressure (Datta et al., 2012; Iftekhar and Islam, 2004).

Changes in local coastal population can arise for many reasons, such as politics (e.g. the result of socialist 'villagisation' in Tanzania, Nurse and Kabamba, 2000), economic migration (e.g. Thailand), conflict and civil war (Cambodia) or governments relocating citizens, such as the internal 'transmigration' programmes in Indonesia (Anon, 1997). It cannot be assumed that the new arrivals will have any knowledge of the mangrove ecosystem, traditional or otherwise, or know how to manage this resource in a sustainable manner (Datta et al., 2012). New arrivals might take over mangrove resources, distancing indigenous people from them and failing to benefit from their knowledge of how to manage a mangrove forest sustainably, to the detriment of the forests' health (India, Bodin and Crona, 2008; Indonesia, Datta et al., 2012). In addition, an increase in population puts additional pressure on related factors such as schools, social services and the availability of alternative livelihoods (Datta et al., 2012).

REFORESTATION PLANTING EFFORTS BY THE GOVERNMENTS AND VILLAGES 1920 - 2007

The earliest replanting efforts in the Philippines started around 1920 for wood production and coastal protection (Primavera and Esteban, 2008). Replanting projects were taken over by the National Mangrove Committee in 1976 (National Mangrove Committee, 1987). In common with Thailand, large-scale government replanting, aided by the World Bank among others, started in the 1980s (Primavera and Esteban, 2008). Similar to the silvicultural issues surrounding boreal forest management (Liira *et al.* 2007), this effort to restock the mangroves produced only a simplified version of the original forests (Bosire et al., 2006; Lewis, 2005), tending to use few species other than *Rhizophora* sp. (Primavera and Esteban, 2008). Despite the Philippine government agreeing in

1994 to the NGO-assisted Community-Based Mangrove Forest Management Approach to rehabilitation of mangroves, and Executive Order No. 263 mandating community-based forest management as the national strategy to ensure the sustainable development of the country's forest resources, mangrove rehabilitation outcomes were poor (Primavera and Esteban, 2008).

EXAMINING MANGROVE MANAGEMENT AND REHABILITATION SINCE 2007

In more recent times, to recover some of the goods and services provided by mangroves lost due to the factors mentioned above, and in light of natural disasters such as the Indian Ocean tsunami of 2004 and cyclone Haiyan / Yolanda in the Philippines in 2013, there have been significant efforts to rehabilitate areas of converted or degraded mangroves (Aung et al., 2011; Primavera et al., 2011; Primavera and Esteban, 2008), and to afforest new areas that were not mangroves previously. Indeed, Lewis (1982) called for not just replanting, but for mangrove ecosystem restoration, including functional hydrological connectivity to the adjacent systems. The FAO claims that restoration is easy (Alongi, 2002; FAO, 1994) and indeed mangroves can self-repair and regenerate, even after an oil spill (Duke, 1996). Most frequently governments have commissioned mangrove rehabilitation through forest and environment departments which have in turn engaged coastal villages to implement or assist. Increasingly, governments are also asking villages to help with the management of the mangroves. Here I studied elements of this community mangrove management process to understand the barriers to success and to indicate what assistance and training outside groups should provide. Chapter 1 describes whether community groups, working with government mangrove agency field office staff, are able to successfully rehabilitate degraded or cleared areas of mangrove and afforest new areas.

Outcomes from mangrove rehabilitation often run contrary to what might be expected, considering the amount of information and published mangrove science available. An online literature search via Google Scholar, using the string 'mangrove restoration', produced 65,300 references, and using Web of Science (v. 5.34) 812 references. However, it is questionable whether this knowledge has been fully applied in either government or NGO rehabilitation projects (Ewel, 2010; Kairo et al., 2001; Primavera et al., 2015, 2011). Lessons learned from previous mangrove projects have not always been published, particularly if the programme itself failed. Where outcomes and learning have been made available, reports are often published as 'grey' literature (Field, 1998) rather than peer-reviewed. Furthermore, it is uncertain whether the relevant scientific literature is accessible and produced in an appropriate format and language for groups that actually implement projects on the ground: NGO staff, mangrove agency field officers and village conservation groups. Chapter 2

explores village understanding of mangrove rehabilitation techniques to determine whether knowledge gaps may contribute to explaining why mangrove rehabilitation outcomes remain poor.

Concurrently, there has been recognition by many mangrove-owning states that mangrove communities should play a greater role in their conservation, management and rehabilitation, since most mangrove nations have insufficient central resources to preserve and rehabilitate mangroves effectively. While rehabilitating degraded or converted areas of mangrove is one element of mangrove management, another component is protecting existing stocks of mangroves. Some of the drivers of losses have been described already. Most countries have laws and regulations that protect mangrove, giving them potentially misleading phrases like 'Reserve Status' (Tanzania) or 'Reserved Forest' (Bangladesh, Myanmar). However, this frequently translates into limited enforcement and protection at ground level (Dahdouh-Guebas et al., 2000; Glaser and da Silva Oliveira, 2004; Iftekhhar and Islam, 2004; Marschke and Nong, 2003; Nurse and Kabamba, 2000; Sudtongkong and Webb, 2008; Zorini et al., 2004). In the Philippines (López-Hoffman et al., 2006) and Brazil (Glaser and da Silva Oliveira, 2004) rarely are the restrictions on extraction of mangrove wood enforced by local authorities, government mangrove agencies or national guard, despite mangrove's legal protection. The mangroves of the Tanintharyi region of southern Myanmar remain under significant illegal commercial extraction pressure for fuelwood for fish processing and charcoal production, despite a national ban on cutting (Zockler, 2016). Hence the reality of national legal protection is often benign neglect by mangrove agencies with potential encroachment for aquaculture or other land uses or urban development into the forests (Marschke and Nong, 2003; Walters, 2004).

As a result of threats to or over-exploitation of mangroves at multiple levels, many villages have developed some form of community mangrove management. Here it should be noted that care must be taken when using terms such as *community* or *village* as it cannot be assumed that these form harmonious, homogenous groups, but rather might be affected by caste, history, religion and many other factors (Agrawal and Gibson, 1999; Waylen et al., 2013). Community forest management (CFM) has the potential of being an effective method of managing natural resources because it can provide efficient and cheap forest management, with the possibility of delivering outputs in a form that is most appropriate to the people living nearby who use them. The underlying assumption is that if a community has a stake in its local forests or indeed relies on them, it has an incentive to look after them sustainably (Datta et al., 2012; Senyk, 2005) and to bring appropriate local knowledge to bear. Living in the vicinity of the mangroves, villagers can patrol, protect, monitor changes and adherence to by-laws more easily than distant officials. Government mangrove managers are starting to recognise the benefits of community mangrove management

and facilitate its development. Villagers can potentially move towards a sustainable use of this natural resource if the community has rules, village-wide enforcement and credible sanctions governing their use. The development and application of community mangrove management rules are explored in Chapter 3.

As discussed, healthy mangroves can greatly enhance the livelihoods of local coastal villagers, and the poorest in particular (Sunderlin et al., 2005), as a result of the ecosystems services and benefits they provide (Moberg and Rönnbäck, 2003; Sinfuego and Buot, 2014). To realise some of these benefits, wood extraction is required to provide materials for construction, fish traps, fish aggregating devices and fuelwood for cooking, as there are often few affordable alternatives (Badola et al., 2012; Glaser and da Silva Oliveira, 2004). In most countries mangroves remain under unquantified levels of informal local cutting pressure that is diffuse and chronic (Walters, 2005b). This unregulated and often covert extraction means that the mangroves are subject to unplanned, passive management-by-default without the planning overview that is the hallmark of sustainable forest management. As a result, government and village mangrove managers are likely to have only a limited understanding of the resulting stand quality and sustainability (terms defined later). Therefore, to assist mangrove-interested organisations and stakeholders, simple qualitative measures of mangrove quality and sustainability are proposed that will help describe current forest health and sustainability, and over time a direction of change. While not attempting to produce absolute quantification of quality and sustainability, these measures, discussed in Chapter 4, will enable ranking of forests and thereby the prioritisation of external assistance and intervention to communities whose mangroves are at the greatest risk of loss.

This thesis concludes with by drawing several ideas together and places some of the findings in a wider context. Chapter 5 also provides some recommendations for mangrove managers at all levels.

CHAPTER 1. MANGROVE AREA AND PROPAGULE NUMBER PLANTING TARGETS PRODUCE SUB-OPTIMAL REHABILITATION AND AFFORESTATION OUTCOMES³

1.1 ABSTRACT

Mangrove rehabilitation projects often fail completely or fail to meet their objectives. This study examines village-level rehabilitation planting carried out in 13 villages (119 rehabilitation attempts at 74 sites) across two countries in southeast Asia, to assess village-level rehabilitation effectiveness, and to identify what factors influenced outcomes. Mean propagule survival across all rehabilitation attempts was 20% with a median of 10%. Sixty six percent of attempts had a survival rate of less than 20%. Mid mangrove zone projects were more successful (mean 30%) than rehabilitation projects at other elevations. Planting on mudflats, representing 32% of rehabilitation / afforestation attempts, achieved only a 1.4% propagule survival rate. The overall low success rate was due to several inter-related factors. Poor site / species matching on high and low elevation sites was common; for example, *Rhizophora* spp. was used alone or in combination at least 65% of the time, including on mudflats where this genus is ecologically unlikely to establish. Site selection was often driven by the desire to achieve centrally defined area or propagule *planting* targets, rather than *survivorship* targets, and thus required large, uncontested project areas. Conversely, the presence of natural regeneration, even if in small amounts, was associated with higher than average success. Therefore, it was estimated that only 16% of planting attempts were actually necessary.

³ This chapter has been published in Estuarine, Coastal and Shelf Science. (Wodehouse and Rayment, 2019). <https://doi.org/10.1016/j.ecss.2019.04.003>

1.2 INTRODUCTION

1.2.1 Mangroves are Particularly Beneficial to the Poorest Coastal Villagers

Mangroves form highly productive ecosystems, (Alongi, 2009a) which provide many direct and indirect benefits and services (Moberg and Rönnbäck, 2003; Saenger, 2002; van Oudenhoven et al., 2015). These services are particularly valuable and relevant to the poorest members of coastal villages (Glaser and da Silva Oliveira, 2004; Kairo et al., 2001; Springate-Baginski and Than, 2011; Stevenson et al., 1999; Sunderlin et al., 2005). They include a nursery function for fish and shrimp (Saenger et al., 2013; Salmo III et al., 2018) and provision of wood for construction and fuel for cooking (Moberg and Rönnbäck, 2003).

1.2.2 Mangrove Losses Declining, but Measurement is Challenging

In previous decades, management of mangrove loss has proved challenging. This was as a result of low-resolution remote sensing imagery and of classifying mangrove as opposed to other types of vegetation. Furthermore, there has been a lack of a definitive methodology for identifying and classifying 'mangrove' at different levels of degradation and canopy cover (Giri et al., 2011; Hamilton and Casey, 2016). Within the 21st century, global losses have been reported to be 0.16% - 0.39% per year, indicating a slowing of the rate of loss from the 1980s (0.99%) and 1990s (0.7%) (Hamilton and Casey, 2016).

Southeast Asia has historically seen some of the greatest losses. For example, mangrove cover in the Philippines has fallen from 450,000ha in 1900 to 120,000ha in 1995 but the rate of loss has slowed to 0.1% per year since 2000 (Long et al., 2014; Primavera and Esteban, 2008). In Thailand, using 1961 as a baseline, less than half of all the mangroves remain (Aksornkoae, 2004). From 2000 - 2012, Thai losses were 0.69% per year (Hamilton and Casey, 2016).

1.2.3 Mangrove Rehabilitation Initiated for Many Reasons and by a Variety of Actors

Following natural disasters such as the Indian Ocean tsunami of 2004 and cyclone Haiyan / Yolanda in the Philippines, and to recover some of the goods and services provided by mangroves, there have been significant efforts to rehabilitate areas of converted or degraded mangroves (Aung et al., 2011; Primavera et al., 2011; Primavera and Esteban, 2008). This effort has included attempts to afforest new areas that were previously not inhabited by mangroves. Most often, governments have commissioned mangrove rehabilitation programs through forestry and environment departments, which in turn have sometimes engaged local villages to assist. Occasionally, communities and villages have initiated their own rehabilitation projects. Examples include Pred Nai in Thailand (Fisher, 2000; Senyk, 2005) and Myanmar (Springate-Baginski and Than, 2011). There are also reports of

rehabilitation by individuals within coastal villages, in the Philippines (Walters, 2004, 2000, 1997; Walters et al., 2005) and Thailand (pers. obs.).

1.2.4 'Restoration' or 'Rehabilitation'?

The scientific literature often uses 'restoration' and 'rehabilitation' interchangeably (van Oudenhoven et al., 2015) or uses other words including repair, reclamation, reforestation, conservation, afforestation or eco-development (Duke, 1996). Restoration might be defined as recovering an area back to an assumed original 'pristine' ecosystem, implicitly including the restoration of mangrove functionality (Kairo et al., 2001; Stevenson et al., 1999; Walters et al., 2008). However, the word is often used more broadly (McDonald et al., 2016). Rehabilitation is an attempt to recover *some* of the ecosystem functions or to find another stable use for the land (McDonald et al., 2016; Stevenson et al., 1999; Walters, 2008 but see Field, 1999). The debate concerning these terms continues (see Dale et al., 2014 for a review). While acknowledging this debate, and the need for clarity of definition for legal purposes and for setting expectations (Dale et al., 2014) this paper will use the term rehabilitation. Similarly, care is needed when describing areas as 'degraded', because the perception of whether an area is partially degraded or not is affected by cultural expectation and land management intensity (Hobbs, 2016). Furthermore, changes to an ecosystem's state may be adjustments beyond those caused by normal forest growth and development processes, leading to a new equilibrium as a result of climate change or long-term variation of weather patterns (Hobbs, 2016; Mansourian et al., 2017).

1.2.5 What is 'Successful' Rehabilitation?

In principle project outcomes should be assessed in relation to stated project objectives, and this is crucial in the planning of any mangrove rehabilitation work (Field, 1996; Lewis, 2000; Saenger, 2002). When viewing rehabilitation outcomes from a narrow standpoint, 'success' may be claimed after five to seven years, because this indicates probable long-term survivorship (i.e. to reproductive maturity) and eventual (re)establishment of a mangrove stand (Bosire et al., 2008; Kodikara et al., 2017b). Salmo III et al. (2013) focused on vegetation and soil parameters in a study of monospecific plantations. Their study suggested that mangrove ecosystem stability might be reached by 11 years, and that ecological characteristics resembled natural mangroves after 25 years. Other indicators of success have focused on the whole ecosystem and consider that success can be claimed when the hydrological normality of a mangrove has returned (Asaeda et al., 2016). Alternatively rehabilitation assessment might compare project sites to natural mangroves (McDonald et al., 2016) but not in terms of succession (Ellison, 2000). Despite sometimes being an appropriate long-term measure, comparing project sites to old-growth mangroves is particularly difficult in countries such

as Thailand and the Philippines. This is because much of the natural mangroves have been cut-over for charcoal or fuelwood and replanted with a less diverse range of species (Alongi, 2002).

Resources permitting, a more comprehensive approach is *ecological rehabilitation* (the literature often uses *restoration* in this case) (Asaeda et al., 2016; Ellison, 2000; Lewis, 2005; Walters et al., 2008). This approach looks for the return of full ecosystem function, including outflow of organic material to, and habitat connectivity with, linked seagrass and coral systems. This can be relatively complete within five years (Saenger et al., 2013).

While social factors are pertinent, in this chapter we focus on a strictly biological (or silvicultural) definition of success – whether planted seeds / propagules survive to establishment.

1.2.6 Rehabilitation and Afforestation Successes and Failures

There have been positive mangrove afforestation survivorship outcomes in Bangladesh (Saenger and Siddiqi, 1993 but see Moberg and Rönnbäck, 2003) and successful mangrove rehabilitation in Florida (Brockmeyer et al., 1996; Lewis, 2005; Lewis and Gilmore, 2007), Philippines (Asaeda et al., 2016; Primavera et al., 2012; Walters, 2004) Indonesia, (Lewis and Brown, 2014) and Myanmar (pers. obs.). However, many rehabilitation projects fail completely or do not achieve their objectives (Elliott et al., 2016; Erftemeijer and Lewis, 1999; Field, 1996; IUCN, 2017; Lewis, 2005; UNEP, 2007) or at best produce limited positive results (Alongi, 2002; Aung et al., 2011; Barbier, 2006; Ellison, 2000; Memon and Chandio, 2011; Moberg and Rönnbäck, 2003). Mangrove rehabilitation projects that have become established often resemble even-age class, mono-specific plantations rather than natural mangrove (Bosire et al., 2006; Ellison, 2000; Field, 1996; Lewis, 2005), bearing little or no similarity to the original mangrove (Alongi, 2002). In addition they exhibit only limited species zoning and biodiversity (Bosire et al., 2008). However, of greater immediate concern are the often extremely low propagule survival rates of these rehabilitation programs.

Sanyal, 1998 reported that in West Bengal more than 9,000ha were planted with only 1.5% probable survival. In the Philippines, despite significant efforts and financial inputs over the last twenty years, survival of planted mangroves remains low at 10-20% (Primavera, 2015; Primavera and Esteban, 2008; Samson and Rollon, 2008; Walters, 1997). Similar conclusions have been drawn from Sri Lankan rehabilitation programs (Samarakoon, 2012).

1.2.7 Technical Reasons for Previous Failures

Why do so many rehabilitation projects fail? Here we consider the suggestion that the most common technical reason for planting failure is poor site / species matching, i.e. choosing an unsuitable species to plant for a given site (Aung et al., 2011; Bosire et al., 2006; Lewis et al., 2016;

Primavera and Esteban, 2008; Walters et al., 2008). What is meant by unsuitable? Individual species have differing tolerances to specific biogeochemical factors and gradients present across the intertidal area (Saenger, 2002). These include salinity, soil type, soil anoxia, sulphate levels, nutrient levels, pH, wave energy, temperature, light levels, inundation regimes (Alongi, 2009b; Tomlinson, 2016; van Loon et al., 2016), tides and wind distribution of propagules and seeds (van der Stocken et al., 2012), and species-selective predation by herbivores (Elster, 2000; Sousa et al., 2003). Species therefore exhibit differing 'preferences' for elevation and location within the intertidal zone (Duke, 2006; Snedaker, 1982; Tomlinson, 2016).

Closely related to site / species matching is poor site choice. Often insufficient regard is given to understanding local hydrology, topography relative to sea level, and the effects these have on soil conditions. These features and affects by high wave energy greatly affect planting outcomes (Aung et al., 2011; Brown et al., 2014; Elster, 2000; Hashim et al., 2010; Kairo et al., 2001). Duration of inundation is particularly important (van Loon et al., 2016). In some cases rehabilitation can be achieved simply by reconnecting or improving site hydrology, e.g. by installing culverts under a road, reconnecting former aquaculture ponds or reopening lagoons (Brown et al., 2014; Elster, 2000; Ferreira and Lacerda, 2016; Lewis, 2014; Twilley et al., 1999). In contrast, sites that have an elevation below that of a natural front mangrove fringe are likely to have permanently saturated soil with poor drainage, leading to anoxic and potentially acidic soil (Holguin et al., 2001; Kristensen and Alongi, 2006). These factors have a significant negative impact on the outcomes of projects attempting to afforest mudflats and seagrass beds (Asaeda et al., 2016; Samson and Rollon, 2008; Stevenson et al., 1999).

Many rehabilitation projects start planting first without fully understanding the original cause of mangrove loss or why there is no natural regeneration on site (Asaeda et al., 2016; Lewis, 2005; Walters et al., 2008). Both of these factors might be mitigated by reducing and removing mangrove stressors specific to a site, such as obstructed hydrology or unsustainable anthropogenic activities (e.g. harvesting of mangrove wood) (Lewis et al., 2016). Other reported reasons for failure include herbivore grazing and footfall damage, poor planting method, lack of aftercare (e.g. weeding) and monitoring (Kodikara et al., 2017b) and barnacle infestation.

In this paper we describe a study of community-level planting projects to assess survival rates and to identify factors that determine success or failure at the project level.

1.3 METHODS

1.3.1 Location of Study Sites

Although specific regional and local contexts are very important and highly variable, multiple villages within two countries were studied in an attempt to produce some general conclusions. Thailand and the Philippines share the same Indo-Malesia bio-geo-climatic zone within the Indo-West Pacific (Duke, 2006; Tomlinson, 2016). They have extensive mangrove areas, on which a substantial proportion of the coastal inhabitants depend for their livelihoods and food (Balmford et al., 2002). Since 1945, both countries have experienced significant mangrove conversion to aquaculture and degradation for charcoal and fuelwood production, among other causes (Richards and Friess, 2016).

Table 1 lists the Thai and the Philippine villages studied in this large-scale investigation. This study combined ecological and social research to examine mangrove rehabilitation in the context of biophysical, silvicultural and social factors. Villages were chosen because they were located either within or near to an extensive riverine mangrove delta or had a significant area of mangroves nearby. In all cases mangroves were considered an important village resource and were used in some ways by a substantial part of the village population. Finally, village members had attempted mangrove rehabilitation or afforestation in the past. The exception to these selection criteria was village P3A in the Philippines (Table 1) which was included as it had conducted a record-setting '1 million propagules in an hour' planting project (Escandor, 2012). Except for this final record-setting planting, all Philippine planting discussed here was funded by the National Greening Program (Department of Environment and Natural Resources, 2016), a large-scale bio-shield establishment scheme initiated after typhoon Yolanda / Haiyan in 2013. Some rehabilitation or afforestation sites had been attempted more than once and each attempt was assessed. A site was defined as an individual plot or area villagers had attempted to rehabilitate or afforest as a discrete project. In total 119 attempts at rehabilitating 74 sites were assessed.

Table 1. Site information of villages studied in Thailand and the Philippines and their mangrove rehabilitation projects

Thailand						
Village Number	1	2	3	4	5	6
Village Code	T1A	T1B	T2A	T2B	T3A	T3B
Approx. Lat Long	6.8° N 99.7° E	6.8° N 99.7° E	7.8° N, 99.1° E	7.8° N, 99.1° E	8.4° N, 99.9° E	8.4° N, 99.9° E
Province	Satun	Satun	Krabi	Krabi	Nakorn Sri Thammarat	Nakorn Sri Thammarat
Number of Rehabilitation Sites Assessed	13	11	9	6	5	3
Village Mangrove Area (Ha) ¹	407	592	319	176	3,894	257
Approximate Research Dates	Sept – Nov 2013	Dec 2013 – Feb 2014	Feb – May 2014	June – Aug 2014	Oct 2014 – Feb 2015	Feb – May 2015

Philippines							
Village Number	1	2	3	4	5	6	7
Village Code	P1A	P1B	P2A	P2B	P2C	P2D	P3A
Approx. Lat Long	10.8° N, 119.5° E	10.8° N, 119.5° E	14.1° N 123.3° E	14.3° N 123.3° E	13.9° N, 123.2° E	14.0° N, 123.2° W	13.8° N, 122.8° E
Province	Northern Palawan	Northern Palawan	San Miguel Bay, Luzon	San Miguel Bay, Luzon	San Miguel Bay, Luzon	San Miguel Bay, Luzon	Camarines Sur, Luzon
Number of Rehabilitation Sites Assessed	10	8	3	3	1	1	1
Village Mangrove Area (Ha) ¹	126	856	Unknown	Unknown	Unknown	Unknown	NA
Approximate Research Dates	Sept – Dec 2015	Jan – Apr 2016	May 2016	May 2016	May 2016	May 2016	May 2016

1. Source: Local Dept. for Marine and Coastal Resources field offices (Thailand) and Dept. of Environment and Natural Resources field office (Philippines).

Many mangrove rehabilitation projects were attempted by Thailand’s Department for Marine and Coastal Resources (DMCR) and the Philippine Department of Environment and Natural Resources (DENR) in the 1980s and 1990s. However, this study looked only at more recent planting from approximately 2007 onwards, which involved participation by local villages. Assessment of village P1A’s (Philippines) rehabilitation ability was expanded because this village was commissioned by the government to plant not only within its own territory, but also in neighbouring villages. All accessible P1A-rehabilitated sites were assessed because the planting team and the techniques used were the same. Some rehabilitation was carried out in both Thailand and the Philippines while the lead author was present in the village, (T1B Jan 2014, T3A Dec 2014, P1A Oct 2015) providing an opportunity to act as an observer and witness techniques.

1.3.2 Assessment Method

1.3.2.1 *Initial Visits with Village Mangrove Expert*

During initial scoping interviews with villagers and village leaders, opinions were sought to ascertain which resident was most knowledgeable about their mangroves. In all villages consensus about a mangrove expert readily emerged, thus negating the need to perform a village expert ranking exercise (Chalmers and Fabricius, 2007; Davis and Wagner, 2003). All rehabilitation sites were then visited initially with the village mangrove expert to record site history, reasons for the previous degradation, history of the rehabilitation effort(s), planting dates, details of site preparation, silvicultural practice and species choice. Site details recorded included presence / absence of trees, presence / absence of natural regeneration (indicating whether a site might naturally regenerate on its own) and hydrological connectivity. Also recorded were site elevation (section 1.3.2.3), soil type (sand, silt or clay), presence of standing water and post-hoc interventions such as the use of fencing. In addition other factors likely to affect rehabilitation and plant establishment were noted, such as evidence or presence of grazing livestock or trampling damage. Soil salinity was measured either from available soil pore water or groundwater sourced from minor excavations up to 15cm deep (Bellingham and Stanley handheld refractometer). However, it should be noted that it was not always possible to measure salinity in some of the high mangrove zone assessments because of a lack of available soil water. This might have skewed the resulting analysis. The direction of this potential skew is uncertain. The locations of the boundaries of all the rehabilitation sites were recorded via a handheld GPS (Garmin 62stc). Subsequently these GPS waypoints were employed to calculate the area of each site using Google Earth Pro. All site features were photographed.

Because several sites were planted more than once, a distinction has been made between 'attempt' (n=119) and 'site' (n=74). Wherever possible, all previous attempts on the same site were evaluated (38% of assessments) as well as the final (or only) attempt on a site (62%). Seventy-five of the attempts were in Thailand, 44 in the Philippines. The majority of the rehabilitation sites were <0.3ha, ranging from 0.001 – 50ha (SD \pm 7.73ha). The cumulative total area assessed was 164ha.

1.3.2.2 *Mangrove Establishment: Counts, Extrapolations and Area Calculations*

Although there are a range of factors that could be measured when assessing rehabilitation (see Dale et al., 2014 for a review), propagule or seedling survival is an unequivocal measure of whether the plants had managed to establish and survive or not. Presence or absence of natural regeneration was noted at the time of assessment - distinguishable from planted material by not being in lines, unevenly spaced, without canes and often of a pioneer species - but which did not contribute to survival scores. Plant health and vigour was also noted at the time of assessment.

Three techniques were used to assess survival depending on different planting ages and types of sites.

Preferentially, a 'full count' method was used for more recent planting events as both Thai and Philippine villages usually used canes which indicated where planting material had been inserted. Planting was frequently conducted in straight lines and even spacing. Therefore, for more recent planting projects (i.e. less than 1-2 years old) in less exposed sites, missing or absent plants were immediately obvious due to the resulting gap left in the lines of plants. Where possible every plant was counted for each generation of planting (if applicable). However, ten large-scale planting attempts were too extensive to allow each surviving plant to be counted. These extensive sites were stratified by elevation, exposure and channel edge / interior. Sub-plots were assessed to incorporate all significant variation of a site in order to achieve a minimum sample of at least 10% of the surviving plants.

Where full count inventory was not possible, totals were extrapolated from surviving patches of planting to the whole site. Some rehabilitation sites were too small or too fragmented to justify planting in lines. If present, surviving patches indicated how densely the site had been planted originally. In combination with a site history and the opinion of the village expert, total numbers planted were estimated and contrasted with survivors present, to produce a survivorship percentage for each generation of planting (if applicable).

In some cases, particularly on mudflat sites, there was often little trace of planting activity, or insufficient survivors to assess survivorship either via the 'full count' method or by extrapolation of surviving patches. Therefore the village expert and participants of the planting indicated as accurately as possible the boundary of the planted area, which was then marked by GPS. Having then counted every surviving plant within this defined planting area, Google Earth Pro was used to determine the area of the planting site. The stated planting spacing, normally 2x2m, was then used to calculate numbers originally planted. By dividing the number of surviving plants by the estimated number that had originally been planted, a survivorship percentage could be produced. For example, a planting area described by the village expert, marked by GPS, drawn as a polygon on Google Earth Pro might be revealed to cover 10ha. If the stated planting density was 2x2m spacing, this area would have originally had 25,000 plants. If the survivors counted within this defined planting area numbered 500, the survivorship was 2%.

These three different methods of survivorship assessment engendered different levels of confidence. To reconcile possible differences between methods, a post-hoc resampling was

conducted using the extensive field photography to reassess all 74 sites. On the assumption that the ‘full count’ method produced the most accurate, bias-free estimate of survival, we recalibrated ‘extrapolation from surviving patches’ against the ‘full count’. This post-hoc reassessment suggested that there was only a minor under-estimation of survival at low levels of survival, and a corresponding minor over-estimation of survival at higher levels of survival. Therefore, once reconciled, all three data sets were subsequently treated in the same manner. ‘Full count’ method was used for 38% assessments, ‘extrapolation from surviving patches’ 52% and ‘counts within a defined area’ 10% of attempts.

1.3.2.3 Mangrove Zones and the Quality of the Hydrological Connection

On any of the sites examined, several biotic and abiotic gradients were potentially affecting where mangroves lived, resulting in distinct bands of species. Most influential among these factors was the frequency and duration of a site’s inundation due to its elevation relative to sea level (van Loon et al., 2016). Following Duke (2006) and Tomlinson (2016), bands of mangrove species were classified into three zones. The ‘low’ zone, which started at approximately mean sea level, received inundation at high tides >45 times a month and was characterised by species such as *Sonneratia alba* and *Avicennia alba*. ‘Mid’ zones were inundated by normal high tides 20 to 45 times a month and were the home of *Rhizophora* spp. and *Ceriops tagal*. ‘High’ or ‘back’ zones received inundation <20 times a month at high tide and included back mangrove species such as *Heritiera littoralis*, *Lumnitzera* spp., *Scyphiphora hydrophyllacea* and *Acrostichum* spp. Mudflats, which normally occurred between lowest water and mean sea level, were inundated by every high tide. Site elevation was estimated by visual assessment of the topography, mangrove species present, level of water in or on the soil and the number of tides per month that inundated the site in the estimation of the village mangrove expert.

Table 2 illustrates the distribution of rehabilitation attempts within these mangrove zones. Most rehabilitation or afforestation attempts were on mid mangrove areas (52%), mudflats (30%), together with high zone areas (13%).

Table 2. Frequency of rehabilitation attempt by mangrove zone, by country

		Position of Rehabilitation Attempt Relative to Tidal Inundation Regime				Total
		Mudflat	Low Zone	Mid Zone	High Zone	
Country	Thailand	7	1	52	15	75
	Philippines	29	4	10	1	44
Total		36	5	62	16	119

Mid and high zone rehabilitation sites varied greatly in hydrological connection to tidal flushing, thus elevation per se was not necessarily a good indicator. Instead better hydrological connection was judged by the following indicators:

- greater number of days a month the site was inundated, according to the village expert
- many seeds / propagules present on the ground not directly under a potential seeding tree (indicating that inundations were able to transport them onto the site)
- greater presence of established mangrove natural regeneration (indicating that soil drainage was adequate for plant growth)
- wet soil and other evidence of the area having been recently inundated (e.g. visible tide line)
- a lack of extensive areas of standing water (indicating better drainage and suggesting a better quality of soil, as saturated soils are less well suited for mangrove establishment)
- a lack of visible salt crystals on the soil surface (indicating that sufficient inundation was avoiding a build-up of salt – a stressor for all mangroves)
- limited plant / tree stress indicators (e.g. canopy die-back, stunted plants, abnormally small leaves, a proliferation of prop roots on *Rhizophora* sp.)
- fewer dead leaves on the ground (indicating that they had been washed away)
- no significant debris within the channels, e.g. from cutting for charcoal production (debris would slow water flows, inhibit the distribution of seeds and propagules and increase the chance of sedimentation within the channels)

A qualitative decision was made by weighting all the above criteria equally. Each site's hydrological connectivity was classified as either 'good' or 'partial / poor' based on the preponderance of indicators of good connection compared to indicators of poor connection. Mudflats and lower mangrove elevations by definition have good connectivity to the local hydrology and therefore were not assessed for the quality of their hydrological connection.

1.3.2.4 Time Since Planting

One hundred and nineteen attempts at mangrove rehabilitation or afforestation were evaluated over 74 sites. Of these attempts 36 were assessed less than 12 months after planting. We attempted to achieve a balance between including the maximum amount of data possible yet avoiding false-positives by excluding planting that had not yet had sufficient time to either establish or fail to establish. The cut-off was set at one year. The exception to this cut-off period was planting attempts where survivorship was $\leq 5\%$ (14 planting attempts) as the planting within these attempts had already clearly failed. Therefore 97 attempts were retained for analysis.

Table 3. Time between planting and assessment, by frequency of rehabilitation attempt

Time between Planting Attempt and Assessment	All Attempts Assessed	Planting Attempts Retained for Further Analysis
< 1 Year	36	14
13 – 24 Months	29	29
> 2 Years	54	54
Total	119	97

1.3.2.5 Criteria for Judging Whether Planting was Required

An assessment was made as to whether each mangrove rehabilitation site might have regenerated naturally, whether rehabilitation should never have been attempted at that site, or whether planting was necessary and appropriate. Whether planting was necessary and appropriate or not was assessed by the following indicators:

- an absence of natural regeneration and / or a lack of successful establishment of natural regeneration. (It should be noted that planted material can encourage natural regeneration, either by physically trapping seeds and propagules or improving the quality of the soil sufficiently for other species to establish.)
- appropriate site elevation for mangrove establishment relative to sea level, and resulting inundation regime, (i.e. within either low, mid or high mangrove zones, with duration and frequency of flooding, as described in section 1.3.2.3.). Mudflats, extending from approximately mean sea level down to lowest water, hydrological channels and areas of standing water were deemed inappropriate places for planting and ecologically unsuitable for mangrove establishment (Lewis, 2005)
- low expected wave energy (the assumption was that young plants that were subject to significant wave energy will be damaged or uprooted and washed away.) Assessment included evidence of erosion, whether the site was directly open to the sea and the opinion of a local mangrove expert
- soil mechanically firm enough to anchor a propagule or seedling appropriately, not so soft as to allow the researcher to sink into the mud up to the knees
- minimal levels of significantly-sized debris on site (which might be lifted by the tide and damage vulnerable plants)

- no inhibiting social factors such as uncontrolled animal grazing, boat impact, damage from footfall or destruction from the use of damaging fishing gear which scrapes along the sediment surface uprooting natural regeneration

A qualitative decision was made by weighting all the above criteria equally, and classifying each site as either requiring planting, able to naturally regenerate on its own, or an inappropriate site that will never become mangrove, based on the preponderance of indicators described above.

1.3.3 Research Method Limitations

More sites were assessed in Thailand than in the Philippines. Where possible, information from the village expert was cross-checked against interviews with government mangrove agency field office staff, villagers, and by direct observation, to reduce recall error.

Plant health, vigour and biomass characteristics were not included in survivorship assessment, but were taken into account for the quality of hydrological connection, the appropriateness of the site and species choice, and whether or not a site required planting. This inevitably involved an element of judgement and site interpretation, and consideration of factors such as the frequent seasonal floods in southern Thailand and watershed-scale hydrological disturbance in villages T3A and T3B (Osbeck et al., 2010; Prabnarong and Kaewrat, 2006), or the reduction of precipitation due to the 'El Nino Southern Oscillation' event that occurred during the research period (L'Heureux et al., 2017).

Separating and discarding 22 planting attempts which were 'too early to judge' (Table 3) from those which had had 'enough time' to establish or fail, may have negatively affected survivorship results, but may also have removed potential real positives as well as false positives. A brief comment on retaining the $\leq 5\%$ survivorship attempts is in the Discussion (section 1.5).

Although benchmarking against other mangroves (McDonald et al., 2016) might have been suitable in countries where there is pristine mangrove nearby, Thailand and the Philippines have very little mangrove which has not been replanted after charcoal / fuelwood concessions, subjected to species-selective felling or had natural *Sonneratia* / *Avicennia* forests replaced by *Rhizophora* spp. planting, such as in Banacon Island, Philippines, or Pak Phanang Bay, Thailand (Macintosh et al., 2002; Osbeck et al., 2010; Walters, 2005b). Mangrove workers who have suggested that rehabilitation projects should aim for and be judged by ecological rehabilitation criteria (Asaeda et al., 2016; Ellison, 2000; Lewis, 2000; Walters et al., 2008) are by implication working towards the conditions which allow the return of full ecosystem function (Saenger et al., 2013). Although appropriate in theory, using such criteria presents a practical problem as a result of the extensive time needed between planting and full recovery of ecosystem function. To have a chance of

returning an area to functioning mangrove forest, the initial planting must first survive any transplant shock and establish itself. The data presented here only describe this initial establishment. We acknowledge that planting which might become established and grow into a new stand and might therefore be deemed successful, could still potentially fail to deliver the full suite of ecosystem benefits. Examples of this later failure include mangroves used to stabilise the walls of aquaculture ponds but which have little hydrological connection, or when mangroves are planted in drainage channels which block the local hydrological connection, leading to eventual ecosystem failure.

1.3.4 Statistical Tests

The difference between 13-24 month and >2-year planting survivorship was tested using a Mann Whitney-U test. The null hypothesis was that there was no difference in survivorship between planting 13-24 months previous to assessment compared to planting older than two years.

The difference in planting survival between Thailand and the Philippines was analysed using a Mann Whitney-U test. The null hypothesis was that there was no difference in survivorship between countries.

The relationship between salinity and survival was explored using a Spearman's correlation. The null hypothesis was that there was no relationship between salinity and survival.

The difference in survival between planting material used was analysed via a Mann Whitney-U tests. The null hypothesis was that planting material (direct planting of propagules, bagged seedlings or wildlings) made no difference to survival rates.

The difference between survival rates in mid or back mangrove areas with good hydrological connectivity as opposed to partial / poor hydrology was examined using a Mann Whitney-U test. The null hypothesis was that good or partial / poor hydrological connectivity made no difference to mangrove survivorship.

Whether there was a significant difference to survivorship if natural regeneration was present or not was examined using a Mann Whitney-U test. The null hypothesis was that there would be no difference in planting survivorship between sites with natural regeneration or without.

1.4 RESULTS

1.4.1 Site Descriptors and Demographics for All 119 Attempts

Hydrological connection, by definition, was complete for mudflats and low zone mangroves. However, for mid and high mangrove zones, some only had partial / poor connection and drainage (section 1.3.2.3) with a limited exchange of water at each tidal flushing, and areas of standing water. Of all the attempts within mid and high mangrove zones (n= 80) only a quarter (26%) had a good hydrological connection. There was no evidence that any measures had been taken to improve hydrological connection in those sites with partial / poor connection. Occasionally, hydrology was made worse (e.g. village T2A), by skimming the grass off a site with a bulldozer during site preparation, thereby filling the drainage channels in the process. On other sites, previous tree felling for charcoal had left brush and debris in the channels (e.g. village P1A), slowing the flow of water and increasing sedimentation in the channels.

High and mid zone mangrove soil salinities (both 27ppt, SD ± 2 and SD ± 8 respectively) were slightly less than low zone salinity (33ppt, SD ± 2.3), which in turn was less than sea water (normally approximately 35ppt). Partial / poor hydrology appeared not to affect average mangrove soil salinity as much as the presence of fresh water input from rivers flowing into mangrove deltas.

A majority of rehabilitation attempts (65%) 'direct planted' propagules into the soil. Thirteen percent of attempts (all in the Philippines) used 'wildlings', young plants with 2-5 leaf pairs, pulled out of their original location and transplanted as bare-root stock. Eleven percent of rehabilitation attempts used polybagged seedlings. Rehabilitation was left to natural regeneration in only two instances, which have been included in the analysis because using this form of rehabilitation was a conscious decision on the part of the village (T2A) conservation group.

Fig. 1 illustrates in which zone the different types of planting material were used. This broad distribution suggests there was little relationship between planting material used and site elevation. Direct planting of propagules was the most common across all species except *Nypa fruticans*.

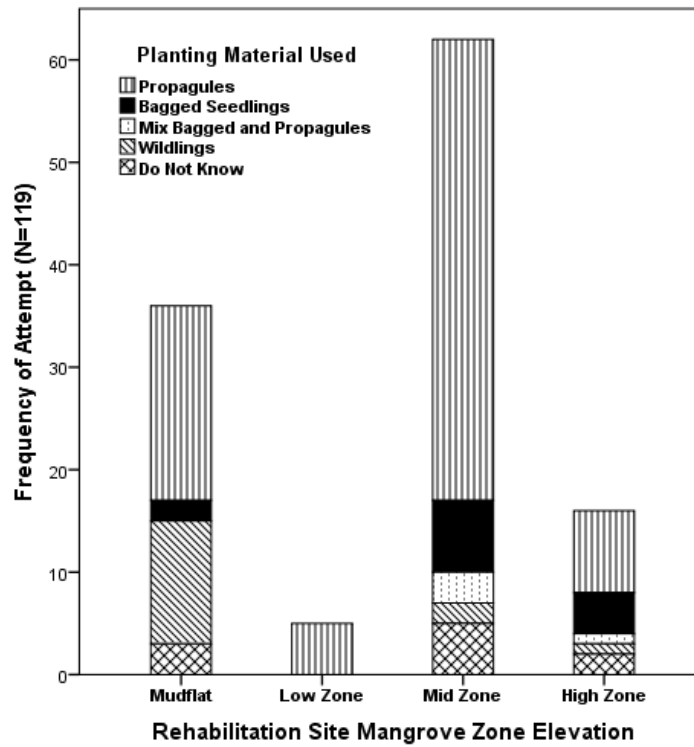


Figure 1. Frequency of planting attempt by, mangrove zone, by type of planting material use. (Nat regen has been excluded for clarity).

By species, *Rhizophora* spp. was used in the majority of planting; alone in 52% of attempts and in conjunction with other mid mangrove species (e.g. *Ceriops tagal*, *Bruguiera* spp.) another 13% of the time.

Other mid mangrove species such as *Ceriops tagal* and *Bruguiera* spp. were planted 19% of the time (Fig. 2). 'Mix' (n=6) denotes when a selection of (rarely more than three) species was used from more than one mangrove zone. These often but not always included *Rhizophora* spp., along with *C. tagal*, *Bruguiera* spp. and very occasionally mangrove associate *Pandanus tectorius* (Kitamura et al., 1998; Tomlinson, 2016).

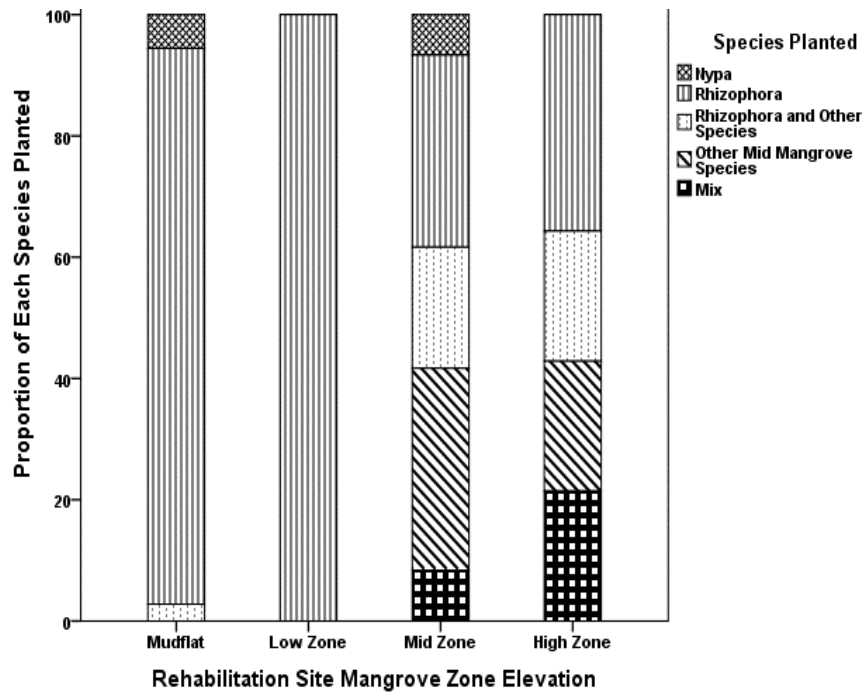


Figure 2. Proportions of mangrove species planted, by mangrove zone

1.4.2 Rehabilitation Successes and Failures

All analyses from this point onwards excludes the 22 attempts assessed as ‘too recent to judge’ (section 1.3.2.4) unless otherwise stated. For this reduced subset of rehabilitation attempts (n=97), the mean survival rate was 20% (SD \pm 23.4) with a median of 10%, Fig. 3, the median or middle score being less affected by a non-normal or skewed distribution of data and extreme scores (Field, 2018).

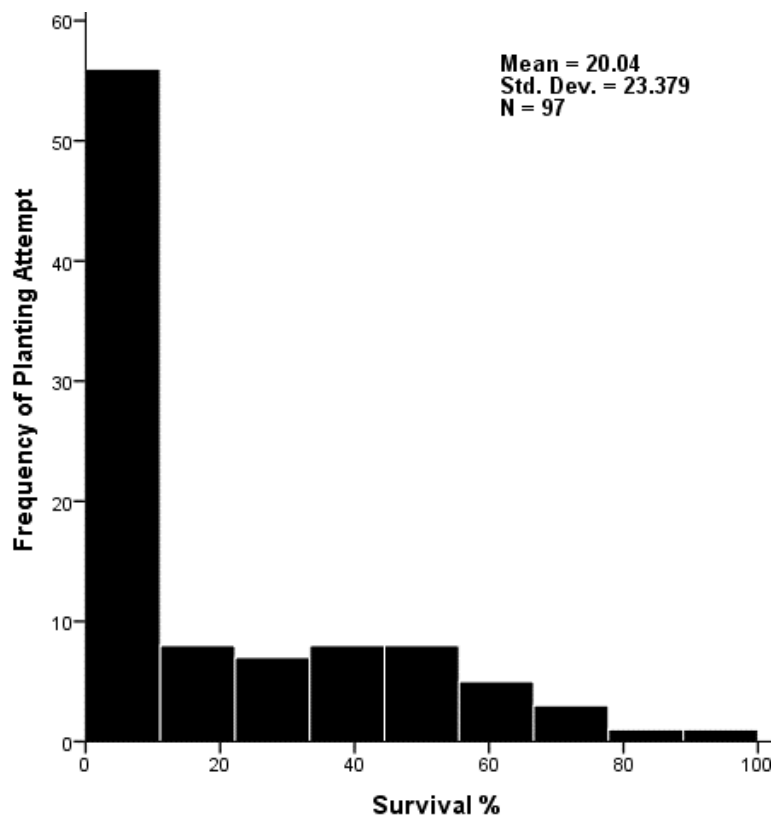


Figure 3. Percentage survival rates by frequency of planting attempt. Mean survival 20%, median 10%

The difference between 13-24 month and >2-year planting survivorship was not significantly different ($U=719$, $Z=-0.61$, $p=0.54$), indicating that most propagule death occurred within the first year after planting, Table 4.

Table 4. Mean (median) survivorship by time between planting and assessment

Mean Survivorship by Time Between Planting and Assessment	< 1 Year	13-24 months	> 2 Years	Total
Mean Survival % (Median)	1.6 (1)	23.9 (10)	22.8 (12.5)	
SD	2	27.4	22	
N	14	29	54	97

Median planting survival varied significantly ($U=570$, $Z=-4.2$, $p<0.001$) between Thailand (19%, SD ± 24.3 , $n=58$) and the Philippines (1%, SD ± 18.8 , $n=39$). This reflected a tendency to attempt to afforest mudflats in the Philippines. The mean survival for mudflats was low (1.4%, median 0.0%, SD ± 3.6 , $n=31$) compared to mid mangrove zones (30.1%, median 23%, SD ± 22.5 , $n=48$) or high mangrove zones (25%, median 10%, SD ± 28.3 , $n=13$). Salinity exhibited a significant inverse relationship with planting survivorship ($r(79)=-0.57$, $p<0.001$).

Fig. 4 shows the survival rates by mangrove species. The mean survival rate of *Rhizophora* spp. was 11% (median 1.5%, SD \pm 20.4, n=50), despite being the most popular choice for planting. The establishment of *Nypa fruticans* was similarly poor (9%, median 5.5%, SD \pm 10.4, n=5). Other mid-mangrove species fared better with a mean survival of 29% (median 17%, SD \pm 26.8, n=20), as did 'Mix' (i.e. a range of species from more than one mangrove zone, 46.2%, median 49%, SD \pm 22.8, n=6).

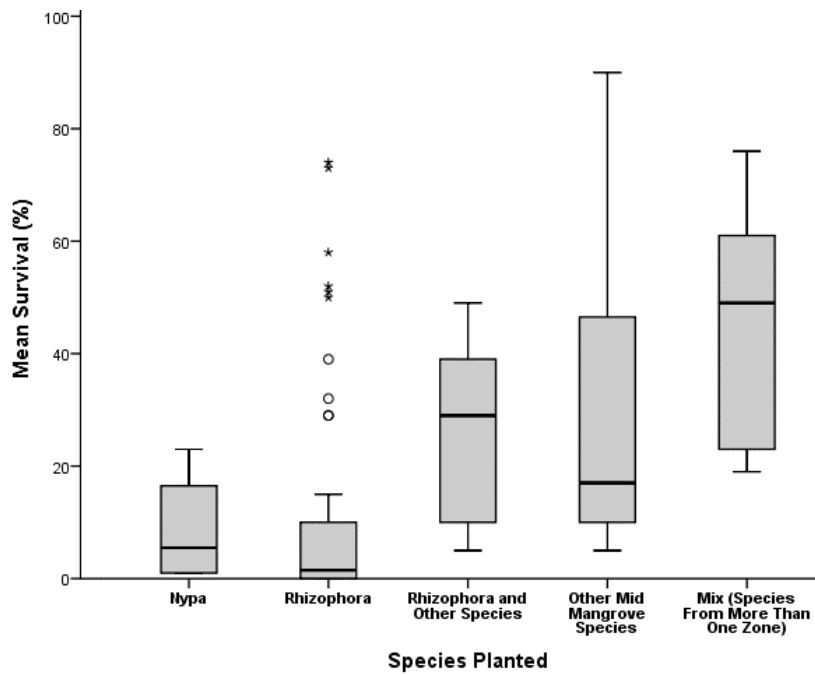


Figure 4. Planting survival rates by species planted

While there was no significant difference in survival between directly planted propagules and bagged plants, ($U=222$, $Z=-0.99$, $p=0.32$), there was a significant difference between propagules and wildlings ($U=267$, $Z=-2.3$, $p = 0.024$), and between bagged plants and wildlings, ($U=27$, $Z=-2.29$, $p=0.023$), Fig 5.

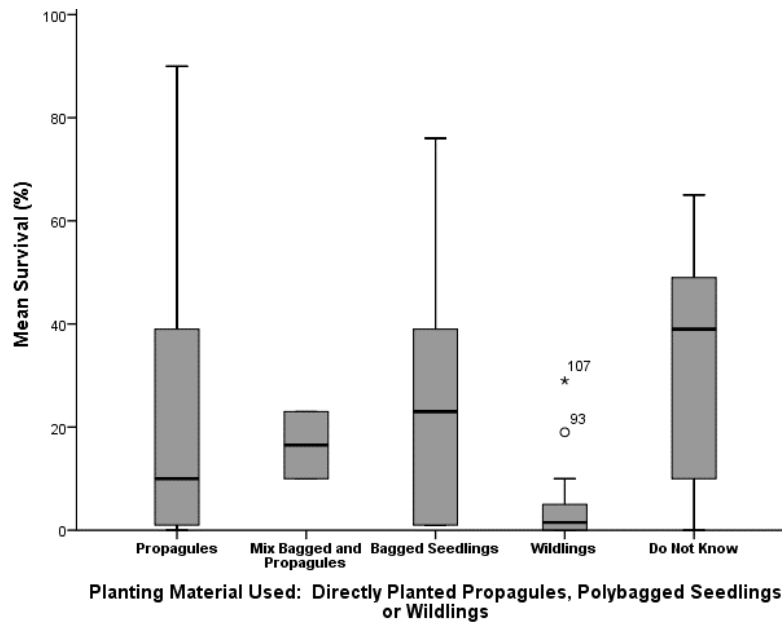


Figure 5. Planting survival by type of planting material used. (Direct planting of propagules, seedlings in polybags or wildlings)

Bagged plants (mean survival 27.6%, median 23%, $SD \pm 26.6$, $n=9$) were either *Nypa fruticans*, *Ceriops tagal* or very occasionally mangrove associate *Pandanus tectorius*. Otherwise, planting was 'direct planting' of propagules into the substrate (mean survival 20.2%, median 10%, $SD \pm 23.9$, $n=62$). Transplanted 'wildlings' (bare root stock, always *Rhizophora* spp., mean survival 5.4%, median 1.5%, $SD \pm 8.6$, $n=14$) were only used in the Philippines.

Within the mid and high zone mangrove areas, mean survival of planted material was significantly lower ($U=232$, $Z=-2.01$, $p=0.038$) in sites with partial / poor hydrological connection at 24.8% (median 19%, $SD \pm 21.9$, $n=48$), compared to areas with good hydrology where the survival rate was 39.9% (median 39%, $SD \pm 26$, $n=15$).

1.4.3 Interactions Between Variables

Table 2 shows that mudflats and mid mangrove elevations were frequently chosen as sites for afforestation / rehabilitation planting. Mudflats proved resistant to planting whatever form of planting material was employed. However, mid and high zone sites had better survival of all planted materials, and bagged plants (n=9) in particular, Fig. 6.

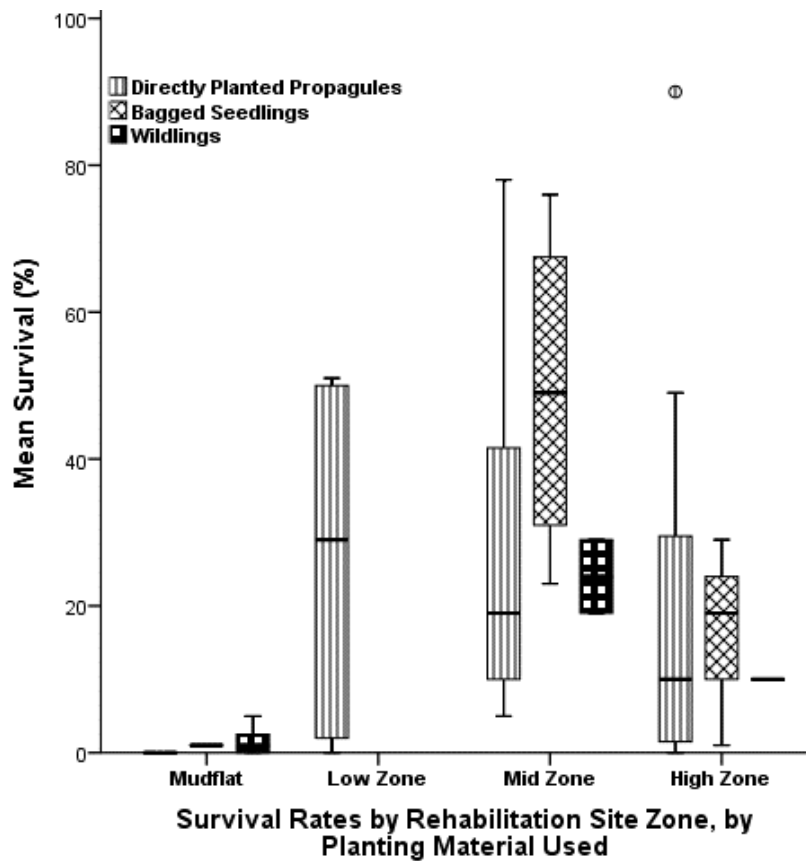


Figure 6. Planting survival by mangrove zone, by planting material. (Planting material 'Don't know' (n=10) and 'Mixed' (n=2) have been omitted for clarity)

Fig. 2 (section 1.4.1) indicated the proportions of different species used for planting, at differing elevations. Fig. 7 illustrates that on mudflats and in back mangrove zones, *Rhizophora* sp. (n=52) was not an appropriate genus to use. However, when *Rhizophora* sp. was used in zones suitable for this genus (low and mid zones), its survival rate improved but was no more successful than 'Other Mid Mangrove Species' (n=21) which was only used in mid to back elevations. *Nypa fruticans* (n=5) also performed poorly on mudflats.

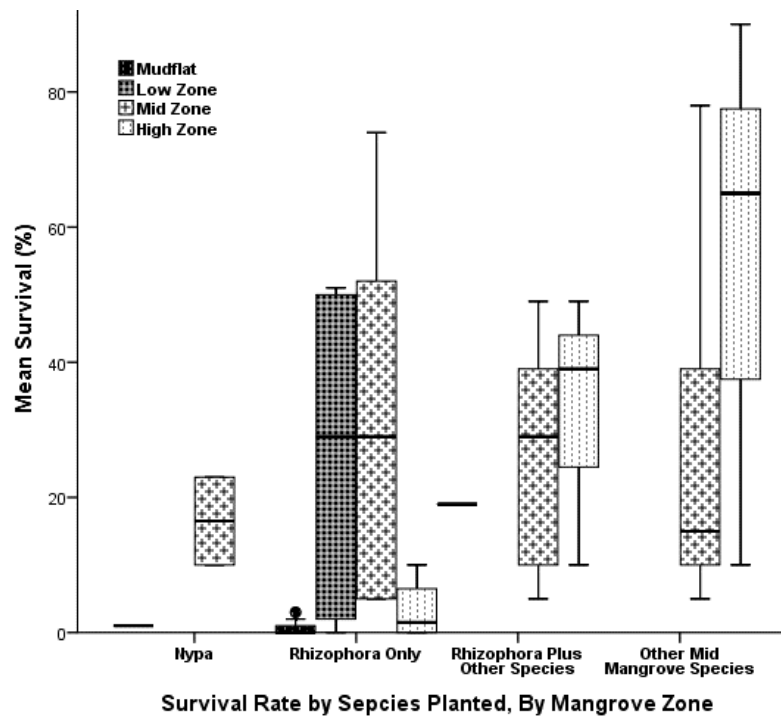


Figure 7. Survival of species planted, by mangrove zone. (Mixed species (n=6), natural regen (n=2) have been omitted for clarity)

1.4.4 Was Planting Necessary?

Planting survivorship was significantly higher ($U=528$, $Z=-4.69$, $p<0.001$) when natural regeneration was present on a rehabilitation site (mean survival 26.3%, median 19% SD ± 20.6 , $n=51$) compared to when there was no natural regeneration present (mean survival 13%, median 1%, SD ± 24.4 , $n=46$).

Using the criteria described previously (section 1.3.2.5) natural regeneration would have been sufficient, and planting unnecessary in 37% of attempts, largely within mid and back mangrove zones. Another 47% of attempts 'will never be mangrove' because of inappropriate hydrology or being located at an unsuitable inter-tidal elevation. For clarity of depiction, these two categories have been combined in Fig. 8 to contrast against the 16% of planting attempts that were considered to have been necessary, by mangrove zone.

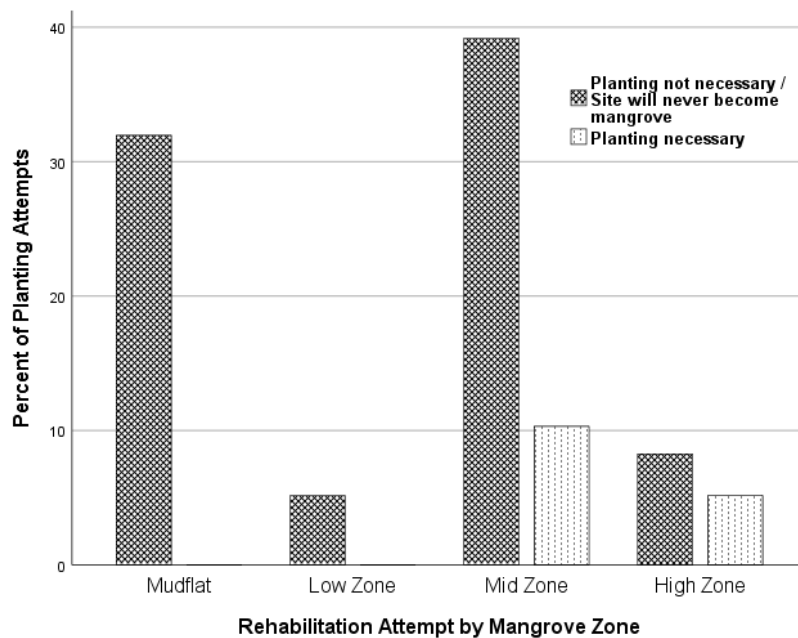


Figure 8. Percentage of unnecessary / inappropriate planting, against necessary planting, by mangrove zone

1.5 DISCUSSION

The majority of sites that would probably have recovered through natural regeneration alone were mid and back mangrove, Fig. 8. Within these zones, some areas viewed by the villagers as 'degraded' were simply mangroves with natural gaps and desirable forest complexity. However, because they were seen as degraded they were re-planted, which sometimes included clearing biodiverse natural regeneration and 'crown lifting' of existing non-*Rhizophora* sp. trees (Walters, 2004). Only a few sites that had previously been mangrove before being cleared or degraded, normally for charcoal, were not regenerating (16%). Typically, this was due to poor hydrology, hard smooth soil making the retention of 'volunteer' propagules / seeds difficult or for other reasons such as a lack of fencing to keep out grazing animals (Field, 1996). In these cases planting was necessary and might ultimately facilitate quicker mangrove succession (Ferreira and Lacerda, 2016; Lewis et al., 2016), but with no guarantee of success because the other site-specific mangrove stressors (discussed here and in sections 1.2.7 and 1.3.2.5), were often not resolved. It should be stressed again that this study only examined mangrove establishment rather than survivorship to long-term reproductive success. Specifically, that seedlings survived the transplant process and that both seedlings and directly planted propagules survived beyond an annual cycle of monsoon and dry season. (However, as mentioned in section 1.3.3, in order to retain as much data as possible, 14 clear results with survivorship $\leq 5\%$ from planting less than a year old were retained, as this did not affect the overall median survivorship score of 10% and only decreased the mean overall survivorship by 2.8% (SD=23.9%) percentage points.)

If planted sites would have regenerated on their own, without planting intervention as demonstrated by Lewis (2005) and Brown et al. (2014), this could avoid planting costs and liberate financial and labour resources for other management tasks. Generally, the presence of natural regeneration is a good indicator that a potential site is suitable for rehabilitation. However, natural regeneration can also start to establish in hydrological channels following the failure of the local hydrology. Similarly, although some of the mudflat afforestation attempts were situated near the fringe of existing mangrove, and hence were interspersed with a limited amount of pioneer species natural regeneration, this did not mean that these sites were potential mangrove areas. In short, open mudflats and mangrove drainage channels (47% of 97 attempts) were not ecologically appropriate sites, and rehabilitation / afforestation should not have been attempted in these locations.

The mangrove zone within the inter-tidal range runs from above mean sea level (Alongi, 2002; Kairo et al., 2001; Lewis, 2005) or upper third (Saenger, 2002) to highest high water. Knowledge of

mangrove species zoning is essential for successful rehabilitation (Kairo et al., 2001). So-called site / species matching has been offered as a key reason for planting failure – i.e. planting inappropriate species for a given site and its inherent conditions (Alongi, 2002; Aung et al., 2011; Bosire et al., 2006; IUCN, 2017; Kodikara et al., 2017b; Primavera and Esteban, 2008; Saenger, 2002; Walters et al., 2008). The failure to improve planting performance despite increased financial spend by NGO-led projects in the Philippines (Samson and Rollon, 2008; Walters et al., 2008) or the 1bn Peso (£14m) ‘National Greening Programme’ in the Philippines (Ranada, 2015) is in part due to the frequent planting of mid zone *Rhizophora* sp. in all zones (Fig. 2). This is possibly because its propagules are easy to collect and handle and do not require growing-on in a nursery (Lewis, 2014; Primavera, 2015; Primavera et al., 2011; Primavera and Esteban, 2008). The research described here demonstrates the improved success rates associated with planting the correct species for the specific mangrove zone (Fig. 7).

While acknowledging the challenges of hydrological assessment (van Loon et al., 2016), an understanding of site hydrology, topography and drainage, and the effects these have on salinity and the species chosen, is vital for successful mangrove rehabilitation (Aung et al., 2011; Elliott et al., 2016; Elster, 2000; Hashim et al., 2010; Kairo et al., 2001; Lewis, 2005; Oh et al., 2017). Some sites can be restored simply by hydrological reconnection or improvement if propagules are available from nearby stands via hydrochory (Prach and del Moral, 2015; Stevenson et al., 1999). Unlike Elster's Colombian experience (2000) and Brown et al. (2014) in Indonesia, hydrology was rarely considered at our study sites, having been discussed only once at one Thai site (village T3A). Occasionally site hydrology was made worse by inappropriate site preparation. This study has documented the significant difference improved / adequate hydrology makes to rehabilitation success. This therefore suggests that many of the mid and back mangrove sites would have benefited from improved hydrological connectivity and drainage. However, guidelines for hydrologic rehabilitation are sparse and communication between researchers and mangrove managers appears to have been insufficient to change rehabilitation activities.

Although there was no significant difference in the survival rates of directly planted propagules and bagged seedlings (Fig. 5), extrapolation of these results should be done with caution. Bagged seedlings tended to be *Ceriops tagal* and *Nypa fruticans* not *Rhizophora* sp. and were likely to be used in a more appropriate zone (Fig. 6). However, planting of bagged *N. fruticans* on mudflats resulted in total mortality (village T3B). Bagged material was only deployed if it was provided by the government, rather than for ecological or silvicultural reasons and used much less often than direct

planting of propagules (section 1.4.1). Excluding special cases, the resulting small sample sizes were too small to make further analysis appropriate.

Clump planting propagules close together (i.e. < 30cm apart) to allow planted material to benefit from a mutually improved rhizosphere (Chan and Baba, 2010; Lavieren et al., 2012) was never attempted. Root-balled 'wildlings' were not attempted by any group. Bare-root wildlings were only used in the Philippines, where villagers and government staff believed they were more reliable than propagules. Contrary to this local belief, bare-root wildlings were significantly less likely to establish than other planting material (Fig. 5). However, because these wildlings were most frequently deployed on mudflats, their very low survival (mean = 5.4%) also found by Primavera et al. (2011), cannot definitively be ascribed to bare-root wildlings being an intrinsically poor silvicultural method. Furthermore, poor handling, for example allowing exposed roots to dry out in direct sunlight before being re-planted, cannot be ruled out. Poor survival of directly planted propagules might also have resulted from propagules being collected from trees before maturity, and planters having only a partial understanding of the effects of pests such as *Poecilips fallax* beetle on propagules.

Protection from storms and strong winds is often a key motivator for mangrove planting and afforestation, particularly in the Philippines where village planting was funded by the 'National Greening Programme' (Department of Environment and Natural Resources, 2016). In the medium-term, the rehabilitation projects described here will produce densely stocked, even-age plantations with limited structural complexity. Structural complexity is characterised by a number of forest attributes such as basal area, tree height, tree species, tree density, biomass, foliage arrangement, canopy cover and understory (McElhinny et al., 2005). This complexity develops over time but could be accelerated through planting a diversity of species at a variety of spatial densities. This lack of complexity should be a cause for concern as research has shown that older plantation stands of *Rhizophora* spp. are more vulnerable to strong winds than other species. Furthermore, they have a poor ability to recover from storm damage because they lack latent buds and cannot re-grow from the base when the stem is damaged (Bosire et al., 2008; Salmo III et al., 2014; Villamayor et al., 2016). In addition the smooth canopy of an even-aged class stand slows wind less than a mixed-aged stand of uneven height (Villamayor et al., 2016).

In order to implement the 'National Greening Programme', the Department of Environment and Natural Resources of the Philippines passes down extensive planting area quotas to the department's field offices. To fulfil these quotas, mudflats are frequently selected as they offer the necessary spatial extent (Primavera, 2015). Although mudflats in both countries might have been considered silviculturally inappropriate, these areas typically have uncontested land tenure (for a

description of the land tenure issues, see Primavera et al., 2015, 2011; Samson and Rollon, 2011). They are therefore easily available, as other researchers have reported (Lewis and Brown, 2014; Primavera, 2015; Primavera et al., 2011; Samson and Rollon, 2008; Walters et al., 2008). Thus despite evidence in the published scientific literature, rehabilitation manuals and national media (Primavera, 2015; Primavera et al., 2011; Ranada, 2015), planting continues on mudflats, and sometimes even seagrass beds, even though mean survival rates were shown here to be <2%. Mudflats are particularly valuable for feeding shorebirds, producing income for local gleaners and food security (Primavera et al., 2011). Therefore on the rare occasions that mudflat planting survived, normally due to rapid accretion or deposition of sediment (pers. obs.), the value of substituting one ecosystem for another has been questioned (Erftemeijer and Lewis, 1999; Lewis, 2005).

Similarly in Thailand much of the mangrove management activity was driven by national propagule planting targets delegated to the mangrove agency field offices. These targets originated from successive four-year National Economic and Social Development Plans (for example, National Economic and Social Development Board, 2011; Office of the National Economic and Social Development Board, 2001). Field offices also received additional directives such as planting 840,000 propagules to celebrate a national event (National News Bureau of Thailand, 2016). Furthermore there was often a general desire by villages to carry out communal planting activity on national holidays. However, some field offices are starting to negotiate the return of aquaculture ponds which had been illegally established within the mangroves and other encroached former mangrove areas. Consequently, more planting was carried out in mid and high mangrove zones (Fig. 7). Although the overall success rate was higher, the question remains as to how much of the planting was actually necessary.

This paper and others (Dale et al., 2014; Lewis, 2005; Primavera and Esteban, 2008; Salmo III et al., 2007; Samson and Rollon, 2008) have suggested that, despite being largely unnecessary, planting has tended to dominate mangrove management activity. This is typically endorsed at the national level. Area planting targets set by the Philippines' National Greening Programme have produced sub-optimal outcomes, and planting has also arguably received too much emphasis in Thailand. Although such target-driven planting provides quantifiable measures (Mansourian et al., 2017), this is unlikely to be aligned with silvicultural best practices. Propagule survivorship would be a more appropriate measure, perhaps combined with an emphasis on recovering abandoned aquaculture ponds. The area of abandoned ponds in Thailand and the Philippines is not known, but in Indonesia alone there is estimated to be around 250,000ha (Gusmawati et al., 2017). Aquaculture ponds are

frequently located in mid and high zone mangrove areas which this study and others have shown to be a more appropriate elevation for mangrove rehabilitation. Restoring hydrological connectivity to these abandoned ponds to rehabilitate them back to functioning mangrove ecosystems (Primavera et al., 2011; Villamayor et al., 2016) would arguably be a more appropriate management task, particularly over the coming decades as sea level rise requires mangroves to retreat landward and upward (Gilman et al., 2008; Primavera et al., 2011).

1.6 CONCLUSION

This research suggests that attention to a few key factors can enhance rehabilitation outcomes. First, mangrove workers should ensure that the appropriate species are planted in the mangrove zone for which they are best suited. Second, appropriate hydrological connectivity with good tidal flushing and drainage improves project outcomes. Third, it is suggested that much mangrove rehabilitation is either unnecessary or conducted on sites which are inappropriate. Fourth, attempted afforestation of mudflat sites usually fails and is not recommended. Finally, rehabilitation projects should focus on survivorship rather than meeting area or propagule number targets which typically produce sub-optimal outcomes.

CHAPTER 2. KNOWLEDGE GAPS CONTINUE TO AFFECT VILLAGE AND GOVERNMENT MANGROVE REHABILITATION TECHNIQUES

2.1 ABSTRACT

Numerous mangrove rehabilitation projects have been executed by governments, NGOs and villagers, but despite many rehabilitation guidebooks, extensive published mangrove science and documented field experience, many planting projects fail or fail to achieve their objectives. Here we examined the mangrove rehabilitation techniques described by villagers in a sample of eight communities across Thailand and the Philippines, and some of the knowledge that underpinned the rehabilitation decisions made. 150 semi-structured interviews were conducted with villagers, village leaders and conservation group leaders to understand their methods, decisions and activities around the most recent mangrove planting event they had taken part in. This was supplemented by 243 tests of knowledge surrounding the science of mangrove rehabilitation, taken by villagers, government mangrove agency staff and key-informants.

Respondents reported that they planted on mid mangrove zones 28% of instances but mudflats most frequently (33%) - 64% of villagers and 77% of government officers believing that mudflats were appropriate places for mangrove planting. Sites were chosen because either they were perceived as degraded or because there was a requirement for available space for planting (both 34% of interviewees). Despite planting at all mangrove elevations as well as on mudflats, 94% of interviewees claimed to have planted mid mangrove species. Low zone pioneer species were never used and generally there was a low level of appropriate site / species matching. Half of all sites were reported to have received no site preparation. If site preparation was described (33% of interviews), this involved cutting back vines, weeds and creepers on mid or back mangrove sites, which might well include 'unwanted' mangrove species, thereby reducing biodiversity.

Improvements to hydrological connectivity were rare despite the widespread understanding from the tests that good hydrological connection played an important role in mangrove rehabilitation. Planting timing was not an ecological consideration but driven by a desire to celebrate national days in Thailand (41% of Thai interviewees), and logistical concerns in the Philippines (56% of Philippine respondents). Furthermore, 22% of Philippine interviewees reported that planting was timed to coincide with low tides to enable access to mudflats. Villagers were consistently over-optimistic about the success of their planting projects with more than half of respondents stating their project had a >70% survival rate. This is in contrast to these villages' planting outcomes assessed in Chapter

1 which found a mean survival rate of 20% and a median of 10%. Planting outcomes, techniques described and the knowledge tests suggest that only a limited amount of the published mangrove science and best practice has been communicated effectively enough to these groups to change behaviour on-site.

2.2 INTRODUCTION

2.2.1 Mangrove Restoration: We Know Enough (But Do Not Communicate It)

Fundamental questions posed by mangrove researchers nineteen years ago are still relevant today: ‘Mangrove restoration: Do we know enough?’ (Ellison, 2000), and to paraphrase Walters (2000), *Are local coast fisherfolk effective restorationists?* Ellison (2000) argued that there was sufficient scientific knowledge (supported by Field, 1996; Samarakoon, 2012; Walters et al., 2008). Furthermore researchers believe that rehabilitation is not particularly difficult (Alongi, 2002; Ellison, 2000; FAO, 1994 but see Primavera et al., 2011) and mangroves should be able to self-repair and regenerate, even after profound disturbances such as oil spills, given enough time (Duke, 1996, 2016).

To assist mangrove workers, a significant body of scientific literature and published work describing mangrove ecology and rehabilitation as well as many guidebooks and attempts at best practice guidelines have already been produced (e.g. Lewis, 2005; Lewis and Brown, 2014; Primavera et al., 2015, 2012, 2011; Mangrove Action Project’s website⁴ amongst others). Some of this guidance moves beyond just planting to encouraged mangrove workers to consider the more holistic process of *ecosystem restoration*: removing or mitigating mangrove stressors and ensuring that the hydrology and topography of a site were suitable to facilitate natural regeneration (Lewis, 2005, 2000, 1982; Lewis et al., 2016; Lewis and Brown, 2014; Lewis and Gilmore, 2007). Despite the numerous published mangrove rehabilitation manuals, there appears to be disagreement about what constitutes best practice, including choices between planting or facilitating natural regeneration, although some differences can be a function of project objectives. This on-going debate notwithstanding, it is questionable whether key principles from the mangrove science have been applied either to government or NGO rehabilitation projects (Ewel, 2010; Kairo et al., 2001; Primavera et al., 2015, 2011). Similar to development project failures that attempt to alleviate poverty (Davies et al., 2014), few mangrove rehabilitation failures are fully documented. Furthermore, it is uncertain whether the relevant scientific literature is accessible to NGO staff, conservation groups and mangrove agency field officers as online journals are located behind academic publishers’ ‘paywalls’, and whether this literature is produced in an appropriate format and language for these groups (Walsh et al., 2015).

⁴ <http://mangroveactionproject.org/emr-illustrated-manuals/> <http://mangroveactionproject.org/emr-method/> Accessed 27.5.2018 The lead author volunteers and occasionally conducts paid work for Mangrove Action Project.

2.2.2 The Need for Evidence-Based (Mangrove) Conservation and Rehabilitation

This potential lack of informed decision-making is unfortunate and unnecessary because, as in the wider literature, the case for evidence-based conservation work has been clearly made. Among elements that define evidence-based conservation is the proper evaluation of projects and elimination of ill-founded dogma (Cvitanovic et al., 2015; Sutherland et al., 2004). Why is there a barrier to information sharing? New information is more likely to be adopted by decision makers only if it is perceived as directly relevant to their own field, free from bias (particularly from commissioning bodies), accurate and uses appropriate techniques. Older practitioners might be less likely to take on new information and evidence-based conservation ideas (Walsh et al., 2015). Concerning marine systems and marine protected areas, Cvitanovic et al. (2015) argue that knowledge gaps exist because some policy makers and resource managers are unaware of the presence of the scientific research output and therefore rely on personal experience and gut feel. It is questionable whether scientists receive institutional encouragement for engagement and outreach activities to communicate their research, or whether a lack of time and funding to do so prevents this (Cvitanovic et al., 2015).

In the mangrove context, government officers and trainers cannot be expected to be aware of all of this output and might be labouring under their own misconceptions or misunderstandings. An example of poor rehabilitation practice which might be remediated by published scientific evidence comes from projects in Tamil Nadu and Andhra Pradesh, southern India. In these states, villagers have been encouraged by the State Forest Department to excavate new, parallel-sided channels for mangrove rehabilitation in back mangrove areas in the shape of a fish skeleton (so-called 'fishbone technique'). However, the inappropriate design of the fishbone channels has been documented as requiring significant, continuous and expensive maintenance (K. Kandasamy, pers. comm.; Selvam et al., 2012a; V. Balaji, pers. comm.). Furthermore, subsequent government planting of *Rhizophora* sp. on the fishbone channel edges runs the risk of hydrological system failure due to prop roots blocking the channels as these trees grow. Further evidence that this is an inappropriate design is provided by nature since different species to those planted naturally regenerate within the poorly designed channels, eventually blocking the hydrological connection to the sea. Unfortunately, the use of this technique persists.

Knowledge gaps can affect not only the application of knowledge in the physical sciences but also the development, conduct and analysis of social research, which often fail to benefit from previously validated social research techniques (St. John et al., 2014). Effective social research is vital for conservation programmes. There is now a recognition that using appropriate theoretic models such as the widely used theory of planned behaviour (TPB) to guide social research programmes (Ajzen,

2002; Montañó and Kasprzyk, 2015; Williams et al., 2012) is of equivalent importance to technical or scientific interventions (Balmford and Cowling, 2006; St. John et al., 2014). The TPB suggests that it is possible to predict behaviour by understanding behavioural intentions. These intentions are affected by attitudes, social norms and perceived behavioural control. Some elements of the TPB are still debated and would benefit from further qualitative research including the link between education activities and conservation-related behaviours as this area has received limited study (Brooks et al., 2013; Nilsson et al., 2016). Others have questioned whether the TPB needs to be supplemented by other variables such as changes in circumstances, the role of past behaviour, the characteristics of the ecological habitat in question (Miller, 2017; Rossi and Armstrong, 1999); and whether Ajzen's (2002) assumption of rational decision making limits the theory's predictive power (Miller, 2017). This is because studies using this model have found that the TPB still leaves a significant amount of behavioural variation unexplained (Miller, 2017; Rossi and Armstrong, 1999). There remains discussion about the similarity between perceived behavioural control (more of an external issue) compared to the self-efficacy concept, which relates more to ideas of internalised control (Bandura, 1994; Hardeman et al., 2002), and debate about the role of social cognitive theory (learning from watching others, and witnessing the outcome of others' actions (Bandura, 1994; Hardeman et al., 2002).

Development programmes that might intuitively sound appropriate, such as pro-poor conservation projects that attempt to link conservation and poverty alleviation, are often based on little empirical evidence that documents their efficacy (Davies et al., 2014). The authors attribute sub-optimal programme outcomes to inappropriate implementation techniques, ambiguous definitions of terms such as 'biodiversity', inappropriate monitoring protocols, unsuitable donor timing and agendas, and limited understanding by field scientists of qualitative and social science techniques.

2.2.3 Previous and Current Government Mangrove Rehabilitation Outcomes

If there is a potential communication gap between the research community and mangrove programme managers, is this lack of information sharing evident on the ground and does it affect rehabilitation outcomes? To assist the restocking of mangroves after the charcoal production concessions, the government of Thailand instigated large-scale mangrove reforestation programmes. For example, between 1991-1996 a \$30m USAID-supported project attempted to restore 40,000ha of mangrove (IUCN, 2017). However, only 35% of this target was achieved as many of the proposed planting sites were aquaculture ponds or still under concession. Of the areas planted, survival rates were reported to be <40% (Memon and Chandio, 2011). Another large-scale

planting programme ran between 1994-2004, with a target area of 800,000ha but with only limited success (IUCN, 2017).

In the Philippines the World Bank-funded the first large-scale mangrove project in Central Visayas Regional Project in 1984 (Primavera, 2000). Other projects followed, funded by the International Bank for Reconstruction and Development (\$25m, 1984-1992), Japanese Bank for International Cooperation (\$89m, 1993-2003) and the Asian Development Bank (\$80m, 1990-1994). A review of these projects suggested a survival rate of 10-20% (Primavera and Esteban, 2008).

Planting events particularly in Thailand often involved little interaction with local people and were rapid, one or two-day mass-planting sessions (IUCN, 2017). Contrary to best practice and effective application of resources, planting was often prioritised over measures to protect existing mangrove (Mukherjee et al., 2015; J. Primavera, pers. comm.), such as the avoidance of unsustainable timber extraction.

To answer Walters' (2000) question regarding whether villagers were effective restorationists, the answer is largely negative (Elliott et al., 2016; Erftemeijer and Lewis, 1999; Field, 1996; IUCN, 2017; Lewis, 2005; Memon and Chandio, 2011; UNEP, 2007; Wodehouse and Rayment, 2019) or at best their rehabilitation attempts have produced limited positive results (Alongi, 2002; Aung et al., 2011; Barbier, 2006; Ellison, 2000; Memon and Chandio, 2011; Moberg and Rönnbäck, 2003). Beyond personal observation, villagers are likely to have few opportunities to learn about mangrove ecology and rehabilitation other than *ad hoc* government training and observing the activities of friends, relatives and government officers who might well have no more knowledge than the observer (Walters, 2000, 1997). From Walters' experience, less successful mangrove restorationists tended to give up, whereas the more entrepreneurial would see failures as a learning opportunity and gain from the experience (Walters, 2004).

Furthermore, many government agencies continue to plant very few species or even single species mangroves in straight lines (Melana et al., 2000). While not inherently wrong, adhering to fixed lines potentially results in changes of elevation or soil suitability being ignored, a failure to optimise site-species matching and inhibiting natural channel development. Planting only a few species engenders only limited biodiversity, (Aung et al., 2011; Field, 1996), although this might be the first rehabilitation stage of a more biodiverse mangrove ecosystem (Aung et al., 2011; Bosire et al., 2008; Ellison, 2000 but see Walters, 2000). If projects succeed, these silvicultural techniques produce dense, even-age class plantations of limited (desirable) structural complexity (McElhinny et al., 2005; Walters, 2004; Walters et al., 2005). Government silvicultural techniques are then mimicked by village planters. Village planting that has survived often resembles even-age class, mono-specific

plantations rather than natural mangrove (Bosire et al., 2006; Ellison, 2000; Field, 1999; Lewis, 2005; Memon and Chandio, 2011) with little or no similarity to the original mangrove (Alongi, 2002), including a lack of species zoning and biodiversity (Barnuevo et al., 2016; Bosire et al., 2008; Saenger, 2002; Sinfuego and Buot, 2014).

2.2.4 The Impact of Village Needs and Objectives on Mangrove Silviculture and Management Remain Poorly Understood

Mangrove rehabilitation activity is significantly affected by project objectives (Lewis, 2000). As a result, nursery techniques, planting densities, species choice and management activities will or should reflect these objectives (Saenger, 2002; Walters et al., 2008). The default objective for state-owned mangrove is likely to be conservation. Commercially owned mangroves might be subject to management objectives such as the production of wood for charcoal or woodchip or ecotourism (Geoghegan and Smith, 2002; Sillanpää et al., 2017). For example, the Metang mangroves of Malaysia are managed for charcoal production in a manner similar to terrestrial production forestry, being densely restocked with *Rhizophora* sp. and coupes clear-felled in rotation (Field, 1996; Khoon and Ong, 1995). A large portion of Bintuni Bay, West Papua, Indonesia, is managed for woodchip production (Sillanpää et al., 2017). Much of the planting by the government in the Philippines is motivated by the desire to produce a protective 'green belt' of mangroves to shield coastal villages from storms and adverse weather (Department of Environment and Natural Resources, 2016; Mukherjee et al., 2015; Primavera and Esteban, 2008), despite the continued debate concerning the efficacy of mangrove plantations protecting coastlines (Forbes and Broadhead, 2007; RAP FAO, 2007).

In a similar manner, coastal communities occasionally adapt their management and planting for specific products or objectives (Datta and Sarkar, 2012; Watson, 1928). For example, *Nypa fruticans* has been propagated to support palm-based livelihoods such as the production of cigarette papers, for land control and implied ownership of the planted area, and developing forests as a store of capital (Kanagaratnam et al., 2006; Walters, 2004). Some communities plant mangroves very densely to provide poles without side branches and dense planting has been recorded in Vietnam on dyke walls for erosion control (J.A. Enright, pers. comm.; Walters, 2004).

However, in practice there is generally an absence of stated rehabilitation objectives and limited available evidence-based management guidance to help achieve the (implicit) objectives and maximise outcomes. In reality, rehabilitation means planting, using the same silvicultural techniques and parameters each time, while post-planting thinning or pruning regimes have rarely

been documented. Therefore, if the planting survives, the default mangrove management outcome is in effect, plantation development, with very limited post-planting silviculture.

While acknowledging differences of opinion about mangrove rehabilitation best practice, here we used an adaptation of the 'community-based ecological mangrove restoration' (CBEMR) technique developed by Lewis and NGO Mangrove Action Project (Erftemeijer and Teunissen, 2009; Lewis, 2009; Stevenson et al., 1999; Trump and Gattenlöhner, 2015) as a framework for assessing village mangrove rehabilitation projects (Appendix B). CBEMR assumes that a project's objective is full ecosystem rehabilitation rather than plantation development. Against this, I contrast planting techniques as reported by villagers, and examine the mangrove knowledge that underpinned these activities. In conjunction with the outcomes of Chapter 1, I hope to identify and describe likely community and government mangrove knowledge gaps in the rehabilitation process, understand why (implicit) rehabilitation objectives were not met and understand how these and other knowledge gaps might inhibit appropriate adaption of rehabilitation techniques to various site conditions. The aim is that this information will assist outside groups to identify and prioritise training requirements for village conservation groups and state mangrove agency field office staff, to ensure they offer the most appropriate assistance to villages that have experienced sub-optimal mangrove rehabilitation and management outcomes.

2.3 METHODS

2.3.1 Location of Study Sites and Village Selection Criteria

Although specific regional and local contexts are very important and highly variable, here we studied multiple villages within two countries in an attempt to produce some general conclusions. Thailand and the Philippines share the same Indo-Malesia bio-geo-climatic zone within the Indo-West Pacific (Duke, 2006; Tomlinson, 2016) and have extensive mangrove areas, on which a substantial proportion of the coastal inhabitants depend for their livelihoods and food (Balmford et al., 2002). Since 1945, both countries have experienced significant mangrove conversion to aquaculture, and degradation for charcoal and fuelwood production, among other causes (Richards and Friess, 2016).

Table 5 lists the Thai and the Philippine villages studied in this large-scale investigation, which combined ecological and social research to examine mangrove rehabilitation and management in the context of biophysical, silvicultural and social factors. Villages were purposefully chosen because they were located either within or near to an extensive riverine mangrove delta or had a significant area of mangrove nearby. In all villages members had attempted mangrove rehabilitation or afforestation in the past (after 2007). Finally, mangroves were considered an important village resource and were used in some way by a substantial part of the village population. Median planting survival scores from Chapter 1 have been incorporated into this table.

Table 5. Details of villages studied in Thailand and the Philippines

	Thailand						Philippines	
Village Number	1	2	3	4	5	6	7	8
Village Code	T1A	T1B	T2A	T2B	T3A	T3B	P1A	P1B
Approx. Lat Long	6.8°N 99.7°E	6.8°N 99.7°E	7.8°N, 99.1°E	7.8°N, 99.1°E	8.4°N, 99.9°E	8.4°N, 99.9°E	10.8°N, 119.5°E	10.8°N, 119.5°E
Province	Satun	Satun	Krabi	Krabi	Nakorn Sri Thammarat	Nakorn Sri Thammarat	Northern Palawan	Northern Palawan
Number of Semi-Structured Interviews	16	19	18	18	21	18	20	20
Number of Rehabilitation Science Test	29	31	35	28	30	31	23	36
Number of Rehabilitation Site Assessed (Chp. 1)	13	11	9	6	5	3	10	8
Median Planting Survival (%)	39%	10%	19%	44%	21%	1%	0%	1%
Village Mangrove Area (Ha)	407	592	319	176	3,894	257	126	856
Approximate Village Population	660	800	700	1,030	680	2,200	3,000	2,600
Approximate Research Dates	Sept – Nov 2013	Dec 2013 – Feb 2014	Feb – May 2014	June – Aug 2014	Oct 2014 – Feb 2015	Feb – May 2015	Sept – Dec 2015	Jan – Apr 2016

Median planting survival scores (Chapter 1). Better half of the villages in green, less good half in red

2.3.2 Semi-Structured Questionnaire Interviews

2.3.2.1 *Purposive Sampling Strategy*

The sampling population was any adult villager within the study village who had taken part in planting mangroves within or near their village. Village leaders had lists of households registered in their village. However, choosing random people / households from this potential sampling frame was deemed unworkable as only a proportion of each village had planted, a further percentage of households were absent from the village for long periods, some villagers such as rubber tappers worked irregular hours, and the alien nature of timekeeping and making and keeping appointments, made using the list impractical. Furthermore, the lists were not accurate as not all households were registered⁵, particularly those of children who had built new houses within the compound of their parents' house.

Similarly, there were occasional lists of villagers who had planted during individual events, but more often than not these were incomplete, inconsistent, or the listed planter had sent a substitute worker in their place. Therefore, purposive sampling was used to find available villagers who had taken part in village planting activities. Every effort was made to find planters from all parts of each village, particularly the village edges, the less well-off and minority groups, female planters and different families and religious groups to attain as representative a sample of villagers as possible. Most respondents were from the village general populace. We ensured that we interviewed at least three or four conservation group members per village as they planted more frequently and were party to more of the decision-making process. We also interviewed every village leader and conservation group leader. (In the Philippines villages formed mangrove planting 'co-operatives' rather than conservation groups but performed similar roles. For ease of description both groups will be referred to as conservation groups or CGs.) In addition, during the course of scoping discussions and other interviews within the villages, residents were asked to identify mangrove experts living in the village. Almost always a consensus quickly appeared, negating the need for a ranking exercise to choose an expert (Chapter 1. Section 1.3.2.1). The village mangrove expert was not necessarily the same person as the conservation group leader, as sometimes village politics inhibited people from working together. As well as being interviewed, at some point during the four months in each village, the local expert would accompany the researcher on an inspection of all the village's planting attempts. Village experts could explain the nuances of planting operations, the

⁵ In Thailand, if a new family wanted to build a new house and have it registered, they had to have the initial documentation signed by the village leader. This document would then be taken to the District Office to start the process. Not all villagers were on positive terms with their village leaders and partly as a result, not all households were registered.

underlying understanding about mangrove ecology, and if present, commonly held misunderstandings.

2.3.2.2 Ethics, Data Collection and Storage Protocol

During the first visit to a village a meeting with the village head was arranged to explain the purpose of the research, the research activities and gain consent. During an initial contact with a potential interviewee, they were asked if they were a resident of the village and whether they had been planting. If they confirmed both questions and were free to talk, an ethics statement was read and explained to them, and a copy provided in the local language (Appendix C). Great care was taken to ensure full comprehension of the ethics statement and gain informed consent, occasionally resulting in a return at a later date to complete the interview, due to the length of time this process took. If other people joined the interview, they too were given a written ethics statement. After oral consent was received, all interviews were carried out either in Thai or Tagalog and translated immediately into English via a translator. This method allowed for additional questions for clarification and resolution of inconsistencies. Where appropriate we used visual guides such as illustrated species charts (Appendix D, Yong undated) or other material to aid comprehension, such as diagrams to help discuss planting depth, Fig 9.



Figure 9. Interviewee referring to visual aids to ensure mutual understanding of species (left, photocard) and planting depth (right, illustration), with a translator.

In general, interviews lasted no more than an hour at a time. Interviews were generally conducted outside participants' residences, in view of the neighbouring villagers, to avoid any possible perceived impropriety. All interviews were administered by the candidate. Data was collected

anonymously on pre-printed SSI questionnaires (Appendix E), together with any additional information. Answers and supplementary information were transcribed later the same day, and together with any photographs, were stored on an encrypted external hard drive. Any points from that day's interviews that were unclear were discussed with the translator during the evening. Written notes were kept either with the researcher or locked in a secure case, at all times. No payment was provided to respondents. Instead the researcher made a significant donation to the village mosque or school and with the translator gave a morning's mangrove ecology lesson in the local school in each village.

An ethics checklist, as required by Bangor University, was completed prior to data collection and indicated that the research did not require further review.

2.3.2.3 Questionnaire Development and Translation

The questionnaire (Appendix E) was developed by the researcher at Bangor University, based on an adapted version of the 'Community-Based Ecological Mangrove Restoration' (CBEMR) process (Appendix B), covering the key stages and decisions within the CBEMR process, as well as taking into account the researcher's previous rehabilitation and teaching experience in the countries. Care was taken to avoid problems of questionnaire design as described by Diefenbach (2009) as much as possible. In both countries, the researcher trained the first translator in mangrove ecology and terminology before translating the semi-structured questionnaire (SSI). The SSI was then checked by a local mangrove NGO, and other mangrove workers within both countries. Both Thai and Tagalog questionnaires were tested on a sub-set from the first villages in both countries (villages T1A, P1A), with particular attention being paid to shared comprehension and inconsistent answers to ensure a clear understanding of the questions and terminology. Feedback and amendments were incorporated. It was found, for example, that the word 'objective' was difficult to translate into Thai and poorly understood. The question was re-worded. And although there is a direct translation for 'sustainable', the concept was not well understood. As recommended by St. John et al. (2014) abstract questions were avoided if possible.

2.3.3 Semi-Structured Interviews Cross-Checked with Key Informant Interviews

Semi-structured interviews (SSIs) can be prone to error and bias. Diefenbach (2009) and Kallio et al. (2016) describe some of the pitfalls. For example, beyond the non-random selection of study villages and interviewees:

- Previous experience can inform or bias question development
- The act of being interviewed can consciously or unconsciously affect how an interviewee responds

- The context of the research can be difficult to describe fully, but only within this context (Appendix F) are the results fully valid
- During analysis, grouping responses into manageable clusters involves subjective judgement, as does writing up the results
- Outlying responses can be ignored or over-emphasized

To counter these potential problems and cross-check the data provided by individual SSIs, other sources of information were acquired. Key informant interviews (KIIs), purposefully sampled due to their role, job or unique knowledge, were conducted with government officials including the mangrove agency field officers (interviewed several times during the fieldwork), district and sub-district⁶ staff and local environment officers. (The mangrove agency offices provided village mangrove boundary maps, explained mangrove features and history, and provided triangulation of information from village sources.) Information was checked against ongoing informal discussions during village homestays, observations, biophysical surveys (Chapters 1 & 4), immersion within village life over a period of three to four months per village and by joining village planting events as they occurred during the research, as per Le Fur et al. (2011).

2.3.4 Rehabilitation Science Test

To provide further triangulation for the semi-structured interviews and explore respondents' knowledge of the mangrove ecology involved in mangrove rehabilitation, a rehabilitation science test was developed by the researcher. The 19-question test combined elements of the scientific literature referred to in Chapter 1, and Saenger (2002) and Tomlinson (2016) in particular, as well as the 'community-based ecological mangrove restoration' process (Appendix B). A copy of the test in all three languages is in Appendix G together with marking scheme used and references. Although not explicitly told to do so, a few questions could have been answered by up to three correct responses for a possible three marks. For example, question 3 asked, *what might damage mangrove juveniles (non-animal)?* Therefore, the maximum total score achievable was 32. However, more than one possible answer was very rarely provided and in effect the maximum score was 19.

In a similar process to the semi-structured interviews, this test was developed at Bangor University by the researcher and translated into the local languages (the Thai version was evaluated with a local NGO), and then tested in the first village for comprehension and clarity of the terminology. The colloquial names of species referred to were checked to ensure they were in common local

⁶ In Thailand, District offices dealt with people, schools and development, whereas the Sub-District offices looked after infrastructure, solid waste management and pollution control.

usage, well known and that the name was indeed used in that region. (For example, *Avicennia* sp. had several different names which varied across southern Thailand.) Additional feedback related to some of the terminology that needed to be translated more literally, such as 'mudflat'.

As with the semi-structured questionnaires, a suitable sampling frame was not available. The sample population was predominantly villagers who had planted mangroves, but also included a minority of villagers who had not planted but who interacted with the mangroves in a significant way, such as mangrove fishers, honey collectors and mud-crab collectors, and as such had a direct interest in the health of their village's mangroves. These additional respondents were reasonably likely to take part in future plantings.

These self-administered tests were completed by 243 villagers (Table 5) including all village leaders and 26 government mangrove agency field office staff from the corresponding offices. Data was collected anonymously for the general populace, but not for the village leaders, conservation group leaders, village mangrove experts and some of the government staff, who were informed beforehand that their tests would not be anonymous but used as aggregated data.

2.3.5 Classification of Mangrove Zones

Species planted and rehabilitation site elevation relative to sea level have been grouped into four zones, following Duke (2006) and Tomlinson (2016), as described in Chapter 1, to allow aggregation of data and ease description during interviews and analysis. Several bio-physio-chemical gradients influence the spatial distribution of mangrove species, such as salinity and wave energy (Alongi, 2009b; Tomlinson, 2016). However, species zoning is predominantly controlled by each species' response to the duration and frequency of tidal inundation over the intertidal zone (van Loon et al., 2016). This response sorts species into distinct bands that follow elevation contours. Following Duke (2006) and Tomlinson (2016), and assuming semi-diurnal tidal regime, the 'low' mangrove zone, which starts at approximately mean sea level, receives inundation at high tides >45 times a month. Species generally found in this low zone are *Sonneratia alba*, *S. ovata*, *S. apetala*, *Avicennia alba* and *A. marina*. 'Mid' zones are inundated by normal high tides 20 to 45 times a month and are the home of *Rhizophora* sp., *Ceriops tagal* and, if the salinity is low, *Bruguiera* sp. 'High' mangrove zones receive inundation <20 times a month at high tide and are likely to include species such as *Heritiera* sp., *Lumnitzera* sp., *Xylocarpus* sp. and plants like *Acrostichum* sp, Fig. 10.

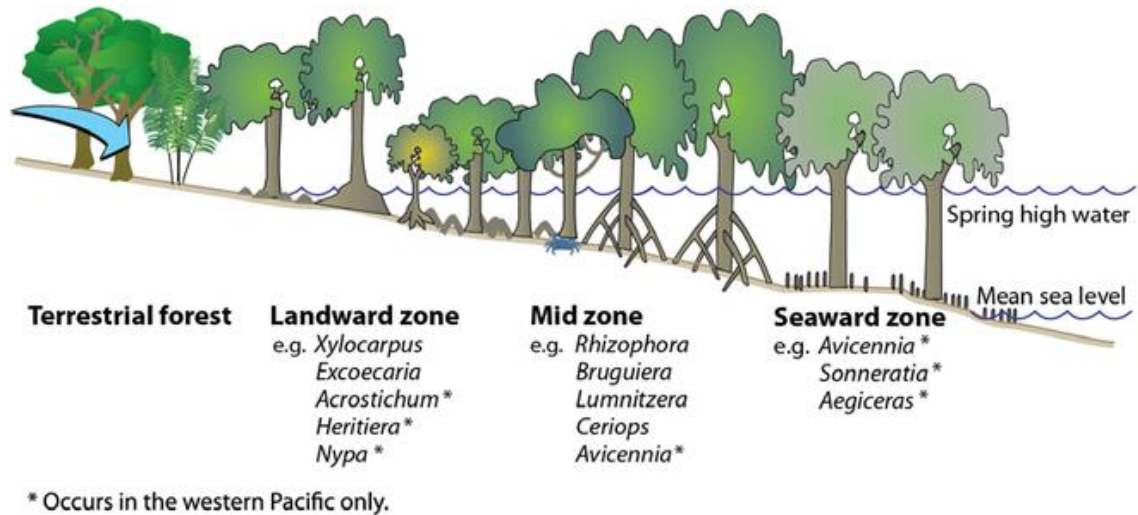


Figure 10. Mangrove species zoning including landward (high) zone, mid zone and seaward (low) zone, and corresponding species. Reproduced with kind permission. Waycott, M.; McKenzie, L.; Mellors, J.; Ellison, J.; Sheaves, T.; Collier C.; Schwarz, A.-M.; Webb, A.; Johnson, J. and Payri, C. (2011) Vulnerability of mangroves, seagrasses and intertidal flats in the tropical Pacific to climate change. In: Bell, J.; Johnson, J. and Hobday, A. (eds.) Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat of the Pacific Community, Noumea, New Caledonia, pp. 297-368.

Mudflats, which normally occur between lowest water and mean sea level, are inundated by every high tide, and are not described as an elevation suitable for mangrove growth in the scientific literature (e.g. Primavera and Esteban, 2008). Furthermore, it should be acknowledged that some mangrove species have bimodal distribution (e.g. *Avicennia officinalis*) or occupy more than one zone (e.g. *Nypa fruticans*, low and mid zones).

2.3.6 Research Issues and Limitations

During the semi-structured interviews (SSIs) respondents were asked to describe the most recent planting event they had taken part in. Unfortunately, using either a hand-drawn map or Google Earth on an iPad, it was evident that it was not possible to unequivocally link the described planting event to a specific rehabilitation site. Maps and remote sensing imagery appeared to be unfamiliar to Thai villagers, in particular. Furthermore, it was evident that many respondents were unconsciously combining details from more than one planting event in their responses. However, neither issue was a significant problem for the semi-structured interviews (SSIs) as planting techniques varied little from site to site.

Despite claims to the contrary, some elements of mangrove taxonomy and ecology were poorly understood by local people. For example, there was confusion about the various species of *Avicennia* sp., and an inconsistent use of local names. These were confirmed with an illustrated species chart (Yong, undated. Appendix D).

Within each village, four different semi-structured interviews (minimum 65 per village) and numerous informal interviews were conducted. Some respondents completed more than one survey. Due to research fatigue, it was not possible to ask all SSI respondents to also complete a rehabilitation science test, and as the science tests were completed anonymously, responses were not linked to respondents' SSI answers. The aggregating effects of village conservation group meetings or Friday prayers were piggy-backed to gain appropriate numbers of science test respondents. Despite clear, repeated instructions, age and gender were sometimes omitted from the answer sheets by the participants. Therefore it was impossible to link the two sets of data other than by village. Despite trying to keep the questions as simple and concrete as possible, literacy was more of an issue than initially realised or indicated by official data⁷. To overcome this the research team sometimes read the questions and wrote down the answers given on behalf of respondents, particularly for village experts.

Most interviews took place either in a public place or on a veranda in front of a villager's house, while the respondents carried out a livelihood activity. As found by Dahdouh-Guebas et al. (2000), when conducting interviews, curious neighbours, other family members and passers-by would join the meeting and leave as they wished. Asking these people not to join an interview was deemed inappropriate and was not attempted. This reduced the ability to target a specific age range, gender, perceived wealth group or occupation group. Very occasionally, people joining an interview hindered free-flowing conversation however, much more frequently the presence of additional respondents led to a more productive discussion where local people would challenge each other's answers, contrary to Sudtongkong and Webb's (2008) experience. For example, on more than one occasion, when discussing cutting of mangrove timber, which was illegal, members of a group would tease one of their own for cutting - information which might not have been forthcoming in a one-to-one interview. Furthermore, it appeared that the interjection of potentially controversial issues or questions by the researcher would permit the local people to discuss topics they would otherwise not raise. Where at all possible, the initial respondent was asked to summarise a group discussion and develop a consensus of opinion, to which they agreed.

⁷ E.g. UNESCO's literacy rates. <https://en.unesco.org/countries/thailand> and <https://en.unesco.org/countries/philippines> Accessed 7.3.2019

2.4 ANALYSIS

Semi-structured interviews (SSIs) were analysed by SPSS v23 and later upgrades. Clustering of responses was produced post-hoc to keep each group of responses to a maximum of five or six factors if possible. Responses were analysed in relation to country, better or worse planting ability or general populace vs community leaders vs government staff, to look for meaningful differences and generalised conclusions. Additional information was collated by nVivo v11. The rehabilitation science tests were marked with the translator and analysed by Microsoft Excel and SPSS V25. Both SSI and science test are in the Appendices (E1, E2 and G).

2.4.1 Statistical Tests

The null hypotheses for comparison between all groups was that there was no significant difference between either country; or villages that were more successful planters compared to villages that were less successful planters; or between responses from government staff, conservation group members and the general populace of the village.

The difference between the site choice of the general populace compared to village leaders was examined with a Fisher's Exact (Chi-Square) Test. The null hypothesis was that there was no significant difference between these two groups.

The difference between the conservation group members and the general populace's belief about the suitability of mudflats for planting was tested by a Fisher's Exact (Chi-Square) test. The null hypothesis was that there was no difference between these two groups.

An initial Kruskal-Wallis test ($X^2(2)=7.69$, $p=0.021$), confirmed by specific Mann Whitney-U tests examined whether there was a significant difference between the overall science tests scores of government mangrove agency staff, village conservation group members and villagers from the general populace. The null hypothesis was that there was no difference between these groups.

A Spearman's correlation examined whether there was a relationship between village planting survival and the different rehabilitation science test scores. The null hypothesis was that there was no relationship between planting survival and science test score.

2.5 RESULTS

2.5.1 Respondent Demographics

One hundred and fifty semi-structured interviews (SSI) were conducted in total. Per village, 16-21 interviews were completed (Table 5), which provided sufficient numbers to reach data saturation in each village, i.e. additional interviewees provided very limited new information. Forty-four were women and 104 were men, with an age range between 18-80 (mean age 50) from Thailand 109 and the Philippines 41. Sixty-eight percent of respondents were villagers from the general populace, 15% were conservation group members and the rest were other leaders. Despite living on the coast, agriculture was a more common main occupation (25% of respondents including rubber tapping, rice growing and oil palm production) than fishing (20%), followed by crab collecting (11%) and running a small business (10%), Fig. 11.

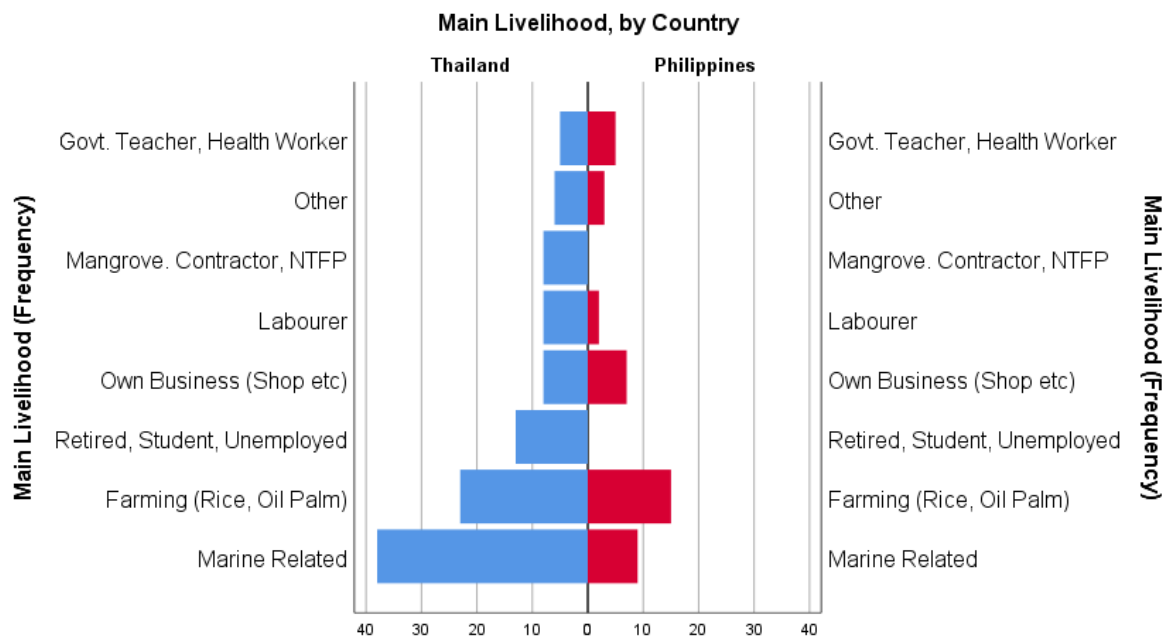


Figure 11. Frequency of main livelihoods, by country

The Thai respondents appeared to be slightly more orientated to marine livelihoods than the Philippine interviewees.

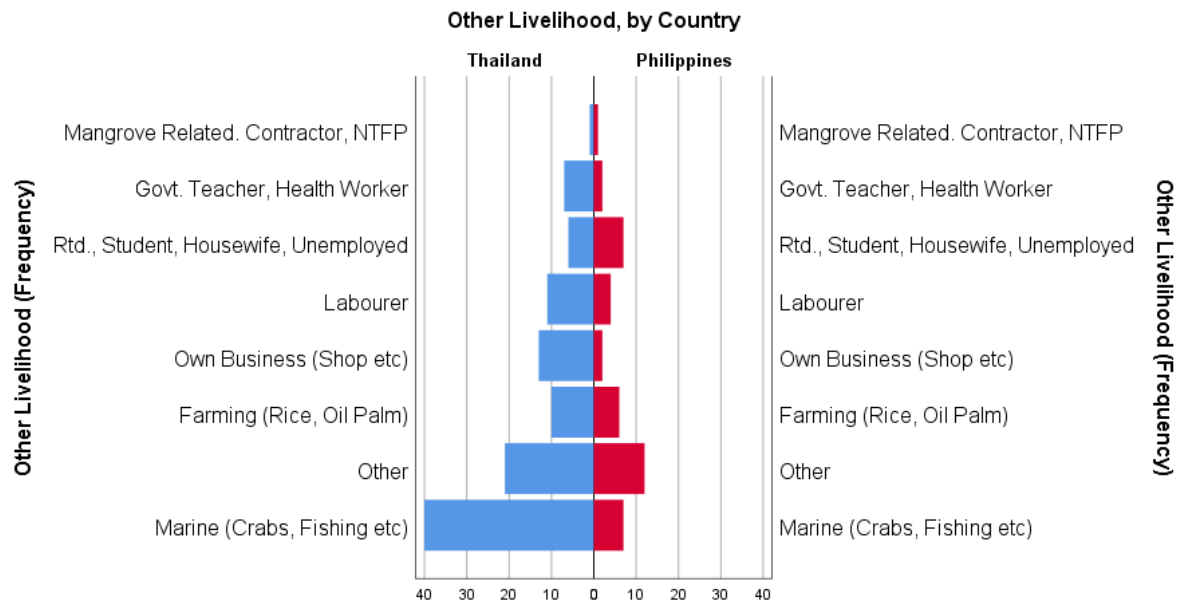


Figure 12. Frequency of secondary livelihoods, by country

A third of respondents claimed not to have a specific second job (33%), but half (47%) collected marine animals as a second pastime from within or near the mangroves, either to feed the family or earn some extra money (Fig. 12).

Each SSI focused on the most recent planting event the interviewee had taken part in. Of the mangrove planters interviewed, about a quarter had planted in the previous three months, another third less than a year previously, and 44% more than a year before their interview. At village level, using planting survival data of each attempt from Chapter 1 from the 8 villages (but not the additional areas in Luzon, Philippines), it was possible to compare responses from the better, more successful four villages (Table 5) by planting success (n=47, villages T2B (n=8), T1A (n=18), T2A (n=12), T3A (n=9)) against the less successful four of villages (n=63, villages T1B (n=20), T3B (n=8), P1A (n=16), P1B (n=19)). Fig. 13 illustrates median survival scores by village.

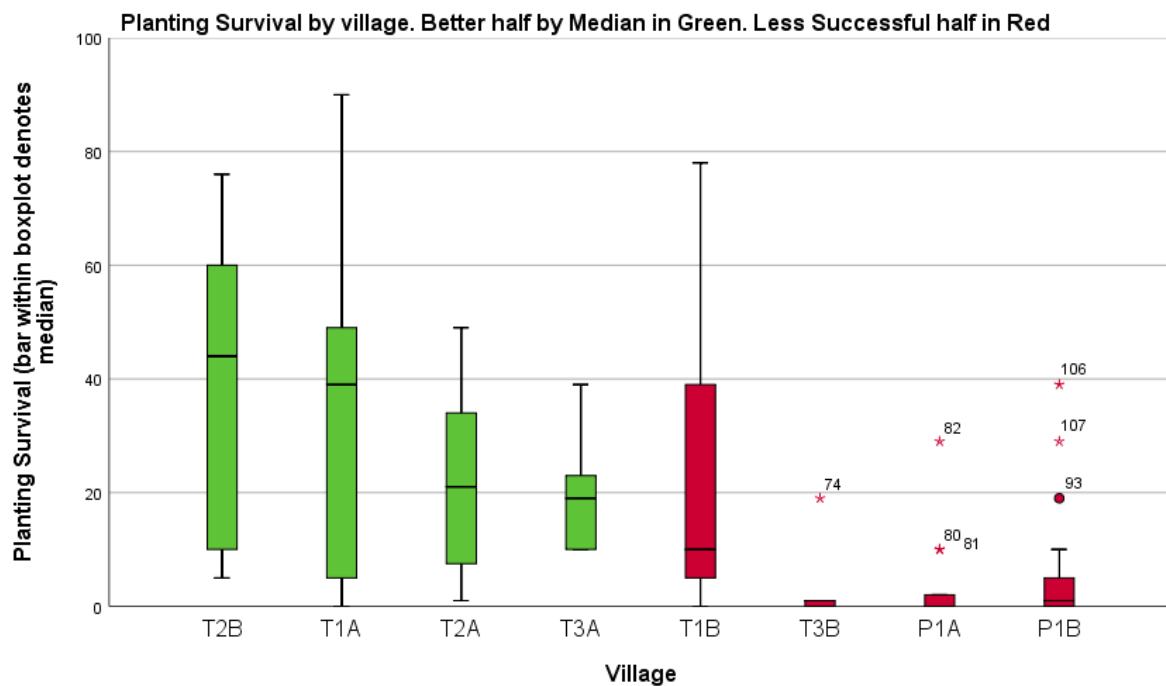


Figure 13. Median planting survival, by village. Village names starting with T are Thai, and P and in the Philippines. Green boxplots are the villages whose median planting score (thick line in the middle of each boxplot) was in the more successful half of villages. Red boxplots describe the less successful villages' median planting survival score.

2.5.2 Site Choice: Mudflats when Planting Space Was Required, or Higher Mid and Back Mangrove for Combating (Perceived) Degradation

The mangrove zone (section 2.3.5, Fig 10) that interviewees reported planting was identified from several factors including: the number of days per month that the site was inundated; the depth of inundation at high tide (if known); mangrove species growing very close by; reported soil characteristics and site shading or openness.

One-third of interviewees described their planting site as mudflat, i.e. from mean sea level down to lowest water, inundated at every high tide and below normal mangrove elevation relative to sea level. Mid mangrove zone (28%) was the next most common planting elevation, followed by back mangrove and low pioneer mangrove zone (both 12%). The better four villages had slightly over twice the number of sites in either mid, back or mix mangrove zones than the less successful villages (32%, n=49 vs 15%, n=23). These higher elevations were more suitable for mangrove growth. In contrast, almost all the mudflat sites planted (90.2%) were described by respondents from the less good four villages (Fig. 14).

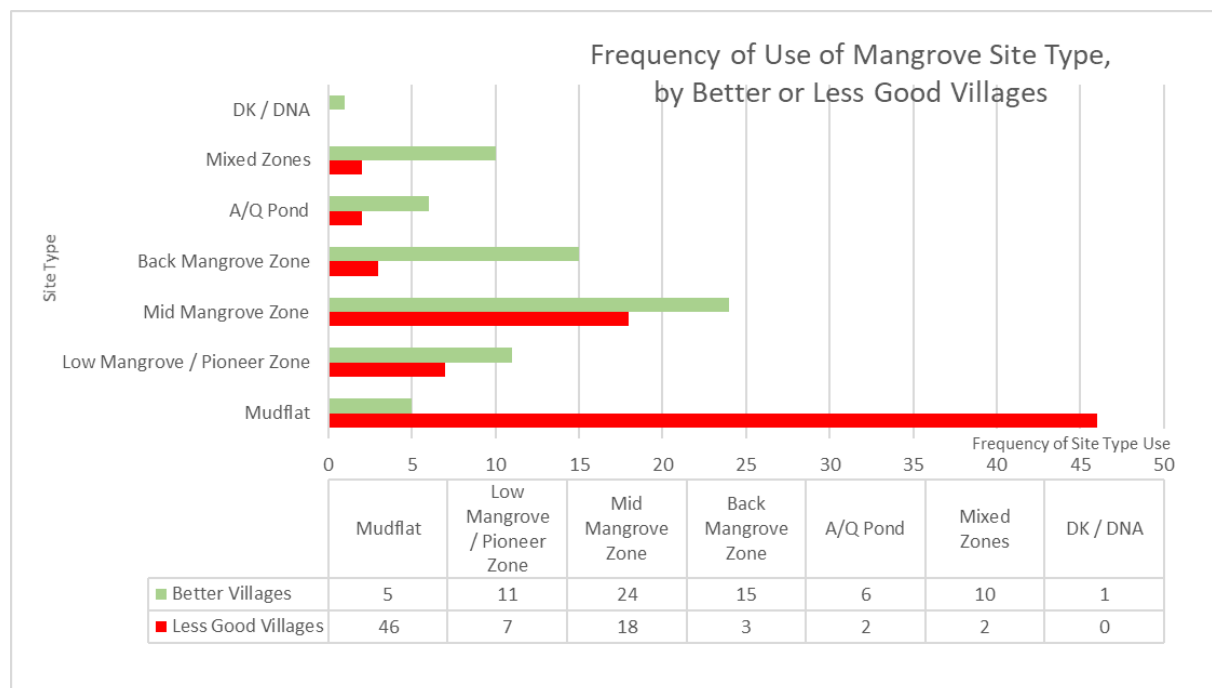


Figure 14. Mangrove zone planted, by more successful half of villages by planting survival (green), compared to the less good half of villages (red).

The most common reasons guiding the choice of site were that the site provided available space for planting (39.3%) or was perceived as degraded and in need of rehabilitation (34%). Responses from the general village populace were not statistically different to those with a village leadership role ($X^2=9.04$, $p=0.39$). Within the better half of the villages by planting survival, respondents were much less likely to choose a site because it was easily available (25%, $n=18$) compared to the less successful villages (52.6%, $n=41$, Fig 15). Of the sites chosen because they were easily available ($n=59$), 65% were mudflats. In contrast, villagers from the better four villages claimed their sites were degraded more frequently (44.4%, $n=32$) than respondents from the less good half (24.4%, $n=19$). Of all the sites in both countries perceived as 'degraded' ($n=51$), 75% were to be found in mid and back mangrove areas.

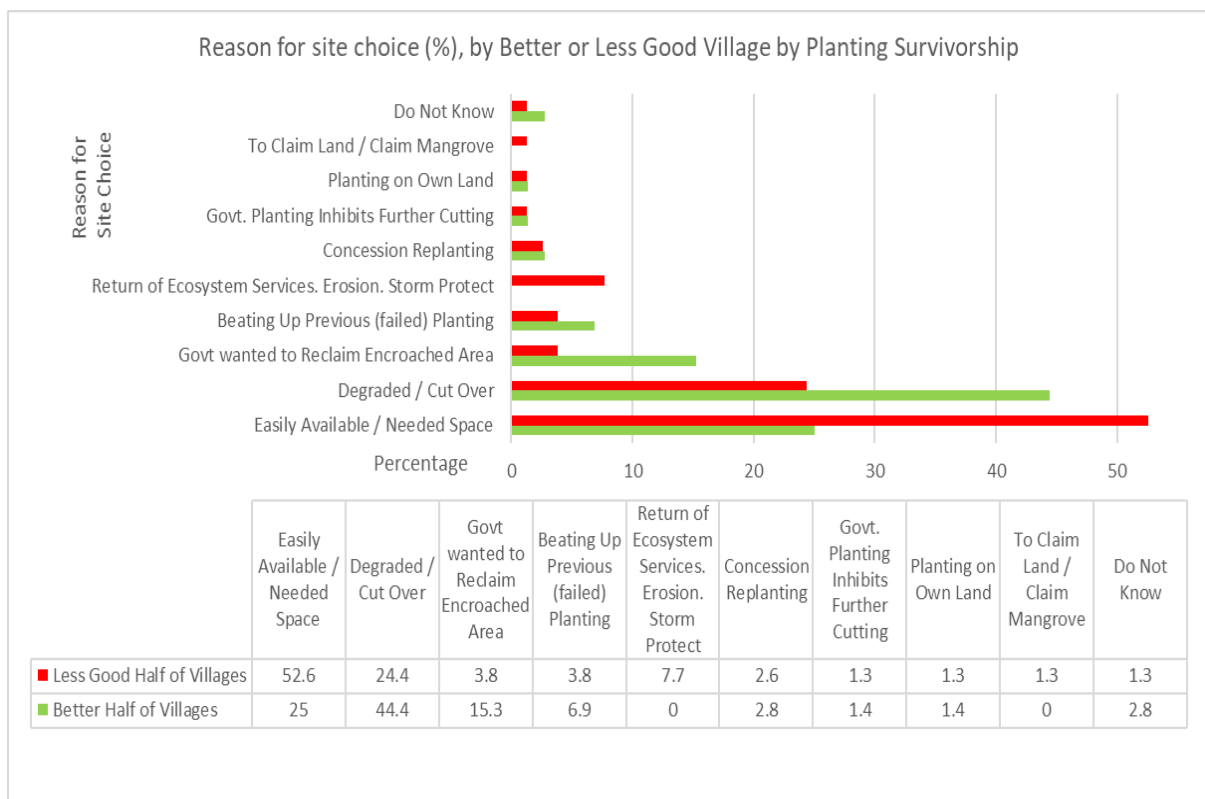


Figure 15. Reason for rehabilitation site choice, by more villages with successful planting survivorship (green) vs less successful villages (red).

Despite the fact that mudflats are generally considered unsuitable for mangrove establishment (Chapter 1), three quarters of respondents to the rehabilitation science test agreed that using areas of very soft mud would be successful, as did 60% of the government officers questioned.

To triangulate this response, when asked directly whether mudflats were suitable places for mangrove planting, 64% of villagers and 77% of government officers believed that they were. The conservation group members were not significantly more knowledgeable about the difficulties of mudflats than the general populace ($X^2=24.5$, $p=.33$), Fig. 16.

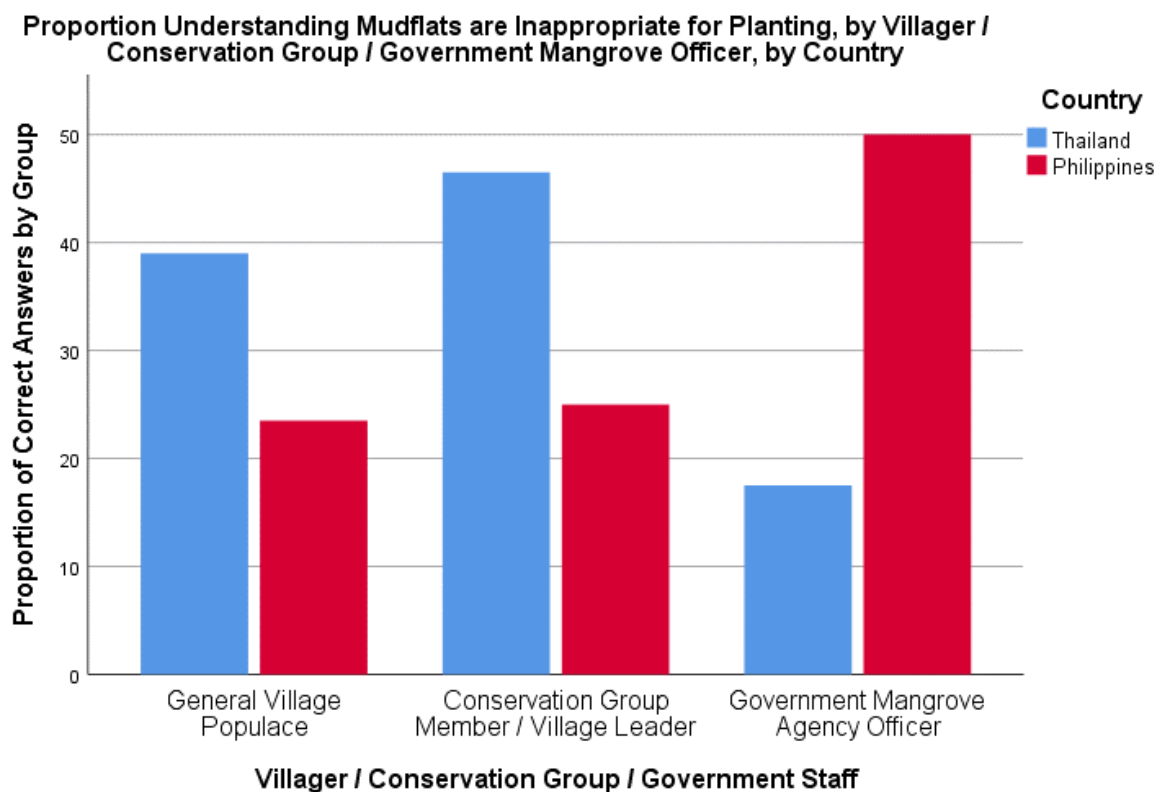


Figure 16. Percentages of the general populace, conservation groups and government mangroves offices that understood that mudflats are inappropriate for mangrove planting, by country (from the science test). Despite the scientific literature and near-zero percent planting survival from mangrove planting projects (Chapter 1), 50% of Philippine government officers still believed mudflats were appropriate.

2.5.3 Limited Site Preparation or Physical Site Amendment Regardless of Elevation

Claimed site preparation was limited. Half the respondents were not aware of any site preparation. Where site preparation was carried out, this typically involved the cutting back of plants perceived as weeds, vines and creepers to make space to plant, or the removal of unwanted plants such as *Phoenix paludosa*, a spiny palm (33% of responses). The general populace provided similar answers to leaders within the villages. Reports of more thorough site preparation were rare, such as weeding

to remove (the roots of) all creepers and vines, the removal of large debris which might float with a high tide and break young plants, or installation of signage or protective fencing (6%). Despite this, when asked in the rehabilitation science test, a majority of villagers (63%) and three-quarters government officers (74%) acknowledged that they should clear large debris from a site to avoid impact damage to young plants. Site preparation and amendment varied by the nature and elevation of a site. Of all mudflat plantings described by respondents, the majority of sites (88%, n=51) received no site preparation. At elevations more suitable for mangroves, lower and mid mangrove zones received more clearance of weeds, vines and creepers only, compared to back mangrove areas. The few sites that received full site preparation (i.e. including large debris removal as well as weeding) were almost always described as degraded and lay within the mid and back mangrove zones. Partly because the better half of the villages by planting survival planted more sites that were within the mangrove zone rather than on mudflats, respondents from these villages were twice as likely to carry out preparatory weeding as villagers from the less good four villages.

Limited site preparation was matched by the lack of improvement of hydrological connectivity, tidal exchange and drainage, and the lack of regrading of the substrate elevation relative to sea level, to make it more suitable for mangrove growth (91%, with another 4% not knowing). For example, there was not one report of a mudflat being physically altered, e.g. by digging drainage channels, regrading or producing mounds of higher elevation substrate. Regrading substrate was never mentioned, even during informal interviews. However, the lack of hydrological intervention was not due to a lack of awareness of the potential benefits of this activity. From the rehabilitation science test, half the villagers (50%) and three-quarters of government officers (75%) acknowledged that simply amending a site's hydrology could be enough to facilitate successful natural regeneration. Furthermore, test participants knew that if a site's hydrology had previously been compromised, an appropriate hydrological connection should be re-established (70% villagers and 90% government officers respectively), and 78% of villagers and 100% of the government staff understood that rehabilitating former aquaculture ponds necessitated reconnecting them with the outside hydrology.

2.5.4 Site-Species Matching and the Over-Application of Mid Mangrove Species

Interviewees answering the semi-structured questionnaire suggested that in terms of site location, mudflats were utilised most frequently (34%), followed by mid zone mangrove sites (28%) (Fig. 14). However, 92% of planting events planted mid zone mangroves species only, mainly *Rhizophora* sp. with decreasing inputs of *Ceriops tagal* and *Bruguiera* sp. (Duke, 2006; Kitamura et al., 1998).

In this study we used three measures to examine site / species matching (Table 6). First, was there an effort to match the rehabilitation site zone by planting species from that same zone?

Respondents claimed that mid mangroves rehabilitation sites were indeed planted with mid zone species 93% of planting events (n=39). However, mid zone mangroves species were also deployed on mudflats in 98% of instances (n=50), and 89% of high / back mangrove sites (n=16), both locations where mid zone species are much less well suited (Table 6, left).

Table 6. Left, the proportion of mangrove sites at different elevations planted with mid zone mangrove species. Right, the proportion of each mangrove zone (indicated by which species was growing on site) planted with mid zone mangrove species. *Green* suggests a good match (mid zone species planted at mid mangrove elevations, or with other mid zone mangroves growing nearby). *Yellow* is a partial match (mid zone mangroves planted too high or too low, compared to elevation (left) or existing species (right)). *Red* is a poor match, unlikely to survive.

Elevation of Planting Site	% Planted with Mid Zone Species		Species Currently Growing on Site	% Planted with Mid Zone Species Only	
	Only	n=		Species Only	n=
Mixed Zones	91.7	11	Back / High Species	87.5	14
Back / High Zone	88.9	16	Mid Zone Species	89.4	42
Mid Zone	93	39	Low Zone Species	100	26
Low Zone	100	18	Nothing Growing on site	96.6	57
Mudflat	98	50			

Second, did the species planted match that of the species already growing on site or naturally regenerating? In addition to sites that had been previously cut-over and had failed to regenerate, almost 40% of respondents reported that their site had nothing growing on it - to be expected if 34% of the sites used were mudflat. Mid zone mangroves (31% of sites) were the most common group of species already growing on rehabilitation sites and here, 90% of the planting was indeed matched by mid-zone mangrove species (n=42) (Table 6 right). However, mid zone mangrove species were always planted in all areas where low zone species were growing (100%, n=26), and almost always amongst high zone species (88% n=14), and on sites where nothing was growing nearby (97%, n=57). Low zone pioneer species (e.g. *Avicennia marina*, *A. alba*, *Sonneratia alba*, *S. apetala*) were never employed, despite a third of sites being mudflats and a further 12% of sites within the low mangrove zone.

Third, in a natural setting and with some species overlap, within the mid mangrove zone *Rhizophora apiculata* would generally appear at a higher elevation than *R. mucronata*, but lower than *Ceriops tagal* and *Bruguiera* sp. If planters were using more than one species, did they attempt to mimic this inter-species zoning relative to each other? Furthermore, did they try to match species planted to elevation, relative to sea level, if there was micro-variation of topography on site? According to these criteria, almost half the planting described was inappropriately located, 29% displayed an awareness of micro-scale zoning and a further 18% of respondents described planting single species in blocks.

This behaviour partially contradicts opinions expressed by villagers and government officers in the rehabilitation science test in which almost half of the villagers (40%) and almost all of the government staff (91%) could name at least one high zone species appropriate for rehabilitating sites at that elevation, and to triangulate this knowledge, 59% of villagers and 80% of government staff knew in which zone they should plant (high zone) *Heritiera littoralis* if they had access to it. In contrast, when asked what species they might use for land appearing at the lower margin of the low zone as a result of sedimentation or accretion, only a fifth of villagers (21%) and a third of government staff (35%) could name a low zone mangrove species such as *Avicennia* sp. or *Sonneratia* sp. and then only to genus level (very rarely to species level). Incorrect answers invariably mentioned *Rhizophora* sp., a mid zone species. When asked a trick question - which mangrove species would be appropriate for planting in seagrass beds, which normally start at lowest water below mudflats, and again unsuitable for mangrove growth - with the exception of the first village, only 11% understood that this was an unsuitable place for mangrove planting, with no significant difference between villagers from the general populace, village leaders or the government mangrove agency staff.

Overall, more than three-quarters of respondents agreed with their species choice (77%) in the planting event they had been describing. Of the 20 respondents who disagreed, 90% (n=18) disagreed with the use of mid zone mangrove but appeared unable to dissuade their colleagues or had been instructed to use mid mangrove species by the government mangrove agency field office staff or village conservation group.

2.5.5 Planting Material Use Dominated by Direct Planting of Propagules

Interviewees reported that seeds and propagules were planted directly into the mud 40% of the time, seedlings grown in polybags in 28% instances, almost always in Thailand (n=42), a mix of the two 19%, and uprooted bareroot 'wildlings' transplanted into place in 9% of cases, all in the Philippines (n=13). Where it was possible to ascertain whether the planted material was inserted at

the correct depth (61% of interviews), a third of these respondents planted either too deep (normally bagged seedlings placed into a planting pit that was too deep, covering the root-ball) or too shallow (i.e. *Rhizophora* sp. propagules not being inserted deep enough), depending on the situation. Polybagged seedlings planted too deep were likely to suffer from a lack of oxygen diffusing down to the roots. Propagules that were inserted too shallow into the mud were more likely to be washed away before having time to produce roots to hold themselves in place.

2.5.6 No Common Definition of Success, But Consistent Over-Estimation of Survivorship

Respondents were asked how they would define ‘success’ in their planting project, Table 7.

Table 7. Definitions of planting success

	Percent
Survival After a Time Period	29.3
Survive & Grow	22.7
Bio-Physical Measures (Appearance of Prop Roots, Canopy Closure, Soil Colour)	14.0
Return of Ecosystem Services	13.3
Social Factors (Participation, No Cutting)	10.0
Do Not Know	8.7
Other	2.0
Total	100

Some were able to suggest survival beyond a specific period (29%), ranging from 15 days to three years with three months to a year being the most commonly cited. Others mentioned plant survival and growth but were not able to suggest an appropriate time length (22.7%). Bio-physical indicators (14%) such as a closed canopy or the production of prop roots (on *Rhizophora* sp.) were also mentioned. Many of the villagers understood that there was a positive relationship between the presence and health of their mangrove and marine creature productivity (Appendix A), and therefore 13% described the return of ecosystem services (i.e. here habitat and nursery functions for marine creatures) as a measure of planting success.

Although village leaders gave similar responses to villagers from the general populace, villages with better planting success referred to more long-term goals such as the return of ecological function and the development of a mature forest whereas the villages which were less successful at planting focused on the more short-term issue of planting survival, Fig 17.

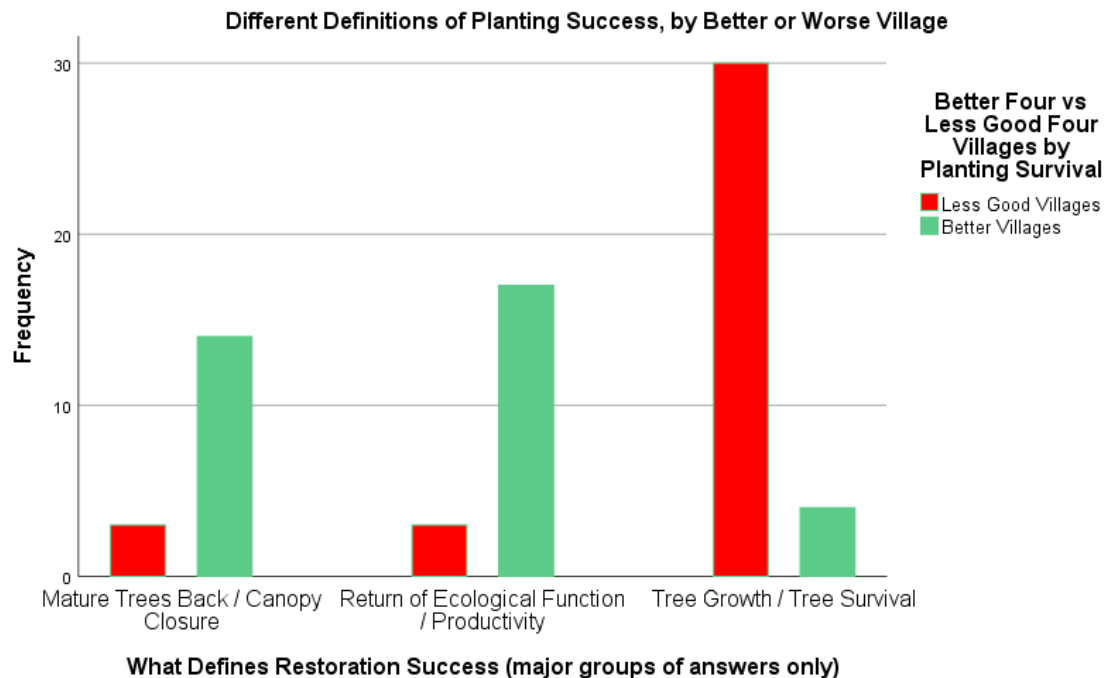


Figure 17. Definitions of planting success, by villagers in the more successful half by planting survival, compared to the less successful half. The more successful villages by planting survival considered more long-term features such as the return of ecosystem services and closed canopies. The less successful villagers by planting survival were more concerned about their planting projects surviving.

Almost half of the respondents believed that the planting they had described had been successful, (we defined success as >70% establishment); 18% were conscious that their planting had failed and 20% stated they had had mixed success. Villagers in the Philippines appeared to be more aware that some of their planting had failed (29%) compared to Thailand (14%). Similarly, whereas half of the Thai interviewees (53%) assumed their planting had successfully established, only a third made that assumption in the Philippines (34%). Of the 'failed' category for both countries (n=27), 70% had been located on mudflats. Thirty-five percent of all the interviewees who planted on mudflats (n=51) believed that their planting had been successful, whereas, in fact survivorship was less than 2% (Chapter 1, Fig 7). Furthermore, 64% of respondents describing mid mangrove zone plantings (n=42), assumed they had been successful (i.e. >70% survival), however mean survival was actually 30.1% (Chapter 1).

2.5.7 Planting Timing was not an Ecological Consideration

The timing of mangrove work was not reported to be an ecological consideration for either the general village populace or village leaders, but in this respect the countries varied. Thai respondents suggested that they planted mangroves to celebrate special national days, accounting for 41% of Thai mangrove rehabilitation events (n=109). Another third of Thai respondents (32%) said that planting timing was influenced by other non-ecological, logistical considerations, such as the availability of villagers or the arrival of funds. Wanting to provide a planting opportunity for visiting guests was also discussed (8%).

Interviewees in the Philippines claimed that logistical rather than ecological issues controlled planting timing for more than half of their planting projects (56%, n=41), citing reasons such as the availability of planting teams, the arrival of funds or the pre-determined start of a government planting project. Another fifth of Philippine planting events (22%) were timed to coincide with low spring tides to access mudflats. In both countries mangrove ecology only influenced timing in relation to the availability of seeds and propagules (10%), not suitable climatic conditions. This is supported by the fact that in the rehabilitation science tests, only one third of both government officers and villagers were aware that the rainy season was a better time to plant (due to lower salinity and cooler weather, Primavera et al., 2012; Ravishankar and Ramasubramanian, 2004), rather than being dictated by logistical or civic schedules.

2.5.8 After Planting – Less Activity than Expected

Although few of the respondents of the semi-structured interviews said that they had witnessed it, 75% reported the understanding that after planting, the site was inspected by either the village conservation group or government mangrove agency staff, and that government staff would order the replacement of dead plants if necessary. Only 12% believed that nothing happened after a planting event. Village leaders suggested that their village's own conservation group were more likely to inspect after planting, whereas villagers believed this was more likely to be conducted by the government mangrove agency. Villagers from the group of four that were more successful planters responded in a similar way to residents from less successful villages.

Other management activities such as installing fencing, signage or clearing debris were believed to happen only rarely (7% in total). While it might be expected that sites which had received ground preparation such as weeding and removal of vines and creepers would require ongoing intervention after planting because unwanted plants were only cut back not dug out, these sites did not receive any more activity after planting than might be expected by random chance.

Asking respondents what they felt *should* happen after planting, some respondents stated that nothing was needed (15%) and perhaps indicatively a fifth could not give an answer (20%). Almost a third suggested that inspection, monitoring or replacing dead plants was necessary (29%), and a further 12% wanted the installation of fencing and protection measures. It is perhaps surprising that so few respondents suggested protection measures because in the rehabilitation science test both villagers (51%) and government mangrove agency staff (84%) could name at least one non-living hazard that might damage small mangroves, such as the impact from boats or fishing gear. Furthermore, when discussing what should happen after planting, 15% suggested in the SSI that weeding was necessary to help the planted mangroves establish. But in the rehabilitation science test 35% of villagers said they would weed out other mangrove species if they started to grow within their new plantation, as would 14% of government mangrove agency staff. Finally, a few suggested that there should be more training given to villagers for planting and maintenance (9%).

Although sample sizes were small, trends suggested that there were slightly different priorities for different groups. Villagers from more successful planting villages were more likely to suggest weeding, and villagers from the less successful groups were more likely to suggest monitoring, replanting and protection measures, Fig 18.

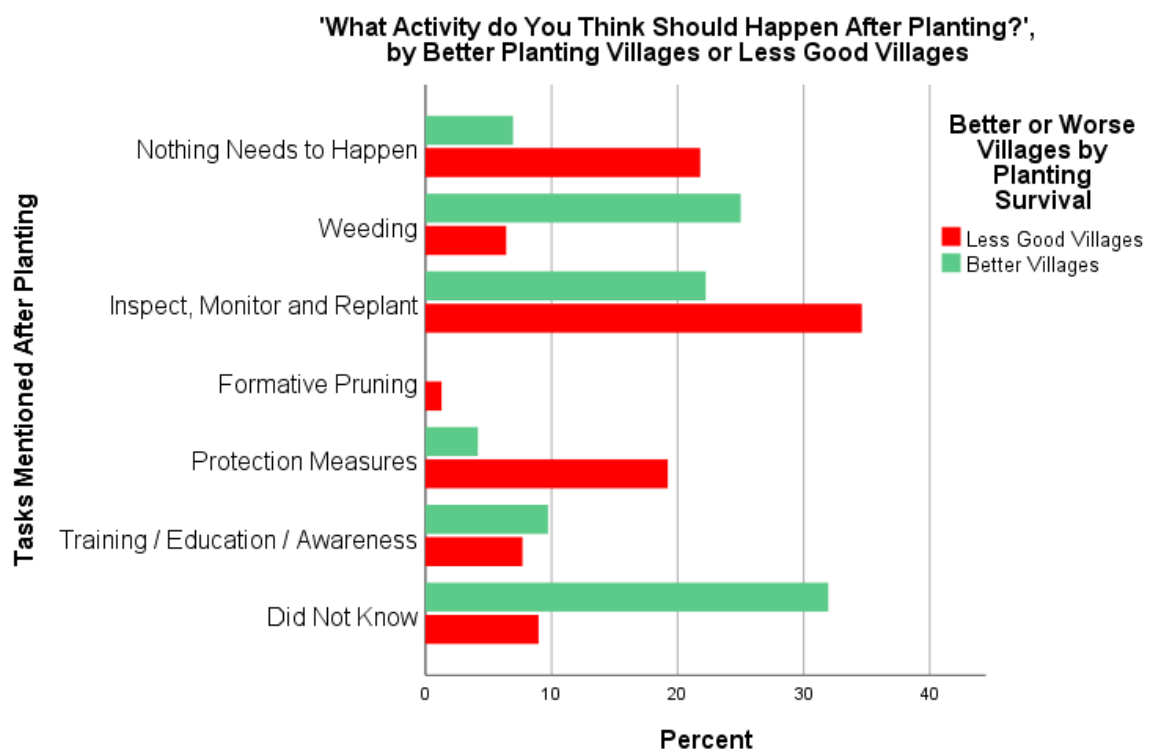


Figure 18. Activities respondents expected to see after planting. The more successful four villages (green) who were planting less on mudflat, hoped to see weeding as well as monitoring, but a significant group did not know what happened or should happen. The less successful four villages (red) expected just monitoring and likely replanting.

Between the general village populace and villager leaders, leaders were keener on protection measures and education, whereas the villagers who believed that anything needed to happen were more likely to suggest weeding, Fig 19.

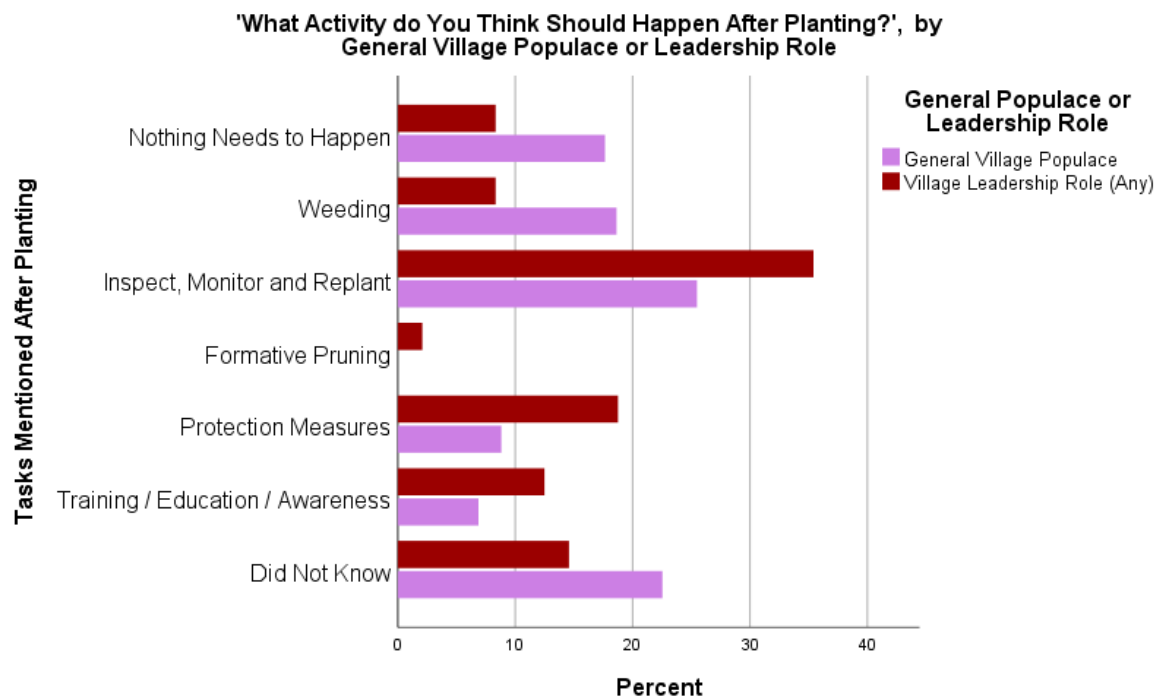


Figure 19. What villagers stated should happen after planting, by role (village populace (purple) vs leaders (dark red)).

More planting training was a minor theme when villagers were asked in the semi-structured interviews what they would have done differently. A majority believed no change of detail was necessary (59%), a fifth would have changed site altogether (21%) and 6% wanted more instruction and training before planting.

2.5.9 Did Village Planters Believe That Their Planting was Necessary?

Half of the planters felt their planting was necessary, a fifth believed the contrary (20%) and another 14% stated that they knew at the time of planting that their efforts would fail. By cross-referencing with elevation zone planted, those who knew that their planting would never work, 95% (n=21) were planting on mudflats. In contrast, of the 51 interviewees who described planting on mudflat, almost half described this planting as necessary as they were consciously attempting to convert (i.e. afforest) mudflat to mangrove. Leadership role or general populace made little difference, but although the sample sizes were small, of those who realised their planting was unnecessary (n=30), two-thirds were from the more successful four villages. And 86% of respondents who knew their planting would never become mangrove (n=21) came from the less successful villages, Fig. 20.

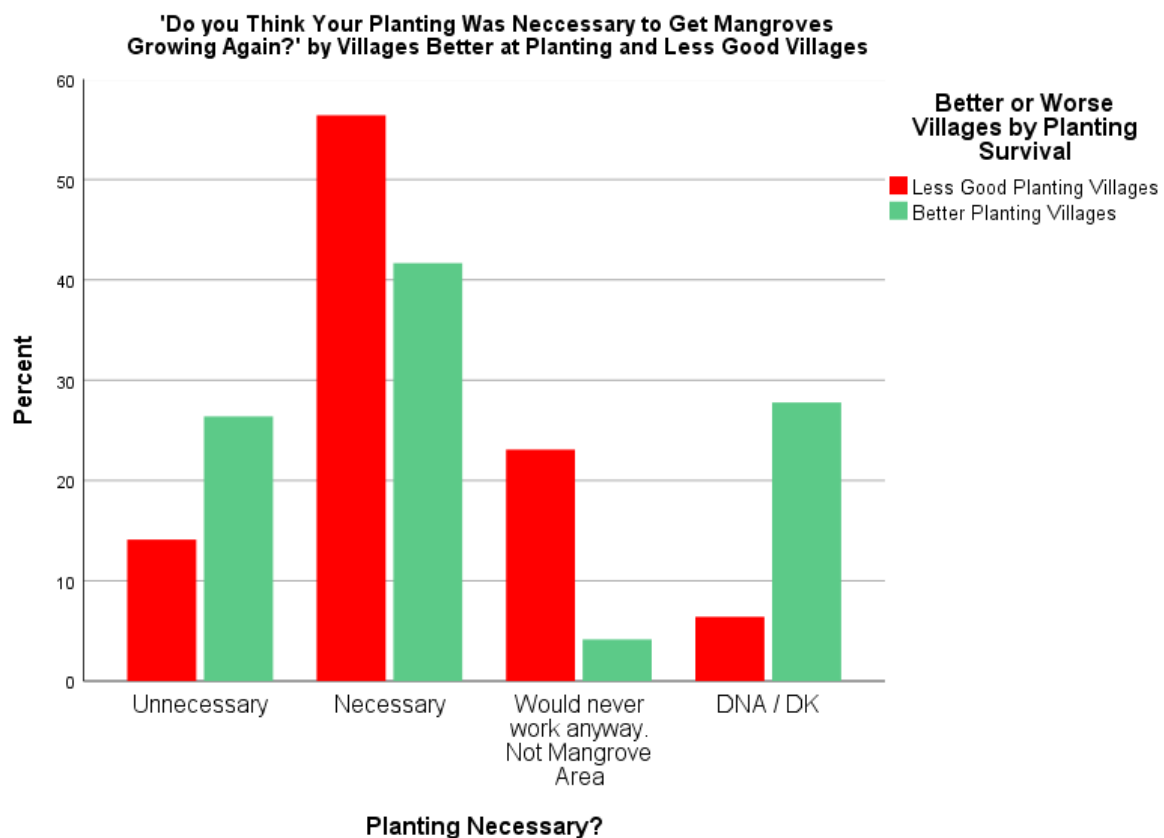


Figure 20. Was planting necessary? Respondents from villages that were less successful planters (red), felt more of their planting was indeed necessary for afforestation, but a significant group also understood that their planting would never succeed, largely because it was at an elevation too low for mangrove growth. Respondents from the more successful four planting villages (green) had a more mixed view about whether planting was necessary, or did not know.

2.5.10 Planting and Establishment Issues from the Rehabilitation Science Test

As described in section 2.3.4 the effective maximum score for the rehabilitation science test was 19. Fig. 21 illustrates that while the science tests from the general populace varied little across villages, ranging from 7 to 9.2, there was more variation between conservation groups (7 to 12.5) and between government mangrove agency field offices (9.6 to 15.8 (N.B. these sample sizes were small)). The difference between the general populace and conservation groups was not significant ($U=30$, $Z=-0.212$, $p=0.83$). However, the government staffs' scores were significantly better than the general populace, ($U=0$, $Z=2.94$, $p=0.03$), and trended towards being significantly better than the conservation groups' score ($U=7$, $Z=-1.9$, $p=0.056$). There was no statistically significant relationship between test scores and planting survival for either the general populace, conservation group or government mangrove staff ($r(21)=0.052$, $p=0.82$).

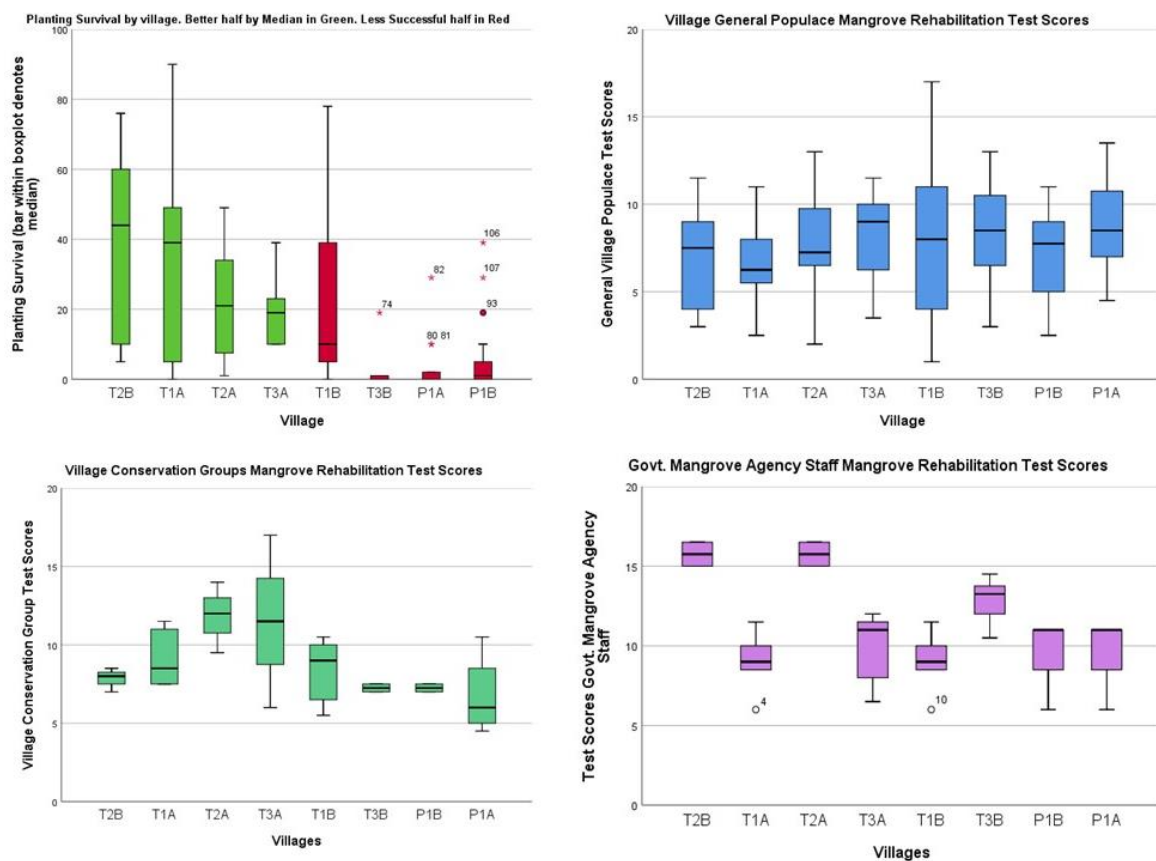


Figure 21. A comparison of the rehabilitation test scores by more successful four villages against the less successful planters, by role (general populace (top right panel), conservation group (bottom left panel) and government mangrove agency staff (lower right panel)). N.B. some of the Govt. mangrove agency field staff offices looked after more than one village. E.g. one mangrove field office looked after both village T1A and T1B, and the government staff scored an average of 9.6. Another office looked after villages T2A & T2B, and a further office took care of P1A & P1B.

Other mangrove rehabilitation science test questions relating to silviculture and plant establishment not already mentioned are described below. Villagers (87%), conservation group leaders (88%) and

government staff (97%) knew that the application of fertiliser when planting mangroves was unnecessary. Asked what could be done about high salinity on a rehabilitation site, most villagers (87%) could not provide an idea of how to mitigate this stressor, by for example, improving hydrology to dilute the salinity and flush away excess salt, deploying more salt-tolerant species (e.g. *Avicennia marina* or *Aegiceras* sp.), changing site or planting in the rainy season. However, almost half (47%) of the government officers were able to suggest at least one of these solutions. When asked how they might improve establishment outcomes on a site which was subject to high wave energy, 40% of villagers and 83% of government staff could suggest at least one idea, such as building a protective bamboo wall⁸ to reduce wave impact, installing brush-fencing to trap sediment seaward of the site, (deep) staking and attachment (Toorman et al., 2018), planting more established seedlings or young trees or changing site.

⁸ Debate continues around the long-term efficacy of bamboo fencing, brush-screens and geo-textile tubes known as 'geotubes', filled with sand, to protect mangrove planting or assist mangrove regeneration. Soil must accrete landwards of these barriers high enough and become firm enough for soil conditions to be appropriate for mangrove growth. When the bamboo or brush eventually decay away or the 'geotubes' split, whether the newly exposed mangroves will be able to survive the renewed wave energy is poorly understood (R.R. Lewis, pers. comm.). Furthermore, there is little peer-reviewed literature reviewing these projects.

2.6 DISCUSSION

2.6.1 Interpreting the Planting Process as the Villagers Understood It

2.6.1.1 *Site Choice Driven by Perceived Degradation and the Need for Planting Space*

Much of the mangroves in Thailand and the Philippines have previously been cut over for charcoal, fuelwood and other uses, and remain under a certain level of harvesting pressure (Chapter 3). Not all the previously affected mangrove areas had recovered or benefited from successful government replanting, and more recent efforts to replant these degraded areas have been only partially successful (Chapter 1).

Deciding and defining what is ‘degraded’ mangrove is challenging, requiring a concurrent assessment of the effects of climate change, species succession and cultural expectations among other issues (Hobbs, 2016). For example, many of the sites chosen in Thailand, and the non-mudflat sites in the Philippines, were perceived as degraded because villagers’ perception of a healthy mangrove was dominated by an expectation that all mangrove zones should be “full” (interviewee T2A#21), which they defined as resembling the densely stocked stands of closed-canopy plantation *Rhizophora* sp. previously produced by government planting in the 1990s and 2000s. Therefore, underplanting naturally more open, back mangrove zones was regarded as restoring a ‘degraded’ mangrove by many villagers (e.g. interviewee T1B#40) but understood by a minority of villagers to be unnecessary (e.g. interviewee T3A#52). Otherwise, within the mangrove zone, villagers were attempting to fill in gaps and rehabilitate remaining open mangrove areas. In addition to planting degraded sites, some Thai Department for Marine and Coastal Resources (DMCR) field office directors used various methods to return illegally encroached areas within the mangroves that had been converted into aquaculture ponds back to state ownership. This included asking village leadership to run an audit of village mangrove areas claimed by local people, and in an attempt to avoid recourse to the law courts⁹, asking trusted elders to negotiate the return of part or all of the abandoned or active aquaculture ponds (interviewee T2A#45). Land and ponds returned in this manner, often severely degraded, would then be planted by the community and signage installed to show that an encroached area had been returned to state owned mangrove. The desire to return former aquaculture ponds back to mangrove was largely driven by the field office directors’

⁹ Using the legal process had risks for all sides. Government agencies could not control nor entirely predict whether police and other agencies would be supportive or the enforcement outcomes and sentencing, which in Thailand might produce a very harsh sentence.

commendable desire to reclaim land within the mangrove zone, not because the aquaculture ponds tended to be sited at an appropriate height for (mid zone) mangroves.

The other main driver of site choice was the need for available planting space. Chapter 1 described how the Philippine government mangrove agency field offices were given specific area planting targets from the National Greening Programme, a bio-shield development project, regardless of whether appropriate inter-tidal areas were available or not. Thailand's government mangrove agency had propagule targets and, to a lesser extent, area targets and on occasion villagers needed to find available space to allow visitors to plant. Propagule planting targets could be compressed into areas available by changing planting density, but area targets encouraged or indeed necessitated the use of mudflats among other coastal elevations and site types, as mudflats were easy to administer and photograph, and unlike areas encroached for aquaculture ponds, were rarely subject to contested land tenure. This did not mean that mudflat planting avoided all controversy as several villagers from T3A and T3B mentioned that local fisherman wanted to fish at high tide over the inundated mudflats that had been planted with mangroves. The planted propagules and canes either obstructed the use of their (illegal) pushnets, or the fishermen destroyed the plantation. In some instances, fishing boat propeller marks were evident in the mud within the planted areas at low tide (e.g. village T3B mudflats, pers. obs.).

A minority of villagers in both countries understood that mudflats were 'too deep' for mangrove growth. Thai villagers had largely managed to divert planting away from mudflats (T3A#29) but in the Philippines this local knowledge was annulled by the perverse incentive of being paid to plant or replant. Village leaders wanted to preserve this earning opportunity for their villagers and mudflat planting provided an opportunity for village planters to collect clams and mussels at the same time.

2.6.1.2 Site Preparation

Despite the published scientific literature describing the importance of good hydrology and drainage for mangrove health (e.g. Aung et al., 2011; Elliott et al., 2016; Lewis, 2005), site amendment and hydrological problems were rarely mentioned during the entire fieldwork period. The rehabilitation science test revealed that there was a widespread understanding that former aquaculture ponds and impounded areas should be reconnected to outside hydrology, and that good or improved hydrology could rehabilitate a site on its own via natural regeneration (if not propagule limited). But for reasons that remain unclear, this knowledge did not translate into action when on site. For example, a site planted by village P1A, which had been subject to chronic tree felling for charcoal, had multiple channels filled with discarded brush. This debris slowed water flows, encouraged sedimentation and inhibited the arrival of seeds and propagules and thereby the natural

regeneration of this site, in spite of being surrounded by mature mangroves. Despite several visits by mangrove agency staff and conservation group members, no understanding of this hydrological problem was evident, or action taken to clear the channels. The village planting team did not consider clearing the channels, expressed surprise when I suggested it and did not question why the site was not regenerating on its own. This was unfortunate as Chapter 1 demonstrates that better hydrological connectivity was associated with improved planting outcomes. Beyond force of habit, a possible explanation for this behaviour, particularly for Thai volunteer planters, was that planting was supposed to be a fun communal activity. Clearing brush and digging clay soils to improve the hydrology would have been arduous work, and therefore not considered. For mudflats, as there was only a limited understanding of why saturated, soft, poorly drained soils were unsuited to mangrove growth, the lack of any attempt to amend these areas was not surprising.

At lower elevations, seaweed, wrack and debris can become entangled around young plants and damage them. Within mid and high mangrove zones, beyond crown-lifting of the lower canopy of existing trees (interviewee T2B#47), weeding might be necessary within more open canopy areas to help establish planted material or natural regeneration and to inhibit vines and climbers from smothering or damaging the young plants (UNEP, 2007). Some villagers reported that mid and back mangrove sites were weeded before planting, normally done by swinging a straight machete or occasionally a small hand scythe through the ground layer, cutting back all vegetation but not digging out the roots. Despite claims to the contrary by the conservation group leaders, frequently this technique resulted in the non-selective removal not only of vines and weeds but all plants including mangrove and mangrove associate species such as *Acrostichum* sp., *Acanthus* sp., *Dalbergia* sp., *Finlaysonia* sp., *Derris* sp. and 'unwanted' mangrove species such as *Phoenix paludosa*. In addition, several villagers from T1B mentioned clearing away *Avicennia officinalis* seedlings (e.g. interviewees T1B#27, #20) and mature *Scyphiphora hydrophyllacea* (interviewees T1B#39, T1B#24) to make way for planting. Weeding before and after planting was a chore as it involved hard, physical, ground-level work, unlike planting which many claimed to enjoy and in Thailand was performed by volunteers. Occasionally dedicated village mangrove volunteers would weed a site. More frequently, if it happened at all, the government had to pay for people to weed, an activity less likely than planting to attract budget or resources.

2.6.1.3 Site-Species Matching

The main reasons cited in the literature for poor mangrove planting outcomes are poor site / species matching, in combination with poor site selection (Alongi, 2002; Aung et al., 2011; Bosire et al., 2006; IUCN, 2017; Kodikara et al., 2017b; Primavera and Esteban, 2008; Saenger, 2002; Walters et al., 2008; Wodehouse and Rayment, 2019). Explaining their strategy for site / species matching,

villagers or government staff claimed to have chosen *Rhizophora* sp. because it was “thriving near the planting site” (interviewee P1B#44), as Hashim et al. (2010) also reported. Although this is a sensible silvicultural principle to adopt, and there is evidence to suggest that propagules from local plants are typically more successful than material that has arrived via hydrochory (Alongi, 2009), two factors were often disregarded. First, although *Rhizophora* sp. might have been thriving nearby, little or no account was taken of the change in elevation between the thriving stand and the planting site – coastal topography is such that elevation can change dramatically over a relatively short distance. This change in elevation was occasionally emphasized by the presence of naturally regenerating low-zone pioneer species (Table 6) such as *Sonneratia alba* (P1A#30) fringing the lower, seaward side of the mid zone *Rhizophora* sp. stands, and the lack of natural regeneration lower down. Furthermore, at no time did any villager or government officer acknowledge that the low zone pioneer mangrove species with their cable roots (Primavera 2015, Primavera et al. 2011) and higher tolerances to inundation were more appropriate for low-zone / mudflat fringe planting than other species, despite recommendations and guidance in the published literature (e.g. Chan and Baba, 2010).

Second, site / species matching was complicated by the fact that much of the mangrove has been significantly altered and natural species zonation has been greatly disturbed. This was due to the loss of old-growth biodiverse mangrove to charcoal and fuelwood concessions and the resulting state mangrove reforestation programmes, which had planted *Rhizophora* sp. almost exclusively, forming mono-specific, first generation, even-age class plantations. This reforestation produced an overabundance of *Rhizophora* sp., which was more widely distributed than it would otherwise have been and an absence of ‘pioneer species’ occupying the low mangrove zone (Fig 10). However, many villagers understood this *Rhizophora*-dominated phenomenon to be natural.

Several interviewees from all villages assured the author that villagers understood species zoning (e.g. interviewee T3B#41), but as the responses, and data from Chapter 1, demonstrated this knowledge was only partial and again failed to translate into appropriate planting activities on the ground, (interviewees T2A#13, #42). For example, sometimes species were planted in blocks not due to changes in elevation, differences in species tolerances or to match an appropriate site, but so that one species did not shade out another if the different species were understood to grow at different speeds (interviewees T3A#22, T3B#1).

If requests were made to government mangrove agencies to plant alternative species, this was because, in the opinion of the villagers, their current mangrove stock was perceived to contain too much *Rhizophora* sp. already (e.g. village T3A) or for livelihood reasons, not for appropriate site-species matching (interviews T1B#16, T3A#4). For example, village T3B planted an extensive area of

mudflat with *Nypa fruticans*, not because they believed it was a more appropriate species than *Rhizophora* sp., but because this palm would provide various products for livelihood activities, despite the fact that the sparse natural regeneration present on the edge of this site was only low-zone mangrove pioneer species. The 25ha of *N. fruticans* planting suffered total mortality, as did various iterations of *Rhizophora* sp. planting.

2.6.1.4 Species Choice was not Affected by a Desire to Increase Biodiversity

During the fieldwork period of almost three-years, the lack of mangrove biodiversity (or the even-age class nature of the post-concession planting) was almost never spontaneously mentioned by villagers or government officers. When questioned, government mangrove agency staff claimed that there was little guidance or encouragement from head office to consider or increase mangrove biodiversity or change planting habits. Both groups had only a partial understanding of the benefits of a biodiverse mangrove ecosystem (Benayas et al., 2009; Davies et al., 2014; Rands et al., 2010), or the inherent risks of planting only two or three mangrove species in the context of the unpredictable nature of climate change and sea level rise (e.g. T1B#DMCR interview 27.1.13).

A minority of both Thai and Philippine villagers believed that *Rhizophora* sp. was the only mangrove genus and everything else was just flora. This is reinforced by the fact that the local word for 'mangroves' is the same as for the genus *Rhizophora* in both countries (Primavera, 2015). As mentioned by other researchers the propagules of *Rhizophora* sp. are easy to collect, direct plant and do not require growing-on in a nursery (Lewis, 2014; Primavera, 2015; Primavera et al., 2011; Primavera and Esteban, 2008), unlike *Avicennia* sp. propagules which are frequently subject to herbivory by crabs until the stems turn woody (N. Sieuwnath, pers. comm.). As a result, some villagers stated that they could not imagine planting anything else. An exception to this *Rhizophora*-dominated view were the villages of T3A and T3B, on the east coast of Thailand. Some of the older generation remembered being paid to fell square kilometres of natural, healthy *Sonneratia* / *Avicennia* mangrove forest (Osbeck et al., 2010), to provide space for planting *Rhizophora* sp. As a result, some were aware that those original low zone genera would be more suitable for the current rehabilitation programmes around the bay.

A desire for certain products also affected species choice. On more than one occasion villagers did not want to leave a site to naturally regenerate as they did not want the low zone pioneer species that would appear first, such as *Avicennia marina* and *Sonneratia alba* (T1B#27). A majority of villagers perceived *Rhizophora* sp. to be the most useful species, producing straight poles, stems, high-quality fuelwood and charcoal, fast-growing and resistant to decay if used in water. Or they desired the mangrove palm *Nypa fruticans*, not necessarily because they believed it was ecologically

suited to a site but because it was used in their livelihood activities, such as the production of roofing shingles, cigarette papers and various products from *N. fruticans*' sap. Others favoured densely planted *Ceriops tagal* as this silvicultural practice produced straight poles with no side branching. These poles were used primarily for squid trap flag poles and pinning crab traps to the mud.

Villager belief about the widespread applicability of *Rhizophora* sp. was reinforced by the activities of the governments. *Rhizophora* sp. was, by-and-large, the genus the government planted, and advised villagers to plant. Government mangrove agency training received by a Philippine village conservation group leader (interviewee P1A#51) reportedly focused only on the application of *R. mucronata* in all situations and did not, for example, suggest the use of more appropriate low-zone pioneer species for sites at lower elevations.

2.6.1.5 *Planting Material*

Bagged seedlings were almost always provided by the government and were perceived by villagers as planting material for visitors and for special occasions (interviewee TA1#17). If the bagged seedlings were planted incorrectly, they were planted too deep, the top of the root-ball buried under the mud, potentially resulting in the roots and rhizosphere receiving insufficient oxygen. In addition, a concern was the lack of care with which the polybags were removed from the root-balls, letting the root-ball mass break up, thereby breaking the fine root hairs and degrading the plant, particularly if children were planting. If propagules were planted inappropriately, they tended to be inserted too shallow into the mud. In a very sheltered site this might not be a problem, but on an energetic mudflat with soft mud providing insufficient mechanical anchorage, propagules could be washed away. Only the Philippines used 'wildling' *Rhizophora* sp. seedlings which were juvenile plants with 2-5 leaf pairs, manually pulled out of the mud without a root-ball. Wildlings were used because of the misconception that these young seedlings were more reliable, as they had already started to grow, whereas some propagules failed to break bud (P1A#16). The belief in superior wildling reliability could in part be a consequence of the poor performance of propagules that had been pulled from the trees before they were ripe, and a partial understanding of propagule-boring beetles. Almost always wildlings were deployed on mudflats, an unsuitable zone for mangrove establishment and as a result performed poorly. This was compounded by the likely root damage during extraction, forcing delicate roots back into soil during replanting and the fact that wildlings were often stored in the sun where the roots would desiccate and die before planting (pers. obs.). However, wildlings formed a convenient seedbank and therefore could be extracted all year (P1A#46).

2.6.1.6 Canes, Lines, Planting Events and Their Timing

More often than not, sites had split bamboo canes inserted a day or two before a planting event by conservation group members to indicate where to plant, rather than for support, as the canes were rarely tied to the propagule or seedlings, making the value of staking doubtful. Asked why they used canes when not attached to the propagule or sapling, villagers could give no answer. For government agencies, the use of canes (often with tops sprayed red) emphasized to potential encroachers that the site was now being actively managed by the state and to deter further encroachment. Staking might help if the planting site experienced energetic waves, such as along Suriname's coast where long stakes were inserted very deep to stop the plants from sinking (Toorman et al., 2018), but at the same time, a high energy site suggests that the location is inappropriate for mangroves. Although not inherently wrong, resources used for staking could be better applied to other management tasks.

If there was sufficient space, canes were always inserted in lines. Although planting in straight lines was not inherently wrong, this practice led to minor variations in topography and channels being ignored and planted inappropriately. At no time was planting in lines questioned by villagers. Indeed, mangrove workers were adamant that planting in lines was the correct method as the government did the same, several people mentioned that straight rows were "beautiful" (interviewee T2A#44, T3B#44) and pleasingly neat, and that other crops were also in lines, such as rice, rubber, oil palm and fruit trees. For the same reason, several Thais (e.g. interviewee T1B#38) commented that they disliked "messy" trees such as *Xylocarpus* sp. and *Melaleuca* sp. as these species shed their bark.

Techniques such as 'clump planting' were discussed only very occasionally but not executed for the mutual soil improvement that tightly planted propagules provide for each other. Interviewee T3B#18 clump planted *Nypa* palm seeds 30-50cm apart in threes only because he felt that the palms spread better and looked aesthetically pleasing.

The various motivations for planting produced different styles of planting events and affected the timing of the activities. Planting in the Philippines was paid work to produce a mangrove bio-shield, and often performed by organised, experienced teams and over several days, when the logistics were all arranged. By contrast, in Thailand, some of the village planting events were chaotic with scores of schoolchildren planting in inappropriate places and significant footfall damage to planted material and natural regeneration (interviewee T1B#16, village T3A pers. obs.). On more than one occasion, a Thai conservation group member mentioned that they had relocated much of a previous day's planting to more appropriate places. The Thai government agency was aware of these

shortcomings, but felt the planting was still worthwhile as an awareness-building and education exercise and as a mechanism to encourage villagers to work with the government rather than perceive the state as the enemy (T1A&B DMCR interview 27.i.2014). Otherwise the timing of Thai planting activity was driven by villagers' desire to carry out collective activities on national holidays. Unfortunately, one of the key holidays is in the middle of the dry season.

2.6.1.7 After Planting Activities and Mangrove Silviculture

In the Philippines, local conservation groups were more likely to inspect plantations than government mangrove agency staff because villagers were paid to manage planting projects. In contrast, because most planting in Thailand was carried out by unpaid volunteers, government inspection was more likely. Disturbance to mangrove plantations appeared to be limited to fringe and mudflat sites. Occasionally this instigated the installation of signage and fencing to keep fishing boats out. Beyond damage from fishing gear, some fishers encircled large areas of more mature mangroves with nets to trap escaping fish, a technique that damaged young mangroves. In general, plantation disturbance was avoided as both government mangrove agencies had started to consult more closely with fishermen who lived nearby before planting. Furthermore in both countries disturbance was poorly interpreted and recorded as losses attributed to damage by fishermen, when it was more likely that the plants that had failed to establish because of poor site selection or site / species matching.

Apart from the dense stand of *Ceriops tagal* that had had the side branches removed at around 5-6 years old (village T1B), and side branches removed from a *Rhizophora* sp. plantation to encourage the production of straight, unbranched stems in another community (T2B), post-planting silviculture was notable by its absence¹⁰. There was very little reported systematic post-planting pruning and thinning.

2.6.2 Knowledge Gaps, Misunderstandings and Access to Information

For conservation groups and villagers, it appears that only a portion of the available mangrove knowledge has been communicated to them. While some study tours were described as very useful, particularly for alternative livelihoods (e.g. interviewee T2A#42), the sporadic mangrove training sessions for planting from the government that a few had received were less helpful as they defaulted to a mono-specific terrestrial plantation approach (interviewee P1A#51), rather than embracing full ecosystem rehabilitation, hydrological restoration and mangrove ecology. As well as failing to avert poor planting outcomes, this training did little to counter the misunderstandings

¹⁰ An exception was the village Nypa palm expert T3B#15 mentioned earlier. He had a great understanding of Nypa palm cultivation and managed his stand of palms for sap production with great skill and knowledge.

about mangroves held by various communities. The consistent choice of *Rhizophora* sp. was due to village misconceptions about this and other genera. For example, one group (village P1A) believed that *Rhizophora* sp. and *Nypa fruticans* were the only species that could withstand undiluted saltwater and therefore the only species they could use. Several Philippine villagers believed that only the *Rhizophora* sp. areas were productive for fisheries because they saw shrimp and fish only within prop roots of this genus at high tide, in contrast to the landward *Ceriops / Bruguiera* zone (there being little or no low zone *Avicennia / Sonneratia* mangrove for comparison). There was a village-wide (T3A) misunderstanding about the large-scale die-off of trees within impounded areas of standing water within their mangroves due to channel blockage from siltation. Local people attributed this die-off to fallen *Rhizophora* sp. leaves decaying in the standing water which turned the water 'sour' (acidic). In addition, in this village, people believed that when *R. mucronata* grew to more than 15m in height the species naturally became unstable and fell over as this was being observed in their mangrove (T3A and T3B). Both these problems were caused by disturbance to upstream hydrology by a watershed-scale dam. Finally, when considering planting on exposed sites subject to higher wave energy, villagers believed that only *Rhizophora* sp. could survive in this erosive environment (e.g. interviewee T1B#36), misunderstanding the superior resistance to erosion due to their cable root systems of *Sonneratia* sp. and *Avicennia* sp. (Primavera, 2015; Primavera et al., 2014).

It would be informative to conduct more detailed research concerning specific choices and activities (or the lack thereof) using the theory of planned behaviour (TPB, Ajzen, 2002). Specifically, how attitudes, subjective norms and perceived behavioural control (PBC) might influence the unwillingness to clear mangrove channels of debris or intentions to plant and thereby planting behaviour. For example, while knowledge about the provision of ecosystem goods and services from mangroves, environmental education and training offered might develop positive attitudes towards mangroves and mangrove rehabilitation, payments for planting in the Philippines might outweigh these attitudes. The earning opportunities from planting produced perverse incentives, sometimes overcoming local knowledge about inappropriate rehabilitation site and species choice (the behavioural control). Villagers understood that many of the sites chosen by the government for planting were unsuitable for mangrove establishment, being too low relative to sea level and with soils saturated for too much of each tidal cycle, thus in this case involuntary behavioural control (Rossi and Armstrong, 1999), but planted anyway for the income (J. Primavera, pers. comm., Primavera, 2015). Similarly, in Thailand, the very positive attitudes towards planting together on national holidays (although with minimal social pressure to do so – the social norms) sometimes

overcame reservations villagers might have had about site and species choice (i.e. belief in their ability to rehabilitate a site - perceived behavioural control).

Mangrove agency field officers were sometimes little better informed than villagers. Few officers mentioned whether they had received specific mangrove rehabilitation training beyond plantation development, and no training similar to Lewis' CBEMR approach (Appendix B) or as detailed as that provided by NGO Mangrove Action Project¹¹ or within ZSL's mangrove manual (Primavera et al., 2015). They would not use a natural reference mangrove site, for example, to guide rehabilitation decision making. Nor would they examine changes in hydrology and rectify those first before any other implementation. Officers in both countries appeared not to be receiving summaries of the scientific research and appeared to be largely unaware of current academic research output. There was little evidence of state-commissioned independent reviews of their planting outcomes or lessons to be learned from the government mangrove rehabilitation work conducted after the end of the mangrove concessions. Of the more recent planting (since 2007), the Philippines Dept. for Natural Resources and Environment was attempting to validate National Greening Program planting¹², although this validation assessment appeared to be poorly executed¹³. Throughout the duration of the research period, government mangrove agency staff appeared to spend only limited time analysing why planting outcomes had been sub-optimal, and these failures rarely resulted in a change of technique, species planted or a move towards evidence-based decision making (as per Sutherland et al., 2004). According to two Thai conservation group leaders, if the mangrove agency actually acknowledged a planting failure, it was more likely to change site than question species choice or technique. More broadly, there seemed to be a lack of willingness in both countries to review previous rehabilitation work, publish and learn from the experience and develop an evidence-based rehabilitation programme, let alone take steps to integrate published best practice, or local / indigenous knowledge as suggested by Tengö et al. (2014).

A possible explanation is that government mangrove targets are related to areas planted or numbers of propagules planted (Chapter 1), negating the need for post-planting review compared to more appropriate parameters such as survivorship after 3-5 years (Chapter 1) or biodiversity (Davies et al.,

¹¹ The author is paid to teach Lewis' 'community-based ecological mangrove rehabilitation' approach for MAP, as detailed in Appendix B.

¹² In the two Philippine villages studied, this was subject to deception as forewarned villagers were relocating natural mangrove 'wildling' saplings to failed planting sites just before the validation visits, to avoid the impression of total planting failure and the termination of their employment to replant.

¹³ In a conference presentation in 2017, the DENR claimed to have a 74% survival rate but presented very little evidence to substantiate this claim. Philippine survival rates found by this author were significantly lower (see Chapter 1). Repeated requests for an interview with senior members of the Dept. for Environment and Natural Resources in Manila to discuss NGP planting and validation failed to produce a response.

2014; Secretariat of the Convention on Biological Diversity, 1992). Fulfilling these quotas was success in itself. In addition, perhaps expectations were low as there appeared to be a lack of accountability or reprimand for planting failure. Rarely did the village mangrove experts appear concerned about the poor planting outcomes when touring planting sites with the researcher.

What are the possible barriers to sharing and attaining mangrove knowledge? The process could start with an acknowledgement by village conservation groups, government mangrove agency staff and officers at head office that previous planting programmes have resulted in poor outcomes. Furthermore, recognition that there is much to learn about mangrove ecology and biology, and that mangroves are significantly different to terrestrial forests, would be beneficial. Many mangrove agencies around the world, including those in Thailand and the Philippines evolved from, are part of, or are hosted by, corresponding Forest Departments, (e.g. Senegal, Tanzania, Myanmar, Guyana, pers. obs.) and thus a terrestrial (production) forestry approach often prevails. However, despite this departmental connection there appeared to be a lack of systematic dissemination of mangrove research and best practice to the field offices, translated and in an appropriate form (rather than as scientific papers). If mangrove agency staff wanted to source their own information, much of the scientific literature is in the format of research papers, possibly in a foreign language and behind a paywall. Moreover, it is questionable whether university-based researchers have communicated their findings effectively, beyond academic publications and conferences, to mangrove agencies and community groups¹⁴ as Cvitanovic et al. (2015) suggested concerning marine protected areas (MPAs). It is arguable that the knowledge-deficit model¹⁵ should encourage researchers to make more of an effort to engage and communicate with mangrove stakeholders and workers but this appears not to be happening (Simis et al., 2016). Instead, as Cvitanovic et al. (2015) suggested of managing MPAs, gut feel and habit seemed to guide mangrove rehabilitation decision making. The output from researchers listed in the Introduction section and in Chapter 1 appear not to have changed behaviour on the ground.

¹⁴ With the honourable and courageous exception of Dr Jurgenne Primavera who has taken the Philippine government to task over their inappropriate mangrove planting in the national media, at some personal risk to herself. E.g. <https://palawan-news.com/scientist-says-government-planting-wrong-mangrove-species/?fbclid=IwAR09NpYhAfYIz2WbxDsbYGnDmUqbQumhzpIUZq0ONXcwKlncLJNLO6IJFZs> accessed 14.6.2019

¹⁵ The knowledge deficit model suggests that the ignorance of, in this case, the collected mangrove knowledge and rehabilitation techniques from published science and manuals, is due to a lack of information which therefore results in limited support for the science and techniques in question.

2.7 CONCLUSIONS

There were many mangrove-related activities that were positive and should be supported. Villagers and government mangrove agency staff in both countries were making significant efforts to regain mangrove coverage, and both agencies recognised that they needed to work with and engage local mangrove communities, rather than have confrontational relationships. Some of the Thai DMCR mangrove field offices were attempting to negotiate the return of aquaculture ponds, initially produced by illegal encroachment, back to state owned mangrove. And there were various *ad hoc* education programmes about the benefits of mangroves (interviewee T1B#12).

However, there appeared to be gaps in the knowledge of what government staff and villagers knew about mangrove ecology and rehabilitation, and a disconnect between this knowledge and actions on-site. In the absence of evidence-based guidance being provided to planting teams, or collecting their own evidence of effective methods, inappropriate methods were repeated with perhaps surprisingly low expectations of success. For example, many projects attempted to afforest mudflat areas. Despite being aware of low zone pioneer species (pers. obs.), villagers and government staff did not attempt to use these more appropriate species even to test extending the front fringe of existing mangroves, let alone on mudflats below this fringe. Developing an understanding of mangrove degradation closer to that described in the scientific literature, while taking into account the influences of climate change and local culture, might alter villagers' perception of what is degraded and facilitate more appropriate rehabilitation site selection. This would include recognising that back mangrove zones are naturally more open and often do not require underplanting, recognising and applying the appropriate species for a site, and understanding why mudflats are not appropriate for afforestation attempts.

Published scientific research and best practice manuals appeared not to be produced in an appropriate form or accessed by these groups. Therefore, outside organisations wishing to help mangrove communities should focus not on one-off planting events, but work to build the capacity of the local village conservation groups and corresponding mangrove agency field office staff, and deliver appropriate training material in a suitable form (Sutherland et al., 2004). This would include illustrated rehabilitation best practices, short films using local languages and face-to-face teaching. This outreach work will require long-term interaction, rather than isolated training sessions, to identify misunderstandings or persistent knowledge gaps and act appropriately, as well as other issues that affect conservation behaviour. Field research and assessment of previous planting should be conducted with government officers and village conservation groups, as recommended by Cvitanovic et al. (2015). Training should encourage rehabilitation of degraded areas using methods

that encourage greater biodiversity to produce mangroves more resistant and resilient to the potentially detrimental effects of climate change (Lewis and Brown, 2014). Community-based action research of this nature might realign expectations of planting survivorship and lead to a virtuous cycle of implementation, analysis of results and improvements of silvicultural techniques and site choices.

CHAPTER 3. COMMUNITY MANGROVE MANAGEMENT: LAWS, RULES, CONTEXT & REALITIES

3.1 ABSTRACT

There is a potential conflict between conserving mangroves for the ecosystem benefits they provide, and allowing the harvesting of wood and timber for economic benefits and to assist village development. Mangroves might be protected by national laws but government agencies responsible for coastal resources such as mangroves or fisheries have limited budgets, limited staff and limited capacity to stop mangrove harvesting and inappropriate local management. Governments are increasingly decentralising resource management and encouraging local communities to look after them. Despite the challenges of a precise definition, community forest management (CFM) is an approach to integrate these disparate objectives. Potential advantages and difficulties of terrestrial community forest management have been described in various case studies, and the importance of local context in success. Researchers have also described and tried to identify certain institutional conditions necessary for successful CFM. CFM has however rarely been explored in the context of community mangrove management.

This study examined the effectiveness of rules in village mangrove management via 157 semi structured interviews, key-informant interviews and informal discussions with mangrove users and village leaders, in eight mangrove villages across Thailand and the Philippines.

Thailand has experimented with CFM but lacked an appropriate legal framework. The Philippines relied much more on national law. All villagers were aware of the mangrove rules and understood the need for them. Most people believed that the village rules or the law were followed by others. Rules were seen as appropriate for the threats to mangroves, particularly unsustainable harvesting, but villagers were concerned by a perceived lack of patrolling and rule enforcement. Previous examples of the application of sanctions, and good leadership, increased the credibility of the rules and potential punishments.

In relation to the necessary conditions described by terrestrial CFM researchers, while only a proportion of the community relied on the mangroves for their livelihood, village boundaries were well understood, even if mangrove zoning was less effective. Although land tenure remained an issue, the rights and obligations of the villagers in respect of CFM were clear, with few, simple rules being easiest to remember. Because these purposefully-sampled villages had reasonably intact mangroves, the direct benefits of cutting restrictions were not clearly identifiable. However as most

villagers did not earn their livelihoods primarily from mangrove wood extraction, but only harvested wood for household repairs, the corresponding costs of refraining from cutting were not significant. We suggest that good social capital and leadership in particular remains central to the effective development of CFM rules and credible sanctions. CFM does not absolve the state from the management of mangroves but changes its role to that of supporting, training and facilitating.

3.2 INTRODUCTION

Not only are mangroves a scientifically interesting coastal ecosystem but they also form a vital natural resource, particularly for the poorest members of a coastal village (Glaser and da Silva Oliveira, 2004; Kairo et al., 2001; Springate-Baginski and Than, 2011; Stevenson et al., 1999; Sunderlin et al., 2005). Healthy mangroves with appropriate hydrological connectivity provide villagers with a wide range of ecosystem goods and services (Appendix A, Moberg and Rönnbäck, 2003). The poorest tend to rely on their mangroves disproportionately more than the rest of society (Sunderlin et al., 2005) even though most mangrove community members often have several streams of income, fishing being the primary livelihood (Datta and Sarkar, 2012), supplemented by mangrove wood collection, crab harvesting and rubber tapping (López-Hoffman et al., 2006; Sunderlin et al., 2005; Walters et al., 2008; Zorini et al., 2004). As well as providing fish, crabs and shrimp, villagers can 'glean' within the mangroves for other marine creatures (Maliao and Polohan, 2008), providing food security for coastal folk too poor to own a fishing boat (Magalhães et al., 2007). Thus conserving and effectively managing a mangrove ecosystem directly helps the most vulnerable people within coastal communities.

By the same token, the resources within a mangrove offer local villagers the potential opportunity to gain significant benefits very rapidly from extraction of timber for sale, cutting of wood for charcoal, or clearing and converting mangrove areas to other land uses, at the expense of this public good and the benefits accrued by other villagers. Thus, there can be conflicting management objectives and preferences between resource conservation and community development (Berkes, 2004; Osbeck et al., 2010).

Most countries that have mangroves along their coasts have policies and laws that protect them. In a sub-set of these countries, although these policies provide titles for forests which might suggest that they are protected, such as 'Reserve Status' (Tanzania) or 'Reserved Forest' (Bangladesh, Myanmar), this does not always translate into actual enforcement of sanctions and protection in practice (Dahdouh-Guebas et al., 2000; Glaser and da Silva Oliveira, 2004; Iftekhar and Islam, 2004; Marschke and Nong, 2003; Nurse and Kabamba, 2000; Sudtongkong and Webb, 2008; Zorini et al., 2004). Government patrolling and enforcement of laws protecting mangroves and stopping deleterious activities within them is challenging because of the diffuse nature of the mangroves and the limited state resources available (Rotich et al., 2016). Therefore some form of management by the local community is a potential alternative approach to administering and protecting a village's mangrove forest and inhibiting unsustainable levels of mangrove exploitation.

3.2.1 Village Common-Resource Management Institutions

There has been a significant amount of academic study around property rights and management of natural resources that are under state, private or common ownership and the resulting institutional arrangements. A property right might be defined as the authority to carry out a specific action, or the right to a specific resource within a designated area (Agrawal and Ostrom, 1999; Slaev and Collier, 2018). Writers such as Slaev and Collier (2018) argued that the main types of property rights are private, common (i.e. collective or communal), state-owned / public, and open access (i.e. the absence of property rights). Hardin (1968) was particularly concerned about open-access resources (although he used the word 'commons') such as fisheries that were not protected by any property rights or customary norms, and would therefore be vulnerable to over-exploitation and severe degradation. Other writers contemporary to Hardin suggested that either private or state ownership were the only effective governance solutions. However, later scholars have recognised that there is a complex variety of additional property regimes and governance structures depending on different ecological conditions, types of natural resources, discount rates applied to natural resources, relevant institutions, socio-ecological circumstances, and that no one solution works in all circumstances (Cole and Ostrom, 2010; Ostrom, 2010, 1999). Most relevant to community-based management are rights concerning common-pool resources. These might be summarised, in the context of a forest, as the rights to enter, harvest (subtractable goods), manage (alter physically), exclude others (by rules or fencing) and alienation (sell or transfer these rights, Agrawal, 2001; Cole and Ostrom, 2010). Within common-pool governance, researchers have attempted to understand and identify arrangements that allow successful, sustainable management and equitable distribution of benefits from a natural resource over the long-term and the collective conditions necessary.

Understanding common-property management more fully has gained in importance as many governments have been working towards decentralising management control of natural resources, and forests in particular, away from the purview of central government to either local government or local community level (e.g. Cinner et al., 2012; Faure et al., 2019; Mulyana, 2017; National Legislative Assembly (Thailand), 1999; Roe et al., 2009), as a way of combatting deforestation, degradation and biodiversity reduction. While the term decentralisation is used here, it should be acknowledged that many other terms are used for this process, including delegation, denationalisation, deregulation, devolution among various terms, the specific meanings of which, in this context, are still debated (Agrawal and Ostrom, 1999). Part of the reason for the lack of clarity of terms relates to who (resource users or elements of the state) is making decisions about operational rules, user-group constitution rules, collective choices and who has responsibility for the resource (Agrawal and Ostrom, 1999).

While there are benefits to this transition of management, it is not without problems and challenges (Balooni and Inoue, 2007). To date it is arguable that while there have been many community-specific or small-scale comparative studies of the success or otherwise of institutions and rules of commons management, the effect of the context within which the communities exist, the influence of the specific features of the natural resource in question, and the general applicability of the conclusions from single-site studies are less well understood (Agrawal, 2001). The nature of the resource itself is an important factor that can make management easier or more difficult. For example, forests are stationary, unlike fisheries under artisanal fishing rights or migrating animals. In addition, the benefits they provide are reliable and predictable, unlike marine creatures affected, for example, by El Nino cycles (National Oceanic and Atmospheric Administration (NOAA), n.d.). Therefore, this makes terrestrial forests and mangroves easier to manage than migrating or ephemeral resources (Agrawal, 2001).

Community-based natural resource management (CBNRM) is one potential decentralised management approach. Within CBNRM much of the scientific and social research has focused specifically on community forest management in terrestrial situations and predominantly within Asian countries (Agrawal, 2001; Bowler et al., 2012). CBNRM enables local people to make decisions about their land and resources, and by transferring decision-making authority to communities, encourages greater local accountability, and management decisions that are more appropriate to local requirements (Roe et al., 2009). This process might involve co-management with the state, legal transfer of the resource and governance responsibility, protected area management, benefit sharing, outreach work and designation of rights and responsibilities. However there is great breadth within this definition and consequently variation as to what CBNRM means to different groups (Roe et al., 2009). Although the terminology used varies, including joint forest management, co-management, community-based forest management (in the Philippines, Faure et al., 2019), participatory forest management among other terms, here we will use the term community forest management (CFM) (Bowler et al., 2012). By CFM we include all forests of all types that at least in part are managed by local people, in a way that provides various social, economic, or ecological benefits to them, even if the state still retains ownership of the forest (Bowler et al., 2012; Rotich et al., 2016). We also acknowledge the potential confusion and inter-changeability between community forest management and community forestry management, where the latter might have a greater interest in wood production and harvesting (e.g. Springate-Baginski and Than, 2011), compared to the former (but see Faure et al., 2019).

3.2.2 The Potential Advantages of Community Forest Management

Whether or not there are national rules limiting or prohibiting the use of natural resources such as a community forests, there are often no effective enforcement mechanisms in place and limited infrastructure and resources to protect natural assets (Curran et al., 2004; Maliao and Polohan, 2008). Appropriate community management of forests can potentially avoid degradation or deforestation and conserve resources more effectively than open access or government ownership (Baland et al., 2010; Pokharel et al., 2007; Porter-Bolland et al., 2012) which in the case of mangroves has often resembled benign neglect (Aksornkoae, 2004). Natural resource conservation and management by exclusion of local people and prohibition of use or access rarely works and is often too costly to implement (Datta et al., 2012; Ostrom, 1999). Structured appropriately with integrated alternative livelihood activities providing economic benefits in return for conservation activities, CFM can not only conserve resources and preserve biodiversity but also contribute towards positive livelihood and income generating activities (Nilsson et al., 2016). It can also provide efficient and cheap forest administration with the possibility of delivering goods and services in a form that are most appropriate for people nearby.

If a community has a stake in their local mangrove forest, they have a greater incentive to manage it more sustainably and bring their local knowledge to bear, rather than view a forest as a government asset to be plundered (Datta et al., 2012). More specifically, allowing people to use and extract resources such as wood and timber, while also being responsible for its sustainable management, is potentially a more productive mangrove management approach than exclusion by government fiat (Glaser and da Silva Oliveira, 2004; Zorini et al., 2004). Proximity facilitates passive patrolling while passing through their mangroves on the way to a livelihood activity such as fishing (Sudtongkong and Webb, 2008). Village fishermen can ensure adherence to by-laws as well as monitor the changes from management activities more easily, effectively and frequently than more distant mangrove agency field office staff.

3.2.3 Establishing Enduring, Effective Community Forest Management is Challenging

Although CBNRM / CFM is instinctively appealing, it has proved difficult to make CFM projects sustainable and effective over the long-term (Pomeroy and Carlos, 1997; Sunderlin et al., 2005; Tole, 2010). The authors questioned whether CFM had become an act of faith, repeated without sufficient justification in the introductions of successful single-site case studies (e.g. Soontornwong, 2006) but with limited evidence to demonstrate that in general community management is better than management by the state (Bowler et al., 2012; Tole, 2010). If community management is the answer, Bowler et al. (2010) stressed the need for evidence-based confirmation and best practice

guidance, but from their study they reported only mixed results. Similarly, from a systematic review of 69 cases of CFM from around the world, 29 were estimated to be failures (Pagdee et al., 2006). These authors and others questioned how to judge success or failure of CFM, what factors contributed to it, and suggested that the results have been poorly analysed and reported (Bowler et al., 2012; Pagdee et al., 2006). Busch and Ferretti-Gallon (2017) found no consistent relationship between community forest management and either greater or lesser levels of deforestation. Roe et al. (2009) attributed the difficulties of getting African CBNRM projects to work well to several factors:

- a failure to produce clear project objectives, particularly when negotiating between conservation and development
- a failure to produce indicators of meaningful long-term outcomes, rather than just lists of activities
- a failure to develop and maintain the long-term capacity building of leaders and managers to facilitate the management of projects
- poorly managed stakeholder participation

Considering mangrove projects specifically, a review of community management projects in the Philippines suggested a low success rate (Pomeroy and Carlos, 1997). These authors attributed the failures in part to poor design and implementation of the community management process, which required thorough, careful planning and extensive social groundwork, including a clear understanding of the true needs of the communities. Furthermore programmes needed to ensure the long-term sustainability after the initial project funding stopped (Datta et al., 2012).

As Roe et al. (2009) mentioned in relation to African CBNRM projects, identifying the stakeholders that should be involved in implantation of mangrove CFM projects was challenging. Many government departments such as the departments of Forestry, Environment, Fisheries, the military, Coast Guard, Interior, Land, Local Authorities believe they have jurisdiction over mangrove zones (Broadhead et al., 2016; Rotich et al., 2016). For example, during a project in Para state, Brazil, seven government stakeholders and more than 30 other groups concerned with the marine environment were identified, all with their own agendas and specialisms (Glaser and da Silva Oliveira, 2004). Unfortunately, managing and running a big group of stakeholders is inherently less effective than a smaller group and it is less likely that appropriate decisions will be taken (Nurse and Kabamba, 2000), even though the various groups might bring additional skills and resources to the project (Ostrom, 1999). In addition there can be conflict between stakeholders for political or financial benefit, despite being equally involved, e.g. the elite of the stakeholders capturing most benefit (Roe et al., 2009). For example, natural resource extraction might enable landless poorer

local people to earn a livelihood, but they might not benefit from timber harvesting as these extraction rights are sometimes controlled, and the profits accrued, by local wealthy elites. Timber extraction requires skills, access and rights to the resources which local people might not have, therefore inhibiting the trickle-down of economic benefits to poorer community members (Sunderlin et al., 2005).

Finally, it should be noted that some of the most successful and high-profile, single-site CBNRM projects have benefited from what is arguably long-term, well-meaning and effective but unsustainable and unrepresentative levels of intensive and highly skilled input from NGOs and universities. Mangrove CFM examples include Pred Nai in Trat, Thailand (Senyk, 2005); NGO Yadfon's support of a community Palian, Thailand (described in the study comparing state management to village CFM, Sudtongkong and Webb, 2008); or in Gazi Bay, Kenya (e.g. Huxham et al., 2015). Walters (2004) acknowledged the unrepresentative nature of his two showcase Philippine mangrove communities as they had been visited frequently by interested parties, thereby being far from representative. Although valuable lessons about community management have been gained from these examples, their wider applicability is questionable.

3.2.4 Brief Summary of the Relevant Mangrove Laws in Thailand & the Philippines

According to Thailand's Forest Act (1941), mangrove belongs to the state unless an area had previously been bought by an individual. By law, cutting of mangrove is forbidden, particularly in Protected Areas or in land controlled by the Department of National Parks (DNP). More recently, according to the National Parks Act (1961), no one can own or utilise mangrove. Later, the Thai constitution of 2007 emphasized the right of local communities to participate in the management of natural resources, but the appropriate and much discussed community forest bill has never been ratified by government¹⁶. The Marine Protected Areas and Marine and Coastal Resources Management Act (2015) prioritises participatory approaches but also states that all mangrove is now 'mangrove conservation area' including that previously defined as 'Mangrove Reserve Forest' and 'Community Mangrove Forest', except mangrove controlled by the DNP which remains under their control. For more details on Thai forest law see Broadhead et al. (2016).

For a listing of the legislation concerning mangroves in the Philippines see Primavera et al. (2014).

On the Philippine island of Palawan where this research took place, all mangrove forests were

¹⁶ It should be noted that despite being drafted in 1992, the Royal Thai Government's 'Community Forestry Bill' has still not been ratified by parliament, even though the 'Marine Protected Areas and Marine and Coastal Resource Management' Act of 2015 (MCRM Act) states that participatory approaches to mangrove management should be encouraged.

declared wilderness areas and forest reserves¹⁷. This was followed by a ban on cutting mangroves in 1982¹⁸ and supported by a Republic Act in 1991¹⁹. In a similar manner to Thailand, until the 1980s and 1990s, mangroves in the Philippines were subject to corporate concessions for charcoal production and fuelwood for bakeries. As a result, the original forests have been cut-over and replanted with either *Rhizophora* sp. or occasionally *Bruguiera* sp. There has been a national ban on logging in natural mangrove forests since 2011²⁰. Similarly, state law mandated no cutting of mangrove wood, including cutting for sale or for making charcoal. Extraction of non-timber forest products (NTFPs) and *Nypa fruticans* leaves was permissible. For terrestrial forests 'community-based forest management' is a national policy²¹, but from the government side, unlike Thailand, there was no informal agreement that allowed limited, small-scale mangrove cutting for household use.

3.2.5 Tentative Steps Towards Community Management in Thailand

The large-scale charcoal concessions were terminated in Thailand by a cabinet resolution in 1996 and since then the government's attitude has started to move towards mangrove conservation. Individual villagers, deprived of their jobs felling mangroves for commercial charcoal producers, attempted to meet the continued demand with their own kilns which were hidden in the mangrove forests. In the late 1990s this resulted in significant and sometimes armed confrontation between villagers and (at the time) the Royal Forest Department. However, an evolving realisation by villagers of the benefits of intact healthy mangroves slowly changed attitudes and encouraged some residents to assist the government's rehabilitation efforts and conserve existing mangrove. At the same time, within the government and particularly the Department for Marine and Coastal Resources (DMCR) field office directors', attitudes and approaches evolved to encourage the establishment of village conservation groups and to support village attempts to manage their mangrove resources. Some DMCR field office directors explicitly stated that if villages co-operated with the DMCR, they should be able to benefit from their mangroves if they managed them appropriately, controlled cutting and helped with planting. To assist this process the government mangrove agency field offices were encouraging the more co-operative villages to develop their own community mangrove management rules. These CFM rules were not legally binding and did not include the transfer of property rights to villages, but once finalised, would be 'acknowledged' by the field office and / or the sub-district government administration office, and could be used by the

¹⁷ Presidential Proclamation 2151 and 2152 (1981)

¹⁸ Presidential Proclamation. 2146 (1982) – Ban on mangrove cutting throughout the Philippines

¹⁹ Republic. Act. 7161 (1991) – Internal Revenue Code: Prohibition on cutting all mangrove species

²⁰ Philippines Presidential Executive Order (2011) No. 23

²¹ Philippines Presidential Executive Order (1995) No. 263

village leadership to enforce sanctions within the village. It should be noted that levels of village cooperation with the DMCR varied greatly and many coastal villages in Thailand had not developed their own rules.

To enable the co-operative villages to benefit from their mangroves, from approximately 2012 onwards, some of the Thai villages had a verbal, informal agreement with their corresponding DMCR field office director that individual villagers could extract mangrove wood for household use only. The numbers of stems permitted within 'household use' was often described as material needed to repair an existing house only, not enough to produce a new house nor continuous extraction for fuelwood for cooking. The maximum allowed for household use was frequently 50 stems per year per household. The expectation was that the village and village leadership would monitor and ensure compliance with this agreement. Based around this stem quota, villages developed their own Community Forest Management (CFM) rules.

3.2.6 The Importance and Complexity of Village Context is often Under-Reported

In an effort to study the institutions that contribute towards successful community resource management, many researchers only partially acknowledge the impact of the context that villages exist within, and adequately report this detail. Contextual factors which are still subject to research and debate include (changing) access to local markets; local road building; technological change relating to harvesting or the resource itself; changes in local demographics, immigration and population pressure among many issues, (Agrawal, 2001) much of which has been discussed in the Introduction section.

Influences affecting benefit sharing, preferences, reciprocity, cohesion and social capital (Agrawal and Gibson, 1999), in turn might affect a community's ability to produce, agree and enforce rules and sanctions governing natural resources. Social capital might be defined as the elements of a community such as values, networks, trust, beliefs and cohesion which allow a community to function appropriately, although there is still disagreement about the definition, Bodin and Crona (2008). Communities are often heterogeneous, divided by (extended) family, caste, religion, income, gender, tribe, length of tenure, political connections and many other factors (Agrawal and Gibson, 1999). Within a legally defined village or community, a group of people living together cannot be assumed to operate well as a single group, e.g. be able to decide village rules agreeable to all or resolve disputes within the village (Waylen et al., 2013). How this community heterogeneity might affect collective action is complex and ill-defined (Agrawal, 2001). Community members might be (forced) immigrants from other parts of the country (Glaser and da Silva Oliveira, 2004; Tanzania's campaign of 'villagisation', Fisher et al., 2005), displaced by recent conflict (e.g.

Cambodia²² 1975-78, Marschke and Nong, 2003) or economic migrants. They might have little knowledge of the village's natural resources and how to manage them sustainably (Agrawal, 2001; Datta et al., 2012; Glaser and da Silva Oliveira, 2004; Islam and Wahab, 2005).

More specifically related to mangroves, socio-economic issues such as corrupted land tenure arrangements have caused many community-based mangrove projects to fail, due to conflict over illegally acquired land for aquaculture (Primavera, 2000). For example, local Thai officials are loath to deny potential shrimp farmers permission to encroach into mangroves, as selling land titles and licences has become extremely profitable (Johnson and Forsyth, 2002). Others have suggested that in Cambodia CFM has been blocked because it runs against the interests of powerful local people (Marschke and Nong, 2003). Land tenure issues (outside the scope of this thesis - for an extensive review see Rotich et al., 2016) and governance issues (section 3.2.1) including indigenous rights, customary usage and the transferability of rights, are extremely challenging, particularly in Thailand due to the seven levels of land ownership (Huitric et al., 2002). Furthermore, management around the transfer of tenure needs capacity building support to ensure new owners can make appropriate, well informed decisions, as tenure does not automatically lead to conservation (Roe et al., 2009).

Mangrove losses (Chapter 1) suggest that management of such a diffuse but valuable ecosystem is difficult and perhaps beyond the resources of many governments. A form of community forest management (CFM), itself difficult to define, might be an appropriate form of mangrove management as there are advantages but also many potential pitfalls to this approach. The output of terrestrial CFM research has produced some useful guidance but also highlights the importance of local context. Therefore, the general applicability of terrestrial CFM principles is uncertain.

Few reports about mangrove CFM have been published, particularly beyond single-site studies that have benefited from long-term facilitation and intensive inputs of expertise from outside organisations. Here we investigate a sample of villages that have some form of mangrove rules to explore what rules they developed, how they managed harvesting of wood from the mangroves, the sanctions employed and whether the rules and sanctions were credible. In addition, we compare these villages' rules and village context (Agrawal, 2001 and Appendix F) to a synthesis of general CFM principles from terrestrial forests, as described by several researchers (Agrawal, 2001; Crona, 2006a; Faure et al., 2019; Nurse and Kabamba, 2000; Ostrom, 1999; Pomeroy and Carlos, 1997;

²² <https://www.cia.gov/library/publications/the-world-factbook/geos/cb.html> Accessed 6.11.2018

Senyk, 2005; Soontornwong, 2006; Sudtongkong and Webb, 2008; Tole, 2010) to assess whether these principles remain relevant for community mangrove forest management.

3.3 METHODS

3.3.1 Location of study sites and village selection criteria

Although specific regional and local contexts are very important and highly variable, multiple villages within two countries were studied in an attempt to produce some general conclusions. Thailand and the Philippines share the same Indo-Malesia bio-geo-climatic zone within the Indo-West Pacific (Duke, 2006; Tomlinson, 2016) and have extensive mangrove areas, on which a substantial proportion of the coastal inhabitants depend for their livelihoods and food (Balmford et al., 2002). Since 1945, both countries have experienced significant mangrove conversion to aquaculture and degradation for charcoal and fuelwood production among other causes (Richards and Friess, 2016).

Table 8 lists the Thai and the Philippine villages studied in this large-scale investigation. Villages were purposefully chosen because they were located either within or near to an extensive riverine mangrove delta or had a significant area of mangrove nearby. In all cases mangroves were considered an important village resource and were used in some way by a substantial part of the village population for either their main or secondary livelihoods. Finally, village members had attempted to produce community mangrove management rules or had rules and laws already.

Table 8. Study villages' approximate location and details.

	Thailand						Philippines	
Village Number	1	2	3	4	5	6	7	8
Village Code	T1A	T1B	T2A	T2B	T3A	T3B	P1A	P1B
Approx. Lat Long	6.8°N 99.7°E	6.8°N 99.7°E	7.8°N, 99.1°E	7.8°N, 99.1°E	8.4°N, 99.9°E	8.4°N, 99.9°E	10.8°N, 119.5°E	10.8°N, 119.5°E
Province	Satun	Satun	Krabi	Krabi	Nakorn Sri Thammarat	Nakorn Sri Thammarat	Northern Palawan	Northern Palawan
Mangrove Rules	14	20	18	21	23	21	21	19
Semi-Structured Interviews								
Number of Rehabilitation Sites Assessed	13	11	9	6	5	3	10	8
Village Mangrove Area (Ha)	407	592	319	176	3,894	257	126	856
Approximate Village Population	660	800	700	1,030	680	2,200	3,000	2,600
Approximate Research Dates	Sept – Nov 2013	Dec 2013 – Feb 2014	Feb – May 2014	June – Aug 2014	Oct 2014 – Feb 2015	Feb – May 2015	Sept – Dec 2015	Jan – Apr 2016

3.3.2 Semi-Structured Questionnaire Interviews

3.3.2.1 Questionnaire Development

The semi-structured questionnaire (SSI, Appendix H1, H2) was developed by the researcher at Bangor University, based on the issues featured in the literature, while cognisant of the potential

problems described by Diefenbach (2009) and Kallio et al. (2016) (Chapter 2, section 2.3.3). After prolonged discussions with the first translator in each country, the questionnaire was translated, and subsequently verbally back-translated to the researcher. The Thai and Tagalog versions of the questionnaire were checked by local NGOs before being tested in the first villages in each country (T1A & P1A) and amends made.

Every effort was made to avoid leading questions and encourage respondents to answer truthfully, rather than elicit a socially desirable answer. For example, rather than asking if they had a positive view of the mangrove rules, interviewees were asked if they would prefer to have the simplicity of no rules so they could cut what they liked. And rather than asking if the respondent cut mangrove wood (illegally), interviewees were asked if others in their village cut mangrove. Abstract questions were avoided as often they proved unproductive. Some open-ended questions were asked in two stages, for a spontaneous response, followed later by a prompted response. For example, when exploring perceived threats to their mangroves the respondents were first asked for a spontaneous answer. Interviewees were then given a stack of cards with possible threats written on them such as 'encroachment', 'sea level rise' or 'over-harvesting / cutting' in the local language and asked to rank them in order of likelihood that they would occur (not severity) and then discuss any key issues around their choices, Fig 22.



Figure 22. A respondent discusses the threats listed on the cards in front of her before ranking them into order of highest to lowest likelihood that that threat might occur. (The bundles are cigarette papers made from dried *Nypa* palm leaves – a common livelihood in that region.)

3.3.2.2 Purposive Sampling Strategy

The sampling population was any adult villager from the study village who used the mangroves in some form. This included extracting wood for repairing a house or for cooking. This also included village artisanal fishermen who fished within the mangroves and nearshore (as they often cut mangroves to use as fish aggregating devices) as they also had a direct stake in the health of their mangroves. These selection criteria were confirmed in an informal discussion before an interview.

Village leaders had lists of all households registered in their village that could have formed a potential sampling frame. However, choosing random people / households from this list was deemed unworkable due to its inaccuracy as not all households were registered²³, particularly houses of children who had built new dwellings next to their parents' house, which were not necessarily registered. Furthermore, only a portion of the village used the mangrove or fished within or near it. Some households were absent from the village for long periods. Others worked irregular work hours, particularly rubber tappers, and few were used to keeping appointments. There were lists of people who had attended various CFM rules development meetings, but these

²³ In Thailand, if a new family wanted to build a new house and have it registered, they had to have the initial documentation signed by the village leader. This document would then be taken to the District Office to start the process. Not all villagers were on positive terms with their village leaders, therefore not all households were registered.

were inconsistent and incomplete. Therefore, purposive sampling was used to contact residents in their homes from all parts of each village, particularly the village edges, the less well-off and minority groups, to attain as representative sample of villagers as possible. Most respondents were from the general populace. We ensured that we interviewed at least three or four conservation group (CG) members per village as they were more likely to have taken part in the rules development process, and others the CG recommend. We also interviewed every village leader and conservation group leader. (In the Philippines villages formed mangrove planting 'co-operatives' rather than conservation groups but performed similar roles. For ease of reading, both groups will be referred to as conservation groups.) Initial conversations with potential interviewees were used to check that they lived in the village.

3.3.2.3 Ethics, Data Collection and Storage Protocol

During initial visits, a courtesy meeting with each village head was arranged to explain the purpose of the research, the activities, and to gain consent. Subsequently, during an initial contact with a potential respondent, they were asked if they were a resident of the village and whether they used or fished in or around the mangroves. If they confirmed both questions and were free to talk, an ethics statement was read to them, with any unfamiliar terminology explained, and a copy provided in the local language (Appendix C). Great care was taken to ensure full comprehension of the ethics statement and gain informed consent, occasionally resulting in a return at a later date to complete the interview, due to the length of time this process took. After oral consent was received, all interviews were carried out either in Thai or Tagalog and translated immediately into English via a translator. This method allowed for additional questions for clarification and immediate resolution of inconsistencies. If other people joined the interview, they too were given a written ethics statement. If the conversation was of a controversial nature the interview was stopped to explain the ethics statement to the newcomer(s). An ethics checklist, as required by Bangor University, was completed prior to the field work and indicated that the research did not require further review.

In general, interviews lasted no more than an hour. Written notes were taken rather than recordings, together with photographs when permitted. Data was collected anonymously. Additional notes were transcribed, and together with the photographs, were stored on an encrypted external hard-drive. Some interview details were discussed later that day to ensure full understanding. Written notes were kept either with the researcher or locked in a secure case, at all times. No payment was provided to respondents. Instead the researcher made a donation to the village mosque or school, and with the translator, gave a morning's mangrove ecology lesson in the local school. Three villages were Muslim, and as the researcher was a European male, interviews normally were conducted outside participants' residences, in view of the neighbouring villagers, to avoid any

possible perceived impropriety. All interviews were administered by the author, assisted by a translator and conducted in the local language.

3.3.3 Villager Interviews Supplemented by Key Informant Interviews

During scoping discussions and interviews with villagers, residents were asked to identify government officers, outside groups or individuals who had some involvement in the origination or running of the mangrove management rules, or other elements of village life that might impact on CFM. This 'snowballing' technique was used to find key informant interviewees who were not obvious targets. These key informant interviews supplemented and cross-checked the data provided by individual SSIs. Beyond the government mangrove agency field officers, this included district or sub-district²⁴ staff, environment officers, local school directors, activity group leaders within the villages and local NGOs. Mangrove agency staff were interviewed several times during the research period in each village, providing village mangrove boundary maps, explaining mangrove features and history, and providing triangulation of information from village sources. Key informant interviews were useful in explaining the context of the rules development process.

Semi-structured and key informant interviews were supplemented by ongoing informal discussions during village homestays, immersion within village life over a period of three-four months per village, and by joining village events as they occurred during the research, as per (Le Fur et al., 2011).

3.3.4 Research Method Limitations

Appropriate translator choice was very important, as Le Fur et al. (2011) observed. Although great care was taken over the choice of translator and subsequent training, it was not possible to engage the same assistant for all villages in either country due to logistical constraints and the length of time of the fieldwork. Issues concerning the influence of translators and the affect the researcher might have had on the research process are discussed in a Reflexivity Statement (Appendix I).

Value statement interpretation was sometimes challenging (Zorini et al., 2004) as the translators were not from the communities studied and these statements were therefore discussed in detail after interviews. Furthermore, some terminology was difficult to translate. Although there are direct translations for English words like 'sustainable' and 'objectives', the local equivalent often meant little to interviewees. Therefore some questions had to be built up over several sentences to ensure full understanding of the questions. Questioning that required abstract or creative thought

²⁴ In Thailand, District offices dealt with people, schools and development, whereas the Sub-District offices looked after infrastructure, solid waste management and pollution control.

from villagers, such as asking villagers to suggest new or better mangrove rules, proved challenging and were generally avoided.

Most of the interviews were conducted on a veranda in front of a respondent's house, in public view while the respondents were carrying out a livelihood activity. As found by Dahdouh-Guebas et al. (2000) when conducting interviews, curious neighbours, family members and passers-by would join the meeting and leave as they wished. Asking these people not to join an interview was deemed inappropriate and was not attempted. This reduced the ability to target a specific age range, gender, perceived wealth group or occupation group. Very occasionally, people joining an interview hindered free-flowing conversation but much more frequently the presence of additional respondents led to a more productive discussion where local people would challenge each other, contrary to Sudtongkong and Webb's (2008) experience. For example, on more than one occasion, when discussing cutting of mangrove timber, which was illegal, members of a group would tease one of their own for cutting - information which might not have been forthcoming in a one-to-one interview. Furthermore, it appeared that the interjection of potentially controversial issues or questions by the researcher would 'permit' the local people to discuss topics they would otherwise not raise. Where at all possible, the main respondent was asked to summarise a group discussion and form a consensus with which they agreed.

Despite frequent village meetings in most communities and much informal conversation, knowledge of events within a village was highly variable. For example, in village T3A, a former village leader was jailed for two years for cutting mangrove wood for sale. However, the villagers' familiarity with this application of the law by the government mangrove agency local field office and the courts was inconsistent. In addition some of the answers about the forest management rules were affected by the stage at which a respondent joined the rules development process, and how many meetings they had attended. This slightly affected their understanding of the process and their perception of it.

3.4 ANALYSIS

Answers to the semi-structured interviews and any additional information were written on pre-printed sheets (Appendix H). Answers were coded, clustered *post hoc* and analysed on SPSS v.25 (IBM). Differences between countries, villages or leaders / general village populace were tested for statistical significance and highlighted where appropriate. Additional information not directly captured within a SPSS variable was transcribed and aggregated on nVivo v.11 (QSR).

3.4.1 Statistical Tests

The difference between respondents describing other villagers following the mangrove rules in Thailand as opposed to the Philippines was tested with a Fisher's Exact Chi Square test. The null hypothesis was that there was no statistical difference between the countries.

Establishing whether village leaders were significantly more aware of their village's (internal) mangrove zones than the general village populace was assessed by a Fisher's Exact Chi Squared test. The null hypothesis was that leaders were no more aware of the mangrove zones than the general populace within their village.

Whether the leaders gave significantly different suggestions for how their rules might be changed, compared to the general village populace, was assessed using a Fisher's Exact Chi Squared test. The null hypothesis was that responses from the village general populace were not statistically different to the leaders' responses.

To test if leaders were more likely to believe that they would be punished if caught cutting illegally compared to the general village populace, a Fisher's Exact Chi Squared test was used. The null hypothesis was that there was no significant difference between the two groups.

3.5 RESULTS

3.5.1 Respondent Profiles

The study of community mangrove rules included semi-structured interviews with 157 people between the ages of 21 – 81. The interviewees were 21% female and 79% male but these interviews sometimes expanded into group discussions (section 3.3.4). Fourteen to 23 interviews were conducted per village, averaging approximately 20 per village. Meaningful differences between either village, country or leader / general village populace are highlighted when they occur. Fig 23 describes the frequency of main occupations, which varied by village.

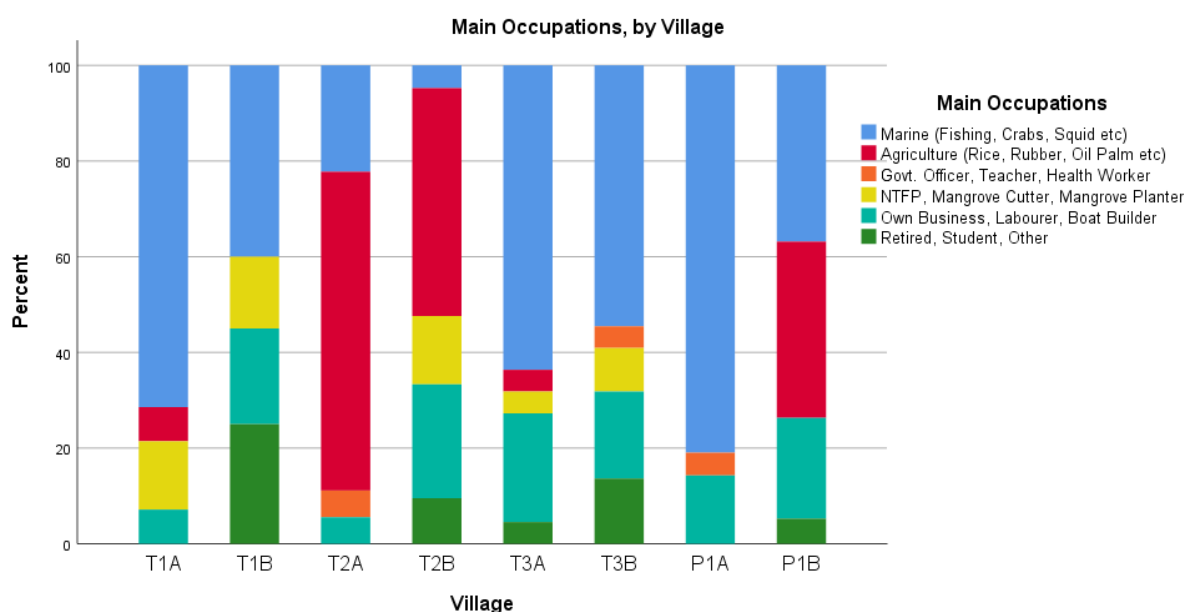


Figure 23. Main occupations by village. Most respondents had more than one job, depending on season or opportunity. Collection of crabs and clams was a popular second or third occupation because the timing was more flexible than labouring. Rubber tapping was impossible during the rainy season as the latex collection cups filled with rain water, diluting the latex.

Seventy-four percent of responders had more than one occupation or income stream. Interviewees' secondary occupations included crab and clam collection, fishing, working as a labourer, running their own small business or farming, which again varied by village. Religion tended to divide by village (Appendix F). In total, 36% were Muslim, 38% Buddhist and 25% Christian. The general populace made up 75% of respondents, 12% were conservation group leaders and village heads, and the remainder were conservation group members and other leaders.

3.5.2 Summary of the Mangrove Management Rules by Village

Table 9. Summary of the village mangrove management rules as understood by the villagers, either from the community rules or national law

	Thai Villages						Philippine Villages	
	T1A	T1B	T2A	T2B	T3A	T3B	P1A	P1B
Villagers believed cutting for HH use informally permitted by village leader? †	Y	Y	<50pa	10-50 pa	<20-50 pa	Y	Mixed	Y
Need verbal explicit permission to cut from village leadership?	Y	Mixed	Y	Y	N	N	N	N
Need permission from 'social' (i.e. nearby) perceived owner?	N	N	N	N	N	N	Y	Y
Cutting for sale allowed?	N	N	N	N	N	N	N	N
Cutting for charcoal allowed?	N	N	N	N	N	N	N	N
Told where in the village mangrove to cut for HH cutting?	N	N	Mixed	N	N	N	NA	N
Allowed to cut outside village boundary?	N	N	N	N	N	Mixed	N	N
Have to spread cutting?	N	N	N	N	Y	Y	N	N
Diameter restriction?	N	N	N	<8-10cm	N	N	N	N
Cutting in new plantation allowed?	N	N	N	N	N	N	N	N
Village has rules to preserve mangrove edges	N	Y	Y	N	N	N	N	N
Village has mangrove zoning (with different rules)?	Y	Mixed	Y	N	N	N	N	N
Rules to plant while cutting? E.g. cut 1, plant 5?	Y	Y	N	Mixed	Y	Y	N	N
Expected to join next planting session if cutting for HH use?	Mixed	Y	Y	Y	N	N	N	N
Village inside a National Park / Protected Area?	N	N	N	N	Y	Part	Y	Y
Rules acknowledged by govt.?	Y	N	Y	N	N	N	Y	N

Y Yes. N No. DK Did not Know. HH household. PA Per Annum

† There was tremendous confusion about whether household cutting was permitted, within all groups. Village leaders knew they did not have the right to give permission. The government agencies and leaders knew villagers would cut, at least for household repairs, regardless of the rules.

To provide an example of a specific set of village rules, beyond the summary in Table 9, village T2A's mangrove rules as have translated and summarised in Appendix J.

3.5.3 Awareness of Mangrove Rules Was High and Attitudes Positive Despite Restricting Cutting

Awareness of the existence of mangrove management rules (i.e. restrictions on cutting and extraction) was near universal. Only two respondents were not able to mention at least one or two village rules (e.g. no cutting) but only half were able to recall more than two or three basic rules, Fig 24.

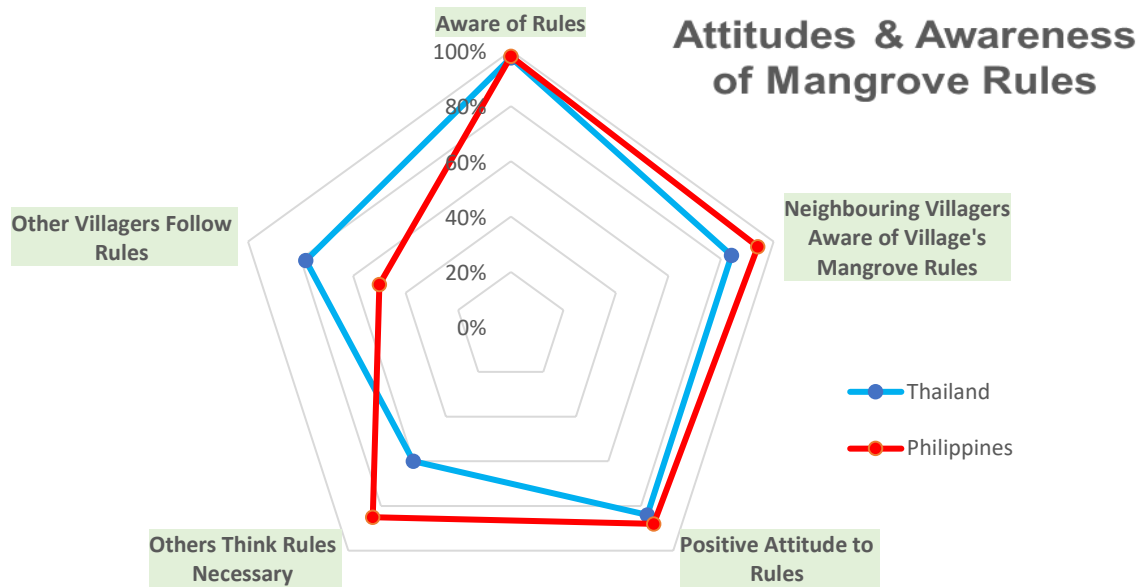


Figure 24. Awareness of mangrove rules was near universal, inside and outside their village. Attitudes towards the rules were also positive as whether they cared about the mangroves or not, villagers appreciated that they were necessary and in general most Thais followed them (Philippines less so).

The majority of respondents (85%) were positively disposed to having rules to manage their mangroves. The greater proportion of negative attitude holders were found in Thailand (15% of Thai respondents), and those with a neutral attitude tended to be in the Philippines (10% of Philippine respondents). The most commonly cited reason for a positive attitude towards the rules was the avoidance of severe degradation by open access cutting (42%), often spontaneously mentioned, followed by the need to protect the mangroves because of the perceived link between the presence of mangroves and marine creature productivity (18%). In contrast, a small group were of the opinion that either the rules were unnecessary (5%) or that livelihoods should be prioritised over mangrove conservation (i.e. livelihoods focused on mangrove wood extraction for charcoal making, 4%). Of the respondents holding a negative attitude towards the rules (n=19), 74% lived in two villages (T3A, T3B) which either had, or had access to, a vast area of mangroves.

In addition to feeling positive about their mangrove rules, two-thirds of interviewees believed that other villagers thought the rules were necessary (15% mixed opinions, 13% stating that other villagers believed the rules to be unnecessary), Fig 25.

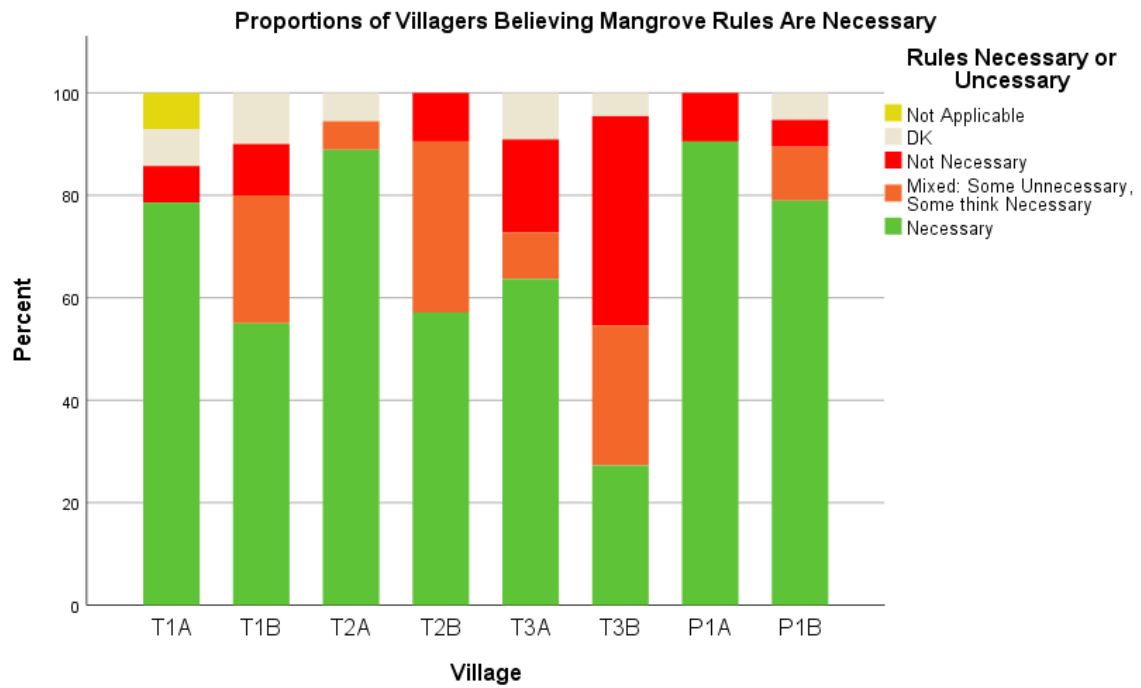


Figure 25. The majority of villagers believed that the rules were necessary. Villagers from T3A and T3B were less enthused by having rules and cutting restrictions because of the huge area of mangrove near them – a seemingly endless resource. T3B was an outlier because it had a huge area of mangrove nearby that belonged to another village, therefore extracting from this extensive forest did not diminish their own resources.

Furthermore, 71% of all respondents claimed that overall, other villagers followed the village mangrove rules (78% in Thailand but only 50% in the Philippines, a significant difference, $X^2=16.23$, $p=0.001$). The village leaders replied in a similar fashion to the general village populace to all these questions, Fig.26.

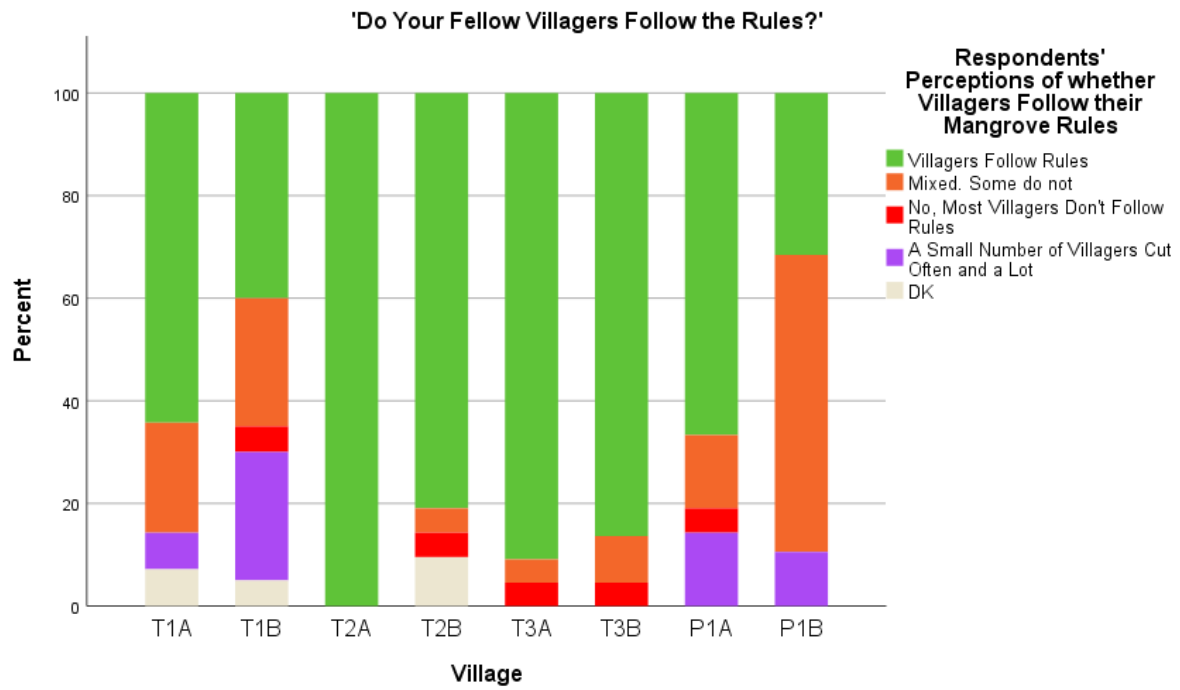


Figure 26. Generally, others were believed to follow the mangrove rules. Village T2A had a particularly fearsome conservation group leader and good village leadership in general. In village T1B villagers were aware that some were cutting for sale, including conservation group members, and that the leader never punished illegal cutting. Villagers in P1B were aware that a few members were making charcoal in the mangrove.

If respondents wanted to check their mangrove rules, government mangrove agency field office staff (33%), their village leader (31%) or conservation group committee (19%) were the key sources of information, although many mentioned that *no cutting* was something they had heard since childhood. Leaders were more inclined to seek advice from the conservation group than villagers. Villagers were also confident that their rules and cutting restrictions were known by residents of neighbouring villages (86%, Fig 24).

Village rules varied if the community had zoned their mangroves, which three had done (all in Thailand). As mangrove zonation was normally designed by the village conservation group, the village leaders were significantly more aware of the zones than the general populace if their village had them ($X^2=18.32$, $p<0.001$). However, all three zonation arrangements were characterised by misunderstanding about their nature and location. A quarter of respondents within these three villages ($n=53$) were not aware of the mangrove zoning at all and another 34% had only a partial

understanding of the zoning. Only the remaining 41% could give a reasonable description of the zone types and locations.

3.5.4 The Main Threat to Mangroves was Unsustainable Harvesting

Although many felt there was no threat to their mangroves (45%), spontaneously mentioned concerns were dominated by unsustainable harvesting of mangrove wood (32%), particularly in the Philippines. Unsustainable harvesting was seen as a bigger issue in the Philippines (n=24) than in Thailand, Fig 27. Otherwise the issues varied by village. For example, in villages T3A and T3B local changes in hydrology due to a water barrier damming the estuary were understood to be adversely affecting the mangroves.

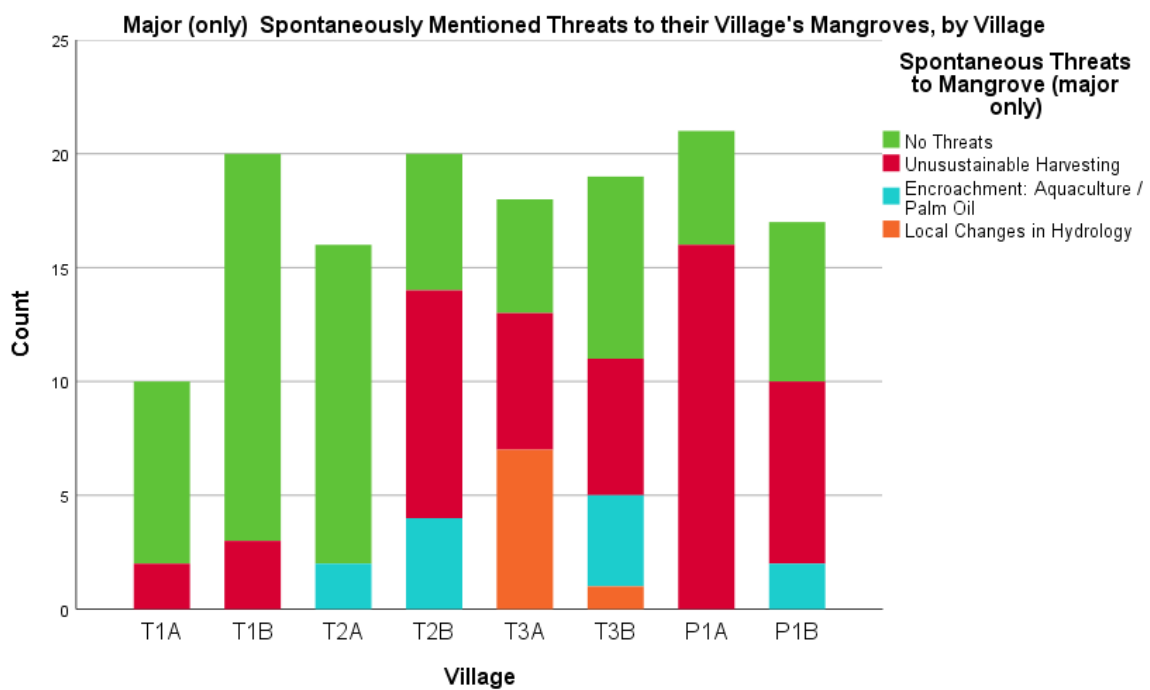


Figure 27. Perceived threats to mangroves (spontaneously mentioned). Almost half felt there were no significant threats. Unsustainable cutting concerned 32%, particularly in the Philippines, which did not have large areas of mangrove relative to the size of village, and T2B where a small number of professional cutters were using chainsaws (rare in Thailand) in their mangrove and neighbouring villages' mangrove, and selling the wood (Appendix F for more detail). Minor threats have been omitted for clarity.

Respondents were then prompted by several hypothetical threats written on cards (Fig. 22) that might affect their mangroves, such as over-harvesting, pollution, encroachment and so on.

Ranking these threats by likelihood, unsustainable harvesting of mangroves was confirmed as the primary concern (44% of all respondents and particularly in the Philippines), 29% stating there was still no threat, Fig 28. In addition, 13% of villagers were concerned about changes in local hydrology negatively affecting their mangroves (all from villages T3A and T3B) and 7% feared encroachment into their mangrove for oil palm or aquaculture. Village leaders of all types had similar concerns to the general populace. Again perceived threats varied by village and situation.

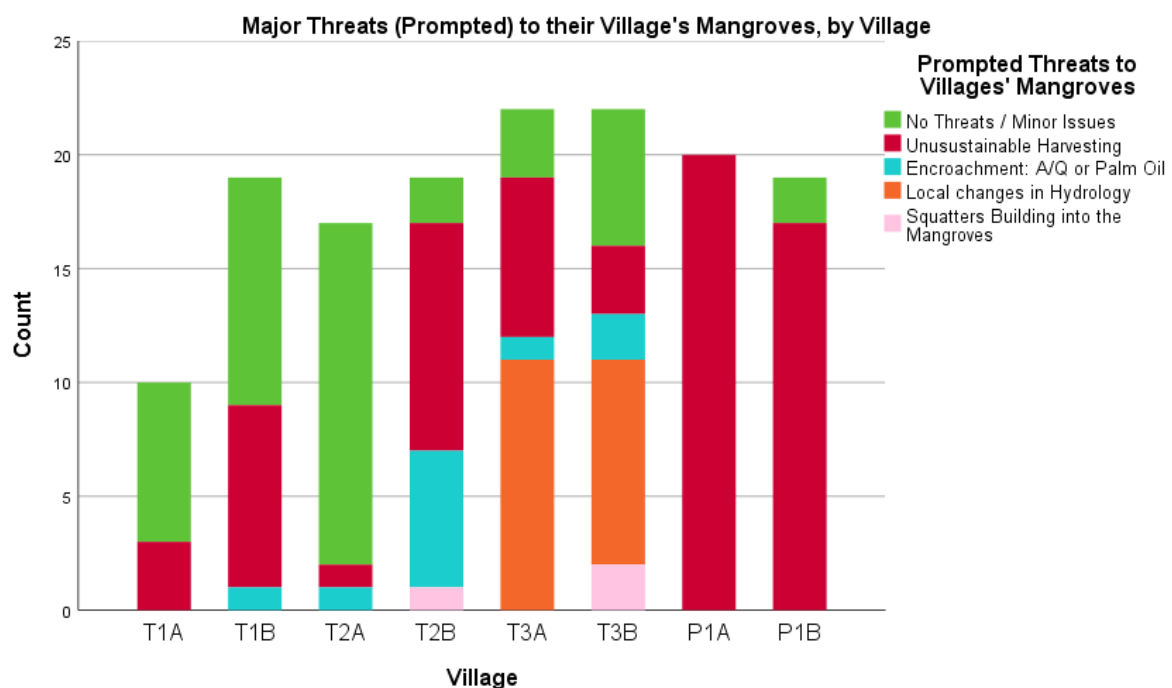


Figure 28. Threats to their mangroves after prompting with suggestion cards (minor threats have been omitted for clarity). Unsustainable harvesting was still the key threat. The mangroves around villages T3A and T3B were suffering from changes in hydrology due to a dam across the river that fed into this river delta, installed to protect upstream agricultural lands. At certain times of year the dam was closed, greatly reducing the flow of water. This was causing siltation within the mangrove channels and these areas were dying off. Village T2B suffered from encroachment by local officials (Appendix F for details).

In light of the threats mentioned, the rules were still perceived as appropriate, (59%: no addition or amendments necessary). In addition, others stated that because there was no or limited threat to their mangroves, whether the rules were appropriate or not was not applicable or relevant to them (34%). Of the respondents who (prompted, n=69) were concerned specifically about over-harvesting, 80% stated the rules were appropriate for this threat. Only a minority of respondents (8%) felt the rules themselves needed to be improved. This group contained significantly more of the leaders (18%, n=39) than from the general populace (4%, n=118). Spontaneous recognition of a

threat to their mangroves did not alter their positive attitude to the rules. For example, when prompted, those concerned about the threat of over-harvesting (n=51), changes in hydrology (n=8) or encroachment (n=12), were as positive about the rules as those who felt there were no threats to their mangroves (n=71).

To examine in more detail whether their mangrove management rules needed to be improved, interviewees were asked how they might amend them. More than half of all respondents (54%) could not make additional suggestions or felt the rules needed no change. Respondents who were able to suggest rule changes said that the informally permitted limited cutting for household use only should be legalised for their own protection (15%), and a similar number were happy with the rules but wanted a stricter application of the village sanctions (15%). Counter-intuitively, responses from leaders were not statistically different from the general village populace ($X^2=16.28$, $p=0.152$).

3.5.5 An Effective Application of the Sanctions in a Village Bolstered Rules Credibility

Most villagers were aware that there were various forms of punishment for illegal cutting of mangrove - 51% were able to summarise these sanctions fully, another 42% of respondents were partially aware of the punishments, Fig. 29. Only about half of interviewees knew these sanctions were graduated (52%, while 39% were not aware).

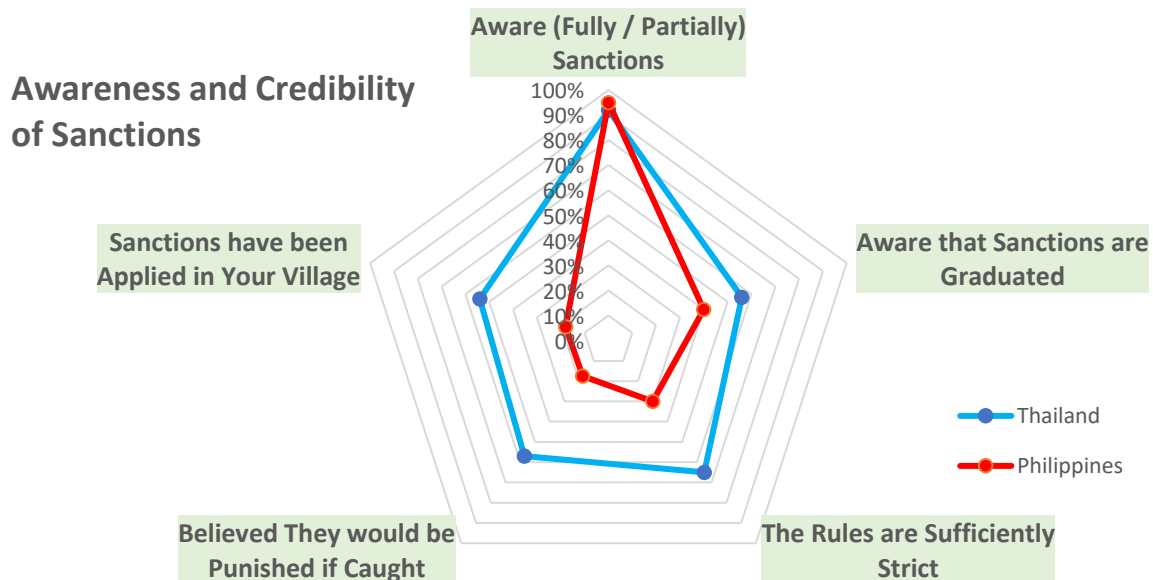


Figure 29. Sanctions - credibility and awareness. Villagers were fully aware that there were punishments for breaking the mangrove rules, but were less sure of the details, their graduated nature or previous application. Belief in being punished seemed to reflect if the village had witnessed other miscreants being punished beforehand.

These sanctions had limited credibility as less than half of all respondents (46%) stated that if they themselves were caught cutting mangroves illegally they would be punished. Others believed they would not be punished (35%) or that it would depend on the situation (15%). This result is broken down by village in Fig. 30. Whether the interviewee was in a leadership role or not within their community made no statistical difference to this overall opinion ($X^2=1.89$, $p=0.79$). Similarly, those with a better understanding of the rules and sanctions were no more likely to believe they would be punished than villagers with only a partial grasp of the rules.

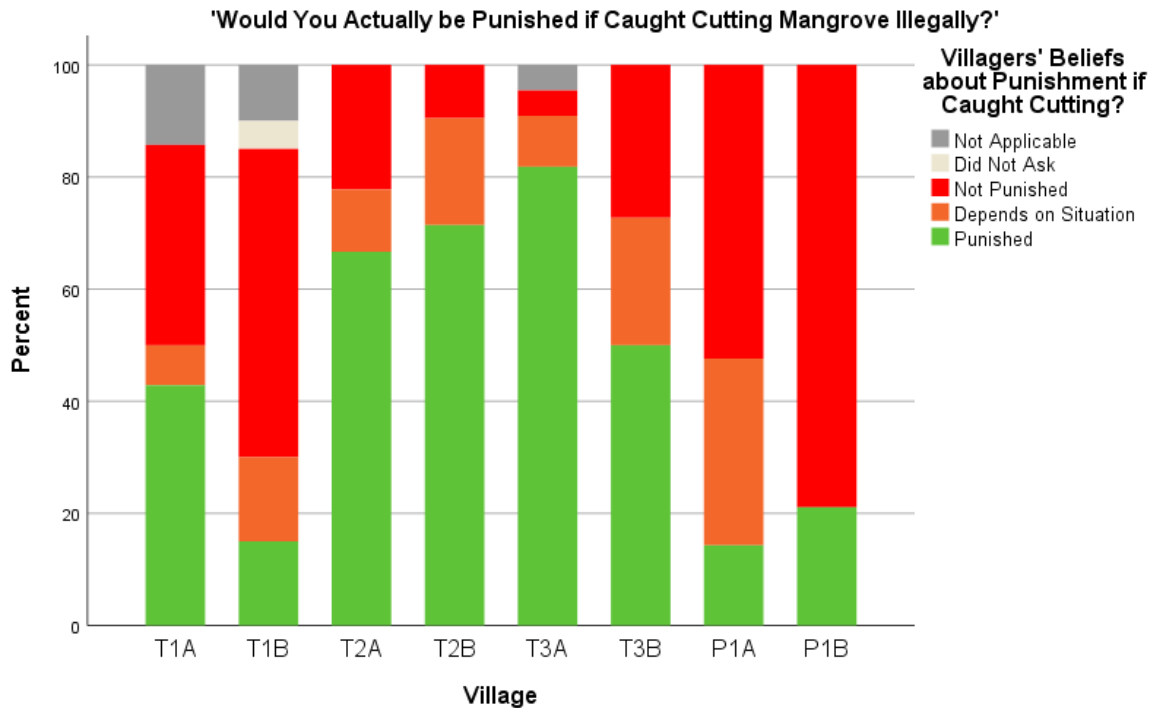


Figure 30. Believing they would be punished varied by village and was greatly affected by the level of (correct) awareness of a previous punishment in their village. Villagers in T1B were sure that they would not be punished as most were aware that a professional cutter was living in the centre of the village, who stored cut stems in sight of the road in front of his house and because he was related to the leader, was never punished. In the Philippines, in addition to no previous punishment examples in either village, the government mangrove agency CENRO field offices were also responsible for terrestrial forest and as such were overstretched.

Whether sanctions had ever been applied in the villager's own community was difficult to interpret, as results appeared to be more a question of awareness of a perpetrator's punishment rather than whether sanctions had actually been applied. For example, in village T3A, 87% (n=23) of respondents were aware (correctly) that one of their own had been jailed for cutting mangrove. But in T2A (n=18), by two to one, villagers believed no one had been punished despite a previously apprehended cutter having to do a week's community service in the village, refurbishing the village mosque. Awareness was important because those villagers who were aware that sanctions had been applied in the past (n=70) were three times more likely to believe that the sanctions were effective. Villagers who were unaware of the application sanctions (n=79) had a limited belief in their effectiveness.

3.5.6 The Issue was Enforcement and a Lack of Patrolling, not the Rules

The second core component of sanctions was the question of patrolling and enforcement. The results varied by village, suggesting that the issues were village and government agency-specific in nature. Most villagers (80%) believed that the government patrolled their mangroves but only a

quarter thought that villagers actively patrolled. As interviewees were aware that government patrols were very infrequent, their value was tempered, and this lack of patrolling was the key issue for 21% of respondents. Others stated that the biggest problem was limited enforcement of mangroves rules (30% of respondents), and appropriate sanctions if either a miscreant was caught cutting illegally or if the village leadership and mangrove agency received a report about illegal cutting. An additional 12% believed that both the lack of patrolling and the lack of application of the sanctions were the problem. This was particularly keenly felt if the mangrove cutters were connected to the village leadership. Leaders were slightly more confident that patrolling was taking place but were also more aware of the lack of enforcement, relative to villagers from the general populace. Villagers' perceptions of these failures to apply the rules and sanctions were not related to whether the rules should be stricter and harsher.

3.5.7 Reporting Mangrove Cutters

Just over half of all respondents claimed that they would report people from outside the village if they found them cutting in their village’s mangrove, 29% would not report them and a further 12% would talk with them directly to try to encourage them not to cut, Fig. 31.

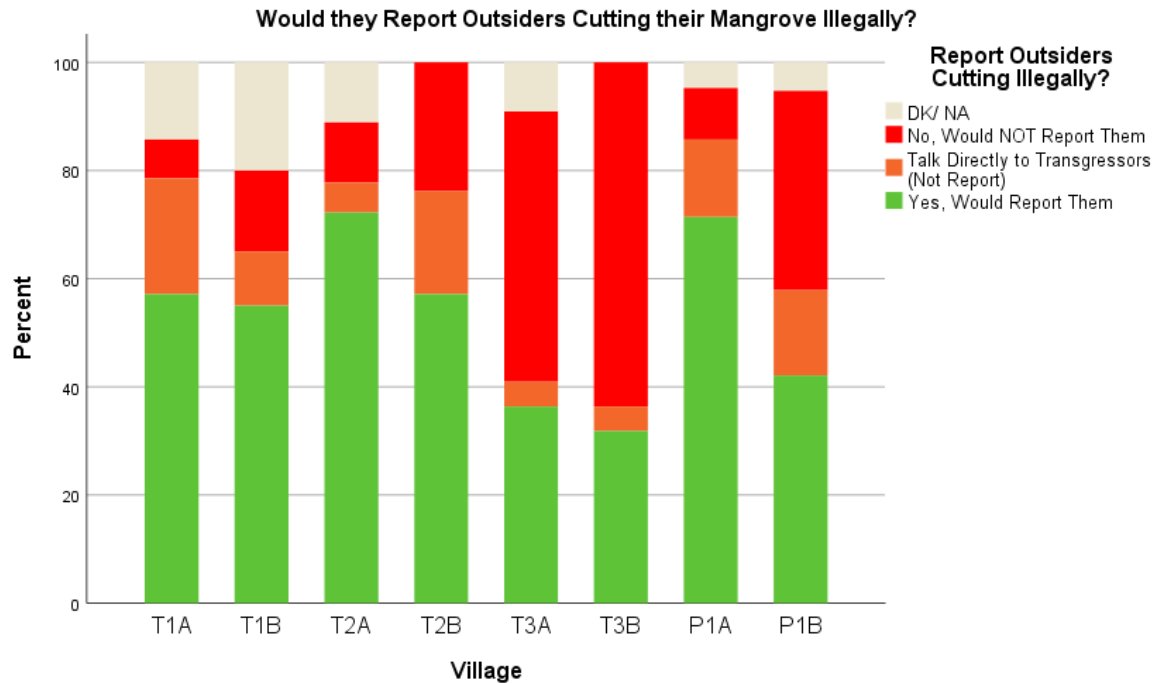


Figure 31. ‘Would you report someone not from your village, cutting your village mangroves?’ T3A and T3B were low partly because they had such a large area of mangrove that it was believed to be an almost limitless resource.

If the illegal cutters came from their own village, only 20% were prepared to report them, with another 18% claiming that they would talk with them directly. The majority (54%) would let them cut, Fig. 32.



Figure 32. 'Would you report someone cutting mangrove illegally from your own village?' Again, T3A and T3B would let people cut due to size of the available resource. Villager hesitance about reporting is partly related to the fact that the interviewee might be related to the cutter. It is impressive that so many people would be prepared to go and talk with miscreants as the people encountered might be unknown, violent, armed, well connected to powerful people or affected by drugs.

The claimed willingness to talk with or report fellow villagers was answered differently by village leaders compared to villagers from the general populace. Reflecting the difficulty of restraining and punishing illegal cutting of mangrove by people in the same village and therefore possibly the same family, it was noteworthy that leaders (n=39) were more willing to report them (36%) and less likely to let them cut (26%) than the general populace, or at least talk with cutters (23%) Fig. 33.

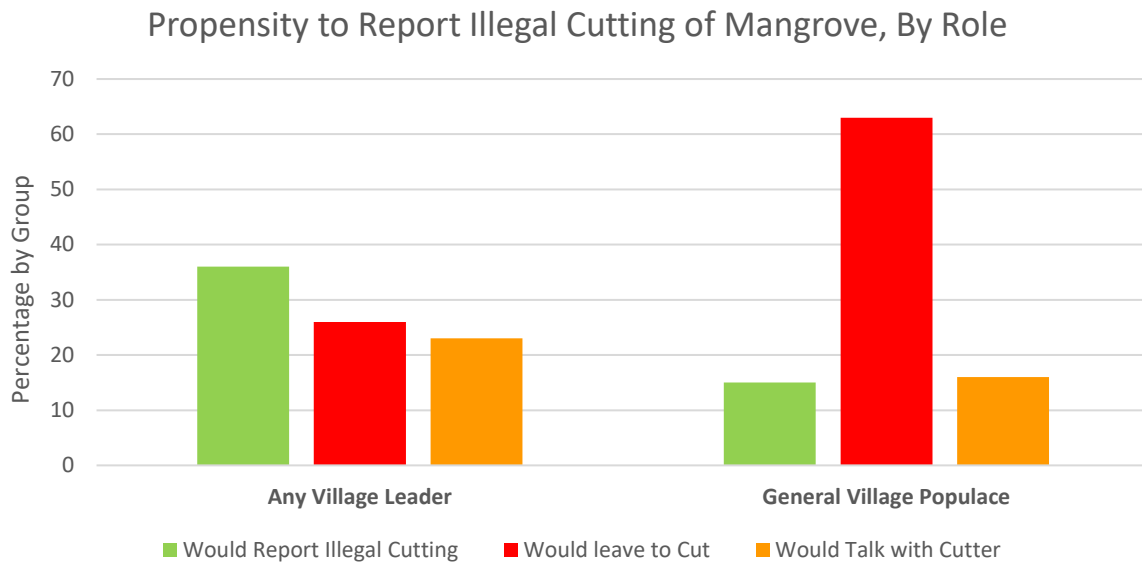


Figure 33. Reporting illegal cutting within own village, by role. The general populace was much more likely than not to let people from their own village cut without reporting them or talking with them.

This partial propensity for reporting cutters was possibly an overstatement as only a few villagers from the general populace (10%) claimed that they had actually reported a fellow villager, and even fewer had reported an outsider (6%). Furthermore, when questioned about the numbers of people reported to them, village heads claimed to have received very few direct reports of cutting or illegal activity.

Cutting mangroves was a risky pastime. For example, a convicted cutter from village T3A spent two years in jail, received a significant fine and had a boat and equipment confiscated. The perceived motivation for taking these risks included the fact that selling the mangrove wood earned very good money relative to other livelihoods (40%). Others believed that the cutters were poor (32%), or that cutting occurred because their village was remote with few alternative earning opportunities (14%). Villagers were certain that all illegal mangrove cutters knew that their activity was illegal and were aware of the basics of the village mangrove management rules. Despite this cutting, a majority believed that in 10 years time there would be more trees (58%), a quarter thought there would be fewer trees (24%) and 18% thought there would be about the same number, with villagers and leaders answering in a similar manner.

3.6 DISCUSSION

3.6.1 Interpreting the Semi-Structured Interview Results

3.6.1.1 *Awareness and Attitudes*

Many in the Philippines claimed to know cutting was banned even from their youth. In both countries villagers were keenly aware of the problems caused by the charcoal concessions that ran up to the 1990s. In addition, some described the abuse of the mangrove concession regulations, where even though concession areas for felling were mapped and defined, mangroves were cut wherever it was easy to handle the trees, particularly near channels. Concession contracts mandated replanting regimes, but this was described by the Thai DMCR as haphazard at best. The charcoal concessions demonstrated to villagers that even large areas (i.e. square kilometres) of mangrove such as those found near T3A and T3B could be converted or lost over just a few years, with the resulting significant reduction of marine productivity, as well as erosion of soils, hotter and drier weather and the lack of resources for house building and cooking.

After the concessions, the *de facto* open access nature of the mangroves meant that even if the indigenous peoples within the villages in the Philippines had an effective form of traditional resource management, similar to that described by Nurse and Kabamba (2000), without rules or laws to prohibit cutting, their mangroves would be vulnerable to ‘outside businessmen²⁵’ paying for wood harvesting, or encroachment for aquaculture and oil palm.

More recently, villagers in Thailand understood that cutting too much for claimed household use (i.e. >100 stems, although the assumed figure varied from 30-200, Table 9), cutting mangrove wood for sale, for charcoal production, fuelwood or cutting within a (recent) DMCR plantation remained illegal and in theory was punishable. In addition, most villagers understood that they could only cut within their village’s mangrove and some were supposed to plant a number of propagules for each stem cut while in the mangrove (Table 9). The leaders of some villages (e.g. T1A, T1B, T2A) had asked villagers to request permission to cut in advance, but this process was not working well and there was confusion about this requirement.

The nature of the verbal agreement (actual in Thailand, assumed by many in the Philippines) that allowed limited cutting for household use left villagers in a legal limbo. Most villagers understood that neither the government agency nor their village head could give formal permission to cut. This

²⁵ The phrase ‘outside businessmen’ was used a lot in both countries. It was a way of avoiding apportioning blame within the village as these outside investors always had people within the village working for them or corrupt leaders handing out land and permissions to them.

was complicated further if the village was located within a National Park or a Protected Area / Non-Hunting Area, as in theory the national ban on mangrove cutting was supposed to be even more strictly enforced. (In practice, the Thai DMCR managed mangroves on the DNP's behalf within park boundaries, and the CENRO was often part of a Protected Area management team in the Philippines.) Villagers who were harvesting wood for household use were encouraged to avoid government patrols and spread their cutting. Village heads would normally intervene if a villager was caught cutting, but only if the leader believed that the wood extracted was genuinely for household use (or the cutter was a relative). The outcome of this intervention was unpredictable.

In the Philippines, the village heads were aware that they did not have the authority to permit villagers to cut mangrove, for any reason, or an informal verbal agreement with the CENRO. In place of community mangrove rules there was a national ban on cutting, supplemented by expected normative behaviour and conventions. Furthermore, there was less CFM experimentation, and the mangrove agency's management was more passive and reactive than Thailand's DMCR field offices. At the time of research, only one of the two villages was starting to discuss among the leaders possible community 'mangrove ordinance' (i.e. rules) for limited usage and sanctions. Despite the widely acknowledged law banning cutting and because the leaders were sympathetic to the poverty of several village members, village heads had been turning a blind eye to cutting 'for household use' (unquantified but more broadly defined than in Thailand, including for building houses and other structures, but not for charcoal manufacture or sale) up until approximately 2015. At this point the leaders had been forced to stop villagers cutting altogether, due to pressure from the local CENRO office, partly because like Thailand this limit was being abused. Therefore, after 2015 the Philippine village leaders discouraged cutting and would not assist villagers who had been caught cutting mangroves.

In spite of this ban, many Philippine villagers assumed cutting for household use was permitted, as so many of their dwellings and outhouses were clearly made of mangrove wood without repercussions from the village leadership or government mangrove agency staff. Others believed that their village leader had negotiated an informal agreement with the government mangrove agency local field office that allowed cutting for household use as long as cutting was within their village boundary. There was widespread confusion among residents about what 'household use' entailed (home building or only repair or building outhouses or cooking) and the number of unofficially permissible stems, varying from 50-200. Many claimed that cutting should avoid the front, more vulnerable mangrove zones, and take place within mid or back mangrove areas (i.e. *Ceriops* sp. / *Bruguiera* sp. zones), behind the perceived 'productive' mangrove area (i.e. the *Rhizophora* sp. zone) (interviewees P1B#04). The belief about *Rhizophora's* superior productivity

arose from being able to see fish, crabs and shrimps only within the roots of this genus (interviewee P1B#04). There was also confusion over whether mangrove cutters needed to ask the village head for permission, or the head and government staff, or only the nearby resident 'social owner' of the mangroves to "show some respect" (interviewee P1B#34). Others believed (incorrectly) that if a villager had planted mangroves, the villager owned them and could utilise them as a crop. Regardless of this confusion, all villagers understood that cutting mangrove wood for sale or for charcoal was illegal.

Finally, it should be noted that although villagers understood many of the ecological values of mangroves, assumed there was a positive link between mangrove (health) and marine productivity (Appendix A and Igulu et al., 2014) and were conscious of the rules or laws protecting mangroves, a substantial minority of villagers in both countries expressed the desire to earn significant money very rapidly, as they did in the late 1990s, by converting much or all of their mangroves to charcoal, regardless of the environmental consequences.

3.6.1.2 Were Other Villagers Following the Rules Cutting Mangroves?

Did other villagers follow the rules? Villagers believed that most people were indeed following the rules, including limiting cutting to household repair levels only, and therefore not significantly affecting the forests (Chapter 4), but the situation was more nuanced. A sub-set of mangrove cutters, only in Thailand, were using the informally permitted household quota as a cover to cut this amount a repeated number of times, claiming it was for various different households. This abuse of the informally permitted extraction quota was described in detail by the conservation group leader of village T2A, but occurred across all Thai villages, similar to the problems portrayed in Kenya by Dahdouh-Guebas et al. (2000). However, this form of over-harvesting was not continuous, but in response to sporadic opportunities to sell the wood to fellow villagers or to external markets. A different and smaller sub-set of only 2-4 residents per village were full-time professional mangrove cutters, affected by village-specific factors. These factors included the strictness of the village leader, the presence of local markets willing to buy mangrove wood, the supportiveness or otherwise of nearby government agencies to support enforcement, the presence of appropriate mangrove products for the local demand and the relationship between the professional cutter and local people in authority. For professional cutters, in the Philippines mangrove felling was used to produce charcoal in the mangrove. In Thailand cutting was driven by orders received for construction timber (e.g. village T1B), or as payment for drugs (village T2B) or for constructing fish net lifts (village T3B, for illustrations, Appendix F T3B photo sheets.)

3.6.1.3 Threats to Mangroves

Even if controlling cutting by villagers within their own boundaries was challenging, in both countries, the mangrove agency field offices had managed to stop most large-scale encroachment by outsiders. In line with trends in the published literature (e.g. Richards and Friess, 2016), respondents in both countries believed that large-scale mangrove cutting or encroachment to produce new aquaculture ponds, for example, was unlikely as government agencies were expected to intervene more than before. However, the threat of small-scale cutting remained, at various intensities in every village, by villagers and residents of neighbouring villages. For example, charcoal production was still taking place in one Philippine village as the village leader and government field office director claimed to be sympathetic to the plight of the village poor, particularly during the El Nino event of 2015-2016 (L'Heureux et al., 2017) concurrent with this research, which had made other livelihoods more difficult. Conveniently, this sympathy avoided the need for conflict with the charcoal producers.

The effects of small scale, informal selective cutting by local communities on the mangroves is poorly understood (Walters et al., 2008). Small-scale cutting changes micro-climates, the amount of sun reaching the mangrove forest floor, canopy closure, the amount of deadwood from collateral damage, canopy height and regeneration ability. Walters et al. (2008) suggested that by clear-felling areas, local people were encouraging more tree species that could exploit larger sunnier openings, such as *Bruguiera* sp. Smaller openings produced by local mangrove cutting may favour coppicing of species that maintain meristematic buds (e.g. *Sonneratia* sp., *Avicennia* sp., *Laguncularia* sp. and *Xylocarpus* sp., but not *Rhizophora* sp. or *Ceriops* sp. as they have no reserve meristem, Saenger, 2002; Walters, 2005a), however, this silvicultural technique was never consciously employed. Furthermore, most cutting in Thailand and the Philippines appeared to be spread throughout a forest, rather than producing small clearings.

Full-time mangrove harvesters had to balance several factors when deciding where to harvest wood. As their activity was illegal, travelling further increased their chances of being caught (Walters, 2005a). When deciding where to cut, professional cutters would consider ease of access and the considerable difficulty of handling heavy material within a mangrove environment, particularly through soft mud and interlocking *Rhizophora* sp. prop roots (Walters, 2005b, 2000). Therefore in Thailand areas of mangrove accessible by a small creak were favoured as this allowed boat access to reduce transport effort and also provided screening from government patrols and other villagers. In the Philippines this was less of a consideration due to the width of their traditional boats with their bilateral outriggers (Appendix F) making small creeks inaccessible. As a result, in the Philippines, wood was converted into charcoal within the mangrove in a makeshift kiln (pers. obs.) as well as

extracted from the front of a mangrove onto a boat or dragged out of the back by water buffalo. Mangrove cutters might travel significant distances to known locations for required resources of specific diameter and species. Researchers have suggested that the size of material generally cut was 4-15cm diameter at breast height (DBH) (Alongi and de Carvalho, 2008; Dahdouh-Guebas et al., 2000; Walters, 2005a, 2005b) for building material and general uses, unless a site was being clear-felled. In this study, although the DBH of cut material was not systematically measured, occasional measurements of cut stems and harvested material found during the study were consistent with these dimensions. Charcoal production for sale favoured larger diameter trees (Dahdouh-Guebas et al., 2000), as experienced in village P1A where trees of 15-25cm DBH were used. And in village T3B 20m tall, >20cm DBH *Rhizophora* sp. trees growing on the edge of a channel were felled by hand directly into the water for static fishnet-lifts posts, (pers. obs., Appendix F village T3B).

Arguably a more serious threat was lack of control and effective monitoring of the mangrove wood extraction, which by its illegal nature was conducted in a covert manner, and its cumulative effect. No group attempted to quantify the extraction rate, species taken or diameter-specific nature of the extraction. As a result, the effects on the quality of the mangrove, biodiversity, sustainability and the mangroves' continued ability to deliver the full suite of ecosystem services was uncertain.

Otherwise threats to the mangroves were generally village-specific. For example, the installation of flood control mechanisms upstream in the watershed feeding in the bay around villages T3A and T3B greatly affected the hydrology of the mangroves. The reduction in water flow speed at key times of the year was causing sedimentation within the mangrove channels resulting in large areas of permanently impounded water and tree die-off (Osbeck et al., 2010; Prabnarong and Kaewrat, 2006).

3.6.1.4 *Patrolling, Enforcement & Sanctions*

The majority of respondents felt the rules were appropriate for the likely threats to their mangroves. Villagers' concerns focused more on the lack of patrolling and / or enforcement of the rules and sanctions. The lack of government patrolling appeared to relate largely to a lack of resources within the government agencies. If patrols took place at all they were so rare as to have only limited deterrent value. In Thailand the agency's patrol boat outboard engines sounded very different to the villagers' 'longtail' engines, which are modified rice tractor engines, thereby giving miscreants advanced warning of a patrol. Villagers also received text message warnings from other fishermen and fellow villagers if they saw the mangrove agency or Fisheries Department patrolling. As much a trust-building and team-building exercise as an attempt to catch mangrove cutters, the Thai mangrove agency field offices also used to patrol with village conservation groups. A couple of field

office directors mentioned that in reality they did not want to catch villagers as this would cause conflict and work counter to the positive relationships they were trying to develop with each village. Instead they hoped that the villages would police themselves.

Only village T2A took advantage of the proximity of the village to the mangrove forests and its fishermen boating through the mangroves to institutionalise passive patrolling. This village had managed to source radios that used the mobile phone network to communicate with the leadership if they saw someone cutting mangrove in their forest. They also used these radios for health and safety issues such as traffic accidents, sadly very common in Thailand (Appendix F). As Fig. 27 and Fig. 28 show, this village had the highest scores of 'no threats to their mangroves'.

Perhaps the greatest challenge facing village leaders was rules enforcement, particularly in Thailand. Thai villages, being generally smaller than Philippine communities, were often made up of only two to four extended families. Leaders would rely on family bonds for many things, particularly when campaigning for election, as happened in both countries. Younger leaders faced an additional challenge when trying to control the behaviour of older family members (very discomforting in Buddhist culture), such as enforcing the repayment of loans back into a village revolving fund. Harsh enforcement of village rules risked a backlash and a lack of co-operation in other areas of village life. As the leader of T1A said, "they are our people" (interviewee T1A#32). Added to these difficulties, leaders could not necessarily rely on the support of outside agencies like the police or mangrove agency to support a punishment, or control the punishment meted out. Potential punishments in Thailand could be several years in prison and a significant fine. Therefore leaders with the will to enforce the sanctions tried to manage this process within their own village.

Social pressure and being unwilling to go against normative behaviour might have been expected to be the first layer of social control and rules enforcement. However some, including a few from the leadership, appeared not to be concerned about saving 'face' and were widely known to be either professional mangrove cutters, revolving fund delinquents, leaders of illegal gambling operations or unethical leaders. Similarly, it might have been assumed that villagers would not be prepared to criticise fellow residents (Sudtongkong and Webb, 2008), but this was not the case. Therefore it appeared that the effectiveness around enforcement was down to the will of the leadership and the moral authority they engendered.

Awareness of the rules and the potential of punishments was widespread, but a majority believed that they would not be punished if caught cutting illegally. What greatly increased the sanctions' credibility was previous examples of their implementation, and these examples being widely known within the village. Village T2A was fortunate to have a core leadership group who had the respect of

the villagers (unpublished data) and a very active conservation group leader (CGL). The fact that the CGL had punished a member of his own family was mentioned frequently by interviewees when explaining their compliance with their mangrove rules.

3.6.2 Necessary Conditions for Effective Community Natural Resource Management

Several researchers studying other types of natural resource have developed overlapping lists of conditions or activities that increase the chance of successful community resource management (Agrawal, 2001; Crona, 2006b; Faure et al., 2019; Nurse and Kabamba, 2000; Ostrom, 1999; Pomeroy and Carlos, 1997; Senyk, 2005; Soontornwong, 2006; Sudtongkong and Webb, 2008; Tole, 2010). Many elements of this list relate to the development or use of a set of community forest management (CFM) rules by a community, mechanisms for the enforcement of these rules and sanctions for rule-breakers. While not claiming to be an exhaustive list of either conditions or researchers - Agrawal (2001) suggests there might be up to 35 factors - the key elements of these largely terrestrial studies have been amalgamated and described below and explored in the context of this mangrove study. Although this collated list of conditions provides useful guidance for establishing and managing (terrestrial) community resources, fulfilling all these criteria will not automatically lead to successful resource management, as each community's context plays an influential role (Agrawal, 2001). Furthermore, he suggests that some researchers within this academic area set out not to objectively study CBNRM, with hypotheses and empirical studies, but to prove CBNRM/CFM works if only a set of factors can be identified and fulfilled. Potential 'omitted variable bias', produced by researchers failing to emphasize or incorporate other important factors that affect CBNRM, might suggest false or misleading relationships and correlations, particularly from single-site studies, and therefore the conclusions from these comparative studies might be limited in their wider applicability (Agrawal, 2001).

3.6.2.1 *Reliance on Mangroves, and a Shared Understanding of their Scarcity*

If a community is fully aware of the ecosystem goods and services their mangroves provide, if they rely on these mangroves (Senyk, 2005) and perceive that the mangroves are scarce or becoming so, and that this scarcity is or will become a community rather than a government problem, they are more likely to be prepared to devote time and resources to manage them (Nurse and Kabamba, 2000; Pomeroy and Carlos, 1997; Springate-Baginski and Than, 2011). Reviewing several CBNRM cases Tole (2010) suggested that the middle classes were more likely to perceive resource problems, degradation of forests and appreciate the need for restorative action. In contrast, poorer villagers with fewer assets were likely to focus more on projects that provided immediate direct benefits, being less concerned with the damage caused to natural resources. A lack of a common perception

and understanding of local natural resource problems might negatively affect how well a group functioned and tackled such challenges (Ostrom, 1999; Tole, 2010).

Within this study, community proximity to mangroves did not necessarily mean that the inhabitants relied on or used this natural resource. As Fig. 23 shows, mangrove village residents might work in a nearby town or on farms or with inland natural resources, away from the inter-coastal zone. And due to the purposive sampling of villages with extensive mangroves, perhaps scarcity was less of a motivating factor than the return of ecosystem services or being paid to plant (Philippines).

3.6.2.2 Well-Defined Boundaries are Important for Successful Community Management

Land tenure and boundary disputes are common problems within mangrove communities (Banjade et al., 2017; Brown et al., 2014; Rotich et al., 2016). Within this study, clear definitions of communities' external boundaries reduced the occurrence of confusion and conflict and aided successful management, which concurred with findings of the importance of well-defined boundaries (e.g. Pagdee et al., 2006). Thai and Philippine government mangrove agencies used global positioning satellite-assisted mapping, physical demarcation such as concrete posts and signboards (Sudtongkong and Webb, 2008) to ensure villagers and outside parties understood shared boundaries, as found by Katon et al. (1998). Problems arose when outsiders or villagers ignored the internal community boundaries by encroaching into mangrove zones for other land uses such as house building (T3A), oil palm (T2A) or aquaculture (T3B).

For villages that had established some form of mangrove zoning (e.g. T2A, T1A) within their overall territory, these internal boundaries worked less well. Zoning of mangroves might be an appropriate management tool used, for example, to exclude villagers from degraded stands to allow them to recover from degradation, but the location and definition of these zones were poorly understood by villagers, which negated their utility. For example, in village T1A, the village leader, conservation group leader and government mangrove agency field office director all had a different understanding of the zone location and definitions within the village's mangrove. Another community had produced a large vinyl poster using Google Earth satellite imagery to depict their village, the external boundary and the mangrove zones therein (T2A, pers. obs.), but this only partially mitigated villager confusion.

3.6.2.3 Clear Legal Framework, Obligations and Land Tenure Arrangements

Clarity about the legal status of community resources, land tenure, governance and property rights is essential, as is an avoidance of confusion or incoherence from over-lapping legal jurisdictions. Regulations about a community's obligations and commitments need to be clearly understood. As these rules entail restricting use and exploitation of mangroves, necessitating some negotiation and

compromise, rules must be seen as fair, legitimate and locally appropriate (Ostrom, 1999). This includes the rights of migrants and indigenous groups and how the law relates to customary arrangements (Faure et al., 2019). Where culture permits, local autonomy of villages and conservation groups to act and manage a natural resource improves the likelihood of successful CBNRM (e.g. Sudtongkong and Webb, 2008; Waylen et al., 2010). Arguably, South Asian cultures are more beholden to their governments, whereas in Southeast Asia there is more of a culture of collective action, particularly at the village level (V. Balaji, pers. comm.). In India, NGO or local mangrove rehabilitation initiatives were viewed sceptically by local people, as they believed it was the government's responsibility to implement rehabilitation programmes (Datta et al., 2012). Autonomous action and management might be resisted by local authorities or mangrove agency field offices who wish to retain control over natural resources and villagers (Datta et al., 2012). In contrast, despite overlapping laws and jurisdictions, some Southeast Asian countries such as Myanmar are permitting or encouraging village conservation groups to manage the community's natural resources, including establishing their own by-laws (e.g. Ministry of Natural Resources and Environmental Conservation (MONREC) Union Minister's Office (Myanmar), 2016; Springate-Baginski and Than, 2011).

Within this study, despite several government departments having an interest in the inter-coastal zone (Dale et al., 2014; Primavera, 2000; Thompson, 2018; Vandergeest et al., 1999), the Thai DMCR was actively encouraging the more co-operative villages to develop their own mangrove management rules. It is likely that the Philippines will soon follow the Thai's example. Although this did not extend to holding land tenure, the villages' obligations were clear, even if villages' own rules were less well recalled. Community rules that were simple and easy to understand were more likely to be remembered and therefore effective, as Faure et al. (2019) found. (The conservation group leader of T2A felt that the village rules in Appendix J were too long and complex for many to remember.) And while villagers near very large areas of mangrove might have believed the rules to be unnecessary, few thought they were unfair.

3.6.2.4 The Costs & Benefits of Restrictions, and Evidence of the Benefits of Behavioural Changes

Ideally, villagers subject to rules and restrictions need to perceive that it is in their interest to stop degrading their mangrove from over-exploitation, to adhere to their natural resource regulations, and understand that a lack of action will result in greater problems later on (Crona, 2006a). They should be able to perceive changes and improvements to their resources due to their positive activities (Ostrom, 1999; Tole, 2010). Demonstrating progress to local villagers and donors can be facilitated by setting appropriate objectives, realistic budgets and suitable indicators of change or improvement (Lewis, 2005; Pomeroy and Carlos, 1997; Roe et al., 2009). The costs of submitting to

the rules, and specifically enforcement or patrolling, should not be too high and the reduction or loss of immediate benefits that come from resource exploitation (e.g. here, mangrove wood harvesting) due to the imposition of community rules, should be roughly proportional to the costs imposed by these rules, where appropriate (Ostrom, 1999). In this study community mangrove rules focused on the prohibition or control of cutting and forest protection, rather than the distribution of benefits. For villagers working as professional cutters, the opportunity cost was high, but they appreciated that their activity was illegal. Most villagers appreciated the need for control of cutting, with the exceptions being concentrated in villages with vast areas of mangroves (T3A, T3B). In all villages, as their mangroves were reasonably intact (Chapter 4), demonstrating that cutting restrictions would improve mangrove quality or sustainability would be difficult, not least because these two criteria were themselves not measured. Furthermore villagers' estimation of rehabilitating degraded areas and planting success was consistently over-optimistic, as shown in Chapter 1 & 2.

3.6.2.5 *Well Developed Community 'Social Capital' and Good Leadership*

Good social capital (defined in section 3.2.6) allows a community to solve shared problems, empower itself and can greatly help villages to agree to appropriate CBNRM rules and by-laws (Glaser and da Silva Oliveira, 2004). Good leadership can strengthen social capital which can draw in outside resources and experts, adjudicate rules development and be the basis of sanctions credibility. Several authors have mentioned that strong, effective leadership was essential for successful CFM (Courtney et al., 2002; Datta et al., 2012; Glaser and da Silva Oliveira, 2004; Muehlig-Hofmann, 2007; Ostrom, 1990; Pagdee et al., 2006; Soontornwong, 2006; Springate-Baginski and Than, 2011), but leadership has rarely been studied in detail in a mangrove village setting²⁶.

Agreements are much easier to achieve if the community has previous experience of CBNRM rule setting, potentially resulting in a portfolio of possible rules and social mechanisms (Ostrom, 1999). In these research villages, another resource that would benefit from community management was restrictions on size and timing of mud crab (*Scylla* sp.) harvesting and having to donate egg-bearing crabs to the communal crab bank rather than selling them, as found by Soontornwong (2006). But the example witnessed twice during the research demonstrated the difficulty of establishing natural resource management rules. Villagers appreciated the need for rules to manage mud crab numbers as they did for mangrove resources. Older villagers reported that 30 or 40 years ago at high tide the mangrove trees used to turn black with the number of crabs climbing up into them (e.g. interviewee T3A#47). At the time of research, villagers had to travel further and further to find sufficient

²⁶ Leading a village can be a dangerous job as several community leaders have been killed in Thailand, often over land disputes, including a local leader in Sudtongkong and Webb's study (2008).

numbers for sale and reported that the crabs found were smaller and smaller. Crab collectors readily agreed that there has been a precipitous drop in crab numbers. But they would not countenance that this reduction was due to their over-harvesting. They ascribed crab reductions to pollution, outsiders, random chance, climate change or the will of Allah (interviewee T3A#54). Villagers fought vigorously to avoid making any sacrifices, such as not collecting during the few days of spawning. Making matters worse, despite their claims to the contrary, village wholesalers bought all crabs offered to them, including undersized or gravid crabs as they could be sold on as bait. Unsurprisingly, the wholesalers did not attend these village rule-setting meetings.

Similarly, when discussing rules in a public meeting, villagers who disagreed with cutting restrictions would not attempt to argue against the head of the village or the government mangrove agency staff in public – very much against Thai and Buddhist culture - but instead just ignore the rules. Changing behaviour required different methods of interaction and discussion, effective patrolling and credible sanctions, as significant social capital on its own should not be taken as an unquestioned solution to all common property problems (Pomeroy and Carlos, 1997; Sudtongkong and Webb, 2008; Tole, 2010). Community forest management can only be as effective as social capital and other community institutions allow (Ostrom, 1999; Tole, 2010).

3.6.2.6 Patrolling, Enforcement and Credible Sanctions

Credible, graduated sanctions are necessary for the appropriate enforcement of community regulations (Fisher et al., 2005; Ostrom, 1999, 1990; Tole, 2010). A community should ideally be cognisant of any previous application of sanctions for their penalties to be credible. And then transgressors need to be discovered by patrolling. CBNRM and social control does not necessarily have to be in the form of by-laws but might take advantage of other forms of authority. Nurse and Kabamba (2000) described a system of tacit traditional village regulations in Tanzania such as the establishment and protection of mangrove sanctuaries (protected areas) for spiritual worship. In Pred Nai, Thailand, community forest protection was led by a monk, Pra Subin Pyuto. Loggers were reported to be deterred from felling trees the monk had blessed, marked with saffron Buddhist ribbons around the trunks (Soontornwong, 2006). However, Forsyth (2004) cautions against holding a 'romantic' belief that Thai village culture and (terrestrial) natural resource management was necessarily older, better and worthier than state management, observing that even though some traditional hill tribes had managed to retain areas of terrestrial community forests surrounding their villages, these were less biodiverse than other communities' forests.

Enforcement is challenging in Southeast Asian societies due to the cultural discomfort with confrontation, particularly between family members (pers. obs.), and therefore a conflict resolution

and enforcement mechanism should be developed that take this into account (Faure et al., 2019). It was noteworthy that despite regular village meetings and much social interaction within these research villages, an accurate understanding about previous punishments or just accurate internal communication²⁷ within the village was often absent. In this study mangrove agency field officers, National Parks staff or local police sometimes supported the application of sanctions if the offenders did not change their behaviour after warnings from their village leadership, as suggested by Katon et al. (1998). However, some village heads suggested that they were not receiving sufficient support from the corresponding mangrove agency field office directors. In turn, some of the field office directors knew that the local police departments or the local judiciary would not support their cases in court.

3.6.2.7 A Change of Role for the State, and External Assistance from Other Groups

A transfer of management responsibility or devolved governance or outright legal transfer from state to the local community does not absolve the state from involvement but suggests a change of role for the government to supporting the communities, together with appropriate NGOs (Faure et al., 2019; Pomeroy and Carlos, 1997). Outside support might not be necessary in every situation (Walters, 2004) but in addition to supporting the application of sanctions, external actors can strengthen social capital and facilitate discussions with local elites and other stakeholders, government departments, surrounding villages and local businesses - activities which a community might not be able to initiate or achieve on its own (Marschke and Nong, 2003; Ostrom, 1999; Tole, 2010). External organisations can provide timely funding, training, information and an explanation of the rights of a village and the relevant laws (Pomeroy and Carlos, 1997). For example, with staff embedded in the village, NGO RECOFTC²⁸ introduced iterative rounds of action research into Pred Nai, Thailand, to identify problems with their CFM and improve their model, as issues arose (Soontornwong, 2006). Thai NGO Yadfon²⁹ worked closely with several communities in Trang Province to enhance all elements of their mangrove management, and facilitate networking along the coast, as well as with government organisations (Sudtongkong and Webb, 2008). Various actors have supported villages around Gazi Bay, Kenya, to bring payment for the preservation of ecosystems to these villages, in the form of voluntary carbon credits and development infrastructure (Huxham et al., 2015; Locatelli et al., 2014).

²⁷ With remarkable regularity, village meetings were announced and the agenda publicised. But when attending these meetings the topic of conversation turned out to be something very different to that advertised.

²⁸ RECOFTC is the Regional Community Forestry Training Centre for Asia-Pacific, based in Bangkok, Thailand. The quoted author Soontornwong (2006) was its director.

²⁹ <https://wiser.directory/organization/yadfon-association/> Accessed 6.11.2018

Appendix K is a summary of the guidance provided by the government to the Thai DMCR field offices for supporting CFM rules development in mangrove villages. However, this research has shown that beyond this guidance, assistance should be provided in many other areas, as described above including leadership training and sanctions support, and take into account the varying context of each village.

3.7 CONCLUSION

Because of the previous experience of mangrove losses from concession clear-felling, many villagers agreed with the need for mangrove rules and mangrove protection, be that national law or community rules. Spontaneously they suggested that open-access to their mangroves would lead to significant degradation. If developed appropriately CFM presented an opportunity to tailor community regulations to better suit the needs of the community and the nature of their resource, compared to a one-size-fits-all national law. As the field office directors in Thailand mentioned, if local villagers managed their mangroves appropriately, then they should be able to benefit from them in a sustainable way.

Within the limits of the village selection criteria of this research, and without losing sight of the context of these villages, many of the lessons learned from terrestrial CFM remained relevant for mangrove community rules development. Knowledge of the location of village mangrove boundaries is important and was clear to all, having been well defined by the government agencies. It might have been difficult for villagers to witness the benefits of restraining from open access-style cutting, but few made their living primarily from mangrove wood extraction and thus the costs of restraint were not high. There was a consensus that villagers were following the rules, but the verbal, informal agreements for limited extraction for household use (i.e. repair only) were not working well and were prone to abuse. Both countries required a ratified legal framework for CFM, particularly to support the enforcement of sanctions, which village leaders found difficult to apply. Any CFM legislation must define the land tenure rights and obligations of the state and local villagers. The law should also directly assist the process of taking back illegally encroached mangrove land and compel other organs of the state to support this process. CMF does not absolve the state from continuing to work with mangrove villages as experience in Myanmar, arguably further along this process, shows that continued support and training will be necessary.

CHAPTER 4. DEVELOPING SIMPLE MANGROVE FOREST QUALITY & SUSTAINABILITY INDICATORS TO HELP NON-SPECIALISTS MANGROVE WORKERS PRIORITISE EXTERNAL ASSISTANCE

4.1 ABSTRACT

Mangroves provide essential goods and services to inhabitants of mangrove villages but in most countries mangroves are owned by the state and national law prohibits cutting and harvesting of mangrove wood. Therefore, states' conservation objectives can be at odds with villagers' desires to realise some of the benefits from their mangrove by extraction of wood and timber. At a local level, some mangrove agency field offices permit informal, limited extraction of wood for household use, but there is minimal monitoring of whether these informal cutting agreements are followed, if mangrove quality is significantly affected and whether this extraction is sustainable. To help non-specialised groups to perform a mangrove quality and sustainability risk assessment, I investigated various forestry and bio-geo-physical measures to assess which could function as simple indicators that could be aggregated to form mangrove quality and sustainability criteria. These criteria could be used to improve targeting of external assistance by permitting the ranking of communities whose resources most need external intervention.

We judged mangrove quality using canopy closure (measured by hemispherical photography, with the assumption that a closed canopy in Southeast Asian river delta conditions indicated better quality mangrove), the Simpson's biodiversity index, the Forestry Structure Complexity index and a tree condition rating. Mangrove sustainability was judged by density of juveniles, levels of cutting per unit area and tree size-class distribution. 2,224 trees were sampled across 57 transects in eight villages in the Philippines and Thailand.

Analysis by generalised linear model and hierarchical multiple regression produced predictive models from a combination of measures for each of these indicators that differed in explained variance from 43-74% for mangrove quality, and 27-66% for mangrove sustainability. Salinity, the proportion of *Rhizophora* sp. in a transect and tree density were influential in the indicators contributing to the mangrove quality criterion. Tree density and tree height played important roles in the indicators that made up the mangrove sustainability criterion. The proposed weighting of indicators to develop the two criteria gave greater influence to indicators with higher explained

variance. These weightings can be adjusted depending on management objectives and definitions of quality and sustainability. By using these easy-to-measure criteria of mangrove quality and sustainability, I hope to encourage the ranking and prioritisation of external intervention to mangrove villages most in need of assistance.

4.2 INTRODUCTION

Healthy mangroves are vital for local coastal villagers, and the poorest in particular (Sunderlin et al., 2005), due to the many ecosystems services and benefits they provide, (Appendix A, Moberg and Rönnbäck, 2003; Sinfuego and Buot, 2014). To realise some of these benefits, wood extraction is required to provide materials for construction, fish traps, fish aggregating devices and fuelwood for cooking, as often there are few affordable, alternative resources (Badola et al., 2012; Glaser and da Silva Oliveira, 2004). In most countries, mangroves are protected by law and cutting is prohibited, but they remain under unquantified levels of informal local cutting pressure from diffuse and chronic extraction (Walters, 2005a). Mangroves have suffered from similar problems to terrestrial woodlands, including a loss of old forest, simplification of structure and biodiversity, patch size decrease and fragmentation by road building and urban development, among other issues (Barreto et al., 2006; Noss, 1999). Due to passive state mangrove management, the effect on mangrove quality and sustainability of this unregulated, unquantified and often covert extraction is poorly monitored. As a result, despite the academic debate and development of (terrestrial) forest indicators (e.g. MCPFE, 2002), government mangrove agency field staff, local NGOs and village mangrove managers are likely to have only a limited understanding of the resulting impact of this extraction and harvesting of mangrove wood on the quality and sustainability of their mangroves. This is partly because many of the (normally terrestrial) indicators that are aggregated to enumerate forest criteria require expensive equipment and training or are technically difficult to measure, particularly within this ecosystem which is challenging to work in due to humidity, soft mud, heat, interlocking prop roots and the corrosive effects of salt water. For example, measuring tree photosynthesis and leaf chlorophyll fluorescence requires costly apparatus³⁰ and while the equipment needed for hemispherical photography to measure canopy closure might be getting simpler (Bianchi et al., 2017), the multi-stage computer analysis required remains challenging. Meanwhile mangrove agencies have limited staff and financial resources.

To assist these mangrove-interested groups, I attempt to identify easier-to-measure bio-physical or social factors that workers who are not forest specialists can use to assess mangrove quality, and the sustainability of wood extraction. With these tools, mangrove stands belonging to different villages can be ranked in terms of quality and sustainability to enable better prioritisation and targeting of external assistance and intervention to communities whose mangroves are under greatest threat.

³⁰ E.g. LI-COR LI-6800 fluorometer. For more information see https://www.licor.com/env/products/photosynthesis/LI-6800/?gclid=EAlalQobChMlj6KOhqGC4wIVx4XVCh3caQBEEAAYASAAEgKdMfD_BwE Accessed 24.6.2019

4.2.1 Mangrove Cutting, Gap Recovery, Stressors and Resilience

Mangroves ecosystems can be affected by various stressors. Lewis et al. (2016) make the distinction between acute and chronic stressors, such as changes in hydrology, sedimentation and significant weather events. Generally, mangrove systems are resilient to changes such as sea-level rise because mangroves appear to be able to keep pace with soil accretion rates and rising average inundation levels due to a large store of underground nutrients, rapid recycling of nutrients, adaptations to their habitat and redundancy (Alongi, 2008). Site-specific factors notwithstanding, conditions within a mangrove plantation are believed to stabilise after disturbance in terms of decreases in soil temperature, redox potential and tree density from self-thinning and inter-tree competition, and increases of soil organic matter, at around 11 years, the canopy usually closing approximately a year beforehand (Salmo III et al., 2013). Mangrove plantations achieve maturity at approximately 25 years old, where the soil resembles substrate found in natural mangrove forests (Salmo III et al., 2013), due to the processes outlined by (Alongi, 2009a), particularly the build-up of organic material in the soil.

One form of disturbance is the cutting and harvesting of mangrove wood. Small-scale cutting and harvesting might be considered an important stressor, as Walters, (2005b) attributed 90% of mangrove tree death in the Philippines to cutting rather than any other cause, and questioned whether there might be cumulative effects on mangrove ecosystem dynamics (Walters, 2005b). The influence of gaps within a canopy is still debated. Some have suggested that there is little difference in juvenile recruitment between areas with forest gaps or with no gaps, only faster juvenile growth within these gaps (Clarke and Kerrigan, 2000). Walters (2005a, 2005b) experienced low-level mangrove extraction in the Philippines which led to small stand gaps as villagers tended to spread their cutting. These gaps recovered quickly on their own. Smaller openings may favour coppicing of species that maintain meristematic buds such as *Sonneratia* sp., *Aegiceras* sp., *Avicennia* sp., *Laguncularia* sp. and *Xylocarpus* sp., (but not *Rhizophora* sp. or *Ceriops* sp. as they have no reserve meristem, Tomlinson, 2016; Walters et al., 2008). However, this silvicultural practice as an active management strategy is rarely reported. Kairo et al. (2002) observed that in the larger forest gaps made by villagers harvesting wood in Mida Creek, Kenya, there was natural regeneration, but not necessarily of the species harvested. As most mangrove species are shade-intolerant, (with the partial exception of *R. mucronata*) clear-felling larger areas might encourage most mangrove species present to exploit these openings (Putz and Chan, 1986). Alongi and de Carvalho (2008) also witnessed much more intense cutting which produced significant forest gaps, large enough to allow continuous sunlight to reach the forest floor, causing considerable evaporation from soils. They observed that soil drying increased the level of sulphides, metals ions and ammonium, and

decreased oxygen levels to the roots, thereby reducing respiration rates of live roots and slowing growth. Live mangrove roots leak nutrients and carbohydrate into the rhizosphere (Saenger, 2002), improving the soil quality and competitive balance of beneficial bacteria. The loss of live roots from harvesting, and therefore this leakage, would negatively affect soil quality and shift the competitive balance of soil bacteria towards a less favourable state, possibly in a non-linear manner (Alongi, 2009a; Kristensen and Alongi, 2006). Specific soil bio-physical changes notwithstanding, the challenge for managers is to monitor these types of changes to ensure sustainable extraction levels.

4.2.2 The Value and Challenges of Indicators and Criteria

Terrestrial forest organisations have developed indicators that are aggregated to compute criteria that describe and monitor forest stressors, changes and sustainability (MCPFE, 1998). Similarly, the Group on Earth Observations - Biodiversity Observation Network has attempted to harmonise biodiversity monitoring by developing Essential Biodiversity Variables to aggregate and distil almost 100 factors to illustrate change and prioritise efforts (Pereira et al., 2013). Indicators are qualitative or quantitative variables that gauge features within a criterion, evaluated periodically, that reveal a direction of change over time (Mäkelä et al., 2012). In a study of British forests, Ferris and Humphrey (1999) advised that indicators should be easily quantifiable, repeatable, subject to minimal subjective or observer bias, cost effective and ecologically meaningful. Other researchers studying temperate forest ecology have developed several ecological indicators that are descriptive and normative, measuring direct or indirect effects, including pressures on forests, responses, states and phenomena (Heink and Kowarik, 2010). Beyond this, 'indicator' is challenging to define (Heink and Kowarik, 2010; Mäkelä et al., 2012) because the word is used for different tasks, such as environmental planning or policy development, and by different groups, resulting in a definition that varies by user group (Heink and Kowarik, 2010). Furthermore many forest indicators were developed for use at a national scale and concerned with wood production (Mäkelä et al., 2012).

Developing indicators that capture the complexity of the system being monitored is challenging (Dale and Beyeler, 2001; Eslami-Andergoli et al., 2015). For example, debate continues around which indicator species to use, or whether to use abundance of rare species, or species and features that are easy to measure. Questions persist about the use of species that are sensitive to habitat loss and the acceptable length of response time-lag of the chosen indicator species (Noss, 1999). Other challenges to developing indicators include insufficient data, poor measurement accuracy, any significant exogenous shock with little warning, interaction of feedback loops between indicators, changes in the external perturbations, changes too subtle to measure (Eslami-Andergoli et al., 2015) and the difficulty of modelling heterogeneous stands (Mäkelä et al., 2012). Even though intuitively

compelling, these indicators are often less than fully validated (Gao et al., 2015; Lindenmayer et al., 2000; Noss, 1999) and to become fully comprehensive these models require further development and testing (Mäkelä et al., 2012).

It could also be argued that not all terrestrial forests (or mangroves) have the same intrinsic value. Some might be biologically very diverse and a valuable seed source for the surrounding patches, but other stands less so (Noss, 1999). Therefore, the choice of indicators used should relate to the management goals of the forest in question, the local conditions and type of site. For example, it is frequently assumed that forest management objectives are ecosystem functionality, connectivity and increased biodiversity (Ferris and Humphrey, 1999; Noss, 1999). If these aims are not clear, explicitly stated or change, the choice of indicators used might not be in line with management goals (Dale and Beyeler, 2001).

4.2.3 Defining Mangrove Quality and Possible Substitute Measures

While acknowledging the benefits of indicators and criteria described by MCPFE (2002), measuring and interpreting indicators such as nutrient cycling and changes in soil organic matter to describe a mangrove forest's health and condition (e.g. Salmo III et al., 2013) would be challenging in a mangrove context of chronic small-scale cutting and other potentially confounding variables such as inundation, sediment erosion / deposition, precipitation patterns and variability of salinity (Alongi, 2009a; Saenger, 2002). Within temperate forests some well-established indicators use levels of coarse woody debris and extensive herb layer composition to describe forest 'naturalness' (Liira et al., 2007). However, this might not be appropriate in other settings where deadwood is collected, or in a mangrove due to tidal inundation removing much of the floor litter, and the general lack of herb layer in a closed-canopy mangrove (Tomlinson, 2016). Additionally, while recognizing the value of tested and validated indicators that capture elements such as stand structure, ecosystem function, connectivity, bio-physio-chemical soil parameters, response to stress, habitat functionality and carbon fluxes, many of these features might be challenging to measure for government mangrove agency staff or NGOs or indeed beyond their capacity (Dale and Beyeler, 2001; Lindenmayer et al., 2000; Pereira et al., 2013).

In response, I suggest narrow, simplified definitions of mangrove forest quality and sustainability. I then assess whether it is possible to substitute simpler alternative bio-physio-socio measures or factors that predict the indicators that are more difficult to measure, that make up the criteria of quality and sustainability. It is hoped that these more straightforward alternatives might increase the likelihood that managers will monitor the quality and sustainability of their mangroves, and be

able to rank and prioritise management assistance to improve the health of the lowest quality mangroves and / or conserve the most heavily exploited mangroves to maintain their sustainability.

The perceived quality of a mangrove forest should be judged in relation to the management objectives, such as timber production, water purification (e.g. Laem Phak Bia, Thailand, Jitthaisong et al., 2012) or for ecological and biodiversity functions, and as such there can be no agreed single measure of mangrove quality. The default silvicultural approach to mangroves rehabilitation in much of Southeast Asia is mono-specific, closed canopy mangrove plantation forestry in straight rows. Although not necessarily mutually exclusive, this approach might be counter to the desirable structural complexity of a biodiverse mangrove, with numerous species at different heights, densities and age-classes, and which would be considered preferable for ecological and biodiversity objectives. Therefore our proposed forest quality indicators, adapted from terrestrial forestry, cover a range of measures: canopy closure, leaf area index, forest structure complexity (index, i.e. FSCI), diversity and a tree condition rating (all defined later), left side of Fig. 34.

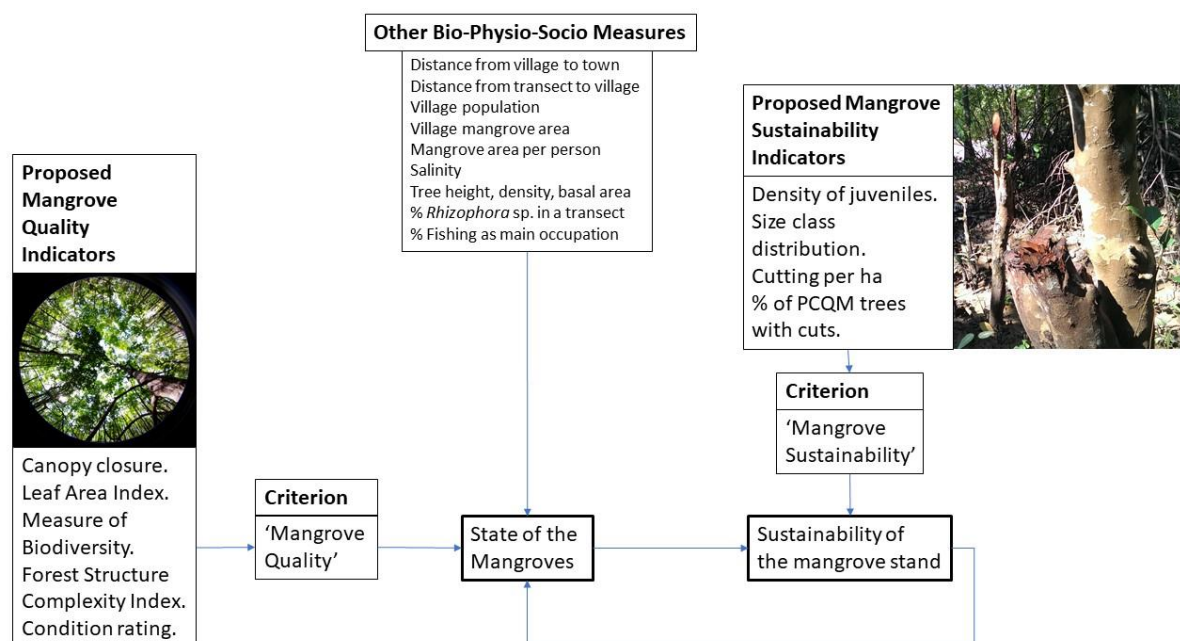


Figure 34. Proposed indicators (L and R) and other measures (centre) for the criteria of mangrove quality and mangrove sustainability

Hemispherical canopy photography (Bianchi et al., 2017; Gonsamo et al., 2011) provides an objective measure of canopy closure. For the predominantly mid zone species plantations encountered in this research, in a deltaic setting, a more closed canopy is generally accepted as being a feature of better

forest quality³¹ (Alongi, 2009b). This feature limits the amount of radiation reaching the forest floor, reduces soil desiccation and warming, and retains the ‘boundary layer’ of moist air within a more closed canopy thereby reducing water loss from transpiration and the resulting tree stress (Evans and Turnbull, 2004; Thomas, 2001). FSCI combines and is characterised by several forest attributes, such as basal area, tree height, tree species, tree density, biomass, foliage arrangement, canopy cover and understory (McElhinny et al., 2005), but in a review the authors acknowledge a variation in definition. Greater stand complexity, described by a higher FSCI score, is seen as higher quality mangrove (in ecological terms), enjoys greater ecological stability and is able to produce a superior adaptive response to disturbance (Alongi, 2008). Greater tree species diversity³², measured by the Simpson’s Diversity Index (Simpson, 1949) suggests a better, more varied habitat for creatures that use mangroves and a higher resilience to climatic change and alterations in other conditions and resources (Alongi, 2008; Saenger, 2002). Finally, an A-D tree condition rating scale described the quality and usefulness of the individual trees that were sampled with better, straighter form (defined in section 4.3.6).

4.2.4 Defining Mangrove Sustainability and Possible Substitutes

Before the Brundtland Commission’s general definition of sustainability (World Commission on Environment and Development, 1987), descriptions of forestry sustainability were based on models of sustainable yield of wood (Monserud, 2003). The Brundtland Commission and Earth Summit in Rio in 1992, paraphrased and adapted, suggested that the concept of sustainability included meeting people’s needs for ecosystem (here, mangrove) goods and services without reducing the ecosystem’s future productivity or intrinsic value, thereby including social and ecological elements to the idea of sustainability. As a result, a review of sustainable management models for North American forests recommended broadening the scope of ‘sustainability’³³, and suggested that models and indicators based only on sustainable yield were inappropriate (Monserud, 2003). Additionally, many of these models were developed for very large or national spatial scales. Within the context of mangroves, a broad definition of sustainability might also take into consideration indicators that measure community activity (Pretty, 1995), carbon sequestration and infrastructure protection by mangroves acting as buffers, and providing connectivity between ecosystems and landscapes. Here I focus on a narrower definition of mangrove sustainability using indicators again

³¹ It is acknowledged that other forms of mangrove such as arid *Avicennia marina*-dominated systems, might be much more widely spaced and open, with significant mangrove stunting due to challenging growth conditions.

³² While acknowledging that biodiversity is usually considered at the genetic, species and ecosystem levels (Agrawal and Redford, 2006; Davies et al., 2014), here only floral species are referred to.

³³ For example, see the 7th Ministerial Conference on the Protection of Forests in Europe (Forest Europe, 2015). https://foresteurope.org/wp-content/uploads/2016/11/Commitments_all.pdf accessed 20.2.2019

adapted from terrestrial forestry, that relate to the likely long-term survival and reproductive success of a mangrove stand. The criterion of greater sustainability might be predicted by indicators such as a higher density of juveniles per hectare (ha), a reverse J-curve size-class distribution of tree diameters (Kimmins, 1996) and a lower rate of stem cutting per hectare (right side of Fig. 34). A higher density of juveniles suggests that when trees grow beyond over-maturity and fail, there are juveniles and young trees ready to take advantage of the new gaps and light to replace the fallen trees. A size-class distribution following a downward exponential curve would indicate a change between younger, more simple stands and more mature, diverse age-class stands (Noss, 1999). If cutting/ha exceeds the annual increment of mangrove wood (more mangrove extracted than growing naturally), this suggests the rate of extraction is unsustainable.

Although counting juveniles and cut stumps per hectare might be straightforward, the analysis of size class distribution is more complex. Consequently, I also included in the analysis other simpler bio-physio-socio measures that might predict, and therefore be substituted for, more difficult-to-measure indicators (centre of Fig. 34). These included tree density, height and basal area, soil water salinity, the proportion of *Rhizophora* sp. within each transect, a village's population, a village's mangrove area, and distances from the village centre to each transect and to the nearest town. Village population size might indicate a level of local cutting pressure. Tree density, height and basal area interact with each other. Densely planted trees will normally have a lower diameter, as trees compete for light and grow upwards as fast as possible. Increased salinity greatly affects and reduces mangrove growth rates (Saenger, 2002). The proportion of villagers whose main occupation was fishing (as reported by their village leaders) might relate to cutting rate as they commonly extracted mangrove branches for fish aggregating devices, among other uses. Towns closer to nearby villages might offer jobs, alternative livelihoods and substitutes for mangrove wood use, or ready markets for mangrove timber. The distance between the village centre and where a transect was conducted might affect covert cutting and extraction.

Use of these simpler measures is not expected to replace the more complex and thorough indicators as suggested by Salmo III et al. (2013), which would require specialist equipment, knowledge, trained staff and difficult analysis. I do not claim to have fully developed and validated mangrove forest quality and sustainability criteria. Further research and testing in different mangrove types and in different conditions would be required - juvenile establishment in particular is complicated and affected by many factors. However, these simpler indicators for the criteria of mangrove quality and sustainability will be able to reveal a direction of change in the quality and sustainability criteria over time (Mäkelä et al., 2012), and therefore assist the ranking and prioritisation of village

mangroves requiring external management assistance where existing management is failing to guarantee the long-term survival.

4.3 METHODS

4.3.1 Country and Village Selection

See Chapter 2, section 2.3.1.

4.3.2 Transect Location Selection

Seven transects per village were conducted (Fig. 10), except in P1B where eight were completed. Each village's mangrove boundary was indicated by the local Thai Department for Marine and Coastal Resources (DMCR) field office or the equivalent Philippine Community Environment and Natural Resources Office (CENRO). If a village had zoned its mangroves (e.g. usage zone, conservation zone, as opposed to ecological zone), these were indicated by the local conservation group leader. The mangrove boundary and any mangrove zones were recorded by re-drawing them as a series of KML polygon files on Google Earth. The area of these polygons was calculated using the University of New Hampshire's Cooperative Extension KML Tools³⁴ webpage, and later by Google Earth Pro's 'Measuring Tool'. Walters (2005a) suggested that mangrove cutting and harvesting is affected by boat or road access due to the difficulty of moving heavy wood or large quantities of material through a mangrove. Villagers were unlikely to attempt extraction of timber through hundreds of meters of dense mangrove and soft mud. As mangrove cutting was illegal in both countries and therefore had to be carried out covertly, transects were purposefully located to take this and other factors into account:

- The transects were within the village's mangrove boundaries
- All mangrove zones were sampled, as defined by the village, if applicable
- The transects incorporated a geographic spread to take a representative sample of a village's entire mangrove area
- Transects were located less than 100-200m from a minor channel which would allow illegal cutters to hide their boats and provide boat access for transportation of cut mangrove wood. Alternatively transects were located near roads close to mangroves or where access was possible by foot via the back mangrove zone.

³⁴ <https://extension.unh.edu/kmlTools/> Accessed 28.3.2017

A polygon was drawn around each approximate transect area, covering 1-3ha. Within each of these polygons the University of New Hampshire's web tool generated a random point for the start of each transect. This start point was located in the field by a Garmin STc62 handheld GPS device.

Table 10. Number of transects conducted per village, by country, and trees surveyed.

	Villages	Transects	Trees Surveyed
Thailand	6	42	1,624
Philippines	2	15	600
Total	8	57	2,224

4.3.3 Point Centred Quarter Method to Gather Tree Demographics

The 'Point Centred Quarter Method' (PCQM) transect method used the techniques developed by Cintrón and Schaeffer-Novelli (1984) and further enhanced by Dahdouh-Guebas and Koedam (2006). Rather than measuring trees within a rectangular belt transect, PCQM involved sampling points along a line, thereby avoiding the subjective judgement of whether trees were inside or outside a transect belt. PCQM provided standard forestry measures of tree density / ha and basal area / ha.

4.3.3.1 Sampling Points

Sample points were normally 10m apart along a transect line unless there was a chance of sampling the same tree twice, when turning a corner or to avoid a minor channel, in which case the distance was increased to 15m. These distances were measured as accurately as possible with a fiberglass 30m tape to avoid choosing convenient spots to sample. Each transect involved 10 sample points, if at all possible, resulting in data for 40 trees. However sometimes rising tides or logistics issues resulted in only nine (36 trees) or very rarely eight (32 trees) points being sampled. PCQM transects were not conducted in straight lines but in shapes that formed a 'W' or 'N' to avoid confounding effects of species zone boundaries or changes in soil types.

A mangrove 'tree' was considered to be at least >1.30m tall and the main stem to be >2.5cm diameter at breast height (DBH) (as per Kairo et al., 2008) measured at 1.30m above the ground (hereafter referred to as DBH¹³⁰). Standing dead trees were ignored as they were not used by villagers. Dying trees were included only if they could still yield useful products (e.g. straight poles, timber, wood for charcoal) for the local people. Trees that had been completely felled were ignored for PCQM. On occasion *Rhizophora* sp. proved difficult to measure if the tree had lost its main stem, as the remaining tree form could 'walk', its prop roots and drop roots spreading laterally with new leading stems formed from branches below the cut point. If stems of *Rhizophora* sp. had been removed several years previous to the survey, some of the lateral connections joining parts of one tree might break, forming independent units. Therefore these sections were measured to a point

where an individual part of this ‘walking’ *Rhizophora* sp. tree could survive as an independent stable unit, following Dahdouh-Guebas and Koedam (2006) protocols.

Table 11. Summary of the data and measurements collected during the transects, which criterion they applied to, and where necessary, a brief description

Criterion	Indicators / Measures	Units	Description
Mangrove Quality	Canopy Closure	%	The ratio of visible sky to canopy overhead, calculated by hemispherical photography
	Leaf Area Index	ratio	The ratio of upper surface leaf area per unit of ground area covered
	Biodiversity	Simpson's Index	A measure of species biodiversity, which takes into account species present and relative abundance of each species
	Forest Structure Complexity Index	Index	Describes stand complexity such as foliage arrangement, canopy cover, tree height, tree diameter, tree density, understory vegetation, tree species and their relative abundance
	Tree Condition Rating	% of 'A' & 'B' trees	A qualitative rating of individual tree quality and usefulness for the local community, from A-D
Mangrove Sustainability	Juvenile Density	Per ha	Number of mangrove plants (not vines or creepers) with less than 3-4 leaf pairs and under 1.3m tall, per hectare
	Tree Diameter (Size Class) Distribution	cm	Diameter measured normally at 1.30m above the ground. Referred to in the text as DBH ¹³⁰
	Cutting per unit area	Per ha	Number of cut mangrove stems or branches over approx. 35mm diameter, per hectare, that are clearly man-made (
	PCQM Sampled trees with Cuts	%	Proportion of all PCQM sampled trees in each transect with stems / branches cut over 35mm, where the cuts are clearly man-made
	Tree Height	m	
	Tree Density	per ha	Trees per unit area
	Basal Area	m ² /ha	Summed cross-sectional area of all the trees in a unit area, measured at 1.30m above the ground
	Proportion of <i>Rhizophora</i> sp. trees in a transect	%	
	Salinity	ppt	Measured in parts of salt per thousand
	Distance, Village to Transect	km	
	Distance, Village to Nearest Town	km	
	Village population		All villagers of any age
	Mangrove Area (per person)	People/ha	
Mangrove Stand Age		Not Available	

4.3.3.2 Point Centre Quarter Method Data Capture

Detail is provided here to facilitate repetition by other researchers. For a full description of the protocol see Dahdouh-Guebas and Koedam (2006).

At each sample point, a pole was firmly inserted vertically into the mud to act as the central measuring point and a GPS point taken. A second stick was placed horizontally on the ground, perpendicular to the direction of travel. The surrounding area was divided into four quadrants, around the vertical stick. In each of the four quadrants the nearest tree was identified. For each of these four trees the following measurements were taken:

1. Distance to the tree
2. Tree Height
3. Tree Diameter
4. Tree Species.

1. **Distance** was measured from the central stick to the tree with the fiberglass tape measure. For trees growing at an angle, the distance to the part of the trunk which was 1.30m above the ground was measured. Multi-stem trees (e.g. *Excoecaria agallocha*) were measured to the centre of the main stem mass, visually judged.

2. Due to the density of much of the mangrove, tree **heights** could only be visually estimated from the ground. Within the mangroves, use of a clinometer frequently proved impossible. On occasion the upper halves of the trees were not visible even from directly underneath them. If possible, a measure of a stand height was taken before entering the mangrove, as many stands were even-age class plantations. For shrubby-formed and often recumbent species like *Scyphiphora hydrophyllacea*, measurements were taken along the tree length, not vertical height.

3. **Diameter** was measured using a Charter House, Richmond fibreglass tree diameter tape to the nearest centimetre, taking care to avoid stem protrusions. Normally diameter was measured at breast height (DBH) 1.30m above the ground. For *Rhizophora* sp. DBH was measured either at 1.30m above the ground or 30cm above the highest emerging prop root, which could be several meters above the ground, whichever was the lower. For multi-stem trees, all the main stems were measured, their DBHs being summed during data analysis. For protocol details about measuring the DBH¹³⁰ of trees with low forks, or measuring multi-stem trees, see Dahdouh-Guebas and Koedam (2006).

4. **Species** were noted, aided by a species chart (Appendix D. Yong, undated).

4.3.3.3 Point Centre Quarter Method and Basal Area

An excel workbook developed by Dahdouh-Guebas and Koedam (2006) calculated basal area, tree density and complexity measures from the raw data. This workbook template is freely available at <http://www.vub.ac.be/APNA/staff/FDG/pub/pub.html> Year 2006, line 39.

4.3.3.4 Size Class Distribution Description and Analysis

Size class (diameter) distribution of the demographics of the PCQM trees and juveniles was analysed for implied sustainability. Relatively high number of juveniles, followed by descending numbers of

trees at larger size classes, which fit an exponential curve when the numbers of each size class are plotted on a chart, is widely assumed to be indicative of an ecologically sustainable forest.

Each transect collected DBH¹³⁰ measurements for up to 40 trees, and numbers of juveniles in the surrounding 250m². To make size class distributions from different transects comparable, distributions were calculated on a per hectare (ha) basis. DBH¹³⁰s were grouped into incremental 5cm size class categories, however the first category was 2.5cm DBH (the minimum for a ‘tree’) to 4.9cm DBH, into which the juveniles were combined. If present, trees larger than 30cm DBH were grouped into a final category. Using the mid-point for each size class category, and 32.5cm DBH for the final category, the distribution for each transect was then plotted in Excel and an exponential line fitted. As an example, Fig. 35 depicts the size class distribution from transect 6 of village P1A.

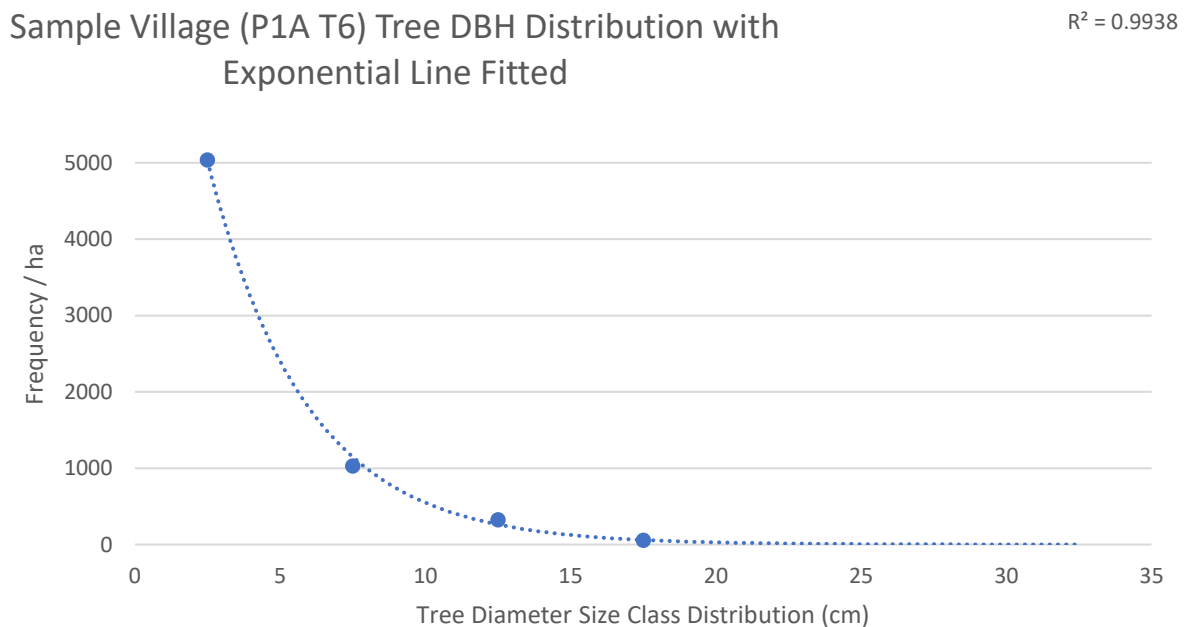


Figure 35. A sample size-class distribution from one transect (P1A, transect #6) with an exponential curve fitted. The figures have been converted to per ha data for ease of comparison. The curve fits this size class profile closely (R²= 0.99)

Size class categories with no trees were omitted as a score of zero in a category inhibited an exponential curve being produced. The closeness of the fit to the curve was described by the ‘R²’ coefficient, which ranged from 1 (perfect fit) to 0.09 (a poor fit). Further analysis involving size class distribution was restricted to transects with a ‘goodness of fit’ R² score of ≥ 0.8 (n=29).

The exponential curve was described by two parameters, ‘X’ and ‘Y’. X described the slope of the line (i.e. the rate of tree mortality) and Y indicated the exponential trendline intercept at zero (number of juveniles per ha needed to suggest a sustainable forest). Fig. 36 illustrates the

relationship between the closeness of the exponential line fit (x-axis) described by an R^2 score, and the steepness of the trend curve slope, described by the x-coefficient (y-axis). The slope measurement was used as a dependent variable for further analysis to assess what other measures size class distribution related to.

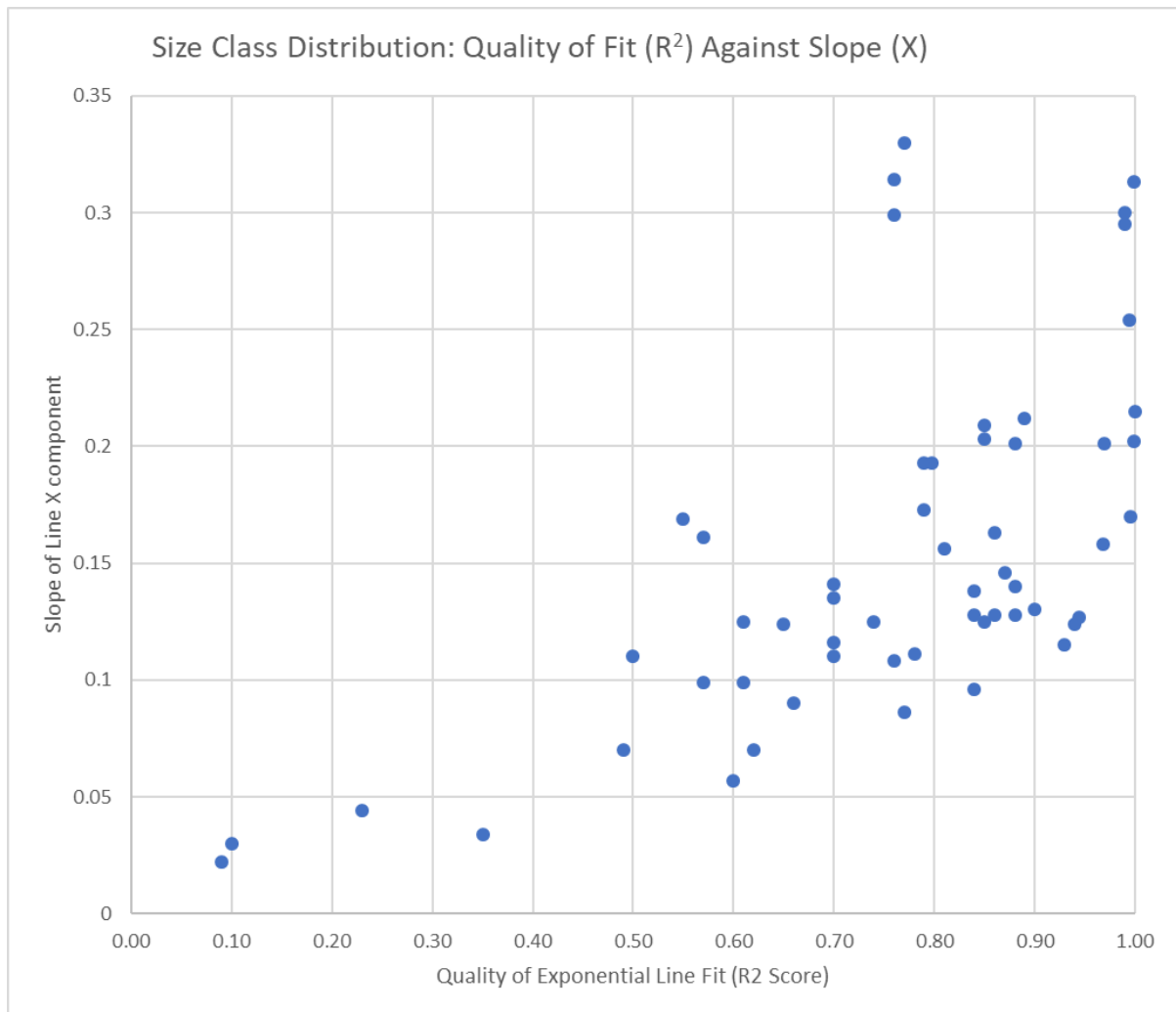


Figure 36. Graph showing the rate of tree mortality (y axis) against the goodness of fit of each transect's size class distribution against an exponential curve, (x axis). Poor fit was due largely to too few juveniles/ha, or in some cases huge numbers of juveniles/ha.

4.3.4 Cutting Assessment Measurements

Further data were captured to assess levels of cutting:

5. Number of Cuts to the PCQM sample trees (stem or branch)
 6. Cut trees / ha.
5. The proportion of all **PCQM sample** trees with cuts to either main branches or stems were counted, if the cuts were at least 35mm diameter and recent enough for the cut to be obviously

man-made rather than by tree fall, storm damage or natural wastage, indicated by blade marks and flat surfaces. Old, decayed cuts which were questionable were not included, as per Walters (2004).

6. On each side of the sample point, perpendicular to the direction of the transect, two 5m² boxes were marked out. Within these boxes cut stems and significant cut branches were counted (excluding cuts to the four PCQM trees). As above, only cut stems / branches >35mm diameter were included, having been clearly cut with a blade (e.g. straight cuts from a chainsaw or blade) and for stems, recent enough not to be dislodged when pushed by foot. Decayed stems that broke or fell over when pushed by foot were excluded.

4.3.5 Additional Mangrove Quality and Sustainability Measures

7. Juveniles / ha

8. Hemispherical photography of the canopy

9. Tree condition rating (A-D)

10. Salinity

11. Stand Age

7. **Juvenile mangrove** seedlings. To qualify as a juvenile, a plant had less than 3 - 4 leaf pairs maximum, <1.30m tall and could still fail to survive, in the judgement of the researcher. Juveniles from two 2.5m x 5m boxes were counted at each sample point. Vines, creepers such as *Acanthus* sp., *Finlaysonia* sp., *Derris indica*, the fern *Acrostichum* sp. and shrub-layer plants were ignored as these species were not used by villagers.

8. **Hemispherical photography** provided an objective method of assessing the ratio of open sky to closed tree canopy. While acknowledging that some more natural arid mangrove forest ecosystems might have sparse trees with significant gaps between them, in these research areas the species encountered, planting densities deployed and the abundance of water permitted an assumption of an eventual closed canopy structure. Therefore, it was assumed that a more closed canopy was indicative of a higher quality forest than an open canopy with more visible sky (section 4.2.3).

Photography of the canopy was taken at three points at each of the 10 PCQM sample points - at the sample point itself and 5m either side of the sample point, perpendicular to the direction of the transect. To avoid selecting points which were easy to photograph, the distance from the PCQM centre point was measured out exactly with the fiberglass tape, the direction of which was judged using a Silva compass. However, the exact location at which a photograph was taken had to be altered occasionally to avoid sunlight striking the lens directly which would adversely affect the

analysis of the photo. The position of the camera would also be amended if there was any vegetation less than 2m above the lens, as this would cause the rest of the photograph to be out of focus and thus make classification impossible.

The photography was taken with a Pentax K7 body and a Sigma 4.5mm F2.8 EX DC Circular Fisheye lens. After experimentation no improvements of photo classification came from changing the camera sensor's focal area or the light metering spot, so these settings were left at overall and total frame metering respectively. The ISO photo quality setting was restricted to a maximum of 800. The shutter release was set to a two second delay to ensure minimal camera movement on the tripod. The camera was mounted onto a carbon fibre tripod at approximately 1m high, but this would vary considerably depending on how deep the feet of the tripod penetrated the mud below or water depth. The top of the camera was aligned to magnetic north by use of a Silva compass. The transparent body of the compass allowed the 'T' of the brand name 'Pentax' on the camera body to be aligned with the north / south needle, thus ensuring that the top of the photograph was pointing directly magnetic north. Hemispherical canopy photography required that the camera pointed precisely vertical. Vertical alignment of the lens was achieved by balancing a 3-direction spirit-level on the lens cap before each photo was taken. Each photograph data file was approximately 4.5MB. For a detailed discussion of hemispherical photography, see Chianucci and Cutini (2012); Promis et al. (2011) and Delta-T Devices Ltd.'s website³⁵.

The hemispherical canopy photography was processed using 'Fiji' thresholding software (Schindelin et al., 2015) and Gap Light Analyser v2.0 (Frazer et al., 1999). Leaf area index was calculated using five rings which took into account a larger area of the sky, from 0-75 degrees.

9. A **condition rating** between A-D was given to each of the four trees sampled at each PCQM sample point. An evaluation scheme using eight factors where appropriate was applied to categorise each tree from A-D. The factors for each category are described below. Photographic examples of each can be seen in the Appendix L.

'A'. Good condition. Stable with very limited or no damage. An appropriate height / diameter ratio, visually judged. Balanced crown. Tree not suppressed by taller neighbouring trees. Limited leaf herbivory. No die back of the crown, particularly at the top. Depending on the species, limited accumulation of dead wood. Tree useful to villagers and appropriate for building, including a straight stem, depending on the species.

³⁵ <http://www.delta-t.co.uk/product/hemiview/#overview> Accessed 28.3.2017

'B'. Reasonable condition. Damage to side branches only, or minimal stem damage only (not at the base). Marginally too tall for its height (due to plantation planting). Partially unbalanced crown or partially suppressed due to near neighbours. Minor levels of leaf herbivory or some dead wood, but nothing significant at the top (which would suggest root die-back). Stem intact but not straight and therefore of less use for villagers, particularly for building, but the timber is still useful for other purposes.

C. Poor condition. Stem damage and significant wounds, particularly near the base of the tree. Suppressed by overhanging trees and therefore unbalanced crown and angled growth. Significantly 'drawn up' by competing for light with close neighbouring trees, being too tall for its diameter and therefore very vulnerable to stem snap if neighbouring trees are removed. Leaves suffering from significant herbivory. Poor tree form, such as bent stems or compression joints at the base between stems. Canopy / top die back due to tree stress or natural damage. Significant deadwood where it would normally not be present on that species. Perhaps useful to the villagers for charcoal or minor wood products such as fencing posts or fish aggregating devices.

D. Dying, significantly stressed or seriously damaged / decayed tree. Serious to existential damage. Perhaps decayed or hollowed out trunk of the tree (particularly mature *Xylocarpus* sp). Unbalanced or lopsided crown or crown only in one direction. Inappropriate height / DBH ratio or perhaps reset by stem snap. Suppressed with closed canopy overhead. Seriously debilitating levels of herbivory. Significant die-back of the crown or tree retrenchment. Significant levels of deadwood, beyond what would be expected for the species. Timber and stem of very limited use for villagers other than for charcoal.

Taking into account these factors, trees that had only one or two issues were given an A. If a tree had three or four of the issues listed, it scored a B. If there were five or six problem areas, the tree was given a C. Trees in very poor condition with many problems gained a D. The analysis used the proportion of 'A's and 'B's within a transect as a measure of better or worse condition rating.

10. **Soil salinity** was measured either from available soil pore water or groundwater sourced from minor excavations up to 15cm deep (Bellingham and Stanley handheld refractometer). This was conducted at two points per PCQM sample point, 5m away perpendicular to the direction of the transect. The refractometer was calibrated daily with fresh water. On several occasions the survey area was flooded, and therefore, general salinity was taken of the floodwater.

11. **Mangrove Stand Age.** No accurate records were available from either government mangrove field offices or local village administrators concerning the post-concession planting activity. It quickly became apparent that stand age estimations were either inaccurate or inconsistent.

All data was recorded on a pre-printed data sheet (Appendix M).

4.3.5.1 *Forest Structure Complexity Index (FSCI)*

FSCI produces a measure of mangrove spatial forest structure by combining tree heights, number of species, tree densities and basal areas (McElhinny et al., 2005). This study used 'maximal average height' for consistency, because in the majority of transects the forest structure was uniformly developed, even-age class plantation without strong seasonal disturbance (Blanco et al., 2001). For FSCI calculations in this study, plants <2.5cm diameter at breast height (DBH) have been omitted. As per basal area (section 4.3.3.3) the FSCI calculations were performed by the excel workbook developed by Dahdouh-Guebas and Koedam (2006). This complexity index (C.I.) was calculated using their formula.

$$C.I. = \frac{m \times Ba \times \bar{h} \times De}{1000}$$

m = number of species

Ba = basal area

h = mean stand height

De = relative density

4.3.5.2 *Biodiversity*

Biodiversity was assessed by the proportion of *Rhizophora* sp. within a transect sample and also by calculating Simpson's diversity index (Simpson, 1949). This produces a measure of biodiversity, taking into account the number of species (here of the mangrove trees species only) as well as the abundance of each species. This was calculated using the following formula.

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

n= the total number of plants of a particular species

N= the total number of plants of all species

The scale runs between 0 and 1. As species richness and evenness rise, the score increases from 0 being the least biodiverse to 1 being the most diverse.

4.3.6 Research Method Limitations

Hemispherical photography was negatively affected if sunlight was shining directly into the lens. Having established the exact point where each photo should be taken, minor lateral adjustments were made to avoid direct sunlight striking the camera. This resulted in fewer photographs taken in the middle of a clearing and therefore minor increases of canopy closure percentages. It proved impossible to measure the heights of many mangrove trees with a clinometer, due to high tree density planting, canopy closure and lower canopy obstructing the view of the tops of the trees. In these cases, estimates were developed guided by standard tree measurements, when conditions and space allowed, and measurements from outside a mangrove stand before commencing a transect. Size class data omitted mangroves above 'juvenile' (three or four-leaf pairs maximum, <1.3m), but smaller than a 'tree' ($\geq 2.5\text{cm DBH}^{130}$, >1.3m tall). As mangroves tend not to have an understory, this resulted in very few plants were omitted. Salinity measurements might have been affected because some of the back mangrove sites were too dry to yield soil-water, even after excavating a small borehole. Salinity measurements could also have been affected by precipitation preceding some of the transects. Size class distribution analysis was occasionally affected by very large numbers of juveniles (most commonly under the canopy of mature *Avicennia* sp. trees) which reduced the level of fit of the exponential curve. Furthermore, some distributions were slightly better than might otherwise have been expected, due to having data in fewer size classes. Distances between transect and village were difficult to measure as most of the villages were formed of clusters of houses scattered throughout the villages' areas, rather being based around true centres. Ages of plantations surveyed were not analysed due to the inaccuracy and inconsistency of reported planting dates and lack of documentation.

In the generalized linear model analysis, forest structure complexity index (FSCI) is a composite measure that includes basal area and tree density. It also includes the number of species which here is reflected in the proportion of *Rhizophora* sp. in a transect. Therefore if these two factors are included there is an element of auto regression. However, they have been retained within the analysis as they still predict FSCI – the objective of this ranking system.

4.4 ANALYSIS

4.4.1 Generalized Linear Model Analysis

Using SPSS v25, a generalized linear model (GZLM) was used to explore and analyse the data taken during the transects, to investigate which of the variables explained a significant portion of the variance for each potential indicator. GZLM analysis is able to examine data sets that contain non-normal distribution, categorical data and does not require the error distributions to follow a normal distribution. Each proposed indicator (section 4.2.3) was tested separately as a dependent variable with the other measures as covariates, due to the limited number of data points (as a rule of thumb, the number of predictor variables should be no less than 10 per dependent variable, Field, 2018). The effect of transects being conducted in different villages was investigated by including 'village' as a fixed factor. In all GZLM tests the Omnibus Test was significant ($p < 0.001$, $df = 17$). This test examines whether the explained variance in a set of data is significantly greater than the unexplained variance overall. All factors and covariates were examined for Type III, main effects.

4.4.2 Hierarchical Multiple Regression Analysis

For more in-depth analysis hierarchical multiple regression (HMRA) was used to validate and expand on the potential predictive models suggested by the GZLM analysis. HMRA allowed analysis of the bio-physio-socio factors to quantify the level of variation within each mangrove quality or sustainability indicator explained by the different combinations of alternative, simpler measures. More specifically HMRA provides a framework to construct a series of regression models by adding additional variables to previous models at each iteration, thus indicating which variables add a significant improvement to the R^2 score (the proportion of explained variance in dependent variable by a model) and which variables have little input.

The statistically significant measure(s) from the GZLM output were used as predictors in the first HMR analysis block and all the other non-significant measures in the second HMR block, hence the 'hierarchical' nature of the analysis. (Grouping all other measures into a second block is referred to as 'forced entry', Field, 2018). Otherwise there was no natural order for analysis of other measures. HMRA is also robust with relatively small sample sizes. Given the small sample size for this type of analysis, all the data were used during this analysis, rather than keeping one half to test a model against the other half.

4.4.3 Statistical Tests

Independent samples t-tests were used to test whether there was a statistical difference between basal areas and tree densities in Thailand and the Philippines. A Levene's test was not significant.

The null hypothesis for both was that there was no statistical difference between countries for either statistic. Furthermore, whether there was a significant relationship between tree density and basal area was explored using a Pearson's Correlation. The null hypothesis was that there was no significant relationship between them.

The difference in tree heights between Thailand and the Philippines were examined with an independent samples t-test. A Levene's test was not significant. The null hypothesis was that there was no significant difference between tree heights in the two countries.

The relationship between tree density and salinity was examined with by Spearman's correlation. The null hypothesis was that there was no significant relationship between tree density and salinity.

The relationship between basal area and salinity was examined with a Spearman's correlation. The null hypothesis was that there was no significant relationship between basal area and salinity.

The difference between Thai and Philippine forest canopy closure was examined by an independent samples t-test. A Levene's test was not significant. The null hypothesis was that there was no significant difference between the canopy closure percentage in the two countries.

The difference between Thai and Philippine forest structure complexity index (FSCI) was examined by a Mann Whitney-U test. The null hypothesis was that there was no significant difference between FSCI in the two countries.

The difference in Simpson's Diversity index between Thailand and the Philippines was examined with an independent samples t-test. A Levene's test was not significant. The null hypothesis was that there was no significant difference between the Simpson's Diversity index in the two countries.

Tree condition rating was examined by an independent samples t-test to explore whether the condition of the trees was significantly different between Thailand and the Philippines. The null hypothesis was that there was no statistically significant difference.

The difference in juvenile density between countries was tested with a Mann Whitney-U test. The null hypothesis was that there was no statistically significant difference between Thailand and the Philippines.

The difference in stem and significant branch cutting (over 35mm diameter) between countries was examined with a Mann Whitney-U test. The null hypothesis was that there was no statistically significant difference between Thailand and the Philippines.

The difference between the levels of cutting of the PCQM trees sampled in Thai and Philippine forest was examined by a Mann Whitney-U test. The null hypothesis was that there was no significant difference between PCQM tree cutting in the two countries.

The sustainability of the forests as suggested by the size class distribution was examined by an independent samples t-test to explore if the closeness of fit to the exponential curve was significantly different between Thailand and the Philippines. A Levene's test was not significant. The null hypothesis was that there was no statistical difference.

4.5 RESULTS

4.5.1 Overall Results

4.5.1.1 *Bio-Physical Overview: Basal Area, Tree Density, Salinity, Condition & Height*

Tree demographics were similar to the results recorded by other researchers (e.g. Alongi and de Carvalho, 2008; Asaeda et al., 2016; Kairo et al., 2008; Saenger, 2002). For transects, basal area ranged from 6 - 48.2m²/ha, with a mean of 22.7m²/ha (N=57, SD±8.7m²/ha). Tree density varied from 720/ha to 8,471/ha. Mean tree density was 2,454/ha (N=57, SD±1,507/ha), close to what would be expected for 2x2m spacing plantation (i.e. 2,500 trees/ha). There was no significant difference between basal area (t(55)=-0.75, p=0.46) or tree density (t(55)=0.78, p=0.44) in the Philippines compared to Thailand. Nor was there an overall relationship between basal area and tree density (r(57)=-0.12, p=0.36). Across all transects, mean tree height was 8.8m (N=57, SD=±2.7m). Thailand's mangroves averaged 9m compared to the Philippines' 8m but the difference was not statistically significant (t(55)=1.26, p=0.95). Salinity extended from fresh water to 41 parts per thousand (ppt), with a mean of 25ppt. The inverse relationship between tree density and salinity was significant at the 5% confidence level, (r(55)=-0.267, p=0.049), and between salinity and basal area (r(55)=-0.274p=0.043). The area of mangrove owned by each village varied from 126 - 3,894ha, the mean being 828ha (median 407ha). Mangrove area appeared not to relate to any other measure, including levels of cutting or biodiversity. Village populations lay between 660 - 3,000 people, the mean being 1,480. Mangrove area per person varied between 0.04 - 5.7ha/person with a mean of 1ha/person (SD±1.8ha/person, median 0.3ha/person).

4.5.2 Mangrove Quality Indicators

Indicators that contributed to the criterion of mangrove quality included canopy closure, leaf area index (LAI), forest structure complexity index (FSCI), Simpson's (biodiversity) index and tree condition rating. Canopy quality was assessed by hemispherical photography to measure canopy closure and LAI. At the planting densities deployed and with time since the end of the concessions to grow, predominantly mid zone species encountered during this research would eventually develop a closed canopy if undisturbed. Therefore any reduction in canopy closure was regarded here as indicating lower quality mangrove. Mean canopy closure was 68.9% (SD=±7%) ranging from 50.8 - 79.6%. The Philippines' forests (mean=61%) were significantly more open than Thailand's mangroves (71.7%, t(55)=6.8, p<0.001). LAI, ranging between 0.8 - 1.67 was at the lower end of findings from Salmo III et al. (2013) and lower than the 3.99 LAI that Kairo et al. (2008) described. LAI formed a very close inverse relationship with canopy closure (R²=0.96), therefore the

relationships described with canopy closure were also observed with LAI. There was no significant difference between Thailand and the Philippines' FSCI, ($U=255$, $Z=-1.08$, $p=0.28$, section 4.3.5.1). FSCI ranged from 4.3 to 214, with a mean of 38 ($N=57$, $SD\pm 34$). Simpson's Diversity Index (section 4.3.5.2) produced a range between zero to one with one being the most biodiverse. Here the mean was 0.64 ($SD\pm 0.16$) with no significant difference between the countries ($t(55)=0.29$, $p=0.77$). It should be noted that even though the proportion of *Rhizophora* sp. had a significant impact on the Simpson diversity Index it was not a linear relationship ($R^2 = 0.07$) with an inflection at 90% *Rhizophora* sp., Fig. 37.

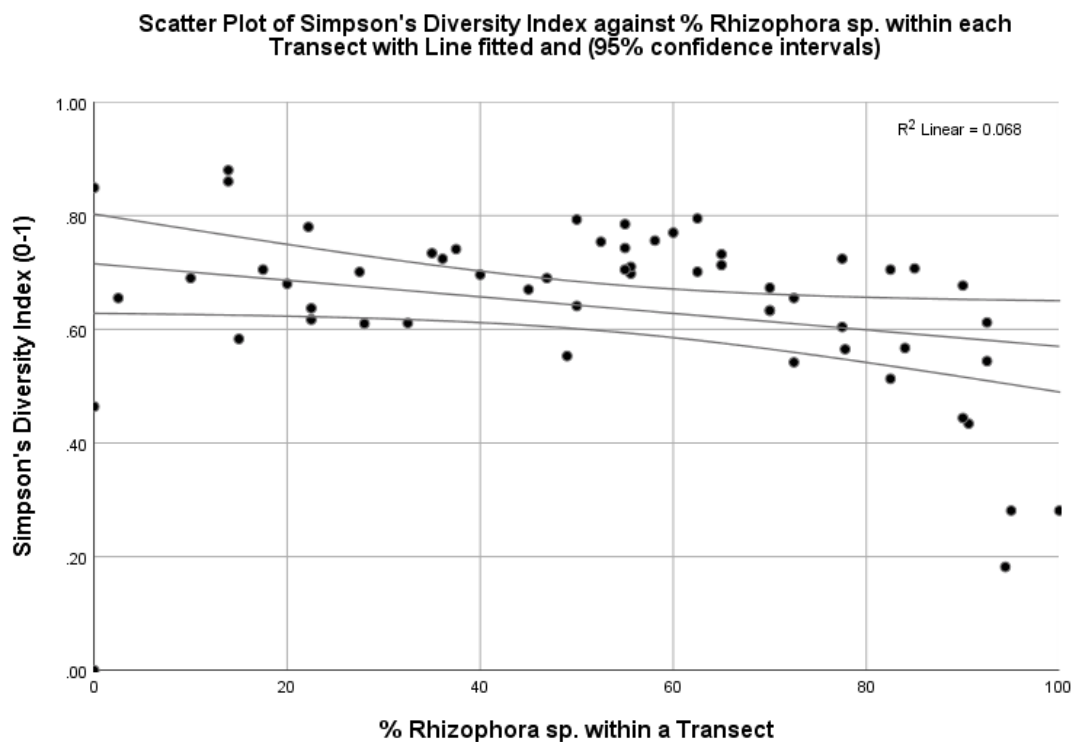


Figure 37. The relationship between biodiversity and the proportion of *Rhizophora* sp. in a transect was approximately linear, with an inflection at the 90% *Rhizophora* mark. The slope was not as steep as might be expected due to the generally limited numbers of other species in these countries' mangroves.

Trees sampled were nominated into one of four condition categories (section 4.3.5), ranging from 'A' (stable, appropriate height to girth ratio, a good specimen, valuable to local people) to 'D' (unstable, dying, diseased, very poor form, severely damaged, of little use to local people). Overall, 7% received an 'A' classification, 27.5% a 'B', 'C's 59% and 7.3% received a 'D' classification. Combining 'A's and 'B's together (i.e. the better 34.6% of trees that were of greater value to local people), the range of 'A' and 'B' trees per transect ranged between 3% and 73% with a median of 34.2% ($SD\pm 15.3\%$) which was similar in both countries ($t(55)=-1.94$, $p=0.06$).

4.5.3 Mangrove Sustainability Indicators

Indicators that contributed to the criterion of mangrove sustainability included juvenile mangrove density, levels of cutting and size class distribution. Juvenile density varied greatly with a mean of 4,620/ha, ranging from 120 to 62,800/ha (N=56, SD±9,080) but with no significant difference between countries (U=309, Z=-0.1, p=0.91). The overall level of cutting of stems and branches was 720/ha (N=55, SD±1,500/ha). The slight difference in cutting levels between Thailand (680 cut stems/ha, n=40, SD±1,170) and the Philippines (828 cut stems/ha, n=15, SD±2,207) was not statistically significant (U=235, Z=-1.23, p=0.22). Point Centre Quarter Method (PCQM) transects necessitate four trees being sampled at each sample point. 2,224 trees were assessed in total with a minimum of at least 30 trees per transect. Significant cutting of these trees (branches or stems cut with a greater diameter than 35mm), was recorded. The proportion of PCQM-sampled trees with significant cuts was 7.3% (N=57, SD±9.2), Thailand's mean being 6.2% of trees with cuts (n=42, SD±8.2) and the Philippines' 9% (n=15, SD±11.8) which was not a significant difference (U=292, Z=-0.42, p=0.64). The sustainability of the mangrove stands suggested by the size class distribution was not significantly different between countries (t(55)=0.05, p=0.96). The closeness of fit to the exponential curve (R²) score had a mean of 0.75, (N=57, SD±0.21) and the distributions 'x' coefficient between the countries had a mean of 0.15, (N=57, SD±0.07).

4.5.4 Mangrove Quality: Generalized Linear Model Analysis

The bio-physical features that made up the potential mangrove quality indicators and other measurements that might predict these indicators were initially assessed via a Generalized Linear Model (GZLM, section 4.4.1). Each mangrove quality indicator was analysed individually due to the different possible definitions of mangrove quality (section 4.2.3) and the restricted number of data points. Table 12, which combines only the significant output at the 95% confidence level or better, from the four GZLMs, summarises the significant relationships. The stronger relationships are highlighted in darker green (key at the bottom of Table 13).

Table 12. Generalized linear model output summary for the four mangrove quality indicators.

Mangrove Forest Quality Indicators	Other Bio-Physical Measures that Related to a Quality Indicator within the GZLM	Df	Significant Model Effects (min. 95% confidence level)
Canopy Closure			
	Tree Density / ha	1	.031
Simpson's Diversity			
	% <i>Rhizophora</i> sp. within a Transect (inv)	1	.000
	Village Effect	7	.034
	Mangrove Area per Person (ha) (inv)	1	.043
Forest Structure Complexity Index			
	* Basal Area m ² /ha	1	.000
	* Tree Density / ha	1	.000
	*% <i>Rhizophora</i> sp. within a Transect (inv)	1	.014
Tree Condition Rating			
	Village Effect	7	.000
	Tree Height (m)	1	.001
	% <i>Rhizophora</i> sp. within a Transect (inv)	1	.015
	Village Population	1	.024
	Distance Between Village & Nearest Town (inv)	1	.027
Dark green, p≤0.001	Mid green, p<0.025		Light green, p<0.05

'Inv' denotes inverse relationship. * Basal area and tree density are components of FSCI. Indirectly, %*Rhizophora* sp. is also an element of the FSCI. See Research Method Limitations section (4.3.6)

Canopy closure was associated with tree density ($p=0.031$, $df=1$). Simpson's diversity index could be predicted by the proportion of *Rhizophora* sp. in a transect ($p<0.001$, $df=1$) as well as the mangrove area per person ($p=0.043$, $df=1$), both inverse relationships. However, there was also a significant village effect ($p=0.034$, $df=7$), i.e. a difference produced by the effect of a change of location. As would be expected, FSCI, was significantly associated with basal area and tree density (both $p<0.001$, $df=1$). However, it was also inversely related to the proportion of *Rhizophora* sp. in a transect ($p=0.014$, $df=1$) but not affected by changing village. and Tree condition rating was associated with tree height ($p=0.001$, $df=1$) and village population ($p=0.024$, $df=1$), and inversely with the proportion

of *Rhizophora* sp. in a transect ($p=0.015$, $df=1$) and the distance between the village and the nearest town ($p=0.027$, $df=1$). However, there was also a significant village effect ($p<0.001$, $df=7$).

4.5.5 Mangrove Sustainability: Generalized Linear Model Analysis

Bio-physical and socio-geographic measures from the mangrove forests that might predict the four mangrove sustainability indicators were also assessed via a Generalized Linear Model in a similar manner. As before, each mangrove indicator was assessed individually due to the number of available data points. Table 13, which combines the significant output from the four GZLMs, summarises the significant relationships. Again, the effect of changing village was included. Darker green indicates a more significant relationship.

Table 13. Generalized linear model output for the four mangrove sustainability indicators

Forest Sustainability Indicators	Other Bio-Physical Measures that Related to a Sustainability Indicator within the GZLM	df	Significant Model Effects (min. 95% confidence level)
Juvenile Density (ha)			
	Tree Density / ha (inv)	1	.044
Tree Size Class Distribution			
	Village	7	.004
	Tree Density / ha	1	.017
Number of Cut Stems & Branches / ha			
	Tree Density / ha	1	.000
	Village	7	.002
	% <i>Rhizophora</i> sp. within a Transect (inv)	1	.012
	Basal Area m ² / ha (inv)	1	.013
% of PCQM Trees with Significant Cuts			
	% <i>Rhizophora</i> sp. within a Transect (inv)	1	.025
Dark green, $p\leq 0.001$	Mid green, $p<0.025$		Light green, $p<0.05$

'Inv' denotes an inverse relationship

Table 13 reveals that juvenile density was inversely related to tree density ($p=0.044$, $df=1$). A sustainable size class distribution appeared to be affected by the change of village ($p=0.004$, $df=1$) as well as tree density ($p=0.017$, $df=1$). Levels of cutting per hectare were most closely linked to tree density ($p<0.001$, $df=1$) and inversely with the proportion of *Rhizophora* sp. in a transect ($p=0.012$, $df=1$) and basal area ($p=0.013$, $df=1$). There was also a significant village effect ($p=0.002$, $df=7$). Finally, the proportion of trees sampled within the transects with significant cuts was inversely associated with the proportion of *Rhizophora* sp. within the transects ($p=0.025$, $df=1$).

4.5.6 Hierarchical Multiple Regression Analysis

Hierarchical multiple regression analysis (HMRA) was used to probe the relationships suggested by the GZLM in greater depth, to cross-check whether it was possible to develop predictive models for mangroves quality and sustainability, and whether is possible to substitute in easier-to-measure forest features to avoid components that were more difficult to measure or analyse. Indicators were analysed one at a time because of the limited data points per indicator. Significant factors revealed from the GZLM analysis (column 2, Tables 12 and 13) were used as the first stage of the hierarchy within each regression (third column in Tables 14 and 15). All other measures formed the second stage of the hierarchy. HMRA suggested between 1-5 possible predictive models for each indicator, made up of a combination of various measures (4th column). Each potential model explained a different amount of variance (R^2 score, 5th column). The model with the highest R^2 value for each indicator has been included in Tables 14 and 15. Again, shades of green indicate significant relationships that are key to these models (eighth column). The output has been collated and summarised in Tables 14 and 15. 'Village effect' refers to the influence of changing research village.

Table 14. A summary of the hierarchical multiple regression analyses for each of the four mangrove quality indicators. A colour code key for column 8 is at the bottom of Table 15. A minus sign (columns 6 & 7) denote an inverse relationship.

Criterion	Indicator	Key Predictor(s) from Generalized Linear Model	Hierarchical Multiple Regression Model Predictors (max explained variance). Model uses the following measures	R ²	Standardised		Sig.	
				(model fit) Variance Explained	Coefficient. Beta	t		
Mangrove Quality	Canopy Closure	Tree density	Village Effect	0.72	-0.524	-1.816	0.076	
			Salinity		-0.445	-3.264	0.002	
			% <i>Rhizophora</i> sp within a Transect		0.292	2.718	0.009	
			Tree Density		0.235	1.934	0.06	
			Distance from a Town Amended (km)		-0.165	-1.164	0.251	
			Mangrove Area per Person Amended (ha)		-0.136	-0.91	0.368	
			Distance from Transect to Village (km)		0.126	1.016	0.315	
			Tree Height (m)		0.032	0.239	0.813	
			Juveniles/ha		-0.013	-0.129	0.898	
			Village Pop		0.006	0.019	0.985	
Simpson's Diversity	% <i>Rhizophora</i> sp within a Transect	Village Effect	% <i>Rhizophora</i> sp within a Transect	0.43	-0.549	-3.537	0.001	
			Salinity		-0.419	-2.132	0.039	
			Mangrove Area per Person (ha)		Tree Density / ha	-0.337	-1.926	0.061
			Village Pop		0.286	0.651	0.518	
			Village Effect		-0.249	-0.598	0.553	
			Juveniles / Ha		-0.201	-1.39	0.172	
			Distance from a Town Amended (km)		0.183	0.898	0.374	
			Tree Height (m)		-0.098	-0.502	0.618	
			Mangrove Area per Person (ha)		0.052	0.242	0.81	
			Distance from Transect to Village (km)		0.039	0.221	0.826	
FSCI	Basal Area m2/ha	Tree Density / ha	Basal Area m2/ha	0.74	0.641	5.871	<0.001	
			Village Pop		-0.442	-1.428	0.161	
			% <i>Rhizophora</i> sp within a Transect		Tree Density / ha	0.352	2.839	0.007
			Village Effect		0.34	1.201	0.237	
			Tree Height (m)		-0.188	-1.283	0.207	
			Distance from Transect to Village (km)		0.175	1.449	0.155	
			Distance from a Town Amended (km)		-0.162	-1.163	0.251	
			Mangrove Area per Person Amended (ha)		-0.16	-1.096	0.279	
			% <i>Rhizophora</i> sp within a Transect		-0.115	-1.059	0.296	
			Salinity		-0.08	-0.542	0.591	
Juveniles / Ha	-0.032	-0.309	0.759					
Tree Condition Rating	Village Effect	Tree Height (m)	Village Effect	0.52	0.734	1.983	0.054	
			Village Pop		-0.363	-0.934	0.355	
			% <i>Rhizophora</i> sp within a Transect		Tree Height (m)	0.343	2.066	0.045
			Village Population		Salinity	-0.183	-1.051	0.299
			Distance Between Village and Nearest Town (km)		% <i>Rhizophora</i> sp within a Transect	-0.108	-0.826	0.413
			Distance from Transect to Village (km)		0.097	0.61	0.545	
			Distance from a Town Amended (km)		0.04	0.223	0.825	
			Tree Density / ha		-0.034	-0.233	0.817	
			Mangrove Area per Person (ha)		-0.02	-0.11	0.913	

Table 15. A summary of the hierarchical multiple regression analyses for each of the four mangrove sustainability indicators.

Criterion	Indicator	Key Predictor(s) from Generalized Linear Model	Hierarchical Multiple Regression Model Predictors (max explained variance). Model uses the following measures	R ²	Standardised		
				(model fit) Variance Explained	Coefficient. Beta	t	Sig.
Mangrove Sustainability	Juvenile Density	Tree Density / ha	Tree Height (m)	0.37	-0.405	-2.085	0.043
			Tree Density / ha		-0.367	-2.117	0.04
			Village Population		0.364	0.803	0.426
			Mangrove Area per Person Amended (ha)		0.355	1.633	0.11
			% <i>Rhizophora</i> sp within a Transect		-0.315	-2.045	0.047
			Distance from a Town Amended (km)		-0.217	-1.038	0.305
			Village Effect		-0.176	-0.407	0.686
			Salinity		0.105	0.515	0.609
			Distance from Transect to Village (km)		0.071	0.386	0.701
			Size Class Distribution		Village Effect	Tree Density / ha	Village Effect
Salinity	-0.422	-2.863		0.006			
Village Population	0.367	1.12		0.269			
Tree Height (m)	-0.364	-2.587		0.013			
Distance from a Town Amended (km)	0.336	2.211		0.032			
Tree Density / ha	0.224	1.789		0.08			
Distance from Transect to Village (km)	-0.161	-1.195		0.239			
% <i>Rhizophora</i> sp within a Transect	-0.071	-0.637		0.527			
Mangrove Area per Person Amended (ha)	0.026	0.168		0.867			
Cutting/ha	Tree Density / ha	Village Effect	Village Pop	0.65	0.823	2.323	0.025
			Village Effect		-0.714	-2.17	0.036
			% <i>Rhizophora</i> sp within a Transect		0.578	3.961	<0.001
			Basal Area		-0.488	-4.024	<0.001
			Mangrove Area per Person Amended (ha)		0.361	2.181	0.035
			Tree Height (m)		0.35	2.031	0.049
			Salinity		0.271	1.574	0.123
			Basal Area m2/ha		-0.186	-1.521	0.136
			Distance from Transect to Village (km)		-0.185	-1.332	0.19
			Distance from a Town Amended (km)		0.006	0.037	0.971
%PCQM trees with Cuts	% <i>Rhizophora</i> sp. within a transect	Village Effect	Village Effect	0.27	-0.725	-1.578	0.122
			Tree Density / ha		-0.383	-2.088	0.042
			Distance from a Town Amended (km)		0.357	1.599	0.117
			% <i>Rhizophora</i> sp within a Transect		-0.235	-1.444	0.156
			Distance from Transect to Village (km)		0.189	0.956	0.344
			Salinity		0.181	0.837	0.407
			Village Pop		0.119	0.248	0.806
			Mangrove Area per Person Amended (ha)		-0.068	-0.294	0.77
			Tree Height (m)		0.02	0.098	0.922

Predictive models for the four indicators making up the mangrove quality criterion had model fits from 43-74% variance explained, and for sustainability 27-66% variance. The standardised coefficient Betas (in units of standard deviation, column 6) allow them to be compared directly with each other.

Similar to the GZLM, the positive or negative value of the Betas and t-test scores indicated the direction of the relationship (negative indicating an inverse relationship). Using these standardised Betas from measures that have significant t-scores only, the figures below illustrate which simpler measures could be used to make up a model for each indicator, and how much each measure contributes to the mangrove quality indicators (Fig. 38) and mangrove sustainability indicators (Fig. 39). Within the figures below, all negatives have been changed to positive to produce cumulative scores.

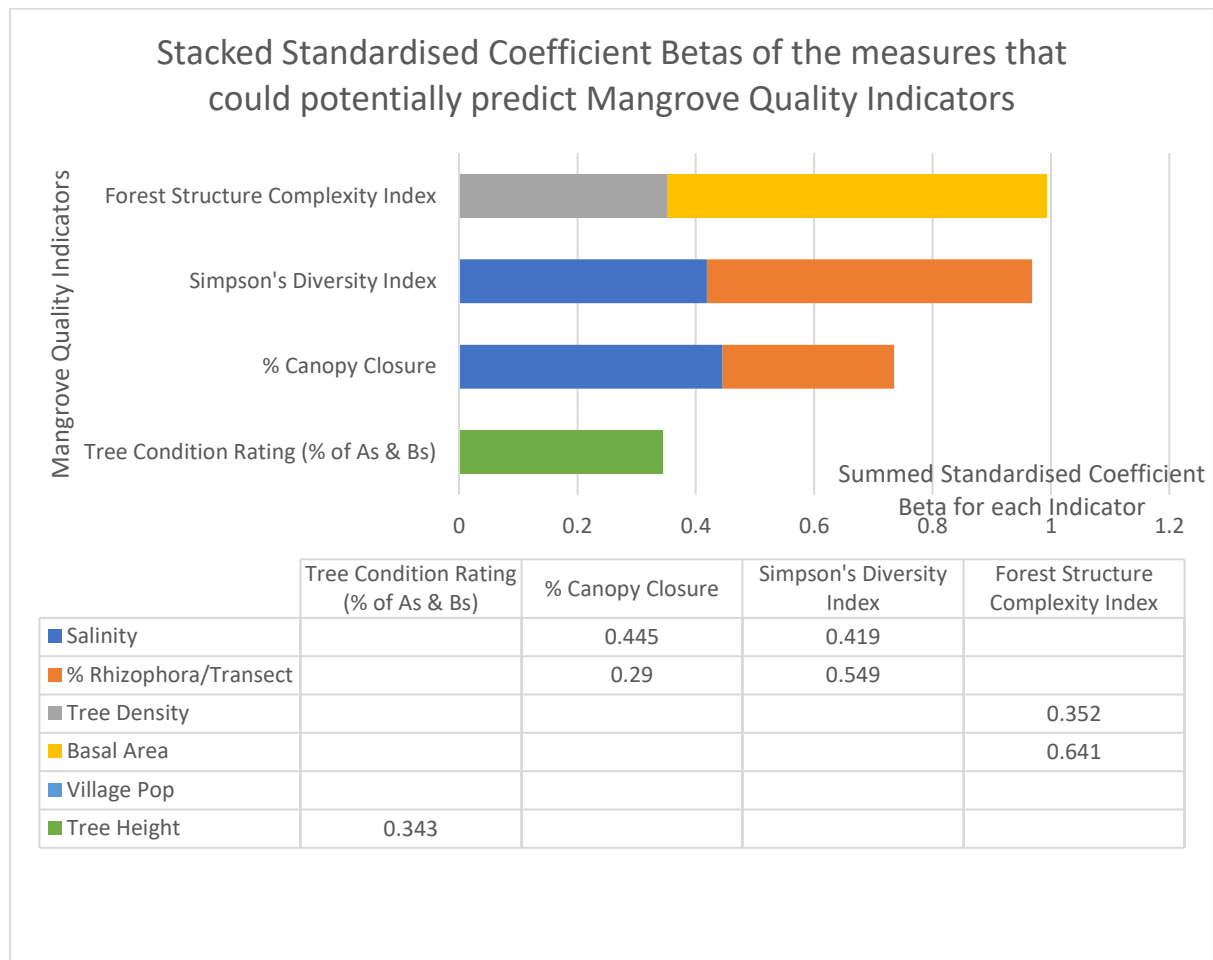


Figure 38. Significant measures that could be used to form mangrove quality indicators and the amount each measure contributes.

For example, for the percentage of canopy closure, which had a model fit of 72% (Table 14), the key measures that could predict the explained variance are salinity and the percentage of *Rhizophora* sp. in a transect (with tree density trending towards significance $p=0.06$), illustrated in Fig 38.

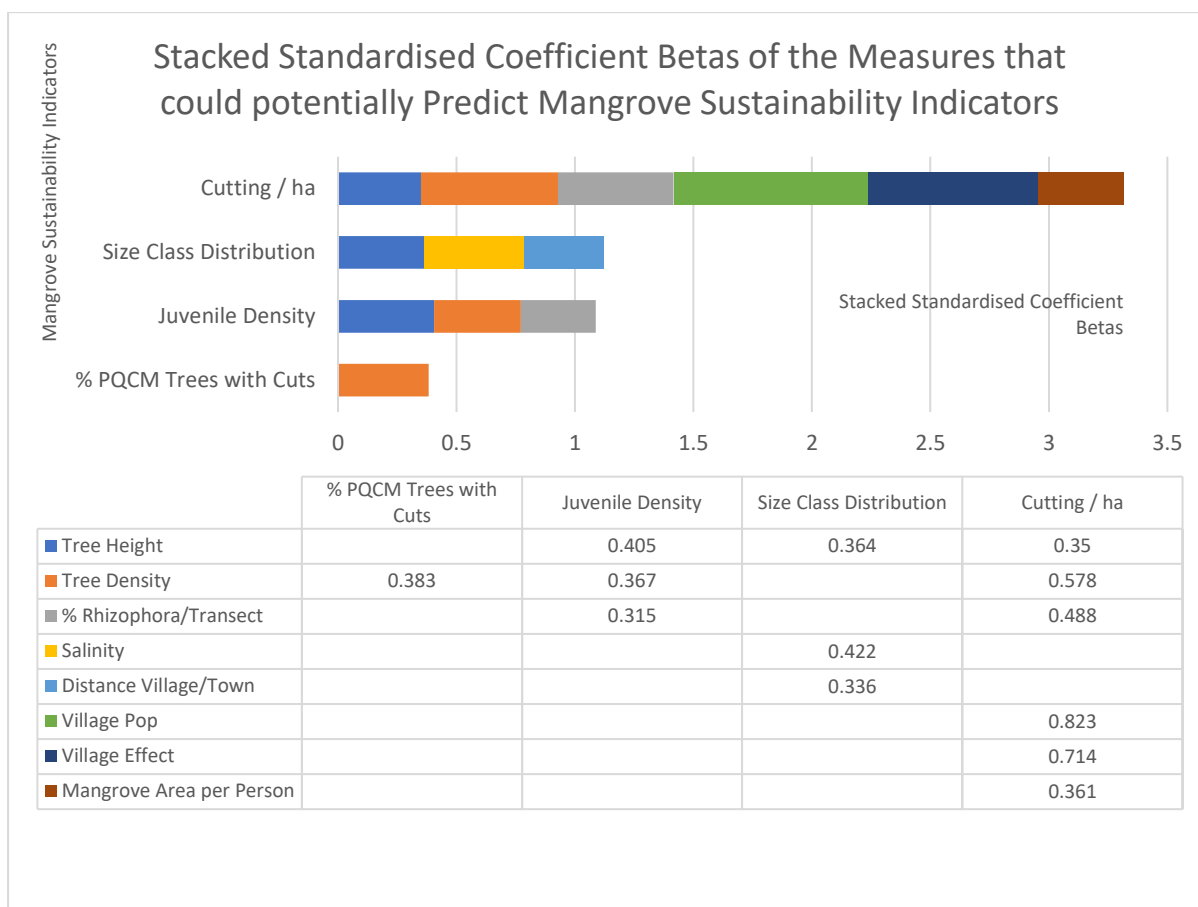


Figure 39. Significant measures that could be used to form mangrove sustainability indicators

The hierarchical regression suggested that 65% of the variance for cutting levels was explained by the proposed model (Table 15, column 5). In this more complex model, illustrated in Fig. 39, six measures that had a significant input into that model were village population, tree density, the percentage of *Rhizophora* sp. within a transect, the mangrove area per person and tree height. In addition, there was also an effect from changing village (t-score = -2.17, p=0.036).

4.5.7 Measures and Their Influence on the Predictive Models

Combining the significant Betas of measures in a transposed direction revealed which measures were the most influential in the hierarchical regression models, Fig. 40. For example, within the mangrove quality measures, where the explained variance ranged between R^2 43–74%, the percentage of *Rhizophora* sp. within a transect and salinity were both influential predictors. These two measures were significant components within the model that explained 43% of the variance of the biodiversity indicator, measured by Simpson’s Diversity index.

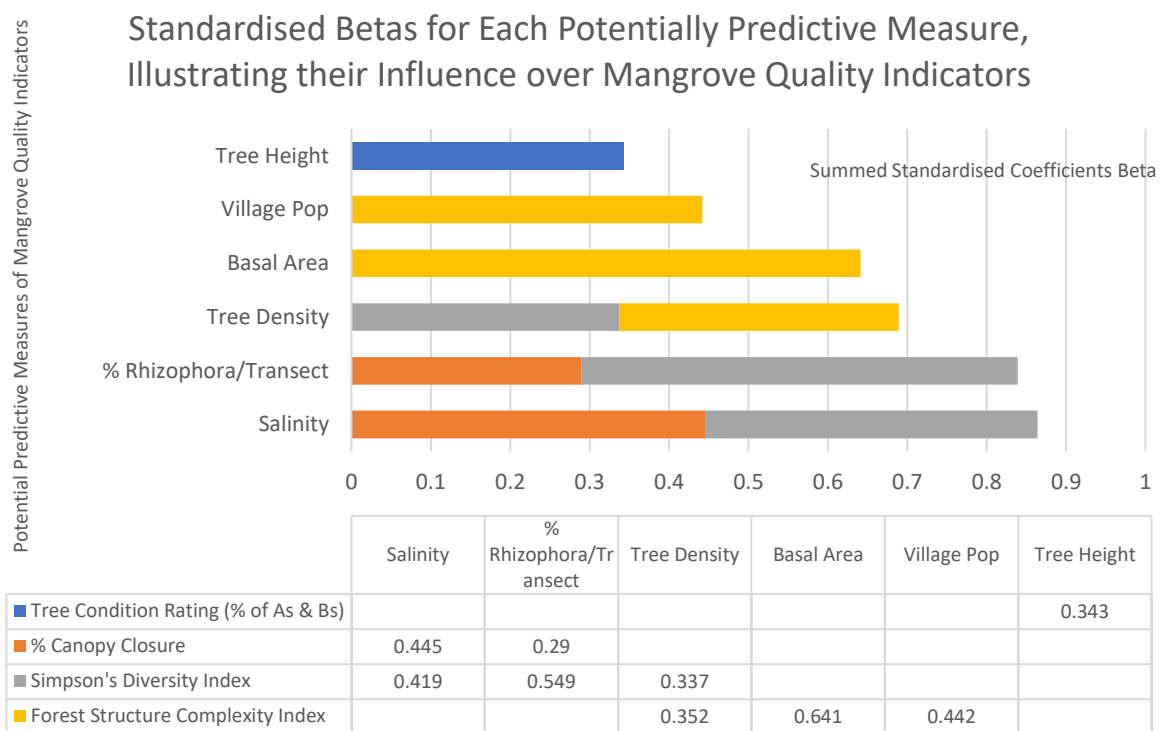


Figure 40. Illustration of the differing influence various components have on the potential mangrove quality indicators

For the mangrove sustainability indicators, the model predictions were less strong, with R^2 scores varying from 27-66% (Table 15). With the models for these indicators, tree density and tree height both influenced three of the four sustainability indicator models. For example, tree height and density were the main components of the model that explained 37% of the juvenile density variance, Fig. 41.

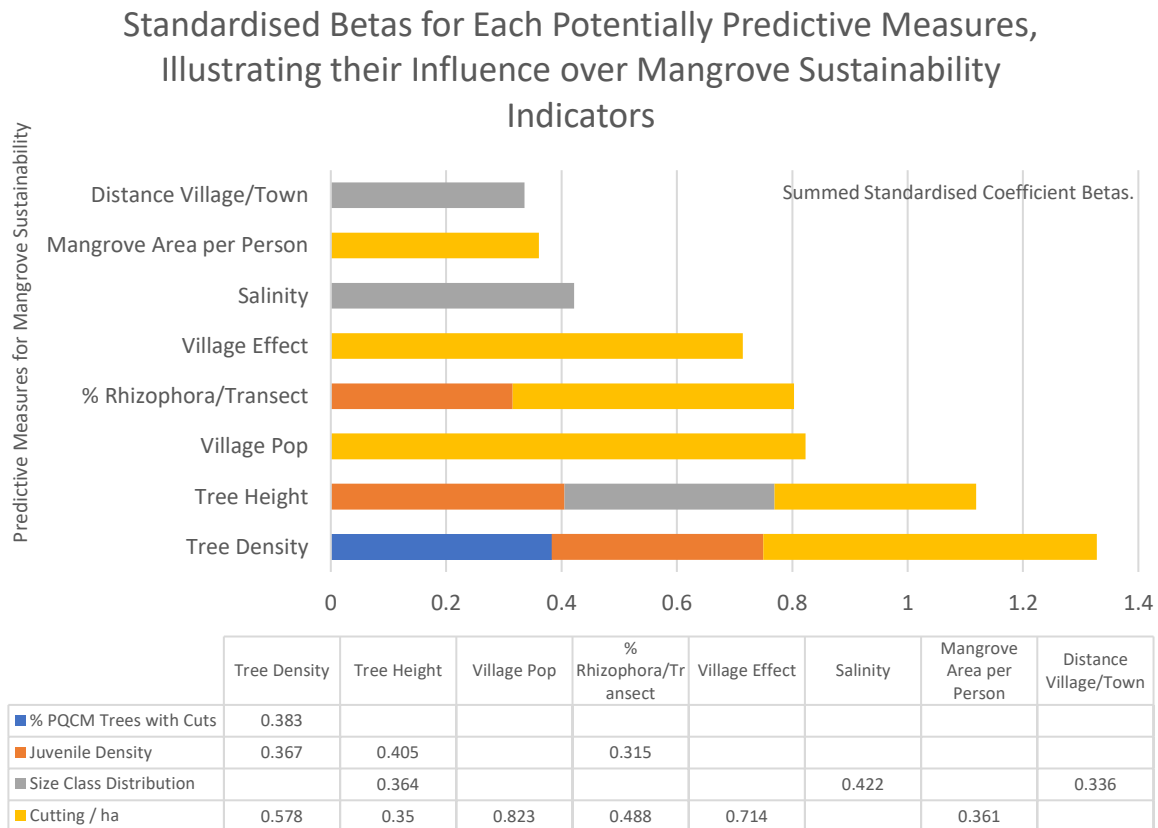


Figure 41. Illustration of the differing influence various components had on the potential mangrove sustainability indicators

Overall the R^2 scores suggest that there is potential for compiling indicators from these measures. It also appears that it is possible to avoid the use of components that are more difficult to measure or analyse, such as hemispherical photography for canopy closure, which can be substituted by easier to measure components, in this case, salinity and the proportion of *Rhizophora* sp. in a transect.

4.5.8 Suggested Indicator Weightings for Ranking Villages' Mangroves

Tables 16 and 17 below summarise the factors (3rd column) that had significant t-scores (6th column) from the regression analysis. In these two tables the indicators appear in order of model fit (R² score) as some models were more effective in explaining variance than others (highlighted by traffic light colouring from green to red).

4.5.8.1 Weighting Within an Indicator

This proposed weighting scheme (Table 16 & 17) allows measures to be combined, if there is more than one, in an appropriate manner to predict an indicator, weighted by the significance of the measures' t-score(s).

- 3 for t-scores of <3.5 (resulting in p<0.001)
- 2 for a t-score of between 2.32 – 3.5 (i.e. p=0.001 to p=0.025)
- 1 for a t-score of 2 – 2.31 (p=0.026 to p=0.05)

For example, for forest structure complexity index (FSCI), as basal area's t-score is strongly significant (p<0.001), the weighing factor is 3, but tree density's input is less significant (t=2.84, p=0.007), and therefore received a lower weighting of 2. For canopy closure intra-factor weighting is unnecessary as both salinity and percentage *Rhizophora* sp. have a similar t-score and significance and therefore receive a weighting of 2 each. For tree condition rating, intra-factor weighting is unnecessary as there is only one significant factor (tree height).

Table 16. A proposed weighting scheme for components that predict mangrove quality indicators

Criterion	Indicator	Hierarchical Multiple Regression Model Predictors (max explained variance). Model uses the following measures	R ² (model fit) Variance Explained	t	Sig.	Suggested Factor Weighting Multiplier	Suggested Weighting for Inter-Indicator Ranking
Mangrove Quality	FSCI	Basal Area m2/ha	0.74	5.871	p<0.001	3	3
		Tree Density / ha		2.839	0.007	2	
	Canopy Closure	Salinity	0.72	-3.264	0.002	NA	3
		% <i>Rhizophora</i> sp. within a Transect		2.718	0.009	NA	
Colour Key	Tree Condition Rating	Tree Height (m)	0.52	2.066	0.045	NA	2
Dark green, p≤0.001							
Mid green, p≤0.025	Simpson's Diversity	% <i>Rhizophora</i> sp. within a Transect	0.43	-3.537	0.001	3	1
Light green, p≤0.05		Salinity		-2.132	0.039	1	

Table 17. A proposed weighting scheme for components that might predict mangrove sustainability indicators

Mangrove Sustainability	Size Class						
	Distribution	Salinity	0.66	-2.863	0.006	2	3
		Tree Height (m)		-2.587	0.013	2	
		Distance from a Town (km)		2.211	0.032	1	
	Cutting/ha	Tree Density / ha	0.65	3.961	p<<0.001	3	3
		% <i>Rhizophora</i> sp. within a Transect		-4.024	p<<0.001	3	
		Village Pop +1s		2.323	0.025	2	
		Village Effect		-2.17	0.036	1	
		Mangrove Area per Person (ha)		2.181	0.035	1	
		Tree Height (m)		2.031	0.049	1	
	Juvenile Density	Tree Height (m)	0.37	-2.085	0.043	NA	1
		Tree Density / ha		-2.117	0.04	NA	
		% <i>Rhizophora</i> sp. within a Transect		-2.045	0.047	NA	
	%PCQM trees with Cuts	Tree Density / ha	0.27	-2.088	0.042	NA	1

4.5.8.2 Weighting Between Indicators

In the final column of Tables 16 and 17, an inter-indicator weighting is suggested, in order to come to an overall mangrove quality or sustainability criterion score. This weighting also runs between 1-3, reflecting variance in the model fit score. This inter-indicator weighting could be adjusted depending on the management objectives stated for the mangrove (for example, high biodiversity or maximum timber production or full ecosystem function). The weighting proposed here is based only on R² strength of explained variance for illustrative purposes, rather than trying to comply with any specific management objective. For want of an objective method of dividing the continuum of explained variance into a workable number of classes, we propose the following weighting, Table 18:

Table 18. Proposed Weightings Between Indicators (For Illustrative Purposes)

Proposed Indicator Weighting	R ² Explained Variance Bands	Subjective Effect Size
3	65 - 100	Significant Effect
2	50 - 64	Medium Effect
1	20 - 49	Small Effect

4.6 DISCUSSION

4.6.1 Interpreting Indicators for Mangrove Quality

4.6.1.1 *Canopy Closure (R² 72%)*

As others have found, increasing canopy closure was associated with reduced salinity (Table 14) (e.g. Walters, 2005b). As less sunlight penetrated the canopy, the soil remained cooler and less soil water evaporated thereby keeping salinity lower. In addition, a closed canopy was more likely to reduce rates of evapotranspiration from the tree canopies because of a more stable, 'boundary layer' of humid, slower moving air within a continuous canopy (Thomas, 2001). As discussed in Chapter 1, Thailand and the Philippines' mangrove stock is dominated by first generation *Rhizophora* sp. plantation, planted densely at 2 x 2m spacing between approximately 1990 and 2005. If fringes of low zone or pioneer mangroves were present, they were likely to be from natural regeneration and, like back mangroves, naturally more open. High and low zone mangroves notwithstanding, tree density trended towards significance in the regression analysis and was significant in the GZLM as a predictor of canopy closure, as *Rhizophora* sp. planted this densely would quickly close canopy.

4.6.1.2 *Forest Structure Complexity Index (R² 43%)*

The forest structural complexity index (FSCI) is a combination of several attributes such as basal area, tree height, tree species, tree density, biomass, foliage arrangement, canopy cover and understory (McElhinny et al., 2005). It is therefore no surprise that key elements of the index's components are central to the predictive model for FSCI. Particularly in combination, basal area and tree density are useful measures. A relatively high basal area can arise if there are a few very large trees, which by their nature will be well spaced out, or if there are many densely stocked smaller younger trees. Tree density distinguishes between the two. Together these measures contribute much to a description the forest structure.

Greater complexity is desirable if the management objectives are conservation and full ecological function. Greater structural complexity provides more niches and variations in conditions and resources and is therefore linked closely to (greater) biodiversity. Greater complexity and biodiversity of mangroves are generally considered to produce greater ecosystem resilience (Bosire et al., 2008). Structural complexity, which might allow other tree species to regenerate naturally, takes time to appear within a mangrove plantation, and in general high planting density excludes them, even decades after planting, as most mangrove species are shade-intolerant (Asaeda et al., 2016; Barnuevo et al., 2016; Sillanpää et al., 2017; Walters, 2000). No seedlings or recruits were found in the Philippine forests studied by Salmo III et al. (2013) until forests were 18 years old.

Mangrove plantations in Banacon Island, Philippines, still lacked understory and recruitment of non-planted species 60 years after planting (Barnuevo et al., 2016). In contrast, others have suggested that reforestation (even mono-specific plantations) eventually facilitated natural recruitment of propagules and seeds by reducing wave energy and trapping propagules (Bosire et al., 2003; Ellison, 2000; Ferreira and Lacerda, 2016; Kairo et al., 2008). The debate around this issue continues.

One of the key objectives of government mangrove planting in the Philippines was to produce a green bio-shield to protect villages from violent winds and weather. Unfortunately, even-age class stands with regular, smooth canopy tops reduce wind speeds less effectively than irregularly-topped canopies of uneven-age class plantations (Villamayor et al., 2016). In contrast, if the management objective is in effect production forestry, even-age class plantations of a few species in a standardised form and regularly spaced are more appropriate. *Rhizophora*-dominant plantations, common in Thailand and the Philippines, also take the extraction pressure off natural mangrove and terrestrial forests if villagers require timber for construction or firewood.

4.6.1.3 *Simpson's Biodiversity Index (R² 43%)*

Both government post-concession, densely stocked replanting, and more latterly, government / village replanting (Chapter 1) lacked biodiversity (Kodikara et al., 2017b; Lewis, 2005), as demonstrated by the strong link between Simpson's Diversity Index and the proportion of *Rhizophora* sp. in a transect (Fig. 37), and by disrupted natural mangrove zonation (Barnuevo et al., 2016; Saenger, 2002; Sinfuego and Buot, 2014). Planting very few species might have been exacerbated by limited knowledge of the other mangrove species' utility and function (Asaeda et al., 2016) and it has occasionally been reported (e.g. Walters, 2004) that local people weed non-planted species either consciously, or by their method of site preparation (Chapter 2). Where there was significant natural recruitment of juveniles from other species, this occurred at the edges of stands (pers. obs.), suggesting that stand biodiversity had to be actively planned and planted into a project (Barnuevo et al., 2016).

The relationship between increasing salinity and a reduction in biodiversity would be expected as increased salinity makes establishment and growth of juvenile mangroves more challenging or impossible for many species that are differentially less tolerant of salinity (Parida and Jha, 2010; Saenger, 2002) as Asaeda et al. (2016) and Kairo et al. (2008) also found.

4.6.1.4 *Condition Rating (R² 52%)*

Condition rating was positively associated with tree height. Despite government mangrove management appearing to favour plantation development, after planting there was very little evidence of management activities that would be expected within a terrestrial plantation, such as

planned thinning of suppressed, stunted and poorly formed trees. Hence, in developing plantations many suppressed or 'drawn up' trees were still alive, even though their stem diameters were too small for their height as they sacrificed girth for height in the competition for light. These were judged to have poor condition. With time, these inferior trees would naturally self-thin and die off, leaving fewer trees of better a condition rating. If tree height was a proxy for stand age³⁶, as the forest matured the quality of the remaining trees will improve (Fig. 42).

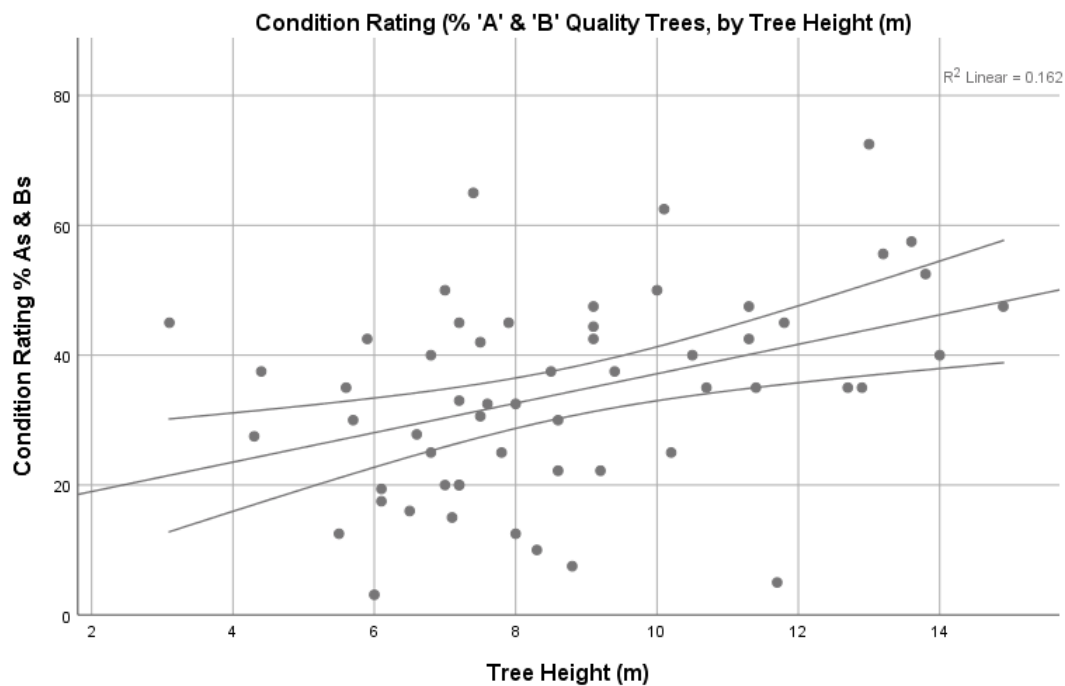


Figure 42. As tree heights increased and suppressed or 'drawn up' trees naturally die off, the condition rating of a forest improved. Line fitted with the 95% confidence interval levels.

In both the GZLM and trending towards significance in the hierarchical regression changing village had an influence on this potential predictive model. This is the influence of changing study village. Average tree height by village varied from 6.6m (village P1A), to 12.9m (village T3B), where the line in the middle of each box plot is the median height, Fig. 43.

³⁶ Care needs to be taken when equating stand height with age. Many factors can affect the tree growth rates, such as salinity, stocking density, nutrient levels, pollution, sulphides, inundation periods, acid sulphate soils, temperature, aridity / precipitation levels and herbivory. It was unfortunate that neither government mangrove agency had accurate records of replanting programmes after the concessions.

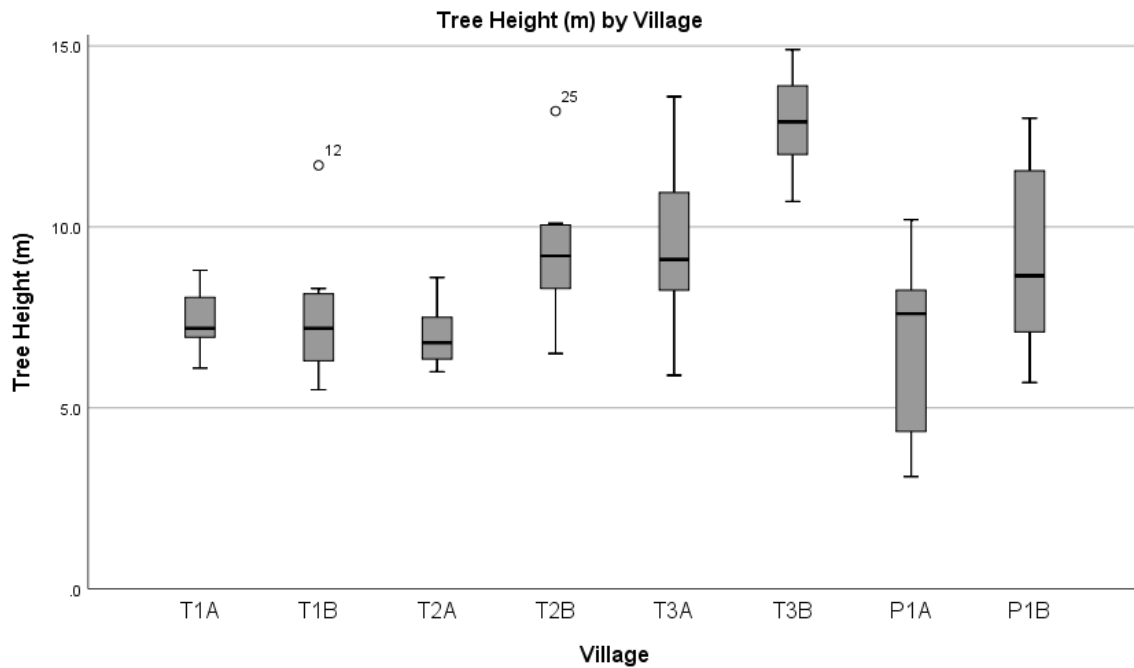


Figure 43. Average tree height by village. With caution, this can be used as a proxy for stand age.

Most were between 7m - 9.5m tall. It is arguable that if most of the mangrove area for a village was planted at approximately the same time after the end of the charcoal concession, a village's stands would all be of a similar height. This might explain the relationship between changing village and condition rating.

4.6.2 Interpreting Predictive Indicators for Sustainability

4.6.2.1 Size Class Distribution (R^2 66%) and Juvenile Density (R^2 37%)

Like terrestrial forest management, it was assumed that the size-class distribution of a sustainable forest was characterised by a high density of juveniles and small trees, followed by progressively fewer trees as the stem diameter increased. Size class distribution and juvenile establishment are closely linked as the juveniles form one end of the distribution curve. Therefore, when a large tree was harvested, fell victim to wind-throw or reached over-maturity and died, there were many juveniles and small trees already established ready to take its place in the canopy. Increasing tree height was linked to a less ideal size-class distribution fit (i.e. a less good fit to an exponential curve) and to lower juvenile density. Plotted on a graph, an ideal tree size class distribution naturally fits an exponential reverse 'J' curve (Fig. 35).

A high density of juvenile mangroves is key to forest sustainability, but plant establishment is influenced by many factors. In a review Krauss et al. (2008) noted that shade and other mangrove factors inhibited understory development in mangroves. Furthermore, inundation, differential

tolerances, sedimentary deposits, nutrient inputs to other bio-chemo-physical gradients (Alongi, 2009b), differential propagule predation (Elster, 2000; Sousa et al., 2003) and salinity (Kodikara et al., 2017a; Wodehouse and Rayment, 2019) all affected the survival and distribution of mangrove juveniles. In addition, juvenile establishment is affected by site type (e.g. river delta, over-wash, fringe, Twilley et al., 1999) and propagule size, as smaller propagules and seeds can move more easily with tidal flows into and within a mangrove, but are less likely to be retained in a forest than heavier, longer seeds such as *R. apiculata* and *R. mucronata* (van Der Stocken et al., 2015). Mutual facilitation between young plants changes to competition as site recovery and establishment moves from early to later stages, balanced by self-thinning (Vogt et al., 2014). Crabs can greatly affect juvenile establishment by either eating or damaging propagules, and by species-specific predation (Kristensen and Alongi, 2006), but this behaviour is poorly understood.

Although plantations might not exhibit the characteristics of a natural mangrove forest (Ellison, 2000; Field, 1996; Lewis, 2005), they might at least contribute to the sustainability of the ecosystem by assisting the return of keystone crab species (Ferreira and Lacerda, 2016). In this study, perhaps with increasing height and therefore by proxy increasing age and canopy closure, fewer juveniles were able to establish within the increasingly shaded plantation due to mangroves' general shade intolerance. Within lower, younger stands there might be more space and light for juveniles to establish before canopies closed overhead. Mature *Avicennia* sp. tend to produce many seedlings, able to survive below the parent tree, partly because the natural crown form of this genus is open and spreading, allowing light to reach the mangrove floor. Therefore, as Walters (2004) also found, juvenile numbers varied greatly from area to area, possibly masking other factors influencing regeneration. In the absence of large trees dating from before the end of the concessions (i.e. more than 40 years old), conclusions should be drawn with caution.

In this study, village T3B was an outlier because here there was no natural regeneration. The most likely reason for this lack of natural recruitment was that the normal hydrology had been disturbed by a dam across the main river running into this system, installed upstream to avoid saltwater intrusion into agricultural areas (Osbeck et al., 2010). The result was a build-up of poorly drained, very soft substrate in the mangroves, similar to mudflat substrate, in which propagules struggled to establish and occasionally large trees fell over. This led to the exclusion from the data analysis of most transects from village T3B because the size class distribution fit score (R^2) to the exponential curve was poor for most transects (section 4.3.3.4). Other outliers from other villages were due to having very large numbers of juveniles (top right of Fig. 36).

4.6.2.2 Levels of Cutting Including Cuts to Sampled Trees (R^2 65%) – Species and Sizes

In descending order of strength of relationship, higher cutting levels were associated with greater tree density and less *Rhizophora* sp. in a transect, and to a lesser extent a higher local population, greater tree height and greater mangrove area per person.

An explanation might relate to the age and make-up of the stands and the informal rules around cutting (Chapter 3). In Thailand some of the government mangrove agency field unit offices had informally sanctioned limited cutting by villagers for household use only, in theory supervised by the village leader and conservation group. Generally, villagers were allowed approximately 50 stems per household per year (Table 9). One of the two Philippine village leaders had previously sanctioned limited cutting by villagers for household use only until 2015 when the Philippine DENR asked for this arrangement to stop. Otherwise, villagers were often harvesting small amounts of mangrove wood illegally whether they were allowed to or not (pers. obs.). Both government mangrove agencies had let it be known that they were more likely to prosecute mangrove cutters who extracted mangrove wood from recently established government plantations (i.e. areas with a high proportion of *Rhizophora* sp. due to planting only this species), rather than other areas of mangrove which tended to be more diverse. The Thai government agency had also asked cutters to spread their cutting rather than to clear-cut only one location. Cutting large stems (i.e. >15-20cm DBH¹³⁰) was challenging as their weight made them difficult and dangerous to handle. If very tall, neighbouring trees would hold up the cut tree and also the sound of using a chainsaw within a mangrove attracted unwanted attention. Felling trees at the edge of a stand, directly into a channel increased the risk of being caught but was the only method of extracting very tall material (required for fish lift nets in village T3B). Normally cutters went to younger, more mixed stands of *Bruguiera* sp. or *Ceriops* sp., outside government plantations, from which it was easier to extract more manageable stems of approximately 4-15cm DBH, as reported by others (Alongi and de Carvalho, 2008; Dahdouh-Guebas et al., 2000; Walters, 2005a, 2005b). As these stands were younger, they were still dense, hence higher cutting levels being associated with higher density stands, which had yet to self-thin.

Mangrove cutting was a complex issue with several confounding factors such as outsiders cutting within a village's mangrove. As it is possible to measure cutting directly in a relatively simple manner, following the protocol described in section 4.3.4, direct measurement would be appropriate as well as using the predictive measures.

Cutting levels and canopy closure were not related to each other, probably because the overall scale of cutting was too low to affect canopy closure ratios. As a result, even though the canopies of the

Philippine mangroves were significantly more open than Thailand's mangroves, cutting levels in the Philippines only trended towards slightly higher levels of cutting.

4.6.3 Potential Interaction between Juvenile Density and Cutting

There was no correlation between cut stems / branches and juvenile density, as Walters found (2005b). This suggested that cutting appeared not to be at sufficient intensities to facilitate juvenile numbers or affect canopy closure and leaf area index (LAI). This is possibly because as cutting was normally spread rather than concentrated and openings were not large enough to provide sufficient light for juveniles. Gaps within the mangrove needed to be of a reasonable size for natural regeneration to take place, as most mangrove species are shade-intolerant, with the partial exception of *R. mucronata* and *A. marina* which appeared better able to develop a shaded understory (Tomlinson, 2016). This might be related to the selection criteria of villages (section 2.3.1) as these purposively sampled communities still had mangroves that were relatively intact and a significant proportion of the village relied upon them, not villages whose mangroves had been converted or heavily degraded.

The inverse relationship between biodiversity and tree height was possibly due to non-*Rhizophora* sp. plantation areas being more biodiverse and naturally more open, producing patches more conducive to natural regeneration and natural succession than tightly stocked plantation, allowing limited understory to develop in gaps which might include other species (Brockerhoff et al., 2009). These non-*Rhizophora* sp. areas were likely to have naturally regenerated in gaps left after the post-concession planting of *Rhizophora* sp. plantations, therefore being younger and lower.

Similarly, a higher local population and an assumed corresponding higher pressure on natural resources led to more cutting. This was a complex issue because whereas local people wanted to cut and collect wood close to their home to reduce transport time and costs, this was balanced against the increased risk of being caught when cutting closer to their village. Because cutting was illegal, cutters might venture further away from their village and find secluded creaks to avoid being seen and caught cutting. In addition, they might have to travel to wherever the diameter, height and species of material required was available.

4.6.4 The Effect of Increased Salinity on Mangroves

In this study, salinity was likely to vary throughout the year as these mangroves were all river delta systems. Increased salinity interacts with other factors such as soil type, tidal inundation, and species, (see Saenger 2002 for a review) producing confounding effects. None of the salinity readings was extreme as might be seen in the Middle East (e.g. Abohassan et al., 2012) or the Saloum Delta, Senegal (pers. obs.), but there was evidence from the rehabilitation assessments

carried out in these villages (Chapter 1) that there had been occasional significant elevations of salinity in village T2A, indicated by deformed prop roots, prop root profusion, unexplained multi-stemming of *Rhizophora* sp. trees at the top of the prop root profusion, and surface salt deposits nearby (pers. obs.). High salinity was at least in part responsible for suppressed biodiversity ($p=0.002$) and FSCI scores ($p<0.001$).

4.7 CONCLUSION

Governments around Southeast Asia are trying to decentralise resource management and encourage communities to take on a greater management role. Community forest management implies that local people are able to make wise use of their forests including extraction of wood, rather than being excluded from them. Monitoring this harvesting to ensure long term sustainability and the continued delivery of ecosystem benefits is difficult, not least because some of the indicators of forest quality and sustainability are difficult to measure, calculate or need expensive equipment. Additionally, the ecosystem is challenging to work in and travel through, which discourages government staff from conducting systematic surveys in the interior of dense mangrove stands.

The proposed qualitative indicators for mangrove quality and sustainability criteria use forestry and bio-socio-physical measurements. A measure of mangrove quality was derived from canopy closure, forest structure complexity index, Simpson's (biodiversity) Index and an A-D tree condition rating. Mangrove sustainability was assessed by measuring tree diameter size class distribution, the levels of stem and significant branch cutting and juvenile mangroves per unit area. Assessment included whether the more difficult-to-measure factors could be predicted by alternative indicators that were easier to collect.

Predictive indicators for mangrove quality appeared to work more effectively than for sustainability as the amount of explained variance was higher. It was possible to predict more difficult-to-measure indicators such as canopy closure levels, which required complex data analysis, by instead measuring a combination of salinity and the proportion of *Rhizophora* sp. within a transect. Similarly, size class distribution could be predicted by a combination of salinity, tree height and a village's distance from the nearest town. A weighting for these indicators was proposed for amalgamating them into quality and sustainability criteria. I do not claim that these criteria are fully validated as Noss (1999) recommended, but they would allow the objective ranking of a group of mangrove stands, indicate change over time and facilitate the prioritisation of assistance to villages whose mangrove most need intervention and better management. These proposed criteria should be tested in non-river delta situations and within mangroves that are more heavily degraded.

If mangrove agencies' role evolves into training and supporting communities in their mangrove management activities (Chapter 3), data collected for these criteria could be particularly useful to guide community-specific extraction rates, and community zoning within a village to help designate areas for usage, protected areas, exclusion zones for recovery from degradation and stands where marine creatures can be collected.

CHAPTER 5. IMPLICATIONS & RECOMMENDATIONS

5.1.1 Rehabilitation: Poor Outcomes, Knowledge Gaps & Remedial Actions

The first half of this thesis asked a straightforward question: what happens when government mangrove agency staff and villagers plant mangroves? It is an important question because this is how almost all mangrove rehabilitation is conducted. The answer was surprising considering that a) the role of the government mangrove agency staff is to look after these mangroves, b) the villagers in question live within or adjacent to mangroves and c) together these two groups have a lot of mangrove rehabilitation experience.

-oOo-

It is encouraging that mangroves are increasingly part of global activities such as the Bonn Challenge (IUCN and the government of Germany³⁷) and Global Mangrove Alliance³⁸ (GMA), that they are a component of nationally determined (carbon storage) contributions³⁹ and that they are discussed explicitly at international meetings such as the United National Framework Convention on Climate Change in Bonn⁴⁰ (2019). Moreover mangroves are the subject of a growing research interest, as demonstrated by the rise in attendance of mangrove-related conferences⁴¹ and increasing research output⁴².

The poor planting outcomes discussed in Chapter 1 have several implications. Organisations such as the GMA have significant ambitions for increasing global mangrove area by 20% by 2030⁴³ - activity at a scale way beyond carefully managed, locally designed on-site projects. Historically, the model for funding large-scale, national or regional projects has been capital transfer to the relevant government, as illustrated by programs such as the EU's Coastal Habitats and Resource Management (CHARM⁴⁴ 2002-2007) project in Thailand. Here the underpinning assumption is that national

³⁷ <http://www.bonnchallenge.org/> Accessed 17.7.2019

³⁸ <http://www.mangrovealliance.org/about/> This includes Wetlands International, Conservation International, WWF, The Nature Conservancy and the IUCN among others. Accessed 17.7.2019

³⁹ <https://www.ramsar.org/fr/node/46136> Accessed 27.7.2019

⁴⁰ <https://unfccc.int/process-and-meetings/conferences/bonn-climate-change-conference-june-2019/bonn-climate-change-conference-june-2019>

⁴¹ <https://www.mmm5singapore.com/> the attendance of which has grown as each iteration to 350 in Singapore 2019. Accessed 17.7.2019

⁴² 2018-2019 'Mangroves' as the search term on Google Scholar produced 15,700 hits, compared to 12,500 for between 2008-2009.

⁴³ <http://www.mangrovealliance.org/gma/> Accessed 27.10.2019

⁴⁴ CHARM was a €20m co-funded project between the EU and the Royal Thai Government.

<http://www.agriconsultingeurope.be/en/references/coastal-habitats-and-resources-management-charm> Accessed 27.7.2019 The administering department was Fisheries who competed with the Department for

agencies are sufficiently competent to use the money effectively. Thus in the CHARM example, rather than provide technical support, education for improved mangrove rehabilitation activities or an independent review of previous activity, the EU transferred €8m to the Thai Fisheries Department which the Royal Thai Government matched with the same amount of money. CHARM failed due to poor planting and livelihood outcomes and inappropriate use of money, and was stopped after its pilot stage. In light of this and other examples, funding groups such as the GMA might be well advised not to assume local mangrove rehabilitation competence but to budget for technical input and extensive education at all levels among other inputs.

It appears to be difficult for government mangrove agencies or funding bodies to concede that their planting has failed or that they lack the technical ability to rehabilitate mangroves. For example, Primavera's mainstream media campaign (e.g. Primavera, 2015, 2013) in the Philippines has not prompted any admissions of poor outcomes or a change of practice by the Department for Environment and Natural Resources. In a similar manner, some offices of the Forest Dept. of India persist in using 'fishbone' canal excavation techniques (Selvam et al., 2012a) despite the well-documented technical problems inherent with this design and the requirement for expensive and continuous hand-dredging years after the initial work (K. Kandasamy, pers. comm.). Similarly, a large-scale, (and well publicised) planting off the Senegalese coast funded by Danone has been conspicuous by the absence of independently produced, long-term survivorship data.

These large and small-scale failures have consequences. Taxpayers' money could have been better allocated to other development projects. Without mangroves coastal villagers have fewer resources that facilitate independent and sustainable living. Failure to (re-)establish protective 'greenbelts' has left areas of the Philippines vulnerable to the typhoons which frequently cross the archipelago. Longer-term, cynicism develops around external aid and the abilities of government agencies, which then discourages local participation in future projects (pers. obs.).

5.1.1.1 More Appropriate Objective Setting from the Centre

Improvements in mangrove conservation and management might come about if more appropriate objectives were set by mangrove agency central authorities for their field offices. Setting survivorship targets beyond three to five years rather than area or propagule targets has been

Marine and Coastal Resources for control of the money and held different objectives. It is perhaps ironic that CHARM's own website www.charm-th.com has been taken over by an online poker site.

discussed in Chapter 1. Additional objectives could increase biodiversity⁴⁵ of the megaf flora and combat the developing problem of even-age class forest stands (M. Jenke, pers. comm.).

Chapter 4 argues that biodiversity can be planned into rehabilitation activity either by planting a variety of species or by using MAP's community-based ecological mangrove rehabilitation method (Appendix B) which facilitates natural regeneration of all species present.

Effective education and the setting of more relevant targets could help change government mangrove agency staff mindsets from that of terrestrial production forestry to evidence-led mangrove management and a focus on optimal mangrove ecological function. In addition, a switch to watershed-scale management (e.g. IUCN and WRI, 2014) would focus on the important mangrove connectivity to adjoining ecosystems (Huxham et al., 2018), thereby improving not only the mangroves but also seagrass beds and coral if present. For funding organisations like the GMA, taking on this educational role among other activities would be a more effective way to sponsor large-scale rehabilitation programmes and improve the health of current mangroves than merely providing money for planting.

These issues suggest that it would be worthwhile investigating the availability and accuracy of information about mangrove ecology and rehabilitation that is accessible to government staff and villagers. For villagers this might include knowledge handed down from parents and villager elders, village peers, previous village experience, experience from neighbouring villages, the internet, radio programmes, biology classes in school, training from NGOs and government extension officers. Government staff might learn from knowledgeable villagers, head office training, NGOs and academics, the internet including 'Google Scholar', rehabilitation manuals, colleagues and so on. It appears from Chapters 1 and 2 that some of these potential sources of information have had only a limited impact, perhaps because of quality, availability, access or format. For example, research papers published in academic publications, including so-called high impact academic journals, appear to have had very limited impact on policy and do not demonstrably change the behaviour of mangrove workers because their narrow influence does not reach far beyond academia.

In contrast there are sources of misinformation and confusion. Arguably, by allowing mangroves to be under concession, governments previously implied that these ecosystems have limited value

⁴⁵ It was a concern that there was a lack of understanding of the importance and benefits of biodiversity and structural complexity. Within the research period, biodiversity was very rarely discussed. No government officer indicated that they were being encouraged to increase biodiversity, and some of their actions reduced it. It appears that lessons from the problems of other single-species systems, such as the collapse of shrimp aquaculture due to 'early mortality syndrome' (e.g. De Schryver et al., 2014), have not changed the behaviour of government mangrove agency staff.

beyond the price of their timber, even when this is (partially) mitigated by increased planting efforts since the concessions. It is encouraging that NGOs and governments are conducting mangrove rehabilitation projects on their own as well as with villagers, but these are often subject to poor site / species matching (i.e. blanket planting of *Rhizophora* sp., interviewee T3B#43), thereby setting an inappropriate example. Younger generations of villagers might assume understandably that the even-age class *Rhizophora* sp. dominated mangroves that they see around their villages is normal, never having seen front fringe of pioneer species or significant back mangrove. The absence of systematic reviews of planting activities, techniques used, decisions taken and resulting outcomes is a missed opportunity to provide clear feedback to villagers and government mangrove agency staff and improve subsequent activity. These missed opportunities and misperceptions might explain the apparent contradiction between villagers' knowledge and the translation of this knowledge into appropriate activity on the ground. For example, the science test in Chapter 2 showed that the villagers had a good conceptual understanding of the importance of good hydrology for mangrove rehabilitation, but this did not lead to action in the field, where they would not act to clear channels blocked by debris or sediment.

5.1.2 Management Rules, Sanctions, Enforcement and Leadership

There were restrictions on mangrove cutting in one form or another in all villages; either national laws and / or community rules. Community forest management (CFM) might be favoured by academics and well aligned with a rights-based approach to development, but from a more practical point of view, there is little alternative. Most governments have too few resources to effectively patrol and enforce regulations at a community level for such a diffuse resource, (e.g. Tanzania, Colombia, Cambodia, Myanmar pers. obs.). Villagers themselves were the first to acknowledge that 'open access' cutting rights to the mangroves, would lead to rapid depletion and degradation of their mangroves. Many of the older villagers had experienced the consequences of losing all their mangroves during the mangrove concession era, witnessing first-hand the drop in marine productivity, significant soil erosion, the destruction of the adjacent sea grass and coral due to sedimentation and warmer drier local weather. In addition to education, using methods that have been effective in reducing illegal wildlife hunting to reduce cutting (and including learning from Nilsson et al.'s 2016 realist synthesis) might be a constructive way to change attitudes and social norms.

Chapter 3 revealed that providing CFM advice to villages needs to be done with great care. The Thai government mangrove agency field staff had received some guidance (Appendix K) for establishing CFM but would perhaps benefit from understanding the experience in Myanmar where 'Community

Forest Instruction' is further advanced (Springate-Baginski and Than, 2011) albeit not without problems (W. Maung pers. comm.). Templates for community forest management rules provided in good faith by the Thai mangrove agency were indeed successful in initiating discussions. However, it appeared difficult for villagers to develop ideas beyond the template, thus producing the impression for many residents that the government had imposed these regulations on the village. Therefore, rather than provide a rules template or a prescriptive list of essential conditions, funding organisations such as the GMA could commission neutral, professional facilitation organisations to officiate village CFM discussions in a more non-directive fashion. These discussions could be guided by the general pre-requisites suggested by Ostrom (1999, 1990) and others (Chapter 3.6.2), since it seems that many of the specified conditions are relevant to mangrove communities, but conducted on a village-by-village basis to take into account village-specific issues that Agrawal (2001), and Cole and Ostrom (2010) recognised as being so important. After adoption and a period of testing, the rules should be reviewed by the village, problems identified and new ideas tested, with other evidence-based best practice solutions provided from outside. The process of developing community rules (operational rules in Agrawal and Ostrom's terms, 1999) could also improve the skills needed to manage a potential transfer of property rights within a Community Forestry Act, transferring rights related to the mangroves from governments to an appropriate form of common-property resource management. In addition, appropriate mechanisms for the development of activity-restricting community rules and sanctions would be useful because villages commonly have other specific challenges, such as solid waste management (Suriname, Sri Lanka, Senegal pers. obs.), crab harvesting restrictions (Thailand, Myanmar, pers. obs.) and drug related issues (Honduras, Kenya, Thailand, pers. obs.) that they need to negotiate internally.

A topic conspicuous by its limited coverage in the scientific literature and conference presentations, despite being the mirror to effective rehabilitation, is the protection and preservation of existing mangrove. In order to patrol mangroves effectively, central funding and commitment from governments is necessary. Anecdotes about providing field offices with government patrol boats but with no money for fuel or maintenance (Thailand, Tanzania, pers. obs.) are too common to be baseless. Making sure villagers are fully aware of all the values of mangroves and how reliant they are on the ecosystem goods and services that healthy mangroves provide might encourage passive patrolling by village fishermen and marine creature harvesters. The provision of radios to village fishermen would speed reporting of rule-breakers, as was demonstrated in village T2A. Patrolling without effective enforcement of the sanctions is, however, of limited value but enforcing rules and implementing sanctions are understandably very difficult for leaders when a good proportion of villagers are friends or family, and all adults were voters. If a miscreant was successfully

prosecuted, word of this event would travel far and fast, but equally if offenders were let off this also sent a powerful message (interviewee P1B#04). A young Thai village leader, not in these research villages, avoided this problem by appointing a group of respected elders from a diverse selection of families within his village, to adjudicate on rules infractions, inappropriate behaviour and sanctions within this village. The selection of elders from across the families neutralised any potential bias of this group and the arrangement worked well. Group judgements had greater moral authority than the decision of just one person and avoided a backlash against the village leader, who was then able to carry out other difficult tasks. Having a neutral group of elders might also help avoid the problem in the Philippines of the relaxation of mangrove wood extraction rules (and terrestrial forest clearance controls) during a village leadership election campaign⁴⁶.

Most leaders said that they preferred to apply sanctions within the village because the legal system was unpredictable. As observed by one villager in T1B, at the time of research in Satun Province, the jail time for being convicted of cutting mangroves by a court was longer than for that of a rape conviction. Cases handled outside the village had to involve the police and courts. These organs of the state were variable and unpredictable because the government mangrove agency field office director, local police and local judiciary all had to be cooperative and willing to prosecute, which was not always the case.

5.1.3 Mangrove Inventory, Quality & Sustainability

As many of the Thai government staff explicitly stated, if a village was prepared to manage and conserve its mangrove, the village should be able to benefit from it, as long as this was done in a sustainable manner. This would include providing for their needs for wood and timber. As described in Chapter 3, some villagers were informally allowed to extract a limited amount of mangrove wood for their own use each year. However, whether the authorities gave permission or not, local people were often going to cut and extract mangrove wood, not for sale or charcoal but for their immediate needs. Cutting and extraction is a complex issue. Experience from terrestrial CFM suggests that proximity to roads and towns might affect extraction rates. Where material they required was present (i.e. diameter, species), villagers sometimes cut in neighbouring communities' mangrove, if they could do so without detection, or if a deal had been agreed with a corrupt village leader (as was the case in a village near T2B). Outsiders from further afield might extract wood from a village's mangrove on an informal basis, as happened to village T3A's mangroves, or for more commercial, systematic reasons, such as is occurring along the Myeik archipelago, Myanmar, for fish

⁴⁶ Village elections are hugely problematic and ethically challenged in both countries but essential as Thai leaders who were elected for life often lost interest in their role and failed to discharge their duties to the village. Unfortunately, the discord from the election sometimes poisoned relations for years after an election.

processing (Zockler, 2016), or within the Rufiji Delta, Tanzania for commercial sale (Tanzania Forest Service, per. comm.). The concern here is that extraction rates and the impact of extraction is not being quantified by either the Thai or Philippine government. Specifically, neither government conducts systematic regular transects with the coverage and sampling necessary to monitor extraction levels or to determine the effects this has on the delivery of ecosystem goods and services. Chapter 1 demonstrated that villagers and government staff could not be depended on to restock degraded mangroves reliably and effectively, and therefore any extraction cannot be regarded automatically as (sustainable) production forestry. This is not to criticise these two countries unduly because very few states monitor mangrove harvesting in any detail and moreover, what level of harvesting constitutes a sustainable yield from a particular mangrove is often poorly understood.

Satellite and drone remote sensing using hyperspectral scanning and 3D LIDAR may soon be able to model forests and monitor extraction to the resolution necessary (i.e. individual trees, D. Lagomasino, pers. comm). Until such technology evolves and becomes available to government field offices at a price and complexity that is manageable, monitoring will need to continue on the ground. For governments, effective ground-level extraction monitoring requires huge resources in an ecosystem that is notoriously difficult to work in. Surveys are challenging to conduct because of extremes of temperature and humidity, hazardous animals and insects, soft mud, tides, interlocking prop roots and the corrosive effects of salt. The understandable temptation is to monitor mangroves only from a nearby road or by boat, but conditions in the interior of a stand can be very different to the apparent continuous forest at the dense edge of a stand.

The Kenyan experience demonstrates that a quota system for allotted mangrove extraction is likely to be abused (Dahdouh-Guebas et al., 2000) in the same manner that the 50 stems per household limit was being abused in Thai villages (Chapter 3). Unlike fisheries monitoring where catches can be measured when landed at a dock or in a local fish market, villagers had no effective method for quantifying offtake by these community mangrove management arrangements. Therefore Chapter 4 suggests easier ways that NGOs or even villages might assess their own mangroves, without having to master the use of previously established but complex (terrestrial) forest indicators. The hope here is that the easier these measures are to use, the more likely they will be applied.

Two criteria would be appropriate in this context: the quality of the mangrove and whether it is being negatively affected by 'wise' use⁴⁷, and whether this use is sustainable. Substitute measures appeared to predict their corresponding indicator more closely for mangrove quality indicators than

⁴⁷ E.g. <https://www.wetlands.org/blog/maimuna-mangroves/>

for mangrove sustainability. Needless to say, both raise issues of definition. What was not attempted here was any direct measure of ecosystem function or quantification of maximum sustainable yield. Similar to assessing carbon stocks in mangrove soils (e.g. Kauffman and Donato, 2012), yield assessments should take into account mangrove type and site-specific factors including rates of covert extraction by cutters from outside the village.

The common denominator and choke point concerning many of these issues is village leadership. Poor or unethical leadership might discourage civic engagement by the general populace in activities such as passive patrolling of mangroves or taking part in planting (pers. obs.). In India the issue of village leadership is even more complex because the village leaders are also political agents for various national parties (pers. obs.). Disengaged or self-interested leadership is unlikely to be interested in sourcing help for their village to establish community mangrove management rules, nor will they have much interest in punishing miscreants. Similarly, poor leadership might inhibit other development programmes, from drug awareness campaigns to encouraging children to learn how to swim. Because village heads become government civil servants in Thailand, it is sometimes difficult for a village conservation group leader to circumvent a recalcitrant village leader if sanctions require external support. To this extent, it is perhaps surprising that village leadership has not been subject to more research.

5.2 RECOMMENDATIONS: LOCAL OR VILLAGE MANAGEMENT TASKS

In this final section, I offer from a personal perspective, recommendations to each of the various groups of actors that I have encountered during this course of my studies.

5.2.1 Village-Level Assistance for Villagers and Village Conservation Groups

- Provide environmental education for villagers focusing on mangrove ecosystem goods and services. Villagers who are fully aware of the benefits of the mangrove will hopefully be less likely to degrade them and more likely to accept and follow community mangrove management rules.
- Provide technical training and long-term support for village conservation group members. Capacity building to help villagers identify appropriate sites and the techniques to rehabilitate mangroves in a biodiverse manner, including community-based ecological mangrove rehabilitation (Appendix B).
- Train conservation group members to be able to recognise mangrove stands that are stressed or unhealthy due to poor hydrology or other factors and disseminate techniques to improve their health.
- Provide non-directive meeting facilitation to develop village-specific mangrove management rules.
- Assist village conservation groups with management planning, mangrove zoning (e.g. usage, no-go, thinning, eco-tourism zones...)
- Use output from Chapter 4 to monitor each village's mangrove in order to rank and prioritise villages that need most assistance.

5.2.2 District or Provincial Level Government Units

- Identify and establish regional best practice villages.
- Facilitate study tours to these communities to enable other villagers and conservation group members to witness examples of good rehabilitation practice, management planning, rules establishment, sustainable livelihoods and sanctions mechanisms. Villager-to-villager education can be hugely effective, particularly within Muslim communities (pers. obs.).

5.2.3 Government Mangrove Field Offices

- Include relevant field office staff in village training sessions (above).
- Redirect the emphasis away from planting targets towards alternative management tasks, particularly mangrove protection and conservation.

- Focus on recovering aquaculture ponds from encroachers and rehabilitate these areas back to mangrove with appropriately connected hydrology (i.e. not the impounded system common in Vietnam where mangroves are used for pond wall stabilisation. The lack of connectivity results in the full suite of ecosystem benefits not being delivered, pers. obs.).
- Plant only when proved necessary, otherwise use facilitation of natural regeneration of mangroves where at all possible.
- Establish mangrove biodiversity targets and provide training for how to use appropriate indicators
- Reduce the potential even-age class issue of the current *Rhizophora* sp. plantations that dominate Thai and Philippines mangroves (M. Jenke, pers. comm). Trial creating canopy gaps within monospecific plantations to encourage the natural regeneration of other species. If necessary, introduce propagules and seeds of other species or plant other species suitable for the site.

5.2.4 National Mangrove Agencies

- Focus on areas and the mangroves therein that are most vulnerable to severe weather such as expected typhoon tracks.
- Promote the development and ascent of national legislation that enables field office directors to take back aquaculture ponds to state ownership and control, using the courts and police if necessary. (Within the current legal framework, this is difficult.)
- Using suitable examples from abroad, explore the potential benefits and pitfalls of transferring the property rights and governance of mangroves from the state to communities or some devolved level of authority, as this often results in better management (Waylen et al., 2010).
- De-couple field office budgets from area targets, propagule planting targets or planting activity.
- Change from area / propagule planting targets to survivorship over an agreed time period such as five years
- Establish biodiversity targets.
- Establish a mechanism to disseminate systematically the relevant scientific literature to field office workers, in an appropriate form and language, and link staff promotion to absorption and application of such knowledge. Develop an education programme for field office staff that covers climate change, sea level rise and the practical implications for mangroves (i.e. facilitating migration of mangroves to higher elevations and inland). Facilitate ongoing study tours programme for field officers to learn about

- mangrove hydrology and hydrological failures
 - appropriate site selection
 - the appropriate use of pioneer species
 - successful community management case studies.
- Define more appropriate management tasks for each field office, focusing on protection and conservation of existing mangroves, forest management planning and activities which facilitate the recommendations mentioned above.

5.2.5 Mangrove Scientific Community, International NGOs, Relevant UN Organisations

- Commission independent, nationwide reviews of rehabilitation outcomes to date.
- Disseminate output from such reviews widely and used these to start discussion with national mangroves agencies about the need for a change of approach, (see the activities above).
- Avoid transferring funds to national mangrove agencies that propose plans for area targets, mangrove plantation establishment and support current activities.
- Design programmes that last for a minimum of eight to 10 years, using well trained extension officers and sufficient technical training, support and on-going monitoring, following the recommendations above.
- Part of this program would be further research examining the attitudes of villagers to rehabilitation, cutting and mangrove conservation; the social norms within these villages and perceived behavioural control over these activities. This research could monitor the effects of the recommended education and training and in conjunction with Nilsson et al.'s (2016) recommendations, ascertain other activities needed beyond education to conserve existing mangroves and rehabilitate more successfully.
- Reproduce academic papers in an appropriate language and form suitable for field officer education programmes, focusing particularly on their practical application.
- Place greater emphasis and support for research with direct applicability, i.e. activities that consider the conservation of existing mangroves, the enforcement of rules and sanctions and mangrove community forest management.

REFERENCES

- Abohassan, R.A.A., Okia, C.A., Agea, J.G., Kimondo, J.M., McDonald, M.M., 2012. Perennial biomass production in arid mangrove systems on the Red Sea Coast of Saudi Arabia. *Environ. Res. J.* 6, 22–31. <https://doi.org/10.3923/erj.2012.22.31>
- Agrawal, A., 2001. Common property institutions and sustainable governance of resources. *World Dev.* 29, 1649–1672. [https://doi.org/10.1016/S0305-750X\(01\)00063-8](https://doi.org/10.1016/S0305-750X(01)00063-8)
- Agrawal, A., Gibson, C.C., 1999. Enchantment and disenchantment: The role of community in natural resource conservation. *World Dev.* 27, 629–649. [https://doi.org/10.1016/S0305-750X\(98\)00161-2](https://doi.org/10.1016/S0305-750X(98)00161-2)
- Agrawal, A., Ostrom, E., 1999. Collective Action, Property Rights, and Devolution in Forest and Protected Area Management, in: *Devolution, Property Rights and Collective Action*. Puerto Azul, Philippines, pp. 21–25.
- Agrawal, A., Redford, K., 2006. *Poverty, Development, And Biodiversity Conservation: Shooting in the Dark?* (No. 26). New York.
- Ajzen, I., 2002. Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. *J. Appl. Soc. Psychol.* 32, 665–683. <https://doi.org/10.1111/j.1559-1816.2002.tb00236.x>
- Aksornkoe, S., 2004. Sustainable Use and Conservation of Mangrove Forest Resources with Emphasis on Policy and Management Practices in Thailand, in: Vanucci, M. (Ed.), *Mangrove Management and Conservation : Present and Future*. United Nations Press, New York, USA., pp. 149–160.
- Alongi, D.M., 2009a. *Introduction in the energetics of mangrove forests*. Springer, Dordrecht, Netherlands, Dordrecht, Netherlands.
- Alongi, D.M., 2009b. Paradigm shifts in mangrove biology, in: Perillo, G.M.E., Wolanski, E., Cahoon, D.R., Brinson, M.M. (Eds.), *Coastal Wetlands An Integrated Ecosystem Approach, Coastal Wetlands: An Integrated Ecosystems Approach*. Elsevier, Amsterdam, pp. 615–640. <https://doi.org/10.1016/B978-0-444-53103-2.00022-3>
- Alongi, D.M., 2008. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuar. Coast. Shelf Sci.* 76, 1–13. <https://doi.org/10.1016/j.ecss.2007.08.024>

- Alongi, D.M., 2005. Mangrove microbe soil relations, in: Kristensen, E., Haese, R.R., Kostka, J.E. (Eds.), *Interactions Between Macro- and Microorganisms in Marine Sediments*. Wiley Online Library, Washington, D. C., pp. 85–103.
- Alongi, D.M., 2002. Present state and future of the world's mangrove forests. *Environ. Conserv.* 29, 331–349. <https://doi.org/10.1017/S0376892902000231>
- Alongi, D.M., de Carvalho, N.A., 2008. The effect of small-scale logging on stand characteristics and soil biogeochemistry in mangrove forests of Timor Leste. *For. Ecol. Manage.* 255, 1359–1366. <https://doi.org/10.1016/j.foreco.2007.10.051>
- Angelsen, A., Kaimowitz, D., 1999. Rethinking the Causes of Deforestation : Lessons from Economic Models 14, 73–98.
- Anon, 1997. A Survey of Indonesia. Generals' preferences. *Econ.*
- Asaeda, T., Barnuevo, A., Sanjaya, K., Fortes, M.D., Kanesaka, Y., Wolanski, E., 2016. Mangrove plantation over a limestone reef - Good for the ecology? *Estuar. Coast. Shelf Sci.* 173, 57–64. <https://doi.org/10.1016/j.ecss.2016.02.017>
- Aung, T.T., Than, M.M., Katsuhiko, O., Yukira, M., 2011. Assessing the status of three mangrove species restored by the local community in the cyclone-affected area of the Ayeyarwady Delta, Myanmar. *Wetl. Ecol. Manag.* 19, 195–208. <https://doi.org/10.1007/s11273-011-9211-9>
- Badola, R., Barthwal, S., Hussain, S.A., 2012. Attitudes of local communities towards conservation of mangrove forests: A case study from the east coast of India. *Estuar. Coast. Shelf Sci.* 96, 188–196. <https://doi.org/10.1016/j.ecss.2011.11.016>
- Baland, J.-M., Bardhan, P., Das, S., Mookherjee, D., 2010. *Forests to the People: Decentralization and Forest Degradation in the Indian Himalayas*. University of Namur, Belgium.
- Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., Kerry Turner, R., 2002. Economic Reasons for Conserving Wild Nature. *Science* (80-.). 297, 950–953. <https://doi.org/10.1126/science.1073947>
- Balmford, A., Cowling, R.M., 2006. Fusion or Failure? The Future of Conservation Biology. *Conserv. Biol.* 20, 692–695. <https://doi.org/10.1111/j.1523-1739.2006.00434.x>
- Balooni, K., Inoue, M., 2007. Decentralized Forest Management in South and Southeast Asia. *J. For.* 105, 414–420. <https://doi.org/10.1093/jof/105.8.414>

- Bandura, A., 1994. Self-Efficacy, in: Ramachaudran, V.S. (Ed.), *Encyclopedia of Human Behavior*. Academic Press, New York, USA., pp. 71–81.
- Banjade, M.R., Liswanti, N., Herawati, T., Mwangi, E., 2017. *Governing Mangroves: Unique Challenges for Managing Indonesia's Coastal Forests*. Bogor, Indonesia, and Washington, DC, USA.
- Barbier, E., Sathirathai, S., 2004. *Shrimp farming and mangrove loss in Thailand*. Edward Elgar Publishing, Cheltenham, UK.
- Barbier, E.B., 2006. Natural barriers to natural disasters: Replanting mangroves after the tsunami. *Front. Ecol. Environ.* 4, 124–131. [https://doi.org/10.1890/1540-9295\(2006\)004\[0124:NBTNDR\]2.0.CO;2](https://doi.org/10.1890/1540-9295(2006)004[0124:NBTNDR]2.0.CO;2)
- Barnuevo, A., Asaeda, T., Sanjaya, K., Kanesaka, Y., Fortes, M., 2016. Drawbacks of mangrove rehabilitation schemes: Lessons learned from the large-scale mangrove plantations. *Estuar. Coast. Shelf Sci.* 2, 432–437. <https://doi.org/10.1016/j.ecss.2017.02.015>
- Barreto, P., Souza, C.J., Noguérón, R., Anderson, A., Salomão, R., 2006. Human pressure on the Brazilian Amazon forests. Washington, D. C.
- Benayas, J.M.R., Newton, A.C., Diaz, A., Bullock, J.M., 2009. Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. *Science* (80-.). 325, 1121–1124. <https://doi.org/10.1126/science.1172460>
- Berkes, F., 2004. Rethinking community-based conservation. *Conserv. Biol.* 18, 621–630. <https://doi.org/10.1111/j.1523-1739.2004.00077.x>
- Bianchi, S., Cahalan, C., Hale, S., Gibbons, J.M., 2017. Rapid assessment of forest canopy and light regime using smartphone hemispherical photography. *Ecol. Evol.* 7, 10556–10566. <https://doi.org/10.1002/ece3.3567>
- Blanco, J.F., Bejarano, A.C., Lasso, J., Cantera, J.R., 2001. A new look at computation of the complexity index in mangroves: Do disturbed forests have clues to analyze canopy height patchiness? *Wetl. Ecol. Manag.* 9, 91–101. <https://doi.org/10.1023/A:1011115220126>
- Bodin, Ö., Crona, B.I., 2008. Management of Natural Resources at the Community Level: Exploring the Role of Social Capital and Leadership in a Rural Fishing Community. *World Dev.* 36, 2763–2779. <https://doi.org/10.1016/j.worlddev.2007.12.002>
- Bosire, J.O., Dahdouh-Guebas, F., Kairo, J.G., Koedam, N., 2003. Colonization of non-planted

- mangrove species into restored mangrove stands in Gazi Bay, Kenya. *Aquat. Bot.* 76, 267–279. [https://doi.org/10.1016/S0304-3770\(03\)00054-8](https://doi.org/10.1016/S0304-3770(03)00054-8)
- Bosire, J.O., Dahdouh-Guebas, F., Kairo, J.G., Wartel, S., Kazungu, J., Koedam, N., 2006. Success rates of recruited tree species and their contribution to the structural development of reforested mangrove stands. *Mar. Ecol. Prog. Ser.* 325, 85–91. <https://doi.org/10.3354/meps325085>
- Bosire, J.O., Dahdouh-Guebas, F., Walton, M., Crona, B.I., Lewis, R.R., Field, C.D., Kairo, J.G., Koedam, N., 2008. Functionality of restored mangroves: A review. *Aquat. Bot.* 89, 251–259. <https://doi.org/10.1016/j.aquabot.2008.03.010>
- Bowler, D.E., Buyung-Ali, L.M., Healey, J.R., Jones, J.P.G., Knight, T.M., Pullin, A.S., 2012. Does community forest management provide global environmental benefits and improve local welfare? *Front. Ecol. Environ.* 10, 29–36. <https://doi.org/10.3969/j.issn.1000-1026.2012.21.010>
- Boyd, C., Slaymaker, T., 2000. Re-examining the “More People Less Erosion” Hypothesis: Special Case of Wider Trend? *Nat. Resour. Perspect.* 63, 1–6.
- Broadhead, J.S., Beresnev, N., Conway, D., Costenbader, J., 2016. Incentive allocation for mangrove protection. Bangkok.
- Brockerhoff, E.G., Jactel, H., Parrotta, J.A., Quine, C.P., Sayer, J., Hawksworth, D.L., 2009. Plantation Forests and Biodiversity: Oxymoron or Opportunity? *Biodivers. Conserv.* 9, 925–951. <https://doi.org/10.1007/978-90-481-2807-5>
- Brockmeyer, R.E., Rey, J.R., Virnstein, R.W., Gilmore, R.G., Earnest, L., 1996. Rehabilitation of impounded estuarine wetlands by hydrologic reconnection to the Indian River Lagoon, Florida (USA). *Wetl. Ecol. Manag.* 4, 93–109. <https://doi.org/10.1007/BF01876231>
- Brooks, J., Waylen, K.A., Borgerhoff Mulder, M., 2013. Assessing community-based conservation projects: A systematic review and multilevel analysis of attitudinal, behavioral, ecological, and economic outcomes. *Environ. Evid.* 2, 1–34. <https://doi.org/10.1186/2047-2382-2-2>
- Brown, B., Fadillah, R., Nurdin, Y., Soulsby, I., Ahmad, R., 2014. Community Based Ecological Mangrove Rehabilitation (CBEMR) in Indonesia. *S.a.p.i.e.n.s. Surv. Perspect. Integr. Environ. Soc.* 7, 1–13.
- Busch, J., Ferretti-Gallon, K., 2017. What Drives Deforestation and What Stops It? A Meta-Analysis. *Rev. Environ. Econ. Policy* 11, 3–23. <https://doi.org/10.1093/reep/rew013>
- Chalmers, N., Fabricius, C., 2007. Expert and Generalist Local Knowledge about Land-cover Change

- on South Africa's Wild Coast: Can Local Ecological Knowledge Add Value to Science ? *Ecol. Soc.* 12, 10. <https://doi.org/10.1042/BST0391533>
- Chan, H.T., Baba, S., 2010. Manual on Guidelines for Rehabilitation of Coastal Forests Damaged by Natural Hazards in the Asia-Pacific Region. International Society for Mangrove Ecosystems and International Tropical Timber Organization, Okinawa, Japan.
- Chapman, V.J., 1975. *Mangrove Vegetation*. Cramer, Vaduz.
- Chianucci, F., Cutini, A., 2012. Digital hemispherical photography for estimating forest canopy properties: Current controversies and opportunities. *IForest - Biosci. For.* 5, 290–295. <https://doi.org/10.3832/ifor0775-005>
- Cinner, J.E., Daw, T.M., McClanahan, T.R., Muthiga, N., Abunge, C., Hamed, S., Mwaka, B., Rabearisoa, A., Wamukota, A., Fisher, E., Jiddawi, N., 2012. Transitions toward co-management: The process of marine resource management devolution in three east African countries. *Glob. Environ. Chang.* 22, 651–658. <https://doi.org/10.1016/j.gloenvcha.2012.03.002>
- Cintrón, G., Schaeffer-Novelli, Y., 1984. Methods for studying mangrove structure, in: Snedaker, S.C., Snedaker, J.G. (Eds.), *The Mangrove Ecosystem: Research Methods*. UNESCO, pp. 91–113.
- Clarke, P.J., Kerrigan, R.A., 2000. Do forest gaps influence the population structure and species composition of mangrove stands in northern Australia? *Biotropica* 32, 642–652. <https://doi.org/10.1111/j.1744-7429.2000.tb00511.x>
- Cochard, R., Ranamukhaarachchi, S.L., Shivakoti, G.P., Shipin, O. V., Edwards, P.J., Seeland, K.T., 2008. The 2004 tsunami in Aceh and Southern Thailand: A review on coastal ecosystems, wave hazards and vulnerability. *Perspect. Plant Ecol. Evol. Syst.* 10, 3–40. <https://doi.org/10.1016/j.ppees.2007.11.001>
- Cole, D.H., Ostrom, E., 2010. *The Variety of Property Systems and Rights in Natural Resources* (No. 2010- 08– 01), Indiana University-Bloomington School of Public & Environmental Affairs Research Paper. <https://doi.org/10.2139/ssrn.1656418>
- Courtney, C.A., White, A.T., Deguit, E., 2002. Building Philippine Local Government capacity for coastal resource management. *Coast. Manag.* 30, 27–45. <https://doi.org/10.1080/08920750252692607>
- Crona, B., 2006a. *Of Mangroves and Middlemen: A study of social and ecological linkages in a coastal community*. Stockholm University.

- Crona, B., 2006b. Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan seascape. *Ecol. Soc.* 11, 32. <https://doi.org/10.5751/ES-01712-110132>
- Curran, L.M., Trigg, S.N., McDonald, A.K., Astiani, D., Hardiono, Y.M., Siregar, P., Caniogo, I., Kasischke, E., 2004. Lowland Forest Loss in Protected Areas of Indonesian Borneo. *Science* (80-.). 303, 1000–1003. <https://doi.org/10.1126/science.1091714>
- Cvitanovic, C., Hobday, A.J., van Kerkhoff, L., Wilson, S.K., Dobbs, K., Marshall, N.A., 2015. Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: A review of knowledge and research needs. *Ocean Coast. Manag.* 112, 25–35. <https://doi.org/10.1016/j.ocecoaman.2015.05.002>
- Dahdouh-Guebas, F., Koedam, N., 2008. Long-term retrospection on mangrove development using transdisciplinary approaches: A review. *Aquat. Bot.* 89, 80–92. <https://doi.org/10.1016/j.aquabot.2008.03.012>
- Dahdouh-Guebas, F., Koedam, N., 2006. Empirical estimate of the reliability of the use of the Point-Centre Quarter Method (PCQM). Solution to ambiguous field situations and description of the PCQM+ protocol. *For. Ecol. Manage.* 228, 1–18. <https://doi.org/http://dx.doi.org/10.1016/j.foreco.2005.10.076>
- Dahdouh-Guebas, F., Mathenge, C., Kairo, J.G., Koedam, N., 2000. Utilization of mangrove wood products around Mida Creek, Kenya, amongst subsistence and commercial users. *Econ. Bot.* 54, 513–527. <https://doi.org/10.1007/BF02866549>
- Dale, P.E.R., Knight, J.M., Dwyer, P.G., 2014. Mangrove rehabilitation: a review focusing on ecological and institutional issues. *Wetl. Ecol. Manag.* 22, 587–604. <https://doi.org/10.1007/s11273-014-9383-1>
- Dale, V.H., Beyeler, S.C., 2001. Challenges in the development and use of ecological indicators. *Ecol. Indic.* 1, 3–10. [https://doi.org/10.1016/S1470-160X\(01\)00003-6](https://doi.org/10.1016/S1470-160X(01)00003-6)
- Damania, R., Russ, J., Wheeler, D., Barra, A.F., 2018. The Road to Growth: Measuring the Tradeoffs between Economic Growth and Ecological Destruction. *World Dev.* 101, 351–376. <https://doi.org/10.1016/j.worlddev.2017.06.001>
- Datta, D., Chattopadhyay, R.N., Guha, P., 2012. Community based mangrove management: A review on status and sustainability. *J. Environ. Manage.* 107, 84–95. <https://doi.org/10.1016/j.jenvman.2012.04.013>

- Datta, S.K., Sarkar, K., 2012. NTFPs and Their Commercialization Issues from the Perspective of Rural Livelihood and the State of Forest Resources: A Study of the Ranibundh Forest Range in West Bengal, India. *J. Sustain. For.* 31, 640–660. <https://doi.org/10.1080/10549811.2012.678097>
- Davies, T.E., Fazey, I.R.A., Cresswell, W., Pettorelli, N., 2014. Missing the trees for the wood: Why we are failing to see success in pro-poor conservation. *Anim. Conserv.* 17, 303–312. <https://doi.org/10.1111/acv.12094>
- Davis, A., Wagner, J.R., 2003. Who knows? On the importance of identifying “experts” when researching local ecological knowledge. *Hum. Ecol.* 31, 463–489. <https://doi.org/10.1023/A:1025075923297>
- De Schryver, P., Defoirdt, T., Sorgeloos, P., 2014. Early Mortality Syndrome Outbreaks: A Microbial Management Issue in Shrimp Farming? *PLoS Pathog.* 10. <https://doi.org/10.1371/journal.ppat.1003919>
- Department of Environment and Natural Resources, 2016. Mangrove, beach forest rehabilitation in Yolanda-hit areas completed. [WWW Document]. URL <http://oldsite.denr.gov.ph/news-and-features/latest-news/2465-mangrove-beach-forest-rehab-in-yolanda-hit-areas-completed.html> (accessed 2.3.18).
- Diefenbach, T., 2009. Are case studies more than sophisticated storytelling?: Methodological problems of qualitative empirical research mainly based on semi-structured interviews. *Qual. Quant.* 43, 875–894. <https://doi.org/10.1007/s11135-008-9164-0>
- Donato, D.C., Kauffman, J.B., Murdiyarto, D., Kurnianto, S., Stidham, M., Kanninen, M., 2011. Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* 4, 293–297. <https://doi.org/10.1038/ngeo1123>
- Duke, N., 1996. Mangrove reforestation in Panama: an evaluation of planting in areas deforested by a large oil spill, in: Field, C.D. (Ed.), *Restoration of Mangrove Ecosystems, Restoration of Mangrove Ecosystems*. International Society for Mangrove Ecosystems, Okinawa, Japan., pp. 209–232.
- Duke, N.C., 2016. Oil spill impacts on mangroves: a global review with recommendations. *Mar. Pollut. Bull.* 109, 700–715. <https://doi.org/10.1016/j.marpolbul.2016.06.082>
- Duke, N.C., 2006. *Australia’s Mangroves: The Authoritative Guide to Australia’s Mangrove Plants*. University of Queensland, Brisbane, Australia.
- Elliott, M., Mander, L., Mazik, K., Simenstad, C., Valesini, F., Whitfield, A., Wolanski, E., 2016.

- Ecoengineering with Ecohydrology: Successes and failures in estuarine restoration. *Estuar. Coast. Shelf Sci.* 176, 12–35. <https://doi.org/10.1016/j.ecss.2016.04.003>
- Ellison, A.M., 2000. Mangrove restoration: Do we know enough? *Restor. Ecol.* 8, 219–229. <https://doi.org/10.1046/j.1526-100X.2000.80033.x>
- Elster, C., 2000. Reasons for reforestation success and failure with three mangrove species in Colombia. *For. Ecol. Manage.* 131, 201–214. [https://doi.org/10.1016/S0378-1127\(99\)00214-5](https://doi.org/10.1016/S0378-1127(99)00214-5)
- Erftemeijer, P., Lewis, R.R., 1999. Planting Mangroves on Intertidal Mudflat: Habitat Rehabilitation or Habitat Conversion?, in: ECOTONE-VIII Seminar “Enhancing Coastal Ecosystem Restoration for the 21st Century.” FAO, Ranong, Thailand, p. 9. <https://doi.org/ISBN:978-92-807-3173-6>
- Erftemeijer, P., Teunissen, P., 2009. ICZM Plan Suriname - Mangrove Report. Analysis of problems and solutions for the management of the mangrove forests along Suriname’s “wild coast”.
- Escandor, J.J., 2012. In Camarines Sur, it took an hour to plant 1M mangroves [WWW Document]. *Inquirer.Net*. URL <http://newsinfo.inquirer.net/159243/in-camarines-sur-it-took-an-hour-to-plant-1m-mangroves> (accessed 9.24.17).
- Esлами-Andergoli, L., Dale, P.E.R., Knight, J.M., McCallum, H., 2015. Approaching tipping points: a focussed review of indicators and relevance to managing intertidal ecosystems. *Wetl. Ecol. Manag.* 23, 791–802. <https://doi.org/10.1007/s11273-014-9352-8>
- Evans, J., Turnbull, J.W., 2004. *Plantation forestry in the tropics. The role, silviculture, and use of planted forests for industrial, social, environmental, and agroforestry purposes.*, 3rd ed. Oxford University Press, Oxford, UK.
- Ewel, K.C., 2010. *Bringing Science and Management to Remote Communities.* Society of Wetland Scientists, University of Florida.
- FAO, 2007. The world’s mangroves 1980-2005. *FAO For. Pap.* 153, 89. <https://doi.org/978-92-5-105856-5>
- FAO, 2003. Status and trends in mangrove area extent worldwide, in: Wilkie, M.L., Fortuna, S. (Eds.), *Forest Resources Assessment Working Paper No. 63.* FAO, Rome, Italy.
- FAO, 1994. *Mangrove forest management guidelines,* FAO Forestry Paper No. 117. FAO, Rome, Italy.
- Faure, N., Ichou, B., Venisnik, T., 2019. *Communities at the heart of forest management: How can the law make a difference? Sharing lessons from Nepal, the Philippines and Tanzania.* London, UK.

- Ferreira, A.C., Lacerda, L.D., 2016. Degradation and conservation of Brazilian mangroves, status and perspectives. *Ocean Coast. Manag.* 125, 38–46.
<https://doi.org/10.1016/j.ocecoaman.2016.03.011>
- Ferris, R., Humphrey, J.W., 1999. A review of potential biodiversity indicators for application in British forests. *Forestry* 72, 313–328. <https://doi.org/10.1093/forestry/72.4.313>
- Field, A., 2018. *Discovering statistics using IBM SPSS Statistics*, 5th ed. SAGE Publications Ltd., London, UK.
- Field, C.D., 1999. Mangrove rehabilitation: Choice and necessity. *Hydrobiologia* 413, 47–52.
<https://doi.org/10.1023/A:1003863415354>
- Field, C.D., 1998. Rehabilitation of mangrove ecosystems: An overview. *Mar. Pollut. Bull.* 37, 383–392. [https://doi.org/10.1016/S0025-326X\(99\)00106-X](https://doi.org/10.1016/S0025-326X(99)00106-X)
- Field, C.D., 1996. *Restoration of mangrove ecosystems*, 1st ed. International Tropical Timber Organization, Okinawa, Japan.
- Fisher, R.J., 2000. Creating incentives for conservation: non-timber forest products and poverty alleviation. *Asia-Pacific Community For. Newsl.* 13, 1999–2001.
- Fisher, R.J., Maginnis, S., Jackson, W.J., Barrow, E., Jeanrenaud, S., 2005. *Poverty and conservation: Landscapes, people and power*. Gland, Switzerland.
<https://doi.org/10.2305/IUCN.CH.2005.FR.LL.2.en>
- Forbes, K., Broadhead, J., 2007. *The role of coastal forest in the mitigational of tsunami impacts*. FAO Regional Office for Asia and the Pacific.
- Forest Europe, 2015. *Madrid Ministerial Declaration 25 years together promoting Sustainable Forest Management in Europe*. Madrid.
- Forsyth, T., 2004. Social movements and environmental democratization in Thailand, in: Jasanoff, S., Martello, M.L. (Eds.), *Earthly Politics: Local and Global in Environmental Governance*, *Earthly Politics: Local and Global in Environmental Governance*, Politics, Science, and the Environment. MIT Press, Cambridge, MA, pp. 195–216.
- Frazer, G., Canham, C., Lertzman, K., 1999. *Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation*. Program. <https://doi.org/citeulike-article-id:4887176>

- Gao, T., Nielsen, A.B., Hedblom, M., 2015. Reviewing the strength of evidence of biodiversity indicators for forest ecosystems in Europe. *Ecol. Indic.* 57, 420–434.
<https://doi.org/10.1016/j.ecolind.2015.05.028>
- Geoghegan, T., Smith, A., 2002. Conservation and sustainable livelihoods: Collaborative mangrove management in St. Lucia. *Int. For. Rev.* 4, 292–297. <https://doi.org/10.1505/ifor.4.4.292.40534>
- Getahun, K., Van Rompaey, A., Van Turnhout, P., Poesen, J., 2013. Factors controlling patterns of deforestation in moist evergreen Afromontane forests of Southwest Ethiopia. *For. Ecol. Manage.* 304, 171–181. <https://doi.org/10.1016/j.foreco.2013.05.001>
- Gilman, E.L., Ellison, J., Duke, N.C., Field, C.D., 2008. Threats to mangroves from climate change and adaptation options: A review. *Aquat. Bot.* 89, 237–250.
<https://doi.org/10.1016/j.aquabot.2007.12.009>
- Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J., Duke, N.C., 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. *Glob. Ecol. Biogeogr.* 20, 154–159. <https://doi.org/10.1111/j.1466-8238.2010.00584.x>
- Glaser, M., da Silva Oliveira, R., 2004. Prospects for the co-management of mangrove ecosystems on the North Brazilian coast: Whose rights, whose duties and whose priorities?, in: *Natural Resources Forum*. Wiley Online Library, pp. 224–233. <https://doi.org/10.1111/j.1477-8947.2004.00092.x>
- Global Aquaculture Alliance, 2012. GAA [Global Aquaculture Alliance] says mangrove report incorrect, misleading [WWW Document]. *Seaf. News*. URL <https://www.intrafish.com/news/490292/gaa-says-mangrove-report-incorrect-misleading> (accessed 9.24.19).
- Global Witness, 2016. EU Review finds European governments failing in fight against multi-billion euro trade in illegal wood [WWW Document]. *Illegal Logging Portal*. URL <https://www.illegal-logging.info/content/eu-review-finds-european-governments-failing-fight-against-multi-billion-euro-trade-illegal> (accessed 3.24.19).
- Gonsamo, A., Walter, J.M.N., Pellikka, P., 2011. CIMES: A package of programs for determining canopy geometry and solar radiation regimes through hemispherical photographs. *Comput. Electron. Agric.* 79, 207–215. <https://doi.org/10.1016/j.compag.2011.10.001>
- Gowing, J.W., Ocampo-Thomason, P., 2007. Exploratory analysis of the comparative environmental costs of shrimp farming and rice farming in coastal areas, in: Bartley, D.M., Brugere, C., Soto,

- D., Gerber, P., Harvey, B. (Eds.), Comparative Assessment of the Environmental Costs of Aquaculture and Other Food Production Sectors. FAO/WFT, Rome, Italy, pp. 201–220.
- Granek, E.F., Compton, J.E., Phillips, D.L., 2009. Mangrove-exported nutrient incorporation by sessile coral reef invertebrates. *Ecosystems* 12, 462–472. <https://doi.org/10.1007/s10021-009-9235-7>
- Grieg-Gran, M., Porras, I., Wunder, S., 2005. How can market mechanisms for forest environmental services help the poor? Preliminary lessons from Latin America. *World Dev.* 33, 1511–1527. <https://doi.org/10.1016/j.worlddev.2005.05.002>
- Gusmawati, N., Selmaoui-Folcher, N., Proisy, C., Mustafa, A., Gendre, R. Le, Laugier, T., Lemonnier, H., Caledonia, N., Caledonia, N., 2017. Surveying shrimp aquaculture pond activity using multitemporal VHR satellite images - case study from the Perancak Estuary, Bali, Indonesia. *Mar. Pollut. Bull.* 4, 1–36. <https://doi.org/10.1016/j.marpolbul.2017.03.059>
- Halide, H., Brinkman, R., Ridd, P., 2004. Designing bamboo wave attenuators for mangrove plantations. *Indian J. Mar. Sci.* 33, 220–225.
- Hamilton, S.E., Casey, D., 2016. Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). *Glob. Ecol. Biogeogr.* 25, 729–738. <https://doi.org/10.1111/geb.12449>
- Hardeman, W., Johnston, M., Johnston, D., Bonetti, D., Wareham, N.J., Kinmouth, A.L., 2002. Application of the theory of planned behaviour in behaviour change interventions: a systematic review. *Psychol. Heal.* 17, 123–158. <https://doi.org/10.1080/08870440290013644>
- Hardin, G., 1968. The tragedy of commons. *Science* . 162, 1243–1248.
- Hashim, R., Kamali, B., Tamin, N.M., Zakaria, R., 2010. An integrated approach to coastal rehabilitation: Mangrove restoration in Sungai Haji Dorani, Malaysia. *Estuar. Coast. Shelf Sci.* 86, 118–124. <https://doi.org/10.1016/j.ecss.2009.10.021>
- Heink, U., Kowarik, I., 2010. What are indicators? On the definition of indicators in ecology and environmental planning. *Ecol. Indic.* 10, 584–593. <https://doi.org/10.1016/j.ecolind.2009.09.009>
- Herteman, M., Fromard, F., Lambs, L., 2011. Effects of pretreated domestic wastewater supplies on leaf pigment content, photosynthesis rate and growth of mangrove trees: A field study from Mayotte Island, SW Indian Ocean. *Ecol. Eng.* 37, 1283–1291. <https://doi.org/10.1016/j.ecoleng.2011.03.027>

- Hobbs, R.J., 2016. Degraded or just different? Perceptions and value judgements in restoration decisions. *Restor. Ecol.* 24, 153–158. <https://doi.org/10.1111/rec.12336>
- Holguin, G., Vazquez, P., Bashan, Y., 2001. The role of sediment microorganisms in the productivity, conservation, and rehabilitation of mangrove ecosystems: An overview. *Biol. Fertil. Soils* 33, 265–278. <https://doi.org/10.1007/s003740000319>
- Hong, P.N., San, H.T., 1993. *Mangroves of Vietnam*, 1st ed. IUCN, Bangkok, Thailand.
- Hosonuma, N., Herold, M., De Sy, V., De Fries, R.S., Brockhaus, M., Verchot, L., Angelsen, A., Romijn, E., 2012. An assessment of deforestation and forest degradation drivers in developing countries. *Environ. Res. Lett.* 7, 044009. <https://doi.org/10.1088/1748-9326/7/4/044009>
- Huitric, M., Folke, C., Kautsky, N., 2002. Development and government policies of the shrimp farming industry in Thailand in relation to mangrove ecosystems. *Ecol. Econ.* 40, 441–455. [https://doi.org/10.1016/S0921-8009\(02\)00011-3](https://doi.org/10.1016/S0921-8009(02)00011-3)
- Huong, N.L., Itoh, K., Suyama, K., 2007. Diversity of 2,4-Dichlorophenoxyacetic Acid (2,4-D) and 2,4,5-Trichlorophenoxyacetic Acid (2,4,5-T)-Degrading Bacteria in Vietnamese Soils. *Microbes Environ.* 22, 243–256. <https://doi.org/10.1264/jisme.22.243>
- Huxham, M., Emerton, L., Kairo, J., Munyi, F., Abdirizak, H., Muriuki, T., Nunan, F., Briers, R.A., 2015. Applying Climate Compatible Development and economic valuation to coastal management: A case study of Kenya's mangrove forests. *J. Environ. Manage.* 157, 168–181. <https://doi.org/10.1016/J.JENVMAN.2015.04.018>
- Huxham, M., Langat, J., Tamooh, F., Kennedy, H., Mencuccini, M., Skov, M.W., Kairo, J., 2010. Decomposition of mangrove roots: Effects of location, nutrients, species identity and mix in a Kenyan forest. *Estuar. Coast. Shelf Sci.* 88, 135–142. <https://doi.org/10.1016/j.ecss.2010.03.021>
- Huxham, M., Whitlock, D., Githaiga, M., Dencer-Brown, A., 2018. Carbon in the coastal seascape: How interactions between mangrove forests, seagrass meadows and tidal marshes influence carbon storage. *Curr. For. Reports* 4, 101–110. <https://doi.org/10.1007/s40725-018-0077-4>
- Iftekhhar, M.S., Islam, M.R., 2004. Managing mangroves in Bangladesh: A strategy analysis. *J. Coast. Conserv.* 10, 139. [https://doi.org/10.1652/1400-0350\(2004\)010\[0139:MMIBAS\]2.0.CO;2](https://doi.org/10.1652/1400-0350(2004)010[0139:MMIBAS]2.0.CO;2)
- Igulu, M.M., Nagelkerken, I., Dorenbosch, M., Grol, M.G.G., Harborne, A.R., Kimirei, I.A., Mumby, P.J., Olds, A.D., Mgaya, Y.D., 2014. Mangrove Habitat Use by Juvenile Reef Fish: Meta-Analysis Reveals that Tidal Regime Matters More than Biogeographic Region. *PLoS One* 9, e114715.

<https://doi.org/10.1371/journal.pone.0114715>

- Islam, M.S., Wahab, M.A., 2005. A review on the present status and management of mangrove wetland habitat resources in Bangladesh with emphasis on mangrove fisheries and aquaculture. *Hydrobiologia* 542, 165–190. <https://doi.org/10.1007/s10750-004-0756-y>
- IUCN, 2017. Mass mangrove restoration: driven by good intentions but offering limited results. [WWW Document]. URL <https://www.iucn.org/news/forests/201702/mass-mangrove-restoration-driven-good-intentions-offering-limited-results> (accessed 2.3.18).
- IUCN, WRI, 2014. A guide to the Restoration Opportunities Assessment Methodology (ROAM): Assessing forest landscape restoration opportunities at the national or sub-national level., (Road-test edition). Gland, Switzerland.
- Jitthaisong, O., Dhanmanonda, P., Chunkao, K., Teejuntuk, S., 2012. Water quality from Mangrove forest: The King's royally initiated Laem Phak Bia Environmental Research and Development Project: Phetchaburi Province, Thailand. *Mod. Appl. Sci.* 6, 1–8. <https://doi.org/10.5539/mas.v6n8p1>
- Johnson, C., Forsyth, T., 2002. In the Eyes of the State: Negotiating a “Rights-Based Approach” to Forest Conservation in Thailand. *World Dev.* 30, 1591–1605. [https://doi.org/10.1016/S0305-750X\(02\)00057-8](https://doi.org/10.1016/S0305-750X(02)00057-8)
- Kairo, J.G., Dahdouh-Guebas, F., Bosire, J., Koedam, N., 2001. Restoration and management of mangrove systems - a lesson for and from the East African region. *South African J. Bot.* 67, 383–389. [https://doi.org/https://doi.org/10.1016/S0254-6299\(15\)31153-4](https://doi.org/https://doi.org/10.1016/S0254-6299(15)31153-4)
- Kairo, J.G., Dahdouh-Guebas, F., Gwada, P.O., Ochieng, C., Koedam, N., 2002. Regeneration status of mangrove forests in Mida Creek, Kenya: a compromised or secured future? *Ambio* 31, 562–568. <https://doi.org/10.1579/0044-7447-31.7.562>
- Kairo, J.G., Lang'at, J.K.S., Dahdouh-Guebas, F., Bosire, J., Karachi, M., 2008. Structural development and productivity of replanted mangrove plantations in Kenya. *For. Ecol. Manage.* 255, 2670–2677. <https://doi.org/10.1016/j.foreco.2008.01.031>
- Kallio, H., Pietilä, A.M., Johnson, M., Kangasniemi, M., 2016. Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *J. Adv. Nurs.* 72, 2954–2965. <https://doi.org/10.1111/jan.13031>
- Kanagaratnam, U., Adhuri, D., Dey, M.M., Schwarz, A.M., 2006. Mangrove Rehabilitation in the West Coast of Aceh ? Issues and Perspectives. *Naga WorldFish Cent. Q.* 29, 10–18.

- Katon, B.M., Pomeroy, R.S., Ring, M., Garces, L.R., 1998. Mangrove rehabilitation and coastal resource management: a case study of Cogtong Bay, Philippines. *Naga, ICLARM Q.* 21, 46–52.
- Kauffman, J.B., Donato, D.C., 2012. Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86., 86. Bogor, Indonesia.
- Khoon, G., Ong, J.E., 1995. The Use of Demographic-Studies in Mangrove Silviculture, in: Wong, Y.S., Tam, N. (Eds.), *Asia-Pacific Symposium on Mangrove Ecosystems. Developments in Hydrobiology.* SPRINGER, DORDRECHT, Hong Kong, pp. 255–261.
<https://doi.org/10.1007/BF00029132>
- Kimmins, J.P., 1996. *Forest Ecology*, 2nd ed. Prentice Hall, New Jersey, USA.
- Kissinger, G., Herold, M., De Sy, V., 2012. *Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers.* Vancouver, Canada.
- Kitamura, S., Anwar, C., Chaniago, A., Baba, S., 1998. *Handbook of Mangroves in Indonesia.* ISME, Okinawa, Japan.
- Kodikara, K.A.S., Jayatissa, L.P., Huxham, M., Dahdouh-Guebas, F., Koedam, N., 2017a. The effects of salinity on growth and survival of mangrove seedlings changes with age. *Acta Bot. Brasilica* 32, 37–46. <https://doi.org/10.1590/0102-33062017abb0100>
- Kodikara, K.A.S., Mukherjee, N., Jayatissa, L.P., Dahdouh-Guebas, F., Koedam, N., 2017b. Have mangrove restoration projects worked? An in-depth study in Sri Lanka. *Restor. Ecol.* 25, 1–12. <https://doi.org/10.1111/rec.12492>
- Krauss, K.W., Lovelock, C.E., McKee, K.L., López-Hoffman, L., Ewe, S.M.L., Sousa, W.P., 2008. Environmental drivers in mangrove establishment and early development: A review. *Aquat. Bot.* 89, 105–127. <https://doi.org/10.1016/j.aquabot.2007.12.014>
- Kristensen, E., Alongi, D.M., 2006. Control by fiddler crabs (*Uca vocans*) and plant roots (*Avicennia marina*) on carbon, iron, and sulfur biogeochemistry in mangrove sediment. *Limnol. Oceanogr.* 51, 1557–1571. <https://doi.org/10.4319/lo.2006.51.4.1557>
- Kuhlmann, D., 1988. The sensitivity of coral reefs environmental pollution. *Ambio* 17, 13–21.
- L'Heureux, M.L., Takahashi, K., Watkins, A.B., Barnston, A.G., Becker, E.J., Di Liberto, T.E., Gamble, F., Gottschalck, J., Halpert, M.S., Huang, B., Mosquera-Vásquez, K., Wittenberg, A.T., 2017. Observing and predicting the 2015/16 El Niño. *Bull. Am. Meteorol. Soc.* 98, 1363–1382.

<https://doi.org/10.1175/BAMS-D-16-0009.1>

- Lavieren, H. Van, Spalding, M., Alongi, D.M., Kainuma, M., Clusener-Godt, M., Adeel, Z., 2012. Securing the future of mangrove. A Policy Brief. UNU-INWEH, UNESCO-MAB with ITTO, FAO, UNEP-WCMC TNC. 53. <https://doi.org/http://www.inweh.unu.edu>
- Le Fur, J., Guilavogui, A., Teitelbaum, A., Rochet, M.-J., 2011. Contribution of local fishermen to improving knowledge of the marine ecosystem and resources in the Republic of Guinea, West Africa. *Can. J. Fish. Aquat. Sci.* 68, 1454–1469. <https://doi.org/10.1139/f2011-061>
- Lee, S.Y., 2004. Relationship between mangrove abundance and tropical prawn production: A re-evaluation. *Mar. Biol.* 145, 943–949. <https://doi.org/10.1007/s00227-004-1385-8>
- Lewis, R.R., 2014. Habitat-specific approaches, in: Bozzano, M., Jalonen, R., Thomas, E., Boshier, D., Gallo, L., Cavers, S., Bordács, S., Smith, P., Loo, J. (Eds.), *Genetic Considerations in Ecosystem Restoration Using Native Tree Species*. FAO, Rome, pp. 195–200. <https://doi.org/https://doi.org/10.1016/j.foreco.2014.07.015>
- Lewis, R.R., 2009. Methods and Criteria for Successful Mangrove Forest Restoration, in: Perillo, G.M.E., Wolanski, E., Cahoon, D.R., Brinson, M.M. (Eds.), *Coastal Wetlands: An Integrated Ecosystem Approach*. Elsevier, Oxford, UK, pp. 787–800. <https://doi.org/10.1016/B978-0-444-53103-2.00028-4>
- Lewis, R.R., 2005. Ecological engineering for successful management and restoration of mangrove forests. *Ecol. Eng.* 24, 403–418. <https://doi.org/10.1016/j.ecoleng.2004.10.003>
- Lewis, R.R., 2000. Ecologically based goal setting in mangrove forest and tidal marsh restoration. *Ecol. Eng.* 15, 191–198. [https://doi.org/10.1016/S0925-8574\(00\)00070-7](https://doi.org/10.1016/S0925-8574(00)00070-7)
- Lewis, R.R., 1982. Mangrove Forests, in: Lewis, R.R. (Ed.), *Creation and Restoration of Coastal Plant Communities*. CRC Press, Boca Raton, pp. 153–172.
- Lewis, R.R., Brown, B.M., 2014. *Ecological Mangrove Rehabilitation A field manual for practitioners*, 3rd ed. Oxfam, Canadian International Development Agency, USAID.
- Lewis, R.R., Gilmore, R.G., 2007. Important considerations to achieve successful mangrove forest restoration with optimum fish habitat. *Bull. Mar. Sci.* 80, 823–837.
- Lewis, R.R., Milbrandt, E.C., Brown, B., Krauss, K.W., Rovai, A.S., Beever, J.W., Flynn, L.L., 2016. Stress in mangrove forests: Early detection and preemptive rehabilitation are essential for future successful worldwide mangrove forest management. *Mar. Pollut. Bull.* 109, 764–771.

<https://doi.org/10.1016/j.marpolbul.2016.03.006>

- Liira, J., Sepp, T., Parrest, O., 2007. The forest structure and ecosystem quality in conditions of anthropogenic disturbance along productivity gradient. *For. Ecol. Manage.* 250, 34–46. <https://doi.org/10.1016/J.FORECO.2007.03.007>
- Lindenmayer, D.B., Margules, C.R., Botkin, D.B., 2000. Indicators of Biodiversity for Ecologically Sustainable Forest Management 14, 941–950. <https://doi.org/doi.org/10.1046/j.1523-1739.2000.98533.x>
- Locatelli, T., Binet, T., Kairo, J.G., King, L., Madden, S., Patenaude, G., Upton, C., Huxham, M., 2014. Turning the Tide: How Blue Carbon and Payments for Ecosystem Services (PES) Might Help Save Mangrove Forests. *Ambio* 43, 981–995. <https://doi.org/10.1007/s13280-014-0530-y>
- Long, J., Napton, D., Giri, C., Graesser, J., 2014. A Mapping and Monitoring Assessment of the Philippines' Mangrove Forests from 1990 to 2010. *J. Coast. Res.* 294, 260–271. <https://doi.org/10.2112/JCOASTRES-D-13-00057.1>
- López-Hoffman, L., Monroe, I.E., Narváez, E., Martínez-Ramos, M., Ackerly, D.D., 2006. Sustainability of mangrove harvesting: How do harvesters' perceptions differ from ecological analysis? *Ecol. Soc.* 11, 14. <https://doi.org/10.5751/ES-01820-110214>
- Lui, D.S., Iverson, L.R., Brown, S., 1993. Rates and patterns of deforestation in the Philippines: application of geographic information system analysis. *For. Ecol. Manag.* 57, 1–16.
- Macintosh, D.J., Ashton, E.C., Havanon, S., 2002. Mangrove rehabilitation and intertidal biodiversity: A study in the Ranong mangrove ecosystem, Thailand. *Estuar. Coast. Shelf Sci.* 55, 331–345. <https://doi.org/10.1006/ecss.2001.0896>
- Magalhães, A., da Costa, R.M., da Silva, R., Pereira, L.C.C., 2007. The role of women in the mangrove crab (*Ucides cordatus*, Ocypodidae) production process in North Brazil (Amazon region, Para). *Ecol. Econ.* 61, 559–565. <https://doi.org/10.1016/j.ecolecon.2006.05.013>
- Mäkelä, A., Del Río, M., Hynynen, J., Hawkins, M.J., Reyer, C., Soares, P., Van Oijen, M., Tomé, M., 2012. Using stand-scale forest models for estimating indicators of sustainable forest management. *For. Ecol. Manage.* 285, 164–178. <https://doi.org/10.1016/j.foreco.2012.07.041>
- Maliao, R.J., Polohan, B.B., 2008. Evaluating the impacts of mangrove rehabilitation in Cogtong Bay, Philippines. *Environ. Manage.* 41, 414–424. <https://doi.org/10.1007/s00267-007-9021-2>
- Manson, F.J., Loneragan, N.R., Skilleter, G. a, Phinn, S.R., 2005. An evaluation of the evidence for

- linkages between mangroves and fisheries : A synthesis of the literature and identification of research directions, in: Gibson, R.N., Atkinson, R.J.A., Gordon, J.D.M. (Eds.), *Oceanography and Marine Biology, Oceanography and Marine Biology: An Annual Review*. Taylor & Francis, Australia, p. 31. <https://doi.org/doi:10.1201/9781420037449.ch10>
- Mansourian, S., Stanturf, J.A., Derkyi, M.A.A., Engel, V.L., 2017. Forest Landscape Restoration: increasing the positive impacts of forest restoration or simply the area under tree cover? *Restor. Ecol.* 25, 178–183. <https://doi.org/10.1111/rec.12489>
- Marschke, M., Nong, K., 2003. Adaptive Co-Management: Lessons from Coastal Cambodia. *Can. J. Dev. Stud. Can. d'études du développement* 24, 369–383. <https://doi.org/10.1080/02255189.2003.9668927>
- Matsui, N., Songsangjinda, P., Wodehouse, D.C.J., 2014. Longevity of simultaneous operation of aquaculture and mangrove forestry as explained in terms of water and sediment qualities. *Wetl. Ecol. Manag.* 22, 215–225. <https://doi.org/10.1007/s11273-013-9312-8>
- Mazda, Y., Wolanski, E., Ridd, P. V., 2003. *The Role of Physical Processes in Mangrove Environments: Manual for the Preservation and Utilization of Mangrove Ecosystems*. Terrapub, Tokyo, Japan.
- McDonald, T., Gann, G., Jonson, J., Dixon, K.W., 2016. International standards for the practice of ecological restoration—including principles and key concepts. Society for Ecological Resotration, Washington, D. C. <https://doi.org/10.1177/15257401070280021001>
- McElhinny, C., Gibbons, P., Brack, C., Bauhus, J., 2005. Forest and woodland stand structural complexity: Its definition and measurement. *For. Ecol. Manage.* 218, 1–24. <https://doi.org/10.1016/j.foreco.2005.08.034>
- McIvor, A.L., Möller, I., Spencer, T., Spalding, M., 2012. Reduction of wind and swell waves by mangroves. *Nat. Coast. Prot. Ser. Rep. 1*. Cambridge Coast. Res. Unit Work. Pap. 40.
- MCPFE, 2002. Improved Pan-European Indicators for Sustainable Forest Management as Adopted by the Ministerial Conferences on the Protection of Forests in Europe (MCPFE) Expert Level Meeting. Vienna.
- MCPFE, 1998. Ministerial Conference on the Protection of Forests in Europe, in: Ministerial Conference on the Protection of Forests in Europe: Recognising the Multiple Roles of Forests, Lisbon, June. (MCPFE). European Commission, Vienna.
- Melana, D.M., Atchue III, J., Yao, C.E., Edwards, R., Melana, E.E., Gonzales, H.I., 2000. *Mangrove management handbook*. Department of Environment and Natural Resources, Manila,

- Philippines through the Coastal Resource Management Project, Cebu City, Philippines.
- Memon, J.A., Chandio, A.A., 2011. A critical appreciation of Restoration and conservation of Degraded Mangroves in Thailand. *Int. J. Environ. Rural Dev.* 2, 108–113.
- Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-Being: Synthesis*. Washington, D. C. <https://doi.org/http://dx.doi.org/10.1016/B978-0-12-409548-9.09206-X>
- Miller, Z.D., 2017. The Enduring Use of the Theory of Planned Behavior. *Hum. Dimens. Wildl.* 22, 583–590. <https://doi.org/10.1080/10871209.2017.1347967>
- Ministry of Natural Resources and Environmental Conservation (MONREC) Union Minister’s Office, 2016. *Community Forestry Instructions*. Myanmar.
- Moberg, F., Rönnbäck, P., 2003. Ecosystem services of the tropical seascape: Interactions, substitutions and restoration. *Ocean Coast. Manag.* 46, 27–46. [https://doi.org/10.1016/S0964-5691\(02\)00119-9](https://doi.org/10.1016/S0964-5691(02)00119-9)
- Monserud, R.A., 2003. Evaluating Forest Models in a Sustainable Forest Management Context. *For. biometry, Model. Inf. Sci.* 1, 35–47. <https://doi.org/10.1039/b507107k>
- Montaño, D.E., Kasprzyk, D., 2015. Theory of reasoned Action, theory of planned behavior, and the integrated behavioral model, in: Glanz, K., Rimer, B.K.R., Viswanath, K. (Eds.), *Health Behavior: Theory, Research and Practice*. Jossey-Bass, San Francisco, pp. 95–124.
- Morrissey, D.J., Swales, A., Dittmann, S., Morrison, M.A., Lovelock, C.E., Beard, C.M., 2010. The ecology and management of temperate mangroves. *Oceanogr. Mar. Biol. an Annu. Rev.* 48, 43–160. <https://doi.org/10.1201/EBK1439821169-c2>
- Muehlig-Hofmann, A., 2007. Traditional authority and community leadership : Key factors in community-based marine resource management and conservation. *SPC Tradit. Mar. Resour. Manag. Knowl. Inf. Bull.* 21, 31–44.
- Mukherjee, N., Dahdouh-Guebas, F., Koedam, N., Shanker, K., 2015. An interdisciplinary framework to evaluate bioshield plantations: insights from Peninsular India. *Acta Oecologica* 63, 91–100. <https://doi.org/10.1016/j.actao.2014.01.005>
- Müller, R., Müller, D., Schierhorn, F., Gerold, G., Pacheco, P., 2012. Proximate causes of deforestation in the Bolivian lowlands: an analysis of spatial dynamics. *Reg. Environ. Chang.* 12, 445–459. <https://doi.org/10.1007/s10113-011-0259-0>
- Mulyana, A., 2017. What’s next for customary forests in Indonesia? [WWW Document]. *Illegal*

Logging Portal. URL <https://www.illegal-logging.info/content/what's-next-customary-forests-indonesia> (accessed 3.24.19).

Mumby, P.J., Edwards, A.J., Ernesto Arias-González, J., Lindeman, K.C., Blackwell, P.G., Gall, A., Gorczyńska, M.I., Harborne, A.R., Pescod, C.L., Renken, H., C. C. Wabnitz, C., Llewellyn, G., 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature* 427, 533–536. <https://doi.org/10.1038/nature02286>

Nagelkerken, I., Blaber, S.J.M., Bouillon, S., Green, P., Haywood, M., Kirton, L.G., Meynecke, J.O., Pawlik, J., Penrose, H.M., Sasekumar, A., Somerfield, P.J., 2008. The habitat function of mangroves for terrestrial and marine fauna: A review. *Aquat. Bot.* 89, 155–185. <https://doi.org/10.1016/j.aquabot.2007.12.007>

National Economic and Social Development Board, 2011. Eleventh National Economic and Social Development Plan (2012-2016). Government of Thailand, Bangkok, Thailand.

National Legislative Assembly, 1999. Determining Plans and Process of Decentralization to Local Government Organization Act B.E. 2542. Royal Thailand Government.

National Mangrove Committee, 1987. Philippines Case Study, in: *Mangroves of Asia and the Pacific: Status and Management*. Ministry of Natural Resources, Manila, Philippines.

National News Bureau of Thailand, 2016. The First Division Army Area Commander launched the conservation and restoration of 840,000 mangrove seedling in Honor of Her Majesty Queen Sirikit in Chonburi area [WWW Document]. *Natl. News Bur. Thail.* URL http://nwnt.prd.go.th/centerweb/News/NewsDetail?NT01_NewsID=WNEVN5904010010013 (accessed 2.21.17).

National Oceanic and Atmospheric Administration (NOAA), n.d. What is El Nino? [WWW Document]. *Pacific Mar. Environ. Lab. El Nino Theme Page*. URL https://www.pmel.noaa.gov/el_nino/what-is-el-nino (accessed 8.3.19).

Ng, P.K.L., Keng, W.L., Lim, K.K.P., 2008. *Private lives: an exposé of Singapore's mangroves*. Raffles Museum of Biodiversity Research, National University of Singapore, Singapore.

Nilsson, D., Baxter, G., Butler, J.R.A., McAlpine, C.A., 2016. How do community-based conservation programs in developing countries change human behaviour? A realist synthesis. *Biol. Conserv.* 200, 93–103. <https://doi.org/10.1016/j.biocon.2016.05.020>

Noss, R.F., 1999. Assessing and monitoring forest biodiversity: A suggested framework and indicators. *For. Ecol. Manage.* 115, 135–146. [https://doi.org/10.1016/S0378-1127\(98\)00394-6](https://doi.org/10.1016/S0378-1127(98)00394-6)

- Nurse, M., Kabamba, J., 2000. Defining institutions for collaborative mangrove management : a case study from Tanga, Tanzania, Forest and social perspectives in conservation.
- Odum, W.E., Heald, E.J., 1975. The detritus-based food web of an estuarine mangrove community, Estuarine Research: Chemistry, Biology, and the Estuarine System.
- Office of the National Economic and Social Development Board, 2001. The Ninth National Economic and Social Development Plan (2002-2006).
- Oh, R.R.Y., Friess, D.A., Brown, B.M., 2017. The role of surface elevation in the rehabilitation of abandoned aquaculture ponds to mangrove forests, Sulawesi, Indonesia. *Ecol. Eng.* 100, 325–334. <https://doi.org/10.1016/j.ecoleng.2016.12.021>
- Ohn, U., n.d. Coastal Resource Management with Special Reference to Mangroves of Myanmar. FREDA.
- Osbeck, M., Powell, N., Boromthanasat, S., 2010. Linking policy processes and stakeholder agency to coastal change: A case study from Nakhon Si Thammarat, Thailand, in: Fujikura, R., Kawanishi, M. (Eds.), *Climate Change Adaptation and International Development*. Routledge, London, UK, pp. 173–191. <https://doi.org/10.4324/9781849775267>
- Ostrom, E., 2010. The Challenge of self-governance in complex contemporary environments. *J. Specul. Philos.* 24, 316–332. <https://doi.org/10.1353/jsp.2010.0020>
- Ostrom, E., 1999. *Self-Governance and Forest Resources*, Occasional Paper. Bogor, Indonesia.
- Ostrom, E., 1990. *Governing the Commons: The Evolution of Institutions for Collective Action (Political Economy of Institutions and Decisions)*. Cambridge University Press.
- Pagdee, A., Kim, Y., Daugherty, P.J., 2006. What Makes Community Forest Management Successful: A Meta-Study From Community Forests Throughout the World. *Soc. Nat. Resour.* 19, 33–52. <https://doi.org/10.1080/08941920500323260>
- Parida, A.K., Jha, B., 2010. Salt tolerance mechanisms in mangroves: a review. *Trees* 24, 199–217. <https://doi.org/10.1007/s00468-010-0417-x>
- Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., Coops, N.C., Dulloo, E., Faith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Höft, R., Hurtt, G., Jetz, W., Karp, D.S., McGeoch, M.A., Obura, D., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak, E., Walpole, M., Wegmann, M., 2013. Essential biodiversity variables. *Science* (80-.). 339, 277–

278. <https://doi.org/10.1126/science.1229931>
- Pokharel, B.K., Branney, P., Nurse, M., Malla, Y.B., 2007. Community Forestry : Conserving Forests , Sustaining Livelihoods and Strengthening Democracy. *J. For. Livelihood* 6, 8–19. <https://doi.org/10.3126/jfl.v6i2.2321>
- Pomeroy, R.S., Carlos, M.B., 1997. Community-based coastal resource management in the Philippines: A review and evaluation of programs and projects, 1984–1994. *Mar. Policy* 21, 445–464. [https://doi.org/10.1016/S0308-597X\(97\)00016-X](https://doi.org/10.1016/S0308-597X(97)00016-X)
- Porter-Bolland, L., Ellis, E.A., Guariguata, M.R., Ruiz-Mallén, I., Negrete-Yankelevich, S., Reyes-García, V., 2012. Community managed forests and forest protected areas: An assessment of their conservation effectiveness across the tropics. *For. Ecol. Manage.* 268, 6–17. <https://doi.org/10.1016/j.foreco.2011.05.034>
- Prabnarong, P., Kaewrat, J., 2006. The Uthokawiphatprasit Watergate: A Man-Made Change in Pak Phanang River Basin. *Walailak J. Sci. Technol.* 3, 131–143.
- Prach, K., del Moral, R., 2015. Passive restoration is often quite effective: Response to Zahawi et al. (2014). *Restor. Ecol.* 23, 344–346. <https://doi.org/10.1111/rec.12224>
- Pretty, J.N., 1995. Participatory Learning For Sustainable Agriculture. *Elsevier Sci.* 23, 1247–1263. [https://doi.org/10.1016/0305-750X\(95\)00046-F](https://doi.org/10.1016/0305-750X(95)00046-F)
- Primavera, J.H., 2015. Stop seafront planting of bakhaw propagules [WWW Document]. INQUIRER.net. URL <http://business.inquirer.net/187523/stop-seafront-planting-of-bakhaw-propagules> (accessed 9.25.17).
- Primavera, J.H., 2013. Shelter from the Storm: Coastal greenbelts of mangroves and beach forests. *Philipp. Star*.
- Primavera, J.H., 2000. Development and conservation of Philippine mangroves: institutional issues. *Ecol. Econ.* 35, 91–106. [https://doi.org/10.1016/S0921-8009\(00\)00170-1](https://doi.org/10.1016/S0921-8009(00)00170-1)
- Primavera, J.H., 1995. Mangroves and brackishwater pond culture in the Philippines, in: Wong, Y.-S., Tam, N.F.Y. (Eds.), *Asia-Pacific Symposium on Mangrove Ecosystems*. Springer, pp. 303–309.
- Primavera, J.H., Altamirano, J.P., Lebata, M.J.H.L., Delos Reyes, A.A., Pitogo, C.L., 2007. Mangroves and shrimp pond culture effluents in Aklan, Panay is., central Philippines. *Bull. Mar. Sci.* 80, 795–804.
- Primavera, J.H., Esteban, J.M.A., 2008. A review of mangrove rehabilitation in the Philippines:

- successes, failures and future prospects. *Wetl. Ecol. Manag.* 16, 345–358.
<https://doi.org/10.1007/s11273-008-9101-y>
- Primavera, J.H., Rollon, R.N., Samson, M.S., 2011. Mangrove rehabilitation in the Philippines: The challenges of coastal protection and pond reversion, in: Wolanski, E., McKlusky, D. (Eds.), *Treatise on Estuarine and Coastal Science*. Waltham Academic Press, pp. 217–244.
<https://doi.org/10.1016/B978-0-12-374711-2.01010-X>
- Primavera, J.H., Sadaba, R.B., Leбата, M.J.H.L., Altamirano, J.P., 2004. *Handbook of mangroves in the Philippines: Panay.*, *Handbook of mangroves in the Philippines: Panay*. SEAFDEC, Tigbauan, Philippines.
- Primavera, J.H., Savaris, J.P., Bajoyo, B.E., Coching, J.D., Curnick, D.J., Golbeque, R.L., Guzman, A.T., Henderin, J.Q., Joven, R. V, Loma, R.A., 2012. *Manual for community-based mangrove rehabilitation*, 1st ed, London, Zoological Society of London, Mangrove Manual Series. ZSL, London, UK.
- Primavera, J.H., Savaris, J.P., Loma, R.J.A., Coching, J.D., Montilijao, C.L., 2015. *Manual for trainers: mangrove and beach forest rehabilitation and conservation.*, 3rd ed. ZSL, London, UK.
- Primavera, J.H., Yap, W.G., Savaris, J.P., Loma, R.A., Moscoso, A.D.E., Coching, J.D., Montilijao, C.L., Poignan, R.P., Tayo, I.D., 2014. *Manual on Mangrove Reversion of Abandoned and Illegal Brackishwater Fishponds–Mangrove Manual Series No. 2.*, 2nd ed. Zoological Society of London, Iloilo City, Philippines.
- Promis, A., Gärtner, S., Butler-Manning, D., Durán-Rangel, C., Reif, A., Cruz, G., Hernández, L., 2011. Comparison of four different programs for the analysis of hemispherical photographs using parameters of canopy structure and solar radiation transmittance. *Waldökologie, Landschaftsforsch. und Naturschutz* 11, 19–33.
- Pulukuttige, J.L., Dahdouh-Guebas, F., 2012. A bibliometrical review on pre- and posttsunami assumptions and facts about mangroves and other coastal vegetation as protective buffers. *Ruhuna J. Sci.* 4, 28–50.
- Putz, F.E., Chan, H.T., 1986. Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. *For. Ecol. Manage.* 17, 211–230. [https://doi.org/https://doi.org/10.1016/0378-1127\(86\)90113-1](https://doi.org/https://doi.org/10.1016/0378-1127(86)90113-1)
- Ranada, P., 2015. “Wrong” mangrove rehab in Yolanda areas wasting funds [WWW Document]. *Rappler News Website Philipp*. URL <http://www.rappler.com/science->

- nature/environment/89163-unscientific-mangrove-rehabilitation-yolanda (accessed 10.25.17).
- Ranasinghe, T.S., 2012. Mangrove Restoration Efforts in Sri Lanka, in: Macintosh, D. (Ed.), *Mangroves for the Future Regional Colloquium: Sharing Lessons on Mangrove Restoration*. Mamallapuram, Chennai, India. MFF Secretariat, IUCN, Bangkok, Thailand, p. 24.
- Rands, M.R.W., Adams, W.M., Bennun, L., Butchart, S.H.M., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J.P.W., Sutherland, W.J., Vira, B., 2010. Biodiversity Conservation: Challenges Beyond 2010. *Science* (80-.). 329, 1298–1303.
<https://doi.org/10.1126/science.1189138>
- RAP FAO, 2007. No Title, in: Braatz, S., Fortuna, S., Broadhead, J., Leslie, R.N. (Eds.), *Proceedings of the Workshop on Coastal Area Planning and Management in Asian Tsunami-Affected Countries*. FAO RAP Publication 2007/06, Bangkok, Thailand.
- Rasolofoson, R.A., Ferraro, P.J., Jenkins, C.N., Jones, J.P.G., 2015. Effectiveness of Community Forest Management at reducing deforestation in Madagascar. *Biol. Conserv.* 184, 271–277.
<https://doi.org/10.1016/J.BIOCON.2015.01.027>
- Rathnayake, P.S., Mapatuna, Y., Dayawansa, P.N., 2012. Restoration of a Deteriorated Wetlands of Yala East National Park, Sri Lanka: A Pilot Project of Mangrove Restoration, in: Macintosh, D. (Ed.), *Mangroves for the Future Regional Colloquium: Sharing Lessons on Mangrove Restoration*. MFF Secretariat, IUCN, Bangkok, Thailand., Chennai, India, p. 24.
- Ravishankar, T., Ramasubramanian, R., 2004. *Manual on mangrove nursery raising techniques*. MS Swaminathan Research Foundation, Chennai, India.
- Richards, D.R., Friess, D.A., 2016. Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proc. Natl. Acad. Sci.* 113, 344–349. <https://doi.org/10.1073/pnas.1510272113>
- Richards, D.R., Friess, D.A., 2015. A rapid indicator of cultural ecosystem service usage at a fine spatial scale: Content analysis of social media photographs. *Ecol. Indic.* 53, 187–195.
<https://doi.org/10.1016/J.ECOLIND.2015.01.034>
- Roe, D., Nelson, F., Sandbrook, C., 2009. *Community management of natural resources in Africa: impacts, experiences and future directions*, 1st ed. International Institute for Environment and Development, London.
- Rönnbäck, P., Crona, B.I., Ingwall, L., 2007. The return of ecosystem goods and services in replanted mangrove forests: perspectives from local communities in Kenya. *Environ. Conserv.* 34, 313–324. <https://doi.org/https://doi.org/10.1017/S0376892907004225>

- Ronnback, P., Kautsky, N., Pihl, L., Troell, M., Soerqvist, T., Wennhage, H., 2007. Ecosystem goods and services from Swedish coastal habitats: Identification, valuation, and implications of ecosystem shifts. *Ambio* 36. [https://doi.org/10.1579/0044-7447\(2007\)36\[534:EGASFS\]2.0.CO;2](https://doi.org/10.1579/0044-7447(2007)36[534:EGASFS]2.0.CO;2)
- Rossi, A.N., Armstrong, J.B., 1999. Theory of reasoned action vs. Theory of planned behavior: Testing the suitability and sufficiency of a popular behavior model using hunting intentions. *Hum. Dimens. Wildl.* 4, 40–56. <https://doi.org/10.1080/10871209909359156>
- Rotich, B., Mwangi, E., Lawry, S., 2016. Where land meets the sea: A Global Review of the Governance and Tenure Dimensions of Coastal Mangrove Forests, CIFOR and USAID Tenure and Global Climate Change Program. Bogor, Indonesia.
<https://doi.org/http://dx.doi.org/10.1016/j.jsams.2014.07.007>
- Saenger, P., 2002. Mangrove ecology, silviculture, and conservation. Kluwer Academic Publishers, Dordrecht; Boston.
- Saenger, P., Gartside, D., Funge-Smith, S., 2013. A review of mangrove and seagrass ecosystems and their linkage to fisheries and fisheries management, Food and Agriculture Organization of the United Nations. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.
<https://doi.org/ISBN:9789251077733>
- Saenger, P., Siddiqi, N.A., 1993. Land from the sea: The mangrove afforestation program of Bangladesh. *Ocean Coast. Manag.* 20, 23–39. [https://doi.org/http://dx.doi.org/10.1016/0964-5691\(93\)90011-M](https://doi.org/http://dx.doi.org/10.1016/0964-5691(93)90011-M)
- Sakho, I., Mesnage, V., Deloffre, J., Lafite, R., Niang, I., Faye, G., 2011. The influence of natural and anthropogenic factors on mangrove dynamics over 60 years: The Somone Estuary, Senegal. *Estuar. Coast. Shelf Sci.* 94, 93–101. <https://doi.org/10.1016/j.ecss.2011.05.032>
- Salmo III, S.G., Lovelock, C., Duke, N.C., 2013. Vegetation and soil characteristics as indicators of restoration trajectories in restored mangroves. *Hydrobiologia* 720, 1–18.
<https://doi.org/10.1007/s10750-013-1617-3>
- Salmo III, S.G., Lovelock, C.E., Duke, N.C., 2014. Assessment of vegetation and soil conditions in restored mangroves interrupted by severe tropical typhoon “Chan-hom” in the Philippines. *Hydrobiologia* 733, 85–102. <https://doi.org/10.1007/s10750-013-1766-4>
- Salmo III, S.G., Tibbetts, I.R., Duke, N.C., 2018. Nekton communities as indicators of habitat functionality in Philippine mangrove plantations. *Mar. Freshw. Res.* 69, 477–485.
<https://doi.org/10.1071/MF17116>

- Salmo III, S.G., Torio, D., Esteban, J., 2007. Evaluation of rehabilitation strategies and management schemes for the improvement of mangrove management programs in Lingayen Gulf. *Sci. Diliman* 19, 24–34.
- Samarakoon, J.I., 2012. Mangrove restoration and planting in micro-tidal barrier-built estuaries and lagoons in Asia - ideology versus sustainable ecosystem science?, in: Macintosh, D.J., Mahindapala, R., Markopoulos, M. (Eds.), *Mangroves for the Future Regional Colloquium: Sharing Lessons on Mangrove Restoration*. MFF Secretariat, IUCN, Bangkok, Thailand, Chennai, India, pp. 141–157.
- Samson, M.S., Rollon, R.N., 2011. Mangrove Revegetation Potentials of Brackish-Water Pond Areas in the Philippines, *Aquaculture and the environment - A shared destiny*. INTECH Open Access Publisher.
- Samson, M.S., Rollon, R.N., 2008. Growth performance of planted mangroves in the Philippines: Revisiting forest management strategies. *Ambio* 37, 234–240. [https://doi.org/10.1579/0044-7447\(2008\)37\[234:GPOPMI\]2.0.CO;2](https://doi.org/10.1579/0044-7447(2008)37[234:GPOPMI]2.0.CO;2)
- Sanyal, P., 1998. Rehabilitation of degraded mangrove forests of the Sunderbans of India., in: Anon (Ed.), *Program of the International Workshop on the Rehabilitation of Degraded Coastal Systems*. Phuket Marine Biological Centre, Phuket, Thailand, pp. 19–24.
- Schindelin, J., Rueden, C.T., Hiner, M.C., 2015. The Image ecosystem: An open platform for biomedical image analysis. *Mol. Reprod. Dev.* 82, 518–529.
- Secretariat of the Convention on Biological Diversity, 1992. *Convention on Biological Diversity*. United Nations Environment Programme, Montreal.
- Selvam, V., Ramasubramanian, R., Ravichandran, K.K., 2012a. Genesis and present status of restoration practices in saline blanks in India, in: McIntosh, D. (Ed.), *Sharing Lessons on Mangrove Restoration*. MFF Secretariat, IUCN, Bangkok, Thailand, Chennai, India, pp. 133–140.
- Selvam, V., Sivakumar, A., Ramasubramanian, R., 2012b. Restoration and return of Mangroves and Fisheries in Abandoned Aquaculture Farms, in: Macintosh, D. (Ed.), *Mangroves for the Future Regional Colloquium: Sharing Lessons on Mangrove Restoration*. Mamallapuram, Chennai, India. MFF Secretariat, IUCN, Bangkok, Thailand, p. 30.
- Senyk, J.P.J., 2005. *Lessons from the Equator Initiative: Community-based management by Pred Nai Community Forestry Group in the mangroves of Southeastern Thailand*. Winnipeg, Canada.
- Sheaves, M., 2005. Nature and consequences of biological connectivity in mangroves systems. *Mar.*

- Ecol. Prog. Ser. 302, 293–305. <https://doi.org/10.3354/meps302293>
- Sillanpää, M., Vantellingen, J., Friess, D.A., 2017. Vegetation regeneration in a sustainably harvested mangrove forest in West Papua, Indonesia. *For. Ecol. Manage.* 390, 137–146.
<https://doi.org/10.1016/j.foreco.2017.01.022>
- Simis, M.J., Madden, H., Cacciatore, M.A., Yeo, S.K., 2016. The lure of rationality: Why does the deficit model persist in science communication? *Public Underst. Sci.* 25, 400–414.
<https://doi.org/10.1177/0963662516629749>
- Simpson, E.H., 1949. Measurement of diversity. *Nature* 163, 688. <https://doi.org/10.1038/163688a0>
- Sinfuego, K.S., Buot, I.E., 2014. Mangrove zonation and utilization by the local people in Ajuy and Pedada Bays, Panay Island, Philippines. *J. Mar. Isl. Cult.* 3, 1–8.
<https://doi.org/10.1016/j.imic.2013.11.002>
- Skov, M.W., Hartnoll, R.G., 2002. Paradoxical selective feeding on a low-nutrient diet: Why do mangrove crabs eat leaves? *Oecologia* 131, 1–7. <https://doi.org/10.1007/s00442-001-0847-7>
- Slaev, A.D., Collier, M., 2018. Managing natural resources: Coasean bargaining versus Ostromian rules of common governance. *Environ. Sci. Policy* 85, 47–53.
<https://doi.org/10.1016/j.envsci.2018.03.017>
- Snedaker, S.C., 1982. Mangrove species zonation: why?, in: Sen, D.N., Rajpurohit, K.. (Eds.), *Contributions to the Ecology of Halophytes. Tasks for Vegetation Science, Contributions to the Ecology of Halophytes.* Springer, pp. 111–125. https://doi.org/https://doi.org/10.1007/978-94-009-8037-2_8
- Soontornwong, S., 2006. Improving rural livelihood through CBNRM: A case of self-organization in community mangrove management in Thailand, in: Mahanty, S., Fox, J., Mclees, L., Nurse, M., Stephen, P. (Eds.), *Hanging in the Balance: Equity in Community - Based Natural Resource Management in Asia.* RECOFTC and East - West Center, pp. 182–199.
- Sousa, W.P., Kennedy, P.G., Mitchell, B.J., 2003. Propagule size and predispersal damage by insects affect establishment and early growth of mangrove seedlings. *Oecologia* 135, 564–575.
<https://doi.org/10.1007/s00442-003-1237-0>
- Southworth, J., Marsik, M., Qiu, Y., Perz, S., Cumming, G., Stevens, F., Rocha, K., Duchelle, A., Barnes, G., Southworth, J., Marsik, M., Qiu, Y., Perz, S., Cumming, G., Stevens, F., Rocha, K., Duchelle, A., Barnes, G., 2011. Roads as Drivers of Change: Trajectories across the Tri-National Frontier in MAP, the Southwestern Amazon. *Remote Sens.* 3, 1047–1066.

<https://doi.org/10.3390/rs3051047>

- Springate-Baginski, O., Than, M.M., 2011. Community Forestry in Myanmar : Some field realities. School of International Development, University of East Anglia, Pyoe Pin Programme and Ecosystem Conservation and Community Development Initiative, Yangon, Myanmar.
- St. John, F.A.V., Keane, A.M., Jones, J.P.G., Milner-Gulland, E.J., 2014. Robust study design is as important on the social as it is on the ecological side of applied ecological research. *J. Appl. Ecol.* 51, 1479–1485. <https://doi.org/10.1111/1365-2664.12352>
- Stevenson, N.J., Lewis, R.R., Burbridge, P.R., 1999. Disused shrimp ponds and mangrove rehabilitation, in: Streever, W. (Ed.), *An International Perspective on Wetland Rehabilitation, An International Perspective on Wetland Rehabilitation*. Kluwer Academic Publishers, The Netherlands, pp. 277–297. https://doi.org/10.1007/978-94-011-4683-8_28
- Sudtongkong, C., Webb, E.L., 2008. Outcomes of State-vs. Community-Based Mangrove Management in Southern Thailand. *Ecol. Soc.* 13, 27.
- Sultana, S., Asif, H.M., Nazar, H.M.I., Akhtar, N., Rehman, J.U., Rehman, R.U., 2014. Medicinal Plants Combating Against Cancer-a Green Anticancer Approach. *Asian Pacific J. Cancer Prev.* 15, 4385–4394. <https://doi.org/10.7314/APJCP.2014.15.11.4385>
- Sunderlin, W.D., Angelsen, A., Belcher, B., Burgers, P., Nasi, R., Santoso, L., Wunder, S., 2005. Livelihoods, forests, and conservation in developing countries: An Overview. *World Dev.* 33, 1383–1402. <https://doi.org/10.1016/j.worlddev.2004.10.004>
- Sutherland, W.J., Pullin, A.S., Dolman, P.M., Knight, T.M., 2004. The need for evidence-based conservation. *Trends Ecol. Evol.* 19, 305–308. <https://doi.org/10.1016/j.tree.2004.03.018>
- Tadesse, G., Zavaleta, E., Shennan, C., FitzSimmons, M., 2014. Policy and demographic factors shape deforestation patterns and socio-ecological processes in southwest Ethiopian coffee agroecosystems. *Appl. Geogr.* 54, 149–159. <https://doi.org/10.1016/j.apgeog.2014.08.001>
- Taillardat, P., Friess, D.A., Lupascu, M., 2018. Mangrove blue carbon strategies for climate change mitigation are most effective at the national scale. *Biol. Lett.* 14. <https://doi.org/10.1098/rsbl.2018.0251>
- Tan, K.H., Ong, J.E., 2008. Coastal vegetation rehabilitation for the mitigation of coastal hazards – The Malaysian experience, in: *Guidelines for the Rehabilitation of Mangroves and Other Coastal Forests Damaged by Tsunami and Other Natural Hazards in the Asia-Pacific Region*. ITTO/ISME, Okinawa, Japan, p. 57.

- Tengö, M., Brondizio, E.S., Elmqvist, T., Malmer, P., Spierenburg, M., 2014. Connecting diverse knowledge systems for enhanced ecosystem governance: The multiple evidence base approach. *Ambio* 43, 579–591. <https://doi.org/10.1007/s13280-014-0501-3>
- Thomas, P., 2001. *Trees: Their Natural History*, 2nd ed. Cambridge University Press, Cambridge, UK.
- Thompson, B.S., 2018. The political ecology of mangrove forest restoration in Thailand : Institutional arrangements and power dynamics. *Land use policy* 78, 503–514. <https://doi.org/10.1016/j.landusepol.2018.07.016>
- Tiffen, M., Mortimore, M., Gichuki, F., 1994. *More people, less erosion. Environmental Recovery in Kenya*, 1st ed. John Wiley & Sons Ltd., London, UK.
- Tole, L., 2010. Reforms from the Ground Up: A Review of Community-Based Forest Management in Tropical Developing Countries. *Environ. Manage.* 45, 1312–1331. <https://doi.org/10.1007/s00267-010-9489-z>
- Tomlinson, P.B., 2016. *The botany of mangroves*, 2nd ed. Cambridge University Press. <https://doi.org/https://doi.org/10.1017/CBO9781139946575>
- Toorman, E.A., Anthony, E., Augustinus, P.G.E.F., Gardel, A., Gratiot, N., Homenauth, O., Huybrechts, N., Monbaliu, J., Moseley, K., Naipal, S., 2018. Interaction of Mangroves, Coastal Hydrodynamics, and Morphodynamics Along the Coastal Fringes of the Guianas, in: Makowski, C., Finkl, C.W. (Eds.), *Threats to Mangrove Forests*. Springer, pp. 429–473. https://doi.org/10.1007/978-3-319-73016-5_20
- Trott, L., Alongi, D., 2000. The Impact of Shrimp Pond Effluent on Water Quality and Phytoplankton Biomass in a Tropical Mangrove Estuary. *Mar. Pollut. Bull.* 40, 947–951. [https://doi.org/10.1016/S0025-326X\(00\)00035-7](https://doi.org/10.1016/S0025-326X(00)00035-7)
- Trump, K., Gattenlöhner, U., 2015. *Mangrove Restoration Guide- best practices and lessons learned from a community-based conservation project*. Global Nature Fund, Radolfzell, Germany.
- Twilley, R.R., Rivera-Monroy, V.H., Chen, R., Botero, L., 1999. Adapting an Ecological Mangrove Model to Simulate Trajectories in Restoration Ecology. *Mar. Pollut. Bull.* 37, 404–419. [https://doi.org/10.1016/S0025-326X\(99\)00137-X](https://doi.org/10.1016/S0025-326X(99)00137-X)
- UNEP, 2007. *After the Tsunami - Coastal Ecosystem Restoration. Lessons Learnt [WWW Document]*. URL https://wedocs.unep.org/bitstream/handle/20.500.11822/17467/after_tsunami.pdf?sequence=1&isAllowed=y (accessed 10.10.17).

- van Der Stocken, T., De Ryck, D.J.R., Vanschoenwinkel, B., Deboelpaep, E., Bouma, T.J., Dahdouh-Guebas, F., Koedam, N., 2015. Impact of landscape structure on propagule dispersal in mangrove forests. *Mar. Ecol. Prog. Ser.* 524, 95–106. <https://doi.org/10.3354/meps11206>
- van der Stocken, T., Ryck, D.D., Balke, T., Bouma, T.J., Nitto, D. Di, Kairo, J.G., Dahdouh-Guebas, F., Koedam, N., 2012. Biological and environmental drivers in mangrove propagule dispersal and recruitment: a field and modelling approach, in: Dahdouh-Guebas, Farid, Satyanarayana, B. (Eds.), *Proceedings of the International Conference: Meeting on Mangrove Ecology, Functioning and Management*. 2-6 July, 2012. Galle, Sri Lanka. ULB/VUB, Brussels, Belgium, p. 181.
- van Loon, A.F., Brake, B. Te, Huijgevoort, M.H.J. Van, Dijksma, R., 2016. Hydrological classification, a practical tool for mangrove restoration. *PLoS One* 11. <https://doi.org/https://doi.org/10.1371/journal.pone.0150302>
- van Oudenhoven, A.P.E., Siahainenia, A.J., Sualia, I., Tonnejck, F.H., van der Ploeg, S., de Groot, R.S., Alkemade, R., Leemans, R., 2015. Effects of different management regimes on mangrove ecosystem services in Java, Indonesia. *Ocean Coast. Manag.* 116, 353–367. <https://doi.org/10.1016/j.ocecoaman.2015.08.003>
- Vandergeest, P., Flaherty, M., Miller, P., 1999. A Political Ecology of Shrimp Aquaculture in Thailand. *Rural Sociol.* 64, 573–596. <https://doi.org/https://doi.org/10.1111/j.1549-0831.1999.tb00379.x>
- Vayda, A.P., Walters, B.B., Setyawati, I., 2004. Doing and knowing: questions about studies of local knowledge, in: Bicker, A., Sillitoe P. & Pottier, J. (Eds.), *Investigating Local Knowledge: New Directions New Approaches*. Ashgate, London, pp. 38–58.
- Villamayor, B.M.R., Rollon, R.N., Samson, M.S., Albano, G.M.G., Primavera, J.H., 2016. Impact of Haiyan on Philippine mangroves: Implications to the fate of the widespread monospecific *Rhizophora* plantations against strong typhoons. *Ocean Coast. Manag.* 132, 1–14. <https://doi.org/10.1016/j.ocecoaman.2016.07.011>
- Vogt, J., Lin, Y., Pranchai, A., Frohberg, P., Mehlig, U., Berger, U., 2014. The importance of conspecific facilitation during recruitment and regeneration: A case study in degraded mangroves. *Basic Appl. Ecol.* 15, 651–660. <https://doi.org/10.1016/j.baae.2014.09.005>
- Walsh, J.C., Dicks, L. V., Sutherland, W.J., 2015. The effect of scientific evidence on conservation practitioners' management decisions. *Conserv. Biol.* 29, 88–98. <https://doi.org/10.1111/cobi.12370>

- Walters, B., 2008. Mangrove forests and human security. *CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour.* 3, 1–9. <https://doi.org/10.1079/PAVSNNR20083064>
- Walters, B.B., 2005a. Patterns of Local Wood use and Cutting of Philippine Mangrove Forests. *Econ. Bot.* 59, 66–76. [https://doi.org/10.1663/0013-0001\(2005\)059\[0066:POLWUA\]2.0.CO;2](https://doi.org/10.1663/0013-0001(2005)059[0066:POLWUA]2.0.CO;2)
- Walters, B.B., 2005b. Ecological effects of small-scale cutting of Philippine mangrove forests. *For. Ecol. Manage.* 206, 331–348. <https://doi.org/10.1016/j.foreco.2004.11.015>
- Walters, B.B., 2004. Local Management of Mangrove Forests in the Philippines: Successful Conservation or Efficient Resource Exploitation? *Hum. Ecol.* 32, 177–195. <https://doi.org/10.1023/B:HUEC.0000019762.36361.48>
- Walters, B.B., 2000. Local Mangrove Planting in the Philippines: Are Fisherfolk and Fishpond Owners Effective Restorationists? *Restor. Ecol.* 8, 237–246. <https://doi.org/10.1046/j.1526-100x.2000.80035.x>
- Walters, B.B., 1997. Human ecological questions for tropical restoration: experiences from planting native upland trees and mangroves in the Philippines. *For. Ecol. Manage.* 99, 275–290. [https://doi.org/10.1016/S0378-1127\(97\)00211-9](https://doi.org/10.1016/S0378-1127(97)00211-9)
- Walters, B.B., Rönnbäck, P., Kovacs, J.M., Crona, B.I., Hussain, S.A., Badola, R., Primavera, J.H., Barbier, E.B., Dahdouh-Guebas, F., 2008. Ethnobiology, socio-economics and management of mangrove forests: A review. *Aquat. Bot.* 89, 220–236. <https://doi.org/10.1016/j.aquabot.2008.02.009>
- Walters, B.B., Sabogal, C., Snook, L.K., de Almeida, E., 2005. Constraints and opportunities for better silvicultural practice in tropical forestry: an interdisciplinary approach. *For. Ecol. Manage.* 209, 3–18. <https://doi.org/10.1016/j.foreco.2005.01.003>
- Watson, J.G., 1928. *Mangrove forests of the Malay Peninsula*, No 6. ed, Malayan Forest Records. Fraser & Neave, Singapore.
- Waylen, K.A., Fischer, A., McGowan, P.J.K., Milner-Gulland, E.J., 2013. Deconstructing Community for Conservation: Why Simple Assumptions are Not Sufficient. *Hum. Ecol.* 41, 575–585. <https://doi.org/10.1007/s10745-013-9594-8>
- Waylen, K.A., Fischer, A., McGowan, P.J.K., Thirgood, S.J., Milner-Gulland, E.J., 2010. Effect of local cultural context on the success of community-based conservation interventions. *Conserv. Biol.* 24, 1119–1129. <https://doi.org/10.1111/j.1523-1739.2010.01446.x>

- Wilkie, D., Shaw, E., Rotberg, F., Morelli, G., Auzel, P., 2010. Roads, Development, and Conservation in the Congo Basin. *Conserv. Biol.* 14, 1614–1622. <https://doi.org/10.1111/j.1523-1739.2000.99102.x>
- Wilkinson, C., Salvat, B., 2012. Coastal resource degradation in the tropics: Does the tragedy of the commons apply for coral reefs, mangrove forests and seagrass beds. *Mar. Pollut. Bull.* 64, 1096–1105. <https://doi.org/10.1016/j.marpolbul.2012.01.041>
- Williams, S.J., Jones, J.P.G., Clubbe, C., Gibbons, J.M., 2012. Training programmes can change behaviour and encourage the cultivation of over-harvested plant species. *PLoS One* 7, 1–9. <https://doi.org/10.1371/journal.pone.0033012>
- Wodehouse, D.C.J., Rayment, M.B., 2019. Mangrove area and propagule number planting targets produce sub-optimal rehabilitation and afforestation outcomes. *Estuar. Coast. Shelf Sci.* 222, 91–102. <https://doi.org/10.1016/j.ECSS.2019.04.003>
- Wolanski, E., 2007. *Estuarine Ecohydrology*, 1st ed. Elsevier, Amsterdam, Netherlands.
- World Commission on Environment and Development, 1987. *Our Common Future*. Oxford University Press, Oxford & New York.
- Zockler, C., 2016. *Bird Fauna of the Southern Myeik Archipelago: Report on Historic and New Surveys in the Tanintharyi Coast of Southern Myanmar*. Report No. 32 of the Tanintharyi Conservation Programme. Yangon, Myanmar.
- Zorini, L.O., Contini, C., Jiddawi, N., Ochiewo, J., Shunula, J., Cannicci, S., 2004. Participatory appraisal for potential community-based mangrove management in East Africa. *Wetl. Ecol. Manag.* 12, 87–102. <https://doi.org/10.1023/B:WETL.0000021672.15252.54>

APPENDIX A. MANGROVE ECOSYSTEM GOODS AND SERVICES

Ecosystem goods and services are categorised by the Millennium Ecosystem Assessment (2005). This provides a useful way to classify and describe mangrove's ecosystem services; supporting, regulating, provisioning and cultural.

PROVISIONING: A RANGE OF FOREST PRODUCTS

Sustainably managed, mangroves are a renewable source of wood for construction (Dahdouh-Guebas et al., 2000) and cooking, directly or as charcoal (Walters, 2005a). Other uses of the wood include material for fish traps (Walters, 2004) or fulfilling other local needs such as house repair (López-Hoffman et al., 2006). Nipa palm (*Nypa fruticans*) leaf fronds are used for roofing panels and cigarette papers, and the juice from a cut fruit peduncle produces sap for vinegar production (Aung et al., 2011; Primavera et al., 2004; Primavera and Esteban, 2008; Walters, 2005a). *Phoenix paludosa* palms provide long-lasting fibres for the production of craft items such as mats and pots (Aung et al., 2011). The bark of many mangrove trees contains high levels of tannins, particularly the *Rhizophoraceae* family (FAO, 1994), which are used for dyeing and tanning and can also be used to preserve wooden canoes and boats by sealing up tiny pores in the wood (Dahdouh-Guebas et al., 2000). The leaves of some species, particularly *Avicennia* sp. are used as high-quality fodder due to their high nitrogen content (Dahdouh-Guebas et al., 2000). *Rhizophora* sp. bark can be beaten off and burnt at dusk to repel mosquitoes (pers. obs., Myanmar 2011). Medicinal preparations can be made from the bark of *Avicennia marina* (Dahdouh-Guebas et al., 2000) and some of the mangrove herbs (Primavera et al., 2004), e.g. the leaves of *Acanthus ilicifolius* for the treatment of liver cancer (Sultana et al., 2014). Being largely insect-pollinated, mangrove stands provide a suitable location for beekeeping which produces honey and bees wax (Nagelkerken et al., 2008), and the mangrove forests are important habitats for shellfish, finfish, crabs and crustaceans (Alongi, 2002).

A Strong Correlation between Mangrove and Fisheries but little Causality

Many marine species use the mangroves for part of their life cycle (Walters et al., 2008). Some use the mangroves when available, before retreating to seagrass beds or coral reefs when the mangroves are inaccessible (Sheaves, 2005). Other species spend all their lives in mangrove forests, while others move in and out with no fixed dependency on any one ecosystem (Manson et al., 2005). Fisheries productivity appears to be strongly related to tidal range and availability of organic

matter (Lee, 2004), i.e. the accessibility of the inter-tidal area, not just mangroves (Sheaves, 2005), and an increase in mangrove cover has been linked to a net gain of faunal numbers (Manson et al., 2005).

The value of mangroves to marine life has been summarised in a review by Manson et al. (2005).

These include:

- Structural complexity providing many refugia of differing sizes for juvenile marine creatures to hide in and reducing visibility of juvenile larvae. With less time spent hiding, the creatures can feed more and grow more quickly
- Mangroves have areas of shallow waters which bigger predators find difficult to access
- Mangrove trees provide overhead cover, reducing sunlight and visibility, cooling the water (which can therefore hold more oxygen) and making it more difficult for birds to find prey
- Turbidity, further helps hide small fish and larvae
- Higher nutrient levels due to 'lateral trapping' (Wolanski, 2007), concentrating nutrients from river water heading downstream, and seawater moving inwards. This increases net primary productivity
- Within the mangroves there is slower moving water which is easier for zooplankton and larvae to move through without being swept away
- Mangroves also have soft muddy substrate that creatures can easily bury into for protection.

This variation and complexity of habitat provides many different types of food stuffs, forms of protection and niches to occupy, therefore reducing intraspecific competition.

The assumption of the link between mangroves and fisheries productivity is not just held by the scientific world but also by coastal folk (Sudtongkong and Webb, 2008 in Thailand; Katon et al., 1998; Philippines; Mumby et al., 2004 in Belize). In Krabi Province, Thailand, villagers in the Krabi Estuary reported a significant decrease in their fish catches when large areas of mangrove were clear-felled for charcoal production (Wodehouse 2009 unpublished, but see Badola et al. 2012).

In his review of commonly held mangrove assumptions Alongi (2009b) draws attention to this widely assumed link between mangroves and adjacent fisheries productivity. He points out that it is very difficult to demonstrate causality or establish the link empirically, and few researchers have attempted it successfully. Despite the lack of causal data, there are many correlations and associations (Lee, 2004; Manson et al., 2005). For example, a greater abundance and diversity of fishes are observed in bays with mangrove in Curacao in the Caribbean than bays without mangroves (Sheaves, 2005). These relationships need to be read with caution as the scale used affects the correlation found due to the 'modifiable areal unit' problem.

SUPPORTING

Supporting services enable other ecosystems to function appropriately, e.g. photosynthesis leading to primary productivity.

Net Primary Productivity Similar to Tropical Rain Forest

Although not all mangroves are particularly productive, as hypersaline conditions or cold can stunt growth, improvements in measurement technology have revealed that mangrove net primary productivity (NPP) can be similar to that of tropical rain forest (Alongi, 2009a). NPP is the amount of new plant material produced (biomass accumulation) as a result of photosynthesis, net of the plant's own respiratory needs. Alongi (2009a) compared data sets from experiments looking at gas exchange, litterfall, litterfall and incremental trunk growth, leaf nodes, light attenuation (including photon flux density and leaf photosynthesis, related to leaf area index) and demographic / allometric studies. Analysing the strengths and weaknesses of each method, Alongi (2009a) estimated that mangroves produce a dry weight increment of 64 tonnes/ha/year, measured above and below ground. When compared with tropical rain forests, and looking at above ground biomass only, the figure is closer to 11 dry weight tonnes/ha/year, which is similar to tropical forest (Alongi, 2009a). This emphasises the importance of measuring below ground carbon cycling and storage. He recommended light attenuation was the most accurate form of measurement, acknowledged a considerable range in measurements and highlighted an inverse relationship with latitude.

Carbon Sequestration and Storage

Like most other forest systems, mangroves sequester carbon by assimilating CO₂ by photosynthesis. Most assimilated carbon is lost in respiration or allocated to root production (Alongi, 2002). Mangroves store $168 \pm 36 \text{ gCm}^{-2}\text{yr}^{-1}$, second only to salt marshes (Taillardat et al., 2018). The amounts stored are difficult to measure as 49-98% of this carbon is stored below ground, and this storage is affected by variable deposition of organic material, erosion dynamics, inundation levels and disturbances (Donato et al., 2011). This site-specific variability and the poor correlation between above and below ground carbon quantities suggests that site-by-site measurement is required. Significant carbon storage is of great interest to potential funders of coastal development programmes in the form of 'blue carbon' projects (e.g. Huxham et al., 2010 in Gazi Bay, Kenya).

REGULATING: NUTRIENTS, WEATHER, CRABS AND BIODIVERSITY

Regulating services provided by an ecosystem might relate to pollination, biological control, nutrient cycling, air and water quality maintenance, temperature regulation, microclimates and maintenance of biodiversity, (Bosire et al., 2008; Gilman et al., 2008; Nagelkerken et al., 2008).

Removal of Sediment and Nutrients from River Water

As river water or ebb flow passes through mangroves the resistance offered by the mangrove trees, prop roots, drop roots and pneumatophores slows the water flow. This reduction in speed, together with mixing of fresh river water and ionic, saline seawater allows suspended solids present in the river water to flocculate and settle out of suspension, potentially forming new mangrove sediment (Mazda et al., 2003). This can lead to accretion and stabilisation of soil to form new land (e.g. in Bangladesh, Field, 1999; the Matang Plantation in Malaysia, Alongi, 2002) and avoids seagrass and coral being smothered by sediment, thereby maintaining their health (Kuhlmann, 1988; Moberg and Rönnbäck, 2003). In reverse healthy seagrass oxygenates water flowing up into the mangrove, thereby improving water quality. Thus these ecosystems are dynamically linked and this link is important for sustainable development (Alongi, 2002).

Furthermore mangroves and the algal and bacterial mats on the mangrove mud can reduce the nutrient load in the water, reducing the risk of eutrophication, 'red tides', and algal epiphytes growing on seagrasses and coral, which reduce their photosynthetic ability (Moberg and Rönnbäck, 2003). Mangroves can also absorb nutrients from urban sewage (Herteman et al., 2011) although this is affected by the type and frequency of discharge, tidal range, hydrological dimensions, climate and plankton productivity and abundance (Trott and Alongi, 2000).

Protection from Waves, Storms, Wind and Tsunamis

Coastal communities are vulnerable to extremes of weather and climate change (McIvor et al., 2012). Mangrove's ability to protect people and communities from the forces of nature was brought in to focus by the Indian Ocean tsunami of 2004 and Cyclone Nargis⁴⁸ of 2008, despite mangroves generally preferring low wave and wind energy habitats (Saenger, 2002). The protective role of mangroves and their wave attenuation from storms and cyclones has been well documented (Mazda et al., 2003; Wolanski, 2007). The protection provided by mangroves is a function of the depth of near-shore water, mangrove quality, mangrove structure, species, wave height and frequency (McIvor et al., 2012) and is a significant motivation for planting and afforestation (Iftekhar and Islam, 2004; Springate-Baginski and Than, 2011; Walters, 2004) particularly in the Philippines (Chapter 1).

While mangrove's protective ability is understood for storms and cyclones, there is still debate about protection from tsunamis (e.g. Forbes and Broadhead, 2007). Cochard et al. (2008) provided a summary of the tsunami protection debate, highlighting the complexity of wave attenuation,

⁴⁸ For more details of cyclone Nargis <https://noaahrd.wordpress.com/2018/05/02/tenth-anniversary-of-very-severe-tropical-cyclone-nargis/> (Accessed 13.02.2019).

highlighting the variable wave energy and speed, and pointing out that the key factors that effect on-shore damage are distance from the epicentre, near-shore bathymetry, flow diversion and funnelling. Therefore mangroves can play only a minor role in protection of coastlines from tsunamis. This is supported by Pulukkuttige and Dahdouh-Guebas (2012) who advised caution about generalisations concerning mangrove's protective abilities from tsunamis when they are not validated by scientific investigation.

Crabs' Varied Diet, Carbon Cycling and the Linkage with the Inshore

The traditional view of mangroves and their value to the marine ecosystem was that mangrove forests exported much leaf, flower and twig detritus, and this formed the basis of the inshore food web (Odum and Heald, 1975). However, it has become clear recently that this model oversimplifies the situation. Alongi (2002) would agree that the food web is ultimately driven by the fixation of carbon by mangrove tree photosynthesis, and that approximately 20-30% of NPP is exported in pulses (Granek et al., 2009) as dissolved and particulate organic matter to the surrounding waters. This notwithstanding, grapsid and ocypodid crabs stop a portion of the detrital material being exported by eating it and / or burying it as fragments, thereby keeping a lot of the nutrients within the mangrove system. In turn their waste is ingested by coprophagous organisms (Kristensen and Alongi, 2006). In addition, detritus from mangrove trees is only part of the crabs' diet as various types of algae are preferred. Grapsid crabs also ingest bacteria, protists and fungi from the sediment (Skov and Hartnoll, 2002), assimilating bacteria very efficiently (Kristensen and Alongi, 2006). This makes nutritional sense as a diet of only mangrove leaves and detritus would be very high in carbon in relation to nitrogenous compounds. Burying the leaves in burrows does not sufficiently change the carbon : nitrogen ratio (Skov and Hartnoll, 2002).

Crabs selectively predate mangrove propagules, thereby affecting the composition of a stand. Their burrows aid the flushing of mangrove soils, reducing soil anoxia, increasing soil surface roughness, improving conditions for microorganisms in and on the soil, and improving the overall stability of the ecosystem (Kristensen and Alongi, 2006).

Mangroves are an Important Store of Microbial Diversity

Arguably, at a macro-flora level, mangrove biodiversity is not that significant compared to other tropical forest types (Saenger, 2002). However, the species richness of bacteria, virus, fungi and protists is much greater, with the number of species of bacteria, for example, running into the thousands (Alongi, 2009a). This in turn supports high invertebrate, insect, crab and bird diversity, as well as epibionts such as sponges, bromeliads and orchid epiphytes on the trunks, prop roots and pneumatophores, resulting in a 'mosaic of vertically zoned organisms' (Alongi, 2002). There are

highly complex and evolved relationships between mangrove trees and soil bacteria, which appear to be supplied by the tree with oxygen, in return for fixing nitrogen, solubilizing phosphorous, and favourably changing the competitive soil bacteria balance away from sulphate reducers towards iron and manganese reducers, which are advantageous for mangrove growth (Kristensen and Alongi, 2006). Emphasizing the importance and abundance of bacteria, Alongi (2005) estimated that bacteria contributed approximately 20% of the dry weight biomass in a *Rhizophora*-dominated mangrove ecosystem in northern Australia.

Part of the importance of biodiversity is in conserving genetic variation, thereby preserving phenotypes that might be better adapted as conditions alter because of climate change, although this link is poorly understood (Field, 1999, 1996). Increased mangrove ecosystem biodiversity has immediate implications as many shrimp pond farmers rely on natural shrimp fry from the mangroves to maintain and stock their shrimp ponds, and migratory birds that feed on mudflats adjacent to roosts in the mangroves are an important ecotourism attraction. However, Field (1999) questioned whether biodiversity (of macro flora) should necessarily take precedent over productivity, as the link between changes in biodiversity and ecosystem function and productivity are poorly understood.

CULTURAL SERVICES: ECOTOURISM, RECREATION AND SPIRITUAL BELIEFS

Documenting mangrove cultural services attempts to recognise the contribution they make to recreation, aesthetics, their education value, creative inspiration, religious enrichment and local people's sense of place (Rönnbäck et al., 2007). Communities existing within mangroves might feel that these forests contribute to a definition of who they are and their sense of self (Walters et al., 2008). Cultural considerations also include customary rights and social controls, which can be an effective form of mangrove preservation and management (Walters, 2004). Ecotourism might take the form of tiger watching in the Sundarbans, crocodile and turtle spotting in the Bhitarkanika mangroves in India (Badola et al., 2012) and bird watching in the Saloum Delta Senegal and Rufiji Delta, Tanzania (pers. obs.).

APPENDIX B. THE COMMUNITY-BASED ECOLOGICAL MANGROVE REHABILITATION PROCESS

With the local community and other key local stakeholders, research the proposed rehabilitation site. Understand the species ecology of the naturally occurring mangrove species at the site, (patterns of reproduction, distribution, and successful seedling establishment). Understand current mangrove stressors and why natural regeneration is not repopulating the site. Understand the normal hydrology that controls the distribution, successful establishment and growth of targeted mangrove species. Understand the social factors affecting the site including land tenure, harvesting rates, grazing levels etc.

Study a natural reference site as close and as similar to the proposed rehabilitation site, to study what a normal mangrove should look like, and the hydrology and topography in particular. Thereby understand what has changed on the rehabilitation site and what needs to happen. This might include social agreements and activity.

With the local community, map the rehabilitation site, discuss, plan action, which might be social as well as technical, set goals and objectives, agree a monitoring protocol, resolve land tenure issues to ensure long-term access to and conservation of the site.

Implement the activity or social programmes.

Monitor the progress, using the initial research as baseline data, and then study changes after 3, 6, 9 months, one year, and then annually after that for at least 5 years.

Utilize planting of propagules or seedlings only after determining through steps 1-5, above, that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth as required for project success

APPENDIX C. PRE-RESEARCH ETHICS STATEMENTS TO POTENTIAL RESPONDENTS FOR INFORMED CONSENT. (ENGLISH, THAI, TAGALOG)

To be read by or read to all prospective research respondents. They will then be given a copy to keep.

We would like to ask you to take part in some research about mangroves. This research will study aspects of village mangrove management and restoration work. The research is being conducted to complete a PhD in Environmental Science at Bangor University in the UK. This study is independent of all Thai governmental or NGO organisations and is being overseen by an Associate Professor from the School of Biological Sciences at King Mongkut University, Thailand. Permission has been granted to run this research from the National Research Council of Thailand.

Any information you supply will be kept securely by me and transferred to my computer for analysis. Due to the challenges of translation we would like to record this interview as well as make written notes, if you are agreeable, to make sure that the full meaning of your responses are completely understood. As soon as practicable all the notes from the research and recordings will be destroyed or deleted. We will not record your name and it will not be entered onto the computer but only an interview number, to protect your anonymity at all times.

The information collected will be used to write a doctoral thesis. This will be published on the internet. In this thesis only aggregated data will be used. Any attribution will be at village level or greater. Responses, activities or facts will not be attributable to any one individual. Quotes might be used but only if they do not reveal the specific individual and will only be attributed at village level.

The output and learning will be presented at conferences and shared with NGOs and mangrove-concerned groups. It is hoped that the new knowledge gained from this research will improve the way NGOs and other groups interact with local villages when trying to conserve and restore mangroves.

Having heard this statement you are entirely free to take part in this research or refuse. You can stop the interview at any time, or decline to answer a specific question. The interview will take between 45 minutes and an hour. Participation involves nothing more than answering questions either verbally or in a written form. Many thanks for your consideration. Are you happy to proceed?

Pre-research statement to potential respondents. Thai

เราอยากขอความร่วมมือจากคุณในการทำงานวิจัยเกี่ยวกับป้าชายเลน งานวิจัยชิ้นนี้ศึกษาเกี่ยวกับการจัดการป้าชายเลนของชุมชนและการฟื้นฟูป้าชายเลน งานวิจัยชิ้นนี้เป็นงานวิจัยปริญญาเอกในด้านวิทยาศาสตร์สิ่งแวดล้อม จากมหาวิทยาลัยแบงเคอร์ ประเทศอังกฤษ งานวิจัยชิ้นนี้เป็นงานวิจัยอิสระ ไม่ขึ้นกับรัฐหรือองค์กรเอกชนใดๆ งานวิจัยชิ้นนี้จะได้รับการตรวจสอบโดยศาสตราจารย์จากมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

สภาการวิจัยแห่งประเทศไทยได้อนุมัติการทำงานวิจัยชิ้นนี้แล้ว

ข้อมูลทุกอย่างที่คุณให้มาจะถูกเก็บไว้โดยผู้วิจัยและส่งเข้าระบบคอมพิวเตอร์เพื่อการวิเคราะห์ เพื่อป้องกันปัญหาที่อาจเกิดจากการฟังผิดหรือแปลผิด

ข้อมูลที่คุณให้มาจะถูกใช้ในการเขียนงานวิจัยปริญญาเอก ซึ่งจะเผยแพร่ทางอินเทอร์เน็ต งานวิจัยชิ้นนี้จะใช้เฉพาะข้อมูลรวมยอด

การอ้างอิงจะอ้างในระดับหมู่บ้านหรือระดับที่สูงกว่า จะไม่มีการอ้างอิงชื่อในระดับบุคคล อาจจะมีการยกคำพูดมาอ้าง แต่จะไม่มีการเปิดเผยชื่อบุคคล จะใช้ชื่อหมู่บ้านเท่านั้น

ผลของการศึกษาและกระบวนการวิจัยจะถูกนำเสนอในงานสัมมนา และแบ่งปันให้กับเอ็นจีโอและกลุ่มอื่นๆ ที่เกี่ยวข้องกับป้าชายเลน

เราหวังว่าองค์ความรู้ที่ได้จากงานวิจัยชิ้นนี้จะช่วยพัฒนาวิธีการร่วมกันระหว่างเอ็นจีโอและหน่วยงานอื่นๆ กับชาวบ้านในการอนุรักษ์และฟื้นฟูป้าชายเลน

นอกจากนี้วิธีการที่ดีที่สุดที่ได้จากการศึกษานี้จะถูกปรับใช้โดยตรงกับหมู่บ้านในประเทศต่างๆ ที่เผชิญปัญหาที่มีลักษณะคล้ายคลึงกัน

หลังจากที่ได้รับทราบคำชี้แจงข้างต้นแล้ว คุณมีอิสระที่จะตัดสินใจให้ความร่วมมือหรือปฏิเสธไม่ให้ความร่วมมือก็ได้

คุณสามารถหยุดการสัมภาษณ์ตอนไหนก็ได้ หรือปฏิเสธการตอบคำถามที่เฉพาะเจาะจง การสัมภาษณ์ครั้งนี้ใช้เวลาประมาณ 45 นาที ถึง 1 ชั่วโมง

การให้ความร่วมมือจะอยู่ในขอบเขตแค่การตอบคำถามซึ่งอาจจะอยู่ในรูปแบบของการพูดหรือการเขียน ขอขอบคุณที่ท่านพิจารณา

คุณยินดีที่จะให้สัมภาษณ์ไหม?

Pre-research statement to potential respondents. Tagalog (Philippines)

To be read by or read to all prospective research respondents. They will then be given a copy to keep.

Nais po naming kayong lumahok sa ilang pag-aaral patungkol sa mga bakawan. Ang pag-aaral po na ito ay tatalakay kung paano ninyo pinangangasiwaan at inaalagaan ang mga bakawan sa inyong barangay. Isinasagawa po namin ang pag-aaral na ito para makompleto ang mga kailangan sa pagka Doktor ng Pilosopiya ng Environmental Science sa Bangor University sa England. Ang pag-aaral po naming ito hindi konektado sa anumang sangay ng gobyerno sa Pilipinas.

Anumang impormasyon na makakalap namin mula sa inyo ay pananatilihin naming sekreto at ililipat sa computer upang pagsamahin. Isusulat po naming ang inyong mga sagot pero, agad po naming itong buburahin (sisirain) kapag nailipat na sa computer. Hindi po namin isusulat ang inyong pangalan at hindi rin po ito ipapasok sa computer, lalagyan lamang po namin ng numero ang bawat panayam bilang palatandaan para protektahan ang inyong pagkakakilanlan.

Ang mga impormasyon na makukuha namin ay gagamitin para sumulat ng isang thesis, at ilalathala sa internet. Ang resulta at napag-aralan ay ipapakita rin sa mga pag-pupulong, ibabahagi sa mga NGO at ibang pang grupo na may kaugnayan sa bakawan, ipipresenta din po ito sa PCSDS, DENR, at ibang kaugnay na sangay ng gobyerno. Sa kabuuan ng pag-aaral, ang ibabahagi lamang po namin ay ang resulta na nakalap mula sa isang buong barangay o munipyo. **Ang mga panayam, sagot o ibang gawain na magtuturo sa mga tao o tiyak na lugar ay hindi isasama.**

Inaasahan po namin na ang bagong kaalaman na matutunan sa pag-aaral na ito, ay magpapabuti sa ugnayan ng mamamayan sa barangay, mga NGO at iba pang grupo sa pangangalaga at pagtatanim ng mga bakawan.

Matapos po ninyong marinig ito, nasa inyo na po kung nais ninyong magpatuloy o tumanggi. Maaring po ninyong ihinto ang usapan anumang oras. Pwede po kayong tumanggi na sagutin ang ibang katanungan. Ang panayam po na ito ay maaring magtagal ng hanggang isang oras. Wala po kayong ibang gagawin maliban sa sumagot sa mga katanungan namin. Maraming salamat po sa inyong pang-unawa.

Maaari po ba tayong magpatuloy?

APPENDIX D. SPECIES IDENTIFICATION CHART

Produced by Prof Jean 'John' Yong (undated), used, with kind permission.

Front





Back.





APPENDIX E1. REHABILITATION SEMI-STRUCTURED QUESTIONNAIRE.

THAI

1	URN		7	Date	
2	Age		8	Gender	
3	Village		9	Village sub-unit	
4	Main Occupation		10	Other Occupation	
5	Mangrove Use		11	Member of a group?	
6	Role in Village		12	Former leader	
13	Religion				

Villagers were asked to describe the most recent planting event they took part in.

1	When is the <u>last time</u> you planted mangroves?	คุณไปปลูกป่าชายเลนล่าสุดเมื่อไหร่?	
2	What species did you plant?	ปลูกต้นอะไรบ้าง?	
3	Can you describe the planting site? [Prompts: Soil sand or clay or silt? Wet how often? Sunny or shaded? Former shrimp pond?] Can you give a brief history of the site?	กรุณาอธิบายลักษณะพื้นที่ที่ใช้ปลูกป่าชายเลน ลักษณะดิน (ทราย ดินเหนียว หรือโคลน) น้ำขึ้นถึง? แดด หรือร่ม? พื้นที่นากุ้งร้าง? เล้าอดีตคร่าว ๆ?	
4	If you were making the decision, would you have used the same species or chosen a (new) different species? [Agreed / Did not agree]	คุณคิดว่ามีพันธุ์ไหนที่เหมาะสมหรือดีกว่าสำหรับบริเวณนี้ไหม?	
5	If you did not agree, what species would you have recommended? Why?	ถ้าไม่ แล้วคุณจะเลือกพันธุ์อะไร เพราะอะไร?	
6	In the planting area, what species was already growing on the site, if any?	ในบริเวณที่ปลูกนั้น มีต้นอะไรขึ้นอยู่แล้วบ้าง?	
7	Was there any site preparation? Can you describe it?	ตอนปลูกป่าชายเลนครั้งสุดท้ายนั้น มีการเตรียมพื้นที่ก่อนปลูกไหม ทำอย่างไรบ้าง?	
8	On that planting day, can you describe the planting process?	แล้วในวันที่ปลูกวันนั้น มีขั้นตอนการปลูกอย่างไรบ้าง?	
9	What depth did you plant the seeds or seedlings?	ระดับความลึกที่ปลูกไม้ป่าชายเลน	
10	If you were planting more than one species, did you mix the species, or plant the species separately. Why?	ตอนที่ปลูกวันนั้น คุณปลูกปนกันหรือแยก? เพราะอะไรถึงทำแบบนั้น?	

11	Is there anything in this planting process that should have been improved or done differently?	มีอะไรที่ควรปรับปรุง หรือเปลี่ยนแปลงไหม?	
12	Do you think the planting was necessary or would mangroves have come back on their own?	วันเวลาความพร้อมของต้นกล้าและเมล็ดพันธ์? สถานที่ที่จะปลูก? หรือมีอย่างอื่น?	
13	Was there any attempt to change the physical features of the planting site? E.g. change the flow of water, for example?	เคยมีการพยายามที่แปลงลักษณะทางกายภาพของบริเวณที่ฟื้นฟูป่าชายเลนไหม? เช่น เปลี่ยนทางน้ำไหล?	
14	Why did you choose to plant in that site?	ทำไมเลือกไปปลูกตรงนั้น?	
15	Before planting, did you (collectively) debate which species to use and which would be appropriate for the site?	ก่อนที่จะทำการปลูกป่าชายเลน คุณได้มีส่วนร่วมระดมความคิดและปรึกษาหารือในการเลือกพันธุ์ไม้ที่เหมาะสมที่จะปลูกไหม ?	
16	For the last planting project, what was the key motivation? [Prompt: Site recovered from encroachment? Big National Day? Availability of seeds and seedlings? Degraded site? Something else?]	โครงการปลูกป่าครั้งสุดท้าย อะไรเป็นปัจจัยหรือเป็นสิ่งที่สำคัญมากที่สุดสำหรับการปลูกป่า? วันเวลา? ความพร้อมของต้นกล้าและเมล็ดพันธ์? สถานที่ที่จะปลูก? หรือมีอย่างอื่น?	
17	Why do you choose to plant on that date?	ทำไมต้องเลือกปลูกในวันนั้น?	
18	In general, what do you look at to indicate a successfully restored mangrove forest? [Prompt: How would you describe a successful restoration to a friend?]	โดยทั่วไป คุณคิดว่า ป่าชายเลนที่ได้รับการฟื้นฟูที่ประสบความสำเร็จ ดูได้จากอะไร?	
19	Have you been back to see this planting effort, you have been describing? Was it successful [percentage]?	เคยได้ไปดูป่าชายเลนที่คุณเพิ่งปลูกหรือยัง? คุณคิดว่ามันประสบความสำเร็จไหม?	
20	What discussion did you have about the activities that should be done on the planting site after planting?	มีการประชุมหรือการอภิปรายเกี่ยวกับกิจกรรมที่ควรทำที่บริเวณที่ปลูกป่านั้นภายหลังการปลูกป่าชายเลนไหม?	
21	If yes, what activities should happen or will happen?	ถ้ามี พูดถึงการทำอะไรบ้าง?	
22	Do either the DMCR or Conservation Group check the planting afterwards?	เจ้าหน้าที่ป่าชายเลน หรือ กลุ่มอนุรักษ์ ไปตรวจดูพื้นที่ที่ปลูกไปแล้วไหม?	

Thank you very much for your time. Is there anything you want to ask us?

APPENDIX E2. REHABILITATION SEMI-STRUCTURED QUESTIONNAIRE.

TAGALOG (PHILIPPINES)

1	URN		7	Date	
2	Age		8	Gender	
3	Village		9	Village sub-unit	
4	Main Occupation		10	Other Occupation	
5	Mangrove Use		11	Member of a group?	
6	Role in Village		12	Former leader	
13	Religion				

Villagers were asked to describe the more recent planting event they had taken part in

1	When is the <u>last time</u> you planted mangroves?	Kailn po kayo huling nagtanim ng bakawan?	
2	What species was planted during your last mangrove restoration activity? Seeds or seedlings	Anong klase po ng bakawan ang tinanim noong huling taniman? Ang itinanim po ba ay mga buto pa o mga punla na nakaplastik?	
3	Can you describe the planting site? [Prompts: Soil sand or clay or silt? Wet how often? Sunny or shaded? Former shrimp pond?] Can you give a brief history?	Pwede po ba ninyong ilarawan ang lugar na pinagtaniman? Bago po nagpatanim sa lugar na yon, ano po yon dati?	
4	If you were making the decision, would you have used the same species or chosen a (new) different species? [Agreed / Did not agree]	Kung kayo po ang masusunod, ibang uri ba ng bakawan ang itatanim nyo o gaya din ng tinanim nila?	
5	If you did not agree, what species would you have recommended?	Kung hindi po kayo sang-ayon sa napili nilang itanim na bakawan, anong uri ng bakawan ang irerekomenda nyo at bakit po yon ang napili nyo?	
6	In the planting area, what species was already growing on the site, if any?	Sa pinagtaniman po na lugar, anong mga bakawan po ang meron na doon nong nagtatanim na kayo?	
7	If there was any site preparation, can you describe it?	Inihanda po ang lugar bago nagpatanim?	

8	On that planting day, can you describe the planting process?	Sa mismong araw po ng pagtatanim, paano po ang naging sistema?	
9	What depth did you plant the seeds or seedlings?	Saan po banda kayo nagtanim?	
10	If you were planting more than one species, did you mix the species, or plant the species separately. Why?	Noong nagtanim po, halo-halo po ba ang klase ng bakawan na tinanim o pinagsama-sama ang magkakatulad?	
11	Is there anything in this planting process that should have been improved or done differently?	Mayroon po na dapat pang baguhin o dapat na sa ibang paraan ginawa?	
12	Do you think the planting was necessary and that mangroves would not have come back unless you had planted?	Sa palagay nyo kailangan po talaga na magtanim doon o tutubo ng kusa ang bakawan doon maliban na lagn kung magtatanim kayo?	
13	Was there any attempt to change the physical features of the restoration site? E.g. change the flow of water, for example?	Meron bang binago sa lugar na pinagtaniman?	
14	Why did you choose to plant in that site?	Bakit yon ang lugar na napiling taniman?	
15	Before planting, did you debate what species to use and what species would be appropriate for the site?	Bago po nagtanim, meron po bang pag-uusap kung anong klase ng bakawan ang naangkop sa lugar?	
16	For the last planting project, what was the key motivation? [Prompt: Site recovered from encroachment? Big National Day? Availability of seeds and seedlings? Degraded site? Something else?]	Meron po bang espesyal na okasyon kaya kayo nagtanim nong panahon na yon? Halimbawa may mga dayo para magtanim? Taunang araw ng pagtatanim? Sa panahon lang na yon merong mga punla? Kalbo na yong lugar?	
17	Why do you choose to plant on that date?	Bakit po noong araw na yon napiling magtanim?	
18	In general, what do you look at to indicate a successfully restored mangrove forest? [Prompt: How would you describe a successful restoration to a friend?]	Sa pangkalahatan po, ano ang senyales na matagumpay na naibalik sa dati ang bakawanan?	
19	Have you been back to see this planting effort, you have been describing? Was it successful [percentage]?	Nabalikan nyo po yong pinagtaniman para makita kung ano ang kinalabasan ng inyong pinagsikapan?	
20	Was there any discussion about the activities that should be done on the restoration site after planting?	May pinag-usapan po ba kung ano ang mga susunod na gagawin sa lugar na pinagtaniman?	
21	If yes, what activities should happen or will happen?	Kung meron po, tungkol saan?	

22	Do either the CENRO or Conservation Group check the planting afterwards?	May pumupunta po ba na taga DENR o CBFM para tingnan ang pinagtaniman pagkatapos magtanim?	
----	--------------------------------------------------------------------------	--------------------------------------------------------------------------------------------	--

Thank you very much for your time. Is there anything you want to ask us?

APPENDIX F. VILLAGE DETAILS AND NOTES

This section contained some informal notes for the initial submission, about the specific nature and context of each village, illustrating the complexity and diversity of village life and situations. This has been redacted for reasons of confidentiality for the publicly available final submission of this thesis but is available by request from the author.

APPENDIX G. REHABILITATION SCIENCE TEST. COMBINED. ENGLISH, THAI, TAGALOG.

1	Gender		7	Village	
2	Age		8	Date	

	Question	Marking Scheme. Acceptable answers	Mark s	Ref
1	<p>Is it possible to restore a site just by changing the flow of water?</p> <p>เป็นไปได้ไหมที่จะฟื้นฟูบริเวณป่าชายเลนโดยแค่เปิดทางกระแสน้ำให้ไหลผ่านเท่านั้น?</p> <p>Posible pa bang maibalik ang bakawan sa isang nasirang lugar na dating may bakawan kapag binago ang agos o daloy ng tubig?</p>	Yes	1	1
2	<p>What is the best time of year to plant?</p> <p>ช่วงไหนของปีที่ดีที่สุดในการปลูกป่าชายเลน?</p> <p>Kailan ang pinaka-mainam na panahon para magtanim ng bakawan?</p>	(Calm end of the) rainy season. Approximately Sept-Dec in east coast Thailand. June-Oct/Nov Palawan, Philippines.	1	2, 14
3	<p>What might damage the seedlings (non-animal) after you have planted them?</p> <p>ปัจจัยอะไรบ้างที่ไม่ใช่สัตว์ ที่อาจจะทำลายต้นกล้าที่คุณได้ปลูกไปแล้ว?</p> <p>Maliban sa mga hayop, anong mga pangyayari o gawain ang maaaring makasira sa mga punla ng bakawan?</p>	<p>One mark for each of the following – max 3. Debris, waves/erosion/ strong flow, too much sun, human footfall, drought, excess sedimentation, abnormal flooding, excess seaweed/algae entanglement, pollution, disease, acid soil.</p> <p>½ for ‘Natural disaster’</p> <p>0 for ‘weather’, ‘water’, ‘wind’, ‘flooding’, ‘charcoal’.</p>	Max 3	14,
4	<p>Is planting in very soft mud (that lets you sink up to your shins/knees) going to be successful?</p> <p>การปลูกป่าชายเลนในบริเวณที่เป็นดินโคลน (ลึกประมาณหัวเข่า) ต้นไม้จะเติบโตเจริญงอกงามไหม?</p> <p>Magiging matagumpay ba ang patanim kung ito ay gagawin sa lugar na may malambot na putik na aabot hanggang tuhod?</p>	<p>No.</p> <p>½ given for acknowledging that very soft mud in sheltered river channels (no waves/wind) might possibly work, as opposed to mudflats exposed to the open sea.</p> <p>½ for <i>R. mucronata</i> for thinking about mechanics of soft mud.</p>	1	3, 4, 15, 16

5	<p>There are dead tree branches, rubbish, dead Nypa palm leaves etc. on your restoration site before you start work. What do you do about it?</p> <p>ถ้ามีกิ่งของต้นไม้ที่ตายแล้ว หรือก้านใบจากที่ร่วงจากต้น และเศษไม้อื่นๆ ซึ่งลอยน้ำได้ในบริเวณคุณกำลังจะเข้าไปทำการฟื้นฟู คุณจะทำอะไรกับเศษเหล่านี้?</p> <p>Sa lugar na pagtataniman, may mga patay na sanga ng puno, basura, mga patay na dahon ng Nipa at iba pang kalat. Ano ang gagawin mo sa mga kalat?</p>	Remove (to avoid impact damage) or pile up (assuming it then can't move)	1	1
6	<p>Are 'mudflats' generally a good place or a bad place for mangrove restoration?</p> <p>บริเวณหาดเลน (เช่นบริเวณปากแม่น้ำ) เหมาะแก่การปลูกป่าชายเลนไหม?</p> <p>Sa pangkalahatan, mainam ba o hindi na pagtaniman ang lugar sa harapan ng bakawan hanggang sa naabot ng pag-hibas ng dagat?</p>	Bad	1	3, 4, 16, 18
7	<p>From fertilisation to being ripe enough to drop off the tree and grow, how many months does it take for <i>Rhizophora mucronata</i> to produce its seeds? 1-5 months, 6-11 months, 12-15 months or 16-24 months</p> <p>ลูกฝักของต้นโกงกางใบใหญ่ ใช้เวลากี่เดือนในการผลิตฝัก เริ่มจากเกสรผสมพันธุ์จนฝักแก่พอที่จะร่วงจากต้น?</p> <p>1-5 เดือน, 6-11 เดือน, 12-15 เดือน หรือ 16-24 เดือน (กรุณาเลือกคำตอบเพียงข้อเดียว)</p> <p>Gaano katagal bago maging magulang ang punla ng Bakawan Babae? Mula bulaklak hanggang maging bunga at mahulog sa puno. 1-5 buwan, 6-11 buwan, 12-15 buwan o 16-24 buwan?</p>	12-15 months	1	9
8	<p>If you're restoring a former aquaculture pond, do you need to keep the pond closed to inundation or open it to tidal flushing?</p> <p>ถ้าคุณกำลังฟื้นฟูบริเวณที่เคยเป็นบ่เลี้ยงกุ้ง คุณจะปิดบ่อไว้ หรือจะเปิดทางให้กระแสน้ำเข้าไปถึง?</p> <p>Kung ibabalik mo sa dati ang isang fish-pond para taniman ng bakawan, kailangan ba na bukas ito o sarado sa agos ng tubig?</p>	Open	1	1, 6, 14,
9	<p>If you were restoring an area that was at the high tide level, can you suggest species you might plant?</p> <p>ถ้าคุณจะปลูกต้นไม้ในบริเวณที่ระดับน้ำขึ้นสูงสุด ต้นอะไรที่คุณควรที่จะปลูก?</p> <p>Kung pagtataniman ang lugar na naabot lamang ng dagat pag mataas ang tubig (taib), anong klase ng bakawan ang imumungkahi mo?</p>	<p>Any of the back mangrove species, e.g. <i>Excoecaria</i> sp, <i>Xylocarpus</i> sp, <i>Lumnitz</i>, <i>Heritiera</i> sp., <i>Casuarina</i> sp., <i>Cerbera</i> sp.</p> <p>½ for <i>Avicennia</i> sp. as this can be a bi-zonal species, <i>Ceriops</i> sp.</p> <p>0 for <i>Rhizophora</i> sp., <i>Bruguiera</i> sp., <i>Sonneratia</i> sp., <i>Acacia</i> sp.</p>	Max 3	9, 17

10	<p>If new land is appearing from sedimentation, in an estuary or the middle of a river, and rising up just high enough for mangroves to colonise, what would be the <u>first</u> species you would expect to see growing?</p> <p>ถ้ามีแผ่นดินหรือเกาะเกิดขึ้นจากการทับถมของตะกอนบริเวณปากแม่น้ำ แล้วเกาะนั้นสูงพอที่จะให้ต้นไม้เจริญเติบโตขึ้นได้ คุณคิดว่า ต้นอะไรจากป่าชายเลนจะเจริญเติบโตขึ้นเป็นชนิดแรก?</p> <p>Kung may bagong parte sa gitna ng bukana na lumilitaw kapag mababaw ang tubig dahil sa mga latak galing sa ilog, anong uri ng bakawan ang una mong makikitang tumutubo dito?</p>	<p><i>Avicennia marina</i>, <i>A. alba</i> <i>Sonneratia alba</i>, <i>S. apetala</i>.</p> <p>½ for '<i>Avicennia</i>' ½ for '<i>Sonneratia</i>'</p> <p>0 for <i>Rhizophora</i> sp.</p>	Max 3	9, 14, 17
11	<p>If the flow of tidal or river water to your site has previously been blocked, should the flow be restored or not disturbed?</p> <p>ถ้าพื้นที่บริเวณพื้นที่น้ำเมื่อก่อนมีกระแสน้ำขึ้นน้ำลง หรือมีน้ำในแม่น้ำไหลเข้า แต่ปัจจุบันมันถูกกั้นไว้ไม่ให้เข้าถึงบริเวณที่ฟื้นฟู เราไม่ควรรบกวนมัน ควรที่จะปล่อยให้มันเป็นเช่นนั้น หรือควรทำให้กระแสน้ำไหลเข้าเหมือนเดิม?</p> <p>Kung mahaharangan ang daloy ng tubig, mula sa ilog o taas baba ng tubig dagat, sa lugar kung saan magtatanim ng bakawan. Kailangan ba na maibalik ang daloy ng tubig hayaan na lamang ito?</p>	Restored	1	1, 14
12	<p>Should you put in fertiliser into the hole you are planting your seedling in?</p> <p>เวลาปลูกต้นกล้าในป่าชายเลน ต้องใส่ปุ๋ยในหลุมด้วยไหม?</p> <p>Kailangan bang lagyan ng abono ang butas na pagtataniman ng bakawan?</p>	No. (only for <i>Sonneratia</i> sp)	1	10
13	<p>If you were going to use <i>Excoecaria</i> or <i>Heritiera</i> in your restoration, where would you plant it? Everywhere, or low down relative to other mangroves or near high water?</p> <p>ถ้าคุณจะไปปลูกต้น หงอนไก่ทะเล/ ดูหูใบใหญ่/ ไชควาย คุณจะปลูกบริเวณไหน? ที่ไหนก็ได้ หรือ เฉพาะบริเวณที่สูงในป่าชายเลน หรือ บริเวณที่ต่ำในป่าชายเลน?</p> <p>Kung magtatanim ka ng Dungon-lati/Balugo o Buton saan mo ito itatanim? Kahit saan, sa baba katulad ng ibang bakawan, o sa lugar na naabot ng tubig pag mataas ang dagat?</p>	High up, back mangrove area or near the high-water mark	1	9, 17
14	<p>If you know your restoration site is very salty, what can be done to help mangroves re-establish?</p> <p>ถ้าคุณรู้ว่าดินบริเวณที่จะฟื้นฟูเค็มมาก จะมีวิธีการอย่างไรที่จะช่วยให้ต้นไม้ในบริเวณนั้นเติบโตได้ดี?</p> <p>Kung alam mo na masyadong maalat ang lugar na pagtataniman, ano ang magagawa para matulungan ang mga bakawan na tumubo?</p>	<p>One mark each.</p> <p>Improve the hydrology / flushing by digging. Improve the fresh water river input into the top of the system. Change species to <i>A. marina</i>. Change site. Wait for rainy season.</p>	Max 2	6, 10

		½ for 'change species' w/o suggesting the alternative species		
15	<p>If the site faces the sea and the waves are sometimes big (energetic), what can you do about it?</p> <p>ถ้าบริเวณที่ฟื้นฟูหันหน้าเข้าหาทะเลและบางครั้งมีคลื่นแรงมาก คุณจะทำอย่างไร?</p> <p>Kung ang lugar na napiling taniman ay nakaharap sa dagat at may panahon na malalaki ang alon, ano ang magagawa mo tungkol dito?</p>	<p>1 for each: Bamboo wall in front of the planting. Change site / do not plant.</p> <p>½ for planting pioneer species, e.g. <i>A. marina</i>, <i>A. alba</i> or <i>Sonneratia alba</i>. ½ Use canes ½ Insert propagule deeper ½ Plant bigger trees ½ Wait for calmer weather</p>	Max 3	6, 11, 12, 14
16	<p>If you are trying to restore old rice paddy back to mangroves, what problems are you likely to incur?</p> <p>ถ้าคุณจะทำพื้นที่ฟื้นฟูบริเวณที่เป็นนาข้าวในอดีตให้กลับมาเป็นป่าชายเลน คุณจะเจอปัญหาอะไรบ้าง?</p> <p>Kung balak mong taniman ng bakawan ang isang dating palayan, anong mga problema ang kinakaharap mo?</p>	<p>1 for each Too high for tidal flushing therefore water can't reach. Poor (acid) soil (sour in Thai). No connection with mangrove.</p> <p>½ for 'No water'</p>	Max 3	6
17	<p>If the seedlings you have planted become covered with barnacles, what can you do about it?</p> <p>ถ้าต้นกล้าที่คุณปลูก ถูกปกคลุมด้วยเพรียง คุณจะแก้ปัญหาได้อย่างไร?</p> <p>Kinapitan ng tagungtong ang itanim mong bakawan, ano ang gagawain mo tungkol dito?</p>	<p>1 for each: Plant a different species. Plant in a different season. Paint propagule with engine oil. Change Site</p> <p>½ for: Leave it, More fresh water</p> <p>0 for: 'Scrape off' as this kills the mangroves</p>	Max 3	7
18	<p>If you see seedlings from different species starting to grow on your restoration site, what do you do with them?</p> <p>ถ้ามีเมล็ดพันธุ์(ผัก)อื่นที่คุณไม่ได้ปลูก เกิดขึ้นในบริเวณพื้นที่ฟื้นฟูที่คุณเพิ่งปลูกต้นกล้าได้ไม่นาน คุณจะทำอย่างไรกับพันธุ์ที่คุณไม่ได้ปลูกเหล่านั้น?</p> <p>Kung may ibang uri ng bakawan maliban sa itanim mo ang tumubo, ano ang ginagawa mo sa mga ito?</p>	Keep / leave them	1	8
19	<p>If you're planting within seagrass, what species should you use?</p> <p>ถ้าคุณจะทำป่าชายเลนบริเวณที่มีหญ้าทะเล ต้องปลูกต้นอะไร?</p> <p>Kung magtanim sa lugar ng damong dagat o baryaw-baryaw, anong uri ng bakawan ang itanim mo?</p>	<p>1 for 'Do not plant'</p> <p>0 for any species suggestion. (Trick question. Ecologically unsuitable elevation for mangroves.)</p>	1	4

References

- 1 Lewis, 2005
- 2 Ravishankar and Ramasubramanian, 2004
- 3 Samson and Rollon, 2008
- 4 Tan and Ong, 2008
- 5 R. Lewis, pers. comm.
6. Stevenson et al., 1999
7. Vayda et al., 2004
8. Walters, 2000
- 9 Kitamura et al., 1998
10. Saenger, 2002
- 11 Chan and Baba, 2010
- 12 Halide et al., 2004
- 13 Ng et al., 2008
14. Primavera et al., 2012
15. Erftemeijer and Lewis, 1999
16. Wodehouse and Rayment, 2019
- 17 Duke, 2006
18. Primavera, 2015

APPENDIX H1. COMMUNITY MANGROVE FORESTRY RULES. SEMI-STRUCTURED QUESTIONNAIRE. THAI (THAILAND)

1	URN		7	Date	
2	Age		8	Gender	
3	Village		9	Village sub-unit	
4	Main Occupation		10	Other Occupation	
5	Mangrove Use		11	Member of a group?	
6	Role in Village		12	Former leader	
13	Religion				

1	Can you take as much mangrove wood as you like without telling anyone? [Knows there are rules / Does not know about rules]	คุณสามารถตัดเอาไม้ป่าชายเลนมาใช้มากเท่าไรก็ได้โดยไม่ต้องบอกใคร?	
2	What are the main points of the rules? [No, partial, full]	กฎป่าชายเลน หลักๆ มีอะไรบ้าง?	
3	[If not mentioned above] Are the mangroves divided up into any sort of zones? [Y/N]	แต่ละเขต มีกฎระเบียบที่แตกต่างกันไหม?	
4	[If there are zones...] Are there different rules in different zones?	แต่ละเขต มีกฎระเบียบที่แตกต่างกันไหม?	
5	Do you want to get rid of the mangrove rules/ not to have the mangrove rules? [Positive / Negative attitude]	คุณอยากให้อยกเลิกกฎป่าชายเลนออกไปไหม/ไม่ให้มีกฎป่าชายเลน?	
6	What is a current threat to your mangroves?	อะไรคือภัยคุกคามต่อป่าชายเลนในปัจจุบัน?	
7	On this pile of cards are possible threats to your village's mangroves. Can you put them in order of most likely to affect your mangroves on the top... [Ranking data]	ในบัตรคำเหล่านี้ เป็นการกระทำต่อป่าชายเลนของหมู่บ้าน โปรดจัดเรียงบัตรเหล่านี้บัตรที่มีผลกระทบมากที่สุดอยู่บนสุด	
8	Do you think that the threats to your mangroves are due to having the inappropriate rules?	คุณคิดว่าภัยคุกคามที่เกิดขึ้นกับป่าชายเลนในข้อ มีสาเหตุมาจากการที่มีกฎระเบียบที่ไม่เหมาะสมในการป้องกันการทำลายป่าชายเลนหรือไม่?	
9	If your rules are not appropriate, what needs to be changed in your opinion?	ถ้ากฎไม่เหมาะสม คิดว่า มีอะไรควรเปลี่ยน?	
10	Do you feel that your village's rules need to be stronger / stricter?	ณคิดว่า ควรมีการปรับกฎป่าชายเลนของหมู่บ้านให้รัดกุมมากขึ้นและเข้มงวดขึ้นไหม?	

11	If there is a rules / enforcement problem, what is it? Lack of patrolling? Lack of enforcement? Uneven enforcement? Something else?	ในกรณีที่มีปัญหาเกี่ยวกับกฎระเบียบและการบังคับใช้กฎระเบียบ คุณคิดว่ามาจากสาเหตุอะไร? ขาดการลาดตระเวน? ขาดการบังคับใช้กฎระเบียบ? ไม่มีการบังคับใช้กฎ? อื่นๆ?	
12	What proportion of the villagers think the rules are unnecessary? [Necessary / unnecessary]	มีชาวบ้านอื่น ๆ ที่คิดว่ากฎป่าชายเลนนั้นไม่จำเป็นมีสัดส่วนประมาณเท่าไร?	
13	Do you think that mangrove users from other neighbouring villages know about your mangrove rules? [Yes / No]	คนที่ใช้ประโยชน์จากป่าชายเลนซึ่งอยู่ในหมู่บ้านใกล้เคียงรู้จักกฎของป่าชายเลนในหมู่บ้านของคุณหรือไม่?	
14	Can you describe the main points of the sanctions relating to the village mangrove rules? [Yes / No] + [Open for summary]	มีบทลงโทษอะไร ถ้ามีการทำผิดกฎป่าชายเลน?	
15	Is there a scale of punishment?	มีระดับของการลงโทษ จากน้อยไปมากไหม?	
16	Do you think that if you were caught breaking the mangrove rules, you would be able to avoid the sanctions and not be punished? [Punished / Not punished / depends on the situation]	สมมติว่า คุณโดนจับข้อหาทำผิดกฎป่าชายเลน คุณมีวิธีที่จะหลีกเลี่ยงบทลงโทษและไม่ ต้องถูกลงโทษได้ไหม?	
17	If you wanted to check the specific details of the village's mangrove rules, how could you do this?	ถ้าคุณต้องการตรวจสอบรายละเอียดของกฎของป่าชายเลนว่ามีอะไรบ้าง คุณจะหาข้อมูลได้อย่างไร?	
18	How often do you think your fellow villagers break the mangrove rules? [Follow rules / ignore rules / mixed]	คุณคิดว่า ชาวบ้านทำผิดกฎป่าชายเลนบ่อยแค่ไหน?	
19	Can you describe the last time the sanctions were actually applied in your village?	เคยมีการลงโทษผู้ที่กระทำผิดกฎป่าชายเลนของหมู่บ้านของคุณล่าสุดเมื่อไหร่ และลงโทษอย่างไร?	
20	After the mangrove rule-breakers have been caught, do you think they break the rules again? [Effective / Not effective]	ผู้กระทำผิดกฎป่าชายเลนที่โดนจับได้แล้ว เพราะอะไรเขาถึงทำผิดอีก?	
21	Is there any deliberate patrolling of the village's mangrove by government staff. How often? [Yes / No]	มีการตรวจตราป่าชายเลนของหมู่บ้านจากเจ้าหน้าที่ของรัฐไหม? บ่อยแค่ไหน?	
22	Is there any deliberate patrolling of the village mangroves by villagers and how often? [Yes / No]	มีการจัดเวรตรวจตราป่าชายเลนของหมู่บ้านโดยชาวบ้านเองไหม? บ่อยแค่ไหน?	
23	If you see outsiders breaking the rules, would you report them? [Yes, Never seen, talk with them directly/let them cut]	ถ้าเห็นคนนอกหมู่บ้านกำลังทำผิดกฎ คุณจะแจ้ง/รายงานให้ผู้ที่มีส่วนรับผิดชอบ รับทราบไหม?	

24	If you saw someone from this village breaking the village's mangrove rules what would you do? Did you report them? [Yes / Never seen / talk with them directly/let them cut]	ถ้าคุณเห็นคนในหมู่บ้านกำลังแหกกฎ คุณจะทำอย่างไร? คุณจะแจ้ง/รายงานให้ผู้ที่มีส่วนรับผิดชอบรับทราบไหม?	
25	Do you think the villagers who cut without permission know about the rules?	คุณคิดว่าชาวบ้านที่ตัดไม้ในป่าชายเลน โดยไม่ได้รับอนุญาต เขาจะรู้ว่าผิดกฎระเบียบไหม?	
26	What motivates them to cut, even though there is the risk of sanctions? Very poor? Good money for the wood? Something else?	มีเหตุผลอะไรที่ทำให้เขาตัดไม้ป่าชายเลน ทั้งหมดที่รู้ว่าเสี่ยงที่จะโดนลงโทษ? จนมาก? ไม้ป่าเลนมีราคาดี? เหตุผลอื่น?	
27	In 10 years time do you expect there to be less mangroves trees in this village?	คุณคิดว่าในอีก 10 ปีข้างหน้าจะมีต้นไม้ในป่าชายเลนเพิ่มขึ้ น หรือเท่าเดิม หรือน้อยลงกว่าปัจจุบัน?	

Thank you very much for your time. Is there anything you want to ask us?

APPENDIX H2. COMMUNITY MANGROVE FORESTRY RULES. SEMI-STRUCTURED QUESTIONNAIRE. TAGALOG (PHILIPPINES)

1	URN		7	Date	
2	Age		8	Gender	
3	Village		9	Village sub-unit	
4	Main Occupation		10	Other Occupation	
5	Mangrove Use		11	Member of a group?	
6	Role in Village		12	Former leader?	
13	Religion				

1	Can you take as much wood without telling permission? [Knows there are rules / Does not know about rules]	Pwede ba tayong kumuha ng bakawan kahit walang permiso?	
2	What are the main points of the rules? [No, partial, full]	Ano-ano ang mga patakaran ukol dito?	
3	[If not mentioned above] Are the mangroves divided up into any sort of zones? [Y/N]	Mayroon po bang pagkakahati-hati ang bakawanan sa lugar natin? Halimbawa lugar kung saan lamang pwedeng manginas, mangisda at lugar na protektado .	
4	[If there are zones...] Are there different rules in different zones?	Mayroon po mga patakaran o kasunduan para sa bawat lugar na ito? Ano-ano po ang mga ito?	
5	Would it easier to get rid of the mangrove rules / not to have the mangrove rules? [Positive / Negative attitude]	Mas mainam po ba na wala ang mga patakaran o kasunduan ukol sa bakawan?	
6	What is a current threat to your mangroves?	Sa kasalukuyan, ano-ano po ang mga banta sa bakawan sa inyong lugar?	
7	On this pile of cards are possible threats to your village's mangroves. Can you put them in order of most likely to affect your mangroves on the top... [Ranking data]	Sa hanay ng mga banta sa bakawan, alin po ang maaring maka-apekto sa bakawan ng lugar ninyo? Pumili po ng isa o dalawa.	
8	Do you think that the threats to your mangroves are due to having the inappropriate rules?	Sa inyo pong pananaw, ang mga banta/problema sa bakawan natin ay dulot ng kakulangan o hindi akmalang batas?	

9	If your rules are not appropriate, what needs to be changed in your opinion?	Sa inyo pong pananaw, ano-ano ang mga dapat baguhin sa patakaran?	
10	Do you feel that your village's rules need to be stronger / stricter?	Sa palagay po ninyo, kailangan po ba na higitan pa ang batas at patakaran sa inyong lugar?	
11	If there is a rules / enforcement problem, what is it? Lack of patrolling? Lack of enforcement? Uneven enforcement? Something else?	no po ang problema sa pagpapatupad na batas o patakaran kung meron man? Kulang ang pagpapatrolya? Maluwag sa pagpapatupad na batas? Hindi patas na pagpapairal ng batas? Iba pang kadahilanan?	
12	What proportion of the villagers think the rules are unnecessary? [Necessary / unnecessary]	Gaano po kalaki o karami sa inyong kabarangay ang sa tingin nila ay hindi kailangan ang mga patakaran?	
13	Do you think that mangrove users from other neighbouring villages know about your mangrove rules? [Yes / No]	Alam po ba ng taga-ibang barangay ang mga patakaran sa bakawan ng inyong lugar?	
14	Can you describe the main points of the sanctions relating to the village mangrove rules? [Yes / No] + [Open for summary]	Ano po ang mga parusa sa paglabag sa mga patakaran patungkol sa bakawan?	
15	Is there a scale of punishment?	Gaano po kabigat ang parusa sa mahuhuling lumabag sa patakaran? Unang paglabag? Ikalawang paglabag?	
16	Do you think that if you were caught breaking the mangrove rules, you would be able to avoid the sanctions and not be punished? [Punished / Not punished / depends on the situation]	Halimbawa, kung kayo po ay nahuling namumutol ng bakawan, mapaparusan ka ba? Makakaiwas ka ba sa parusa?	
17	If you wanted to check the specific details of the village's mangrove rules, how could you do this?	Paano mo malaman ang mga detalye ng patakaran ng isang barangay tungkol sa bakawan, saan ka maaring magtanong, saan ka pupunta?	
18	How often do you think your fellow villagers break the mangrove rules? [Follow rules / ignore rules / mixed]	Mayroon po bang lumalabag sa patakaran ayon sa bakawan sa inyong lugar, gaano po kadalas?	
19	Can you describe the last time the sanctions were actually applied in your village?	Natatatandaan po ninyo kung kalian huling may naparusahan sa inyong barangay?	

20	Do you think potential illegal cutters would be deterred by these sanctions?	Sa tingin mo, ang mga lalabag ba sa patakaran ay natatakot sa mga parusa?	
21	Is there any deliberate patrolling of the village's mangrove by government staff. How often? [Yes / No]	Mayroon bang nagpapatrolya sa mga bakawan mula sa munsipyo? Gaano kadalas?	
22	Is there any deliberate patrolling of the village mangroves by villagers and how often? [Yes / No]	Mayroon bang nagpapatrolya sa mga bakawan mula sa barangay? Gaano kadalas?	
23	If you see outsiders breaking the rules, would you report them? [Yes, Never seen, talk with them directly/let them cut]	Kung taga-ibang lugar ang makikita mong namumutol sa inyong barangay, ano ang gagawin mo? Hahayaan mo lang ba sila o irereport mo ito?	
24	If you saw someone from this village breaking the village's mangrove rules what would you do? Did you report them? [Yes / Never seen / talk with them directly/let them cut]	Halimbawa kung meron kang kabarangay na nakita mo sa akto na pumuputol ng bakawan sa inyong lugar, ano ang gagawin mo? Hahayaan mo lang ba sila o irereport mo ito?	
25	Do you think the villagers who cut without permission know about the rules?	Sa palagay mo ng mga gumagawa ng ilegal, tulad ng nagbebenta o nag-uuling, alam ba nila ang patakaran o batas?	
26	What motivates them to cut, even though there is the risk of sanctions? Very poor? Good money for the wood? Something else?	Ano ang nagtutulak sa kanila para mag-ilegal kahit na alam nila ang maaring parusa? Mahirap? Malaki ang kita? Iba pang dahilan.	
27	In 10 years time do you expect there to be less mangrove trees in this village?	Sa Kabila ng mga naputol na mga kahoy at iba pa, pagkalipas ng sampung taon, Ano ang mga inaasahan/situation sa inyong barangay?	

Thank you very much for your time. Is there anything you want to ask us?

APPENDIX I. REFLEXIVITY STATEMENT

Reflexivity Statement of the Researcher

I am a British, Caucasian, middle class, heterosexual male, 43-46 years old over the duration of the fieldwork, unmarried, 178cm tall, athletic build, blue eyes.

I grew up in south and southeast of England, the last of three children in a traditional family that was calm, stable and supportive. Living away from home for months at a time at a private school between the ages of 11-18, a process I enjoyed, developed an ability to live in a situation and with people not of my own choosing but having to get on with them. The school actively (and family passively) placed great emphasis on self-discipline, being organised and a strong work ethic.

A business undergraduate degree from Edinburgh University (1988 – 1992) led to working in advertising in London. I hoped it would be as interesting as I found the advertising at the time. The private sector experience was mixed: pressured project management and working with others in a client-facing situation developed communication and presentation skills and professional empathy. I was quickly able to put most clients at ease. But the corporate experience was negative as various agencies demonstrated very limited loyalty to their staff or willingness to development them. Dealing with internal agency politics was not a skill.

1997-1999 was in Kiev, Ukraine, within the network I worked for in London. The London office made it clear that they took no responsibility for a transfer nor would they offer a place at the end of the two-year contract. Kiev was a formative and stressful experience, developing a new agency with people with a very different history. Working abroad did not solve my dislike and disinterest of the core activity of advertising, but did ignite an enjoyment of teaching / mentoring staff, travelling and living abroad and learning from the process of being abroad. Much time in Kiev was spent isolated as very few people spoke English, which accelerated a developing introverted nature. The second expatriate posting was to Jakarta, Indonesia, with a different agency (2000-2001). There was much infighting in the office and poor client – agency relationships. Managing people who did not want to work was difficult and I did not do this well. Similar to Kiev, the travel and learning about a new region was something I enjoyed much more than the work, which remained very stressful, became less and less interesting and more political with a promotion to Bangkok to take up a regional post. At the end of 2002, a mass redundancy of several staff including myself and ill parents meant a return to London and decision to change career.

A growing environmental consciousness and a decision to follow a passion for trees and forests suggested a new life path, using amenity arboriculture as a way into tree-based conservation. Wide reading led to mangroves. Volunteering with UK NGO the International Tree Foundation led to time with Mangrove Action Project, an NGO I still volunteer and teach for. MAP's training in India with Robin Lewis (2005) confirmed mangroves as my new direction. "What is required is informed supervision between the scientists and the mangrove workers on the ground." A part-time MSc (2006-2009 at distance from Imperial / SOAS) greatly helped with the environmental academic backfill and allowed me to move to Thailand late 2006 to work for the local office of a global wetlands NGO. Unfortunately the office manager was inappropriate for that position and ended up collapsing that office due to gross financial mismanagement. Despite the intensely negative employment experience with this NGO, I remained in Thailand until 2011, continuing to volunteer for MAP, until returning to the UK for family reasons. In London, acting as the carer at home provided the opportunity to take part-time PhD in the UK.

Professional Context as a Mangrove Rehabilitation Educator

In 2011, MAP invited me to assist the teaching of their community-based ecological mangrove rehabilitation training. I have continued to do this teaching throughout the part-time PhD process, becoming lead trainer in 2014. Teaching has been conducted in Thailand (x2), Cambodia, Myanmar (x4), Suriname, Colombia, Indonesia, Honduras (x2), Senegal and Tanzania. This teaching is something I really enjoy and has been the main motivator for the PhD degree. Trainees have varied from academics and university deans, Forest Department (or equivalent) staff, NGO staff to village conservation group members.

This professional activity has provided the experience required to interpret new mangrove rehabilitation sites when visited, which can be challenging as there are many bio-physio-chemical gradients present. But it also suggests that I have a bias, conscious or subconscious towards mangrove conservation and against other forms of land use within the intertidal zone, regardless of the economics or situation of the local people. It is likely that I lean towards education as a solution to many mangrove degradation problems due to the role I play within Mangrove Action Project. I am also likely to think of mangroves primarily as a tree-based system due to having been an arborist previously, more than a social or ecological system. This is not to say that mangrove trees should never be cut, but cut or the resources used in the context of 'wise use', in a sustainable manner.

Choice of Translators

Finding translators was difficult. Some were too expensive. Others could not commit to living away from their homes for the long periods required. The most important quality was being able to

communicate effectively and very accurately. They were also judged on whether they were good at engaging me in conversation and comfortable striking up a conversation with others. Particularly for Muslim villages, it was important to choose a female translator as this made it easier to approach individual female villagers for an interview.

Much more so in Thailand than in the Philippines, the effect on the translator of being bilingual to this level and therefore travelling and / or working with foreigners affected the translators, as I saw with my team of 14 Thais in advertising in Bangkok in 2002. This level of exposure to influences from outside Thailand encouraged them to question their world view, the conservative nature of Thai culture and many mores and assumptions, such as traditional gender stereotypes. The advantage was that this helped them understand how a foreigner might view Thai and Philippine rural life, but conversely might have compromised their ability to fully understand village life.

In the Village

As much time as needed was taken to train the translators in mangrove biology and ecology and become familiar with the technical terms such as pneumatophore. This might have produced a bias for a more scientific, rational view of mangroves but ensured that questions from the researcher during interviews were immediately and fully understood, and accurate answers translated back. In the same manner, time was taken over the ethics statement to fully communicate the idea and necessity of informed consent and the importance of confidentiality.

Homestays in the villages were challenging. Local sensitivities had to be observed at all times, which for a foreigner are particularly intricate within Thai Muslim villages. The houses were hot, even at night, making sleeping difficult. Interior walls do not reach the ceiling or a dropped roof, so at night any sound within a house is reflected off the inside of the roof and travels far. Mornings could start at 5:15am for first prayer and in some places people were coming and going all night due to overnight rubber tapping activity. Therefore only three of four weeks of research were conducted at any one time before break was necessary. We deliberately changed homestay regularly to be able to give money to different families and gain different perspectives during informal conversations. To this end we stayed in homes whose owners were related to the leader as well as those not related. The informal conversations were extremely useful, primarily to understand village politics and how politics effected the operation of the village. Without breaking confidences, we could cross-check unexpected discussion topics that arose during the interviews. We also found that interacting with homestay hosts day after day meant that the message circulated around the village that we were indeed conducting PhD research and were harmless, rather than conducting covert research for the

Thai or Philippine government or some other organization. The village leader also announced our presence and activity in village meetings.

Interviewees' Potential Perception of Me

What questions did they ask of me personally? First was always how old I was, as this affected the language used by Thais when addressing me. Their ability to guess my age (ranging between 34-55) was as poor as my ability to guess theirs. Their second question was always whether I was married and whether I had children. Not being married and having no children was a surprise as for someone of my age, being single was very rare in these villages. I would joke in Thai that I was too lazy to get married which would dissipate any awkwardness. For many Thais the UK was navigated by Premier League football clubs and therefore Bangor University was described as 50km west of Liverpool. Football clubs were less helpful in the Philippines as they generally follow US basketball. Beyond this point, personal questioning usually stopped as my interests, activity, and life history appeared to be outside their frame of reference and any discussion centred around issues or concepts brought up by the ethics statement, such as the nature of a PhD. In both countries they expressed surprise that someone would be interested in an ecosystem that was not in their own country, and therefore assumed that my knowledge of mangroves was very limited. All further questioning would be directed towards the translators, particularly the female translators in Thailand. In Thai Muslim or Buddhist culture, a bilingual unmarried Thai woman, without children, working with a foreigner was unusual and piqued interest. The benefit of this question-and-answer session was the development of mutual understanding, which put most interviewees at ease. I consciously dressed as I hoped was appropriate and in a similar manner to local men – cargo pants, dark polo shirt and flipflops. In Thai culture, the idea of 'shabby-chic' or dressing down by wearing worn 'gardening' clothes does not work as this looks slightly disrespectful to the person being interviewed. (A suitable analogy is that whereas many state airline flag carriers lease previously used aircraft, the Thai government would never consider doing so.)

The only people who declined to be interviewed were three active 'professional' cutters in T2B and one professional cutter in T3A, and for two of these four, they only refused a second interview. Otherwise people seemed to be happy to talk with us about mangrove issues, community forest rules and village life, normally while they carried out their livelihood activity outside their house.

APPENDIX J. SAMPLE SET OF COMMUNITY MANGROVE MANAGEMENT RULES, FROM VILLAGE T2A.

Mangrove timber use only for:

- house repairs
- new family house (with permission)
- village building like the mosque

Cutting from the usage areas is only for what is needed and no more. This will be assessed by the conservation group (CG). Cut only within the village boundaries. Cut one mangrove stem, plant two (later in the same doc, 5) propagules and these need to be maintained.

Where there is a lot of timber poaching, the CG will establish an active patrol group. If minimal cutting villagers are to patrol passively (i.e. while fishing).

If rule breakers are caught, evidence such as the wood and cutting tools will be confiscated. First offence results in a warning. Repeat offence reverts to national law.

Other Permitted Activities

- Collection of mangrove NTFPs, e.g. mushrooms, ants eggs, insects, herbs, honey, but not for sale
- Collection of dry /dead wood for firewood. But not more than one truck a year.
- Collection of plants for weaving (e.g. *Pandanus* sp. leaves)
- Extraction of timber to rebuild a house in the event of destruction by fire. Requires permission form CG before.
- Extraction of wood for cremation needs permission from CG. Maximum three stems and must be dry.

Part 2 Prohibitions

No cutting mangrove wood for sale, firewood or charcoal, only household (hh) use.

No cutting or collection in the 'Red Zone' (i.e. their designated Conservation Area) or fringe mangrove

No cutting for hive collection / ants eggs etc.

No ringbarking of trees.

No encroaching, burning except for firebreaks

Non-villagers cannot use the village's mangrove, except with permission from the CG

No sluicing of chemical tanks into the mangrove area

No littering

No hunting, otter, monkey, flying squirrels etc, civet cats, snakes, seagulls, orchids for sale

No livestock in the mangroves

Do not change or stop the flow of the water

APPENDIX K. RECOMMENDED STATE COMMUNITY FOREST MANAGEMENT INPUT FROM THE THAI GOVERNMENT

As an example of potential state encouragement and input to develop community forest management (CFM) within a village, the following is a brief summary of the guidelines from the DMCR headquarters to Thai field offices for assisting villagers to develop their own management systems⁴⁹.

Goals and methods

Trying to ensure that the local people benefit from the mangroves directly and indirectly. Encourage villages to participate with government organisations in order to:

- be aware of their duties to take care of the mangrove
- protect and take care of the resources
- plant and restore degraded areas
- use wisely
- be knowledgeable and understand the ecosystem, so as to comprehend the cause and effect from degradation and extraction.

Pattern and Range of Villagers' Participation

- The village conservation group should help produce their own conservation rules
- Degraded ecosystems have an affect wider than just one village. Villages should form a network, collaborating with outside groups to solve natural resource degradation issues
- Villages should establish working groups of villagers to study and solve management problems
- If there is conflict between villagers and the government concerning marine and coastal resources, such as around policy or projects, these should be solved by a public meeting, so the people have the right to make their own decisions. Decision making should be supported by data from a neutral (external) organisations.

DMCR Guidelines for Community Mangrove Management Rules

- They must be set by the community including establishing villagers' mangrove usage rights
- They must be accepted by villagers

⁴⁹ Translation by the researcher's field assistants. Summarised by the researcher.

- Rules breakers should be fined and punished according to the community's rules
- To ensure the rules are effective the conservation group needs to be strong
- The conservation group needs to be supported by outside organisations such as universities to learn about how to manage their group and village resources more effectively
- Villages should survey their mangrove boundaries and map them.
- Conservation group managers need to run stakeholder analysis to understand who benefits from the mangroves, and identify issues and problems stakeholders and others face
- The conservation group should meet and plan together and co-ordinate with the relevant government agencies

APPENDIX L. TREE CONDITION RATING PHOTOS



'A' Rated Trees

Good condition. Stable with very limited or no damage. An appropriate height / diameter ratio, visually judged. Balanced crown. Tree not suppressed by taller neighbouring trees. Limited leaf herbivory. No die back of the crown, particularly at the top. Depending on the species, limited accumulation of dead wood. Tree useful to villagers and appropriate for building, including a straight stem, depending on the species.





'B' Rated Trees

Reasonable condition. Damage to side branches only, or minimal stem damage only (not at the base). Marginally too tall for its height (due to plantation planting). Partially unbalanced crown or partially suppressed due to near neighbours. Minor levels of leaf herbivory or some dead wood, but nothing significant at the top. Stem intact but not straight and therefore of less use for villagers, particularly for building, but the timber is still useful for other purposes.





'C' Rated Trees

Poor condition. Stem damage and significant wounds, particularly near the base of the tree. Suppressed by overhanging trees and therefore unbalanced crown and angled growth. Significantly 'drawn up' by competing for light with close neighbouring trees, being too tall for its diameter and therefore very vulnerable to stem snap if neighbouring trees are removed. Leaves suffering from significant herbivory. Poor tree form, such as bent stems or compression joints at the base between stems. Canopy / top die back due to tree stress or natural damage. Significant deadwood where it would normally not be present on that species. Perhaps useful to the villagers for charcoal or minor wood products such as fencing posts or fish aggregating devices.





'D' Rated Trees

Dying, significantly stressed or seriously damaged / decayed tree. Serious to existential damage. Perhaps decayed or hollowed out trunk of the tree (particularly mature *Xylocarpus* sp). Unbalanced or lopsided crown or crown only in one direction. Inappropriate height / DBH ratio or perhaps reset by stem snap. Suppressed by a closed canopy overhead. Seriously debilitating levels of herbivory. Significant die-back of the crown or tree retrenchment. Significant levels of deadwood, beyond what would be expected for the species. Timber and stem of very limited use for villagers other than for charcoal.



APPENDIX M. TRANSECT DATA COLLECTION SHEET

Mangrove Transect Number

Village Code

Zone.

Date.

Time start

GPS Start Point

Sample Point	Quarter	PCQM Distance (m)	DBH (cm)	Height (m)	Con. Rating (A-D)	Species	# Cut Branches on PCQM tree	Salinity Av	Hemi-spherical Photo Ref #	Juvenile Count Per 12.5m ² Left	Juvenile Count per 12.5m ² Right	# Cut stumps per (25m ² each side)	
1	A							L				L	
	B											R	
	C												
	D												
2	A							L				L	
	B												R
	C												
	D												
3	A							L				L	
	B												R
	C												
	D												
4	A							L				L	
	B												R
	C												
	D												
5	A							L				L	
	B												R
	C												
	D												
6	A							L				L	
	B												R
	C												
	D												
7	A							L				L	
	B												R
	C												
	D												
8	A							L				L	
	B												R
	C												
	D												
9	A							L				L	
	B												R
	C												
	D												
10	A							L				L	
	B												R
	C												
	D												
Notes													