RESTORATION FROM WITHIN:

AN INTERDISCIPLINARY METHODOLOGY FOR TROPICAL PEAT SWAMP FOREST RESTORATION IN INDONESIA

Thesis submitted for the degree of

Doctor of Philosophy

at the University of Leicester

by

Laura Linda Bozena Graham BA Cantab

Department of Geography

2013

Abstract

Between 1985 and 2006 about 47% of tropical peat swamp forest (TPSF), mainly found in SE Asia, became degraded through logging, drainage, fire and agriculture. In response to global agendas, several large-scale TPSF restoration projects have been initiated, although knowledge is limited and successful, transferable methods are yet to be established. Restoration ecology is an inter-disciplinary science encompassing ecology, sociology, economics and politics, but methodology to integrate these disciplines is lacking. This study explored the social and ecological factors affecting the regeneration of a degraded TPSF in Central Kalimantan, Indonesia. An ecological investigation revealed that seed rain, animal-dispersal, flooding, increased light levels and lowered soil nutrient and mycorrhizae levels had become forest regeneration barriers, whilst seed banks, drought and competition with invasive species had not. In the adjacent village, focus groups and interviews revealed other factors influencing forest regeneration; the community's lack of livelihood options, their dependency on the forest, the lack of funding for restoration and their dislike of 'outsiders'. Not all factors were negative however; the community's ecological knowledge, and their attitude towards restoration were positive. Social and ecological data were equally important in understanding the factors influencing the landscape. Furthermore, the data were closely linked and were often combined to better explain each factor. This study therefore proposes a new methodology for integrating these two disciplines within restoration ecology: the factors influencing the landscape are investigated through a process (using social and ecological methods) described as 'anticipation and engagement'. Social and ecological data are then combined to explain the factors using the categorizations: 'negative', 'potential negative', 'in-active', 'positive', and 'compound'. This methodology then facilitates development of a site-specific restoration action plan. The broader implications of this

methodology, the interlinking of social and ecological data, the transferability of methods, and the restoration of Indonesian TPSF are discussed.

‘On the Sabangau river, there wasn’t a single tree or anything that died, and it was all forest, no human scars because there were no humans, and my granddad found the Sabangau river… and he surveyed it; finding good soil and lots of fish, and trees that you could collect lots of sap from, so my granddad cleared an area’ (Female participant, granddaughter of first settler, Interview 20, Topic 1)

‘Dayak people, since becoming humans in this world, believe there is a God, and that’s it, but there’s also spirits, but not for worshipping, just they should be respected, so that there is stability between human life and nature. Dayak people, from the time before, considered that when there was not harmonization between life and nature’s life, then nature could become furious, and the Almighty can become furious and create natural disasters, like floods, sickness, plagues etc.’ (Male participant, Interview 12, Topic 1)

‘We wish for [forest restoration]. [The forest] can be like before, so that it can still be enjoyed by our children and grandchildren’. (Female participant, Interview 1, Topic 3)

Acknowledgements

My thanks go to OuTrop and CIMTROP for introducing me to tropical peat swamp forests and the challenges they are currently facing, and for facilitating all this research. To all my field assistants; Eben Eser, Salahuddin, Andri Thomas, Yudhi Kuswanto, Muhamad Idrus, Ari Purwanto, Hendri, Marta Bina, Elisabeth Ungga Ria and Eva Eka Sinta Asi who supported, strengthened and many times led me by the hand and pulled me out of holes, physically and metaphorically, as I negotiated the forest and the village. To my two supervisors, Dr. Susan Page, for her breadth and depth of knowledge regarding tropical peatlands, her guidance, and excellent editing, and to Dr. Jenny Pickerill who painlessly and patiently introduced me to the world of social science, taught me how to study myself and my participants, and gave me and the thesis much guidance and direction. My heart-felt thanks go to all the participants from Kereng Bangkirai who generously opened their lives and hearts to me, and helped me to far better understand the forest, this culture and the depth that goes into land restoration. Finally my thanks go to my parents and especially my husband Thomas, for their critiques, moral support and patience.

I. Contents

II. List of Tables

III. List of Figures

IV. Glossary and Abbreviations

Abbreviations

%N	Percentage-nitrogen
%-Org.C	Percentage organic carbon
BD	Basal diameter
CCDisF	Closed-canopy disturbed forest zone
CIMTROP	The Centre for the International cooperation in the Management of Tropical Peatlands
CKPP	Central Kalimantan Peatland Project
Con	Control (seedlings)
CR	Competition removed
DBH	Diameter at breast height
DegF	Degraded forest zone
ER	Ecological restoration
ES	Ecosystem services
FE	Forest edge zone
FZ	Forest zone
KFCP	Kalimantan Forest and Climate Partnership
LN	Leaf number
MEA	Millennium Ecosystem Assessment
MPSF	Mixed peat swamp forest
MRP	Mega-rice project
NA	Nutrient additions
NF	Natural forest zone
NLPSF	The Natural Laboratory of Peat Swamp Forest
NPK	Nitrogen/Phophorus/Potassium (plant fertilizer)
NRL	Non-reproductive litter
NTFP	Non-timber forest products
OCDisF	Open-canopy disturbed forest zone
P-Total	Total phosphorus
RAP	Restoration action plan

RE	Restoration ecology
REDD+	Reduction in Emissions through Deforestation and Degradation plus
RL	Reproductive litter
SC	Shade covered
SD	Standard deviation
TEEB	The Economics of Ecosystems and Biodiversity
TEK	Traditional ecological knowledge
TPSF	Tropical peat swamp forest
UNFCCC	United Nations Framework Convention on Climate Change
VAM	Vesicular arbuscular mycorrhizae

Glossary

Adat	The cultural and traditional laws and rights developed by the Dayak people before national, governmental laws became dominant.
Compound factors	Factors that are not necessarily negative or positive, but which are complex factors affected by numerous events and as yet unresolved.
Disturbance	A significant and often irreversible change in environmental conditions, population size and/or the magnitude and direction of some ecosystem-level processes – typically by reducing numbers of individuals, species or habitat. Can be caused by natural or human-induced disturbance factors (van Andel and Aronson 2012a).
Degradation	The subtle or gradual changes that reduce ecological integrity and ecosystem health post-disturbance (SER 2004).
Ecological restoration	The practice of restoring ecosystems as performed by practitioners at specific project sites (SER 2004).
Ecosystem services	The direct and indirect contributions of ecosystems to human well-being (TEEB 2010). The Millennium Ecosystem Assessment defined four categories of ecosystem services that

	contribute to human well-being: provisioning services, e,g, food and water, regulating services e.g. carbon sequestration and climate regulation, supporting services, e.g. seed dispersal, and cultural services, e.g. spiritual inspiration and recreational experiences (Millennium Ecosystem Assessment 2005).
In-active factors	Factors that have neither a negative nor a positive effect on regeneration, and as such, would not need to be addressed in restoration activities.
Interdisciplinarity	When concepts, models, methods and findings of different scientific disciplines are merged together and integrated to address an idea, or to solve a societal problem (Schoot Ulterkamp and Vlek 2007); taken from van Andel and Aronson (2012a).
Landscape	A landscape consists of a mosaic of two or more ecosystems that exchange organisms, energy, water and nutrients. A natural landscape or ecosystem is one that has developed by natural processes and that is self-organizing and self-maintaining. A cultural landscape or ecosystem is one that has developed under the joint influence of natural processes and human-imposed organization (SER 2004). This thesis regularly refers to a landscape and its meaning should be understood to be in relation to a 'cultural landscape'.
Local community	A group of people that were not only the 'geographical local community' (Gusfield 1975) to the degraded site but also those who, as McMillan and Chavis (1986) describe have membership, influence, a fulfillment of need, and a shared emotional connection to the relevant topic, in this case, the land, which is what creates a distinct community.
Mega-rice Project	An Indonesian Government initiative, in 1995, to facilitate Indonesia to become self-sufficient in rice production; a million hectares of Central Kalimantan's tropical peatlands were designated as land to be drained to make it suitable for rice production (Muhamed and Rieley 2001). The drainage of

	the peat led to excess drying, and in 1997, exacerbated by an extended dry season driven by an El Niño Southern Oscillation)event, extensive wildfires spread through the area, affecting 1.45 million hectares (Page et al. 2002).
Negative factors	Also called regeneration barriers, these are factors acting upon the degraded area such that they would need to be directly removed or overcome in order for regeneration to take place.
New Order	The political regime that was in place in Indonesia under President Suharto from 1966-1998.
Positive factors	Factors which support regeneration activities, and awareness of these factors and their incorporation into a RAP would be advantageous.
Potential negative factors	Factors causing some degree of negative impact on regeneration, or may become active negative factors based on an external trigger. These factors should be considered in developing a RAP, but are not as problematic as negative factors.
Regeneration barriers	Alterations to an ecosystem's environmental conditions post-disturbance that affect the ecosystem's ability to regenerate.
Restoration ecology	The science upon which the practice of ecological restoration is based, and which studies the impacts of ecological restoration. Restoration ecology ideally provides clear concepts, models, methodologies and tools for practitioners in support of their practice (SER 2004).
Rehabilitation	Rehabilitation shares with 'restoration' a fundamental focus on historical or pre-existing ecosystems as models or references, but the two activities differ in their goals and strategies. Rehabilitation emphasizes the reparation of ecosystem processes, productivity and services, whereas the goals of restoration also include the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure. (SER 2004).
Restoration	An intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability.

	Frequently, the ecosystem that requires restoration has been degraded, damaged, transformed or entirely destroyed as the direct or indirect result of human activities (SER 2004).
Sustainability	The Indonesian word for 'sustainability' is '*lestari'*, which more literally translates as 'ever-lasting'. In an economic context, it can be defined as the capacity of a system to remain productive indefinitely for future generations. It is increasingly recognized that sustainability includes economic, social, ecological and environmental components (van Andel and Aronson 2012a).
Traditional ecological knowledge	Ecological knowledge derived through societal experiences and perceptions accumulated within traditional societies during their interaction with nature and natural resources (van Andel and Aronson 2012a).
Western science	Or 'modern science', as opposed to 'traditional ecological knowledge' or 'indigenous knowledge', develops in a more abstract form, through meticulous recording and theoretical experimentation as opposed to the 'knowledge-practice-belief complex' of TEK (Berkes *et al.* 2000).

V. List of data provided on accompanying CD

- Published paper: Graham, L. L. B and Page, S. E. (2012) Artificial bird perches for the regeneration of degraded tropical peat swamp forest: A restoration tool with limited potential. Restoration Ecology 20: 631-637
- Published paper: Graham, L. L. B, Turjaman, M. and Page, S. E. (2013) ***Shorea*** *balangeran* and *Dyera polyphylla* (syn. *Dyera lowii*) as tropical peat swamp forest restoration transplant species: effects of mycorrhizae and level of disturbance. Wetlands Ecology and Management (DOI) 10.1007/s11273-013-9302-x
- Raw ecological data:
    - Characterizing the forest zones
    - Level of seed-rain and seed-dispersal
    - Abundance of seed banks
    - Nutrient availability and peat soil properties
    - Water level
    - Light levels
    - Competition with herbaceous vegetation
    - Mycorrhizal availability
    - Seedling data for Con, NA, SC and CR seedlings
- Social data:
    - Indonesian transcripts from interviews and focus groups Topics 1-3
    - Participants' translated quotes Topics 1-3
    - Participants' biometric data

1. Introduction

1.1 Restoration Ecology: the science, the landscape, the challenges

1.1.1 The practice of ecological restoration

For centuries, the natural resources of our planet have facilitated humans to develop and increase their distribution and population size. In recent years however, natural resources have become exploited, reduced, and their associated ecosystem services (ES) lost (Daily 1995, Turner 2005, van Andel and Aronson 2012a). 6% of the Earth's total land area, and 1 billion hectares (Ha) of previously forested land is degraded (Stern 2006). Ecological restoration (ER) is the practice of assisting a degraded ecosystem in its recovery of health, integrity and sustainability (SER 2004). This practice developed through the realization that human use of natural resources was unsustainable and needed to be addressed, and where possible reversed (Turner 2005, van Andel and Aronson 2012a). This field is relatively new, with most work only emerging in the last fifty years, but with a dramatic increase in the number of studies and applications in the last twenty years (Turner 2005, Aronson *et al.* 2010a). This field of science and practice offers great potential in overcoming the problems of land exploitation, loss of ES and climate change (Alexander *et al.* 2011, Manning *et al.* 2006).

1.1.2 Indonesia

Indonesia supports 6% of the world's tropical forest (FAO 1993), including the world's largest area of tropical peat swamp forest (TPSF) (Page *et al.* 2011). In the last 100 years it has been under Dutch colonization and then Japanese occupation, leading to a national revolution and eventual independence (Ricklefs 2008, Taylor 2003). Following independence an authoritarian regime was established which lasted for 35 years; the primary goal of this regime was economic growth through commercialization of the country's natural resources, which left many local communities feeling exploited and abused (Tsing 2005). The regime finally came to an end in 1998 (Furman *et al.* 1998). In the last fifteen years, democracy has been established, the economy has somewhat recovered, corruption is being challenged and repair of land exploitation is starting to be addressed (Ricklefs 2008). Indonesia has also become one of the leading developing nations in addressing climate change (DNPI 2010).

1.1.3 Restoration of tropical peat swamp forest

Indonesia may host the world's greatest area of tropical peat swamp forest (TPSF), but this ecosystem is being degraded at a rapid rate; between 1985 and 2006 about 47% (121,000 km^2) of SE Asia's TPSF became degraded; i.e. logged, burned, drained or converted to agricultural use (Hooijer *et al.* 2006, 2010) and at the current time only 4% of the TPSF in Sumatra and Kalimantan is still in a pristine condition, with 37% classified as degraded forest (Mietinnen and Liew 2010). The peatlands upon which TPSF grow are vast reservoirs of carbon and in Indonesia they contain a carbon store of 57 Gt, which comprises 74% of Indonesia's total forest soil carbon pool (Page *et al.* 2011). Upon their degradation, largely through fires, logging and drainage (Page *et al.* 2009), they become a source of carbon emissions to the atmosphere; in 1997 between 0.81 and 2.57 Gt of carbon were released to the atmosphere as a result of the burning of peatlands in Indonesia. This was equivalent to 13–40% of the mean annual global carbon emissions from fossil fuels for that year (Page *et al.* 2002). Indonesia's TPSF provides important ES; biodiversity support (Posa *et al.* 2011), hydrological regulation (Wösten *et al.* 2006, 2008) and particularly, carbon storage (Page *et al.* 2011). In light of the recent developments in international policy targeting climate change, especially REDD+ (Alexander *et al.* 2011), the restoration of Indonesia's tropical peatlands and its TPSF has become a topic of international interest. Program targets include reducing carbon emissions, restoring biodiversity and other beneficial ES (Spracken *et al.* 2008, van Noordwijk *et al.* 2008, Alexander *et al.* 2011).

1.1.4 The barriers

The science and practice of ecological restoration encompasses ecology, sociology, politics, geography and economics, amongst other disciplines and all must be investigated and combined to facilitate the design and implementation of appropriate restoration action plans (RAP) (McManus 2006, Collier 2011, Tongway and Ludwig 2011). Interdisciplinary science, however, is complex and still in the early stages of development, resulting in a socio-ecological gap with contemporary ecological restoration activities having access to few case-study examples of interdisciplinary methods or teaching aids (Hobbs 2007, Clewell and Aronson 2013, Aronson *et al.* 2010a, Norgaard *et al.* 2007). Furthermore, there are few academic faculties that can support this breadth of inter-disciplinarity, with geography, which encompasses space, place, time and scale, being one of the few. For ER to move forward, methods for integrating social, ecological, economic and political disciplines are necessary (van Andel *et al.* 2012).

Restoration ecology (RE) is the science upon which ER is based, and which studies the impacts ER. One aspect of RE explores the regeneration barriers existing at a specific site and examines methods as to how to overcome these barriers (Holl *et al.* 2012, Aide *et al.* 2000). These can then be used to help design and implement a RAP for the specific location together with all stakeholders, and to monitor the progress (SER 2004, Tongway and Ludwig 2011, 2012). The regeneration barriers and appropriate RAP are unique based on the natural history, disturbance history and sociology of any given site (Curran *et al.* 2012, Holl *et al.* 2000). Given the vast areas of land degraded across the globe, landscape-restoration has become an important topic of research and practice (Lamb *et al.* 2005, Manning *et al.* 2006). There is a need for large-scale solutions and transferability of data, and yet the site-specific nature of the regeneration barriers creates a challenge: how can this work be undertaken in a way that is both successful and also has a wide-scale impact (van Andel and Aronson 2012b)?

Indonesia is a country with a complex history, and whose government has only recently begun acknowledging the rights and voices of its local communities (Tsing 2005, Engel and Palmer 2006). Under the Dutch, Japanese and particularly the authoritarian regime of the New Order (1966-1998; see 3.6), extensive land exploitation occurred, mainly with little regard for the long-term impact on the land and the needs of the surrounding communities (O'Connor 2004, McCarthy 2000). It is a country which is undergoing rapid change and development, looking to overcome corruption (Schütte 2012), to better represent the voices of small communities (Engel and Palmer 2006), and to tackle deforestation, land-use change and associated carbon emissions (DNPI 2010). The challenges it faces, however, in terms of its weak, although strengthening economy, its decentralised government leading to confused laws and continued corruption, its continued need to develop economically and its need to prove to the local communities that the government can be trusted and will support them, all pose large barriers to the potential success of land-management activities, such as restoration of degraded forests.

Restoring degraded tropical peatlands and TPSF has become the focus of several developed countries, such as Australia and the Netherlands, as a potential solution for targeting climate change (Spracken *et al.* 2008, Clements *et al.* 2010). Restoration, however, requires intimate knowledge of an ecosystem's processes (Aide *et al.* 2000), and the study of TPSF has only developed in the last thirty years (Page and Rieley 2005) with, at present, little of that knowledge being applied to ecosystem restoration (Page *et al.* 2009). Degraded TPSF have poor forest regeneration capabilities, following instead retrogressive vegetation succession, driven in particular by fire and flooding (Page *et al.* 2009, Hoscilo *et al.* 2011). Much scientific study is still required to understand TPSF's regeneration barriers and the external influences that impact upon a degraded tropical peatland landscape.

1.2 This study

The aim of this study was to explore the restoration of degraded TPSF at multiple levels. Firstly, to investigate regeneration barriers at the local scale; what were the regeneration barriers, both ecological and social, influencing the recovery of a specific site? Then to consider this at a more national and international scale; how applicable were these data to other sites in Indonesia? What was the relevance of these findings in relation to the current political, economic and social situations within Indonesia? Could this data or these methods be used and applied at a landscape-scale? This study did not just wish to purely provide 'data' for restoring a specific type of forest at a specific location. By investigating both the social and the ecological factors influencing a specific landscape, this study explored how these two disciplines might be bridged at all stages in the process: methodology, data collection, results analysis and discussion. It considered new methods and approaches to facilitate inter-disciplinarity in a multi-faceted practice and the transferability of methods in a science governed by its site-specific nature.

Based on this, the following research objectives were developed:

- At a given degraded tropical peat swamp forest study site in Indonesia, identify and explore the active regeneration barriers (covering both the social and ecological aspects of RE) that are affecting the site's recovery.
- Explore routes as to how these regeneration barriers might be addressed or alleviated to facilitate restoration, specifically for this site and more generally for the TPSF ecosystem and for other ecosystems.
- During this process, explore methods as to how the socio-ecological gap facing RE might be addressed.
- Make observations and address the larger debate of how appropriate ER is with regard to Indonesia's TPSF.

It should be noted that as this research is inter-disciplinary, the various writing styles for each separate discipline had to be considered when writing both the methods, results and discussion chapters. Whilst physical science has a more abstract writing style, social science is acceptably, and necessarily, often written in the first person. In this thesis, both styles are adopted, depending on the section being addressed. When discussion from the two disciplines came together, one writing style was chosen that best matched the topic. This is one further barrier that complicates the joining of these two disciplines, and adds to the socio-ecological gap (Norgaard *et al.* 2007).

Furthermore, whilst this study considers both ecological and social data, and aims to merge the two disciplines and findings in the discussion, the weighting across these two studies was not and was not intended to be equal. From the outset of this work a

70:30 ecological:social split between field time and thesis content was expected and achieved.

1.3 Clarification of some definitions

The terminology linked to ER and RE is under continual development, revision and discussion, due to the changing face and needs of the practice (van Andel and Aronson 2012a, Shackelford *et al.* 2013). The Society of Ecological Restoration provides definitions for many of the key terms (SER 2004). In the thesis' glossary a list of the terminology commonly used in this thesis is provided, with definitions either taken from general literature sources, or defined specifically for the purposes of this thesis. Definitions of some terms, for example, 'sustainability', are under much debate. This section does not aim to explore these various definitions, but rather to provide an exact definition of the meaning as intended in this thesis:

This study is primarily one of restoration ecology (RE), in that it is conducting and exploring aspects of the science upon which the practice of ecological restoration (ER) is based (SER 2004). However, in sections of the thesis the wider implications of this study are considered, as to how they might be linked to the practice of ER. These two terms, therefore, are inter-changed as appropriate, depending on whether the science or the practice are under discussion.

The terms 'rehabilitation' and 'restoration' have a slightly different focus; rehabilitation emphasizes the reparation of ecosystem processes, productivity and delivery of services, whereas restoration also includes the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure (SER 2004). This study is a restoration study, investigating the regeneration barriers that are preventing an area of TPSF from recovery. TPSF is situated, however, on tropical peatland. It is the peatland component of this ecosystem that stores large quantities of carbon, and which has become the international focus of climate change discussions. Whilst this study is restoration based, various other studies and discussions focus on tropical peatland rehabilitation. The goal of these is not the restoration of the TPSF, but primarily the recovery of the ES of the tropical peatland to prevent continued high carbon emissions. In relation to this study, therefore, the appropriate terms are *TPSF* and *restoration*. In reference to other studies and the larger debates, however, sometimes the *rehabilitation* of *tropical peatland* is also discussed.

Finally, the definitions for the degradation of TPSF and tropical peatland can be numerous and varied, and in some cases misleading. To avoid this, the Kampar Science Based Management Support Project developed a key definition in their ‘statement on tropical peatland conservation and the possibilities for sustainable development’, which is used as the definition for degraded TPSF through-out this thesis.

‘Degraded tropical peatland is peat swamp forest that has been severely damaged by the excessive harvesting of wood and/or non-wood forest products, poor management, drainage, fire, or other disturbances or land-uses that damage the peat and vegetation to a degree that inhibits or severely delays the re-establishment of forest after abandonment (modified from ITTO 2002). Degraded peat swamp forest is unlikely to recover its former forestry resource value without active rehabilitation and may no longer support the livelihoods of local communities. Nevertheless, the peat still contains a large amount of carbon that will continue to be released to the atmosphere as CO_2 (a greenhouse active gas) as a result of oxidation and fire.’ (Hooijer *et al.* 2008)

1.4 <u>Chapter summaries</u>

Chapter 1: Outlines the principal argument and objectives of this thesis; it describes what themes and debates will be addressed within the thesis, discusses some of the more complex definitions used in this thesis, and provides a chapter-by-chapter overview for the thesis content.

Chapter 2: Provides a literature review of the current status of ecological restoration, with a tropical focus. This covers a history of the science of restoration ecology, and why it originated, looks at the process of tropical forest restoration, in particular the common regeneration barriers. It considers the social, then briefly, the political and economic aspects of RE, and the problems in combining these through an inter-disciplinary method.

Chapter 3: Provides a literature review of Indonesian political, social and ecological issues past, present and future, in the context of ER and TPSF. At the end of this chapter the study's research objectives are outlined.

Chapter 4: Details the methods of this study. The study-location is described, with a detailed presentation of the quality of the forest zones (from natural to degraded) used in this study. The methods used to investigate the ecological regeneration barriers are described, and the methods used in community participation to learn of their understanding of the perceived and real regeneration barriers (or lack of) to forest restoration at the study site. The approach taken to bridge these two fields is also described.

Chapter 5: Provides a detailed over-view of the study location in relation to the social-demographics of the community who participated and the other stakeholders linked to the study site.

Chapter 6: Presents the ecological results of the study, describing the quantitative data obtained on the potential ecological regeneration barriers and an assessment of whether they are in operation at the study location.

Chapter 7: Presents the discussion to accompany the ecological results, providing ecological explanations for the findings, comparing them to studies in other comparable ecosystems and detailing the potential ecological implications of the findings for the development of a RAP.

Chapter 8: Presents an overview first of the social data collected, then of all the factors influencing the landscape, splitting them into categories: negative, potential negative, non-active, positive, compound. All factors are described in relation to their ecological and social components, with social data further presented. How the social and ecological data might be combined to develop a RAP is described.

Chapter 9: This chapter returns to the study's research objectives and considers how they have been addressed. It explores the transferability of data and methods, the socio-ecological gap, and the challenges and ways forward facing TPSF restoration in Indonesia. This thesis closes with an appraisal of the limitations of this study, and future directions for further studies.

Given the complexity of this thesis in relation to its interdisciplinarity and its level of scale, from local to international, a simple diagram depicting the disciplines(s) and scales in each chapter is presented in Fig.1.1.

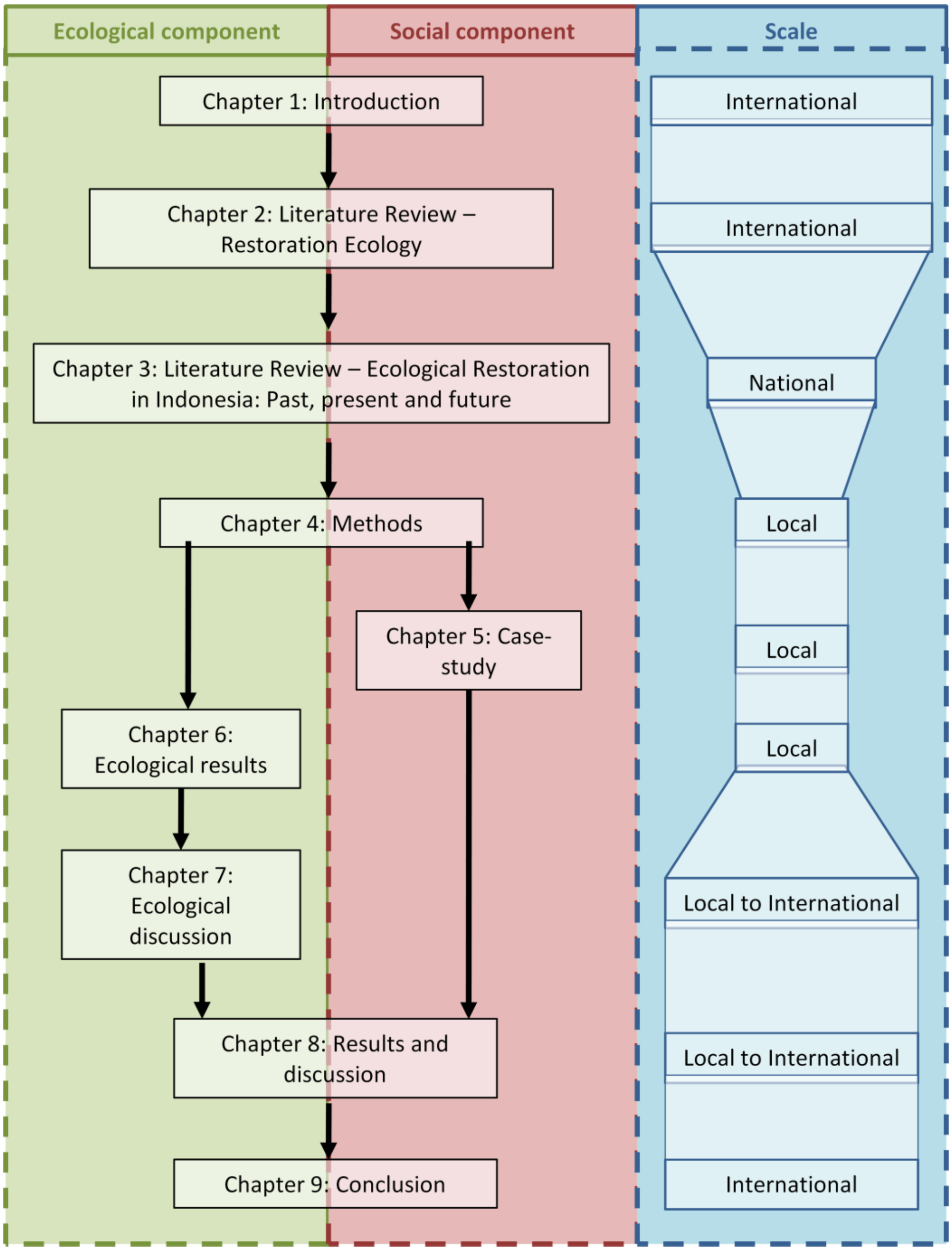
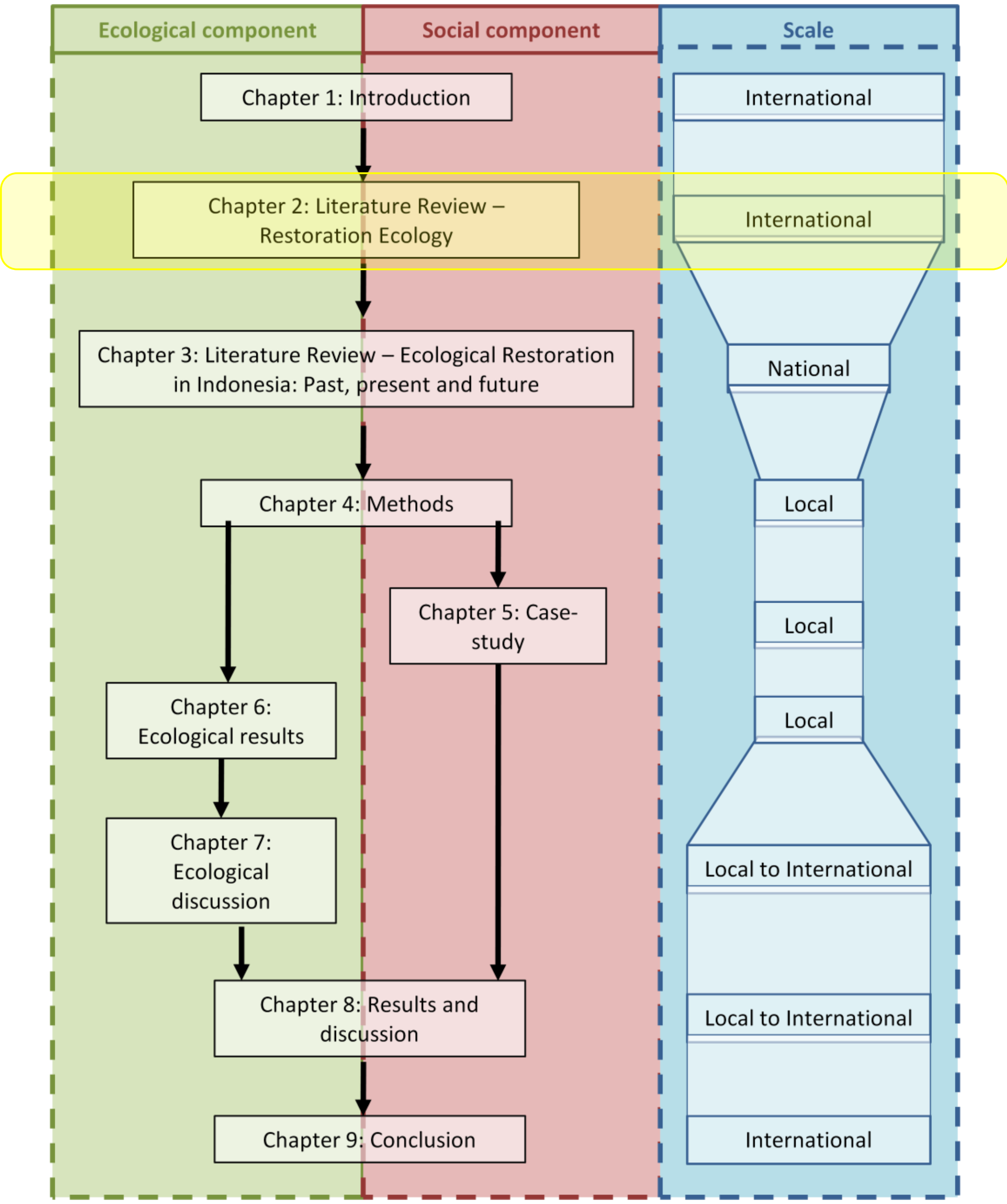


Figure 1.1 Diagrammatical outline of the thesis depicting the discipline(s) and scale of each chapter.

1.5 Conclusions

This chapter has presented an overview of the work and debates to be addressed within this thesis, outlining the objectives of the study, clarifying some of the relevant definitions and providing a chapter-by-chapter overview. The following two chapters provide the in-depth literature reviews on RE and Indonesia to set the scene and provide justification for the research that follows.

2. Literature review 1 – Restoration ecology



2.1 Introduction

Internationally, the past few decades has seen the realisation that as much as we rely on nature and its natural resources, we are now in a relationship with nature that is imbalanced. Through this understanding, there has evolved a need for the development of sustainable land-use practices, and to determine routes to allow people and nature to co-exist. One practice which has developed is ecological restoration (ER), the process by which degraded land is restored, recovering the ecological functions and biodiversity, whilst re-assessing the relationship between humans and the ecosystem, such that future degradation might be avoided and local communities can benefit from the process.

The process of ER is complex, with the specific goals subject to contention and debate. Furthermore, the process by which ER objectives are achieved is slow and challenging, particularly as a result of its interdisciplinary nature. The practice of ER is supported by restoration ecology (RE), which investigates the best methodologies for bringing about and assessing successful restoration.

This chapter introduces and defines the concept of ER, and discusses the reasons that led to its development. The various disciplines within RE are then discussed. The aspects of ecological science necessary for successful ER and the need to involve local communities and their concerns in the process are described in depth, and the roles of institutions, history and economics are also touched upon. Finally, the problems and challenges facing the practice of ER are discussed, and potential future directions that ER research should take are highlighted.

The practice of ER is highly dependent on 'place'; the site chosen, and its natural and social history can be used to understand the factors acting upon the landscape. The subsequent chapter focuses on the location of this study, an area of degraded TPSF, and provides an overview of Indonesia's social and political history with particular reference to land-use and its impacts on TPSF. These two literature review chapters provide the foundation for subsequent methods and empirical chapters.

2.2 Changing land use and human perceptions

2.2.1 The importance of ecosystem services

In a variety of forms, humans across the globe are dependent on natural resources and the ecosystems that provide them. These benefits may be obtained in indirect or direct forms. The TEEB – The Economics of Ecosystems and Biodiversity study, which developed out of the G8+5 countries determining in 2007 to initiate the process of analysing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation – defines these 'ecosystem services' (ES) as 'The direct and indirect contributions of ecosystems to human well-being' (TEEB 2010). The Millennium Ecosystem Assessment (MEA) defined four categories of ES that contribute to human well-being: provisioning services, e,g, food and water, regulating services e.g. carbon sequestration and climate regulation, supporting services, e.g. seed dispersal, and cultural services, e.g. spiritual inspiration and recreational experiences (Millennium Ecosystem Assessment 2005).

Costanza *et al.* (1997) estimated the total global economic cost of ES would come in at $33 trillion per year. Balmford *et al.* (2002) went further than this, arguing that whilst the estimates of Costanza *et al.* were acceptable, they were also limited by two factors. Firstly, the extrapolations did not take into account a sliding-scale in relation to availability of resources; as fewer resources remain, their value will increase. Secondly, they did not consider the cost-benefit of land-conversion. Their study considered five different ecosystems, from coral reefs, to tropical forests. It showed, in each instance, that the 'total economic value'of each ecosystem decreased significantly after conversion, to the extent that their calculations would need to be inaccurate by an order of 100 to make land-conversion economically advantageous.

The ES also includes cultural services, and habitat or supporting services, which are harder to represent in markets. These, and other, services can be considered as ecosystem benefits: what society is willing to pay for it (Barbier *et al.* 2011).

The most rapid land-conversion rates exist in developing countries, where biodiversity is also highest (Myers *et al.* 2000). For the residents of these countries, who are often struggling under unstable government, education and health systems, their priorities lie with their own and their families' safety, health and education. To develop their and their countries' land may seem to provide the only route to the economic benefits they desire in order to improve their standards of living (Rosenzweig 2003). It is therefore necessary to provide definitive evidence in the form of economic benefits and costs associated with protection of their land (TEEB 2010, Rodrigues *et al.* 2011, Clewell and Aronson 2013).

2.2.2 Global land degradation

Over the last century dramatic losses in ecosystem services and species biodiversity have been observed (Daily 1995, Pimm *et al.* 1995). Daily (1995) illustrated in her global study that the direct value of an area of land with regard to human usage is declining across the world. By assessing global soil degradation (17% degraded through overgrazing, deforestation and other agricultural activities), dry land degradation (70% degraded, through similar agricultural activities, leading to desertification) and tropical moist land degradation (over 427 M Ha of tropical systems across the globe), she estimated that global land degradation came to 43% of total land cover. Furthermore, she calculated that the cost of restoration was far cheaper than the cost of maintaining productivity on degraded lands, and that if land recovery were not attempted, land value would drop by 20% in 25 years. Similarly, a study by Stern (2006) described how 6% of the Earth's total land area, 1 billion Ha of previously forested land, is degraded but restoration efforts would yield cost-effective benefits.

2.2.3 Limitations of protected areas

Initial and mainstream conservation methods to protect biodiversity and halt land-conversion often take the form of protected areas (Rosenzweig 2003, Lele *et al.* 2010). Globally, there are 24 million km^2 of protected land, across over 133,000 designated sites, with an annual increase of 2.5% (Butchart *et al.* 2010). In the 1992 Convention of Biological Diversity, world leaders committed to reduce the rates of biodiversity loss by 2010 (Rands *et al.* 2010), yet despite these efforts, rates of biodiversity loss are not reducing (Butchart *et al.* 2010).

In some instances, particularly in developed countries, the creation of these areas has created safe-havens for ecosystems and biodiversity, for example, Yellowstone National Park, US (Huff and Varley 1999), or Wicken Fen National Nature Reserve, Cambridgeshire (Friday 1997). It is often developing countries which struggle to create effective protected areas, as their priorities necessarily lie elsewhere (Lele *et al.* 2010, Rands *et al.* 2010). Protected areas can lead to resentment and exclusion of those surrounding the land, with issues of encroachment and illegal harvesting (Salafsky and Wollenberg 2000, Lele *et al.* 2010, Lawson and MacFaul 2010).

Often the land which is protected is economically less valuable and represents a biased sample of habitat types (Rodrigues *et al.* 2004, Lele *et al.* 2010), poorly representing the areas' biodiversity (Cowling and Pressey 2003).

Even after land is protected, it does not guarantee the protection and sustainability of the biodiversity within (Curran *et al.* 2004). Encroachment and illegal harvesting have already been mentioned. Invasive species can also undermine the work of conservation parks (Rands *et al.* 2010). For example in New Zealand, over 30% of the land is protected, yet 40% of the terrestrial birds are extinct and 40% of the total bird species are threatened, due to invasive species, largely rats, stoats and cats, which continue to predate the birds (Clout and Russell 2006).

There is also the issue of the size and range of conservation parks. For larger mammals to have a large enough park area to support a sustainable population size is rare (Caughley 1994). Species such as birds and butterflies follow migration routes, meaning numerous locations across regional and national boundaries must be protected (Rands *et al.* 2010). Furthermore, in response to climate change, animals' and plants' ranges and tolerance niches are changing, often outside the parks' established boundaries (Parmesan and Yohe 2003, Holmes *et al.* 2013, MacLean *et al.* 2008).

In recent years much has been done to move protected land away from the classic, exclusionary protected area form, such as community-based, enterprise-based and payments-based conservation (Lele *et al.* 2010, Adams 2004). Equally, many landscape-scale approaches have been developed, such as trans-boundary conservation, payments for environmentally-sensitive farming, and large-scale habitat creation and restoration (for review see Rands *et al.* 2010). Yet, these concepts are still face challenges on the ground, such as poor management, lack of funding and development of methods (Balmford and Whitten 2003, Leverington *et al.* 2008, Lele *et al.* 2010).

Given the extent of degraded lands, the continued high rates of biodiversity losses and other ecosystem services, and the limitations of conservation parks and related activities, whilst conservation obviously forms a crucial form land protection, other routes to sustainable land management are needed, within which ecosystem services can be protected, whilst the still meeting other human needs.

2.2.4 Towards sustainable land-use

Sustainable development is the ability to “meet the needs of the present without compromising the ability of future generations to meet their own needs”, as defined in the Brundtland Commission (1987). The World Summit on Sustainable Development, held in Johannesburg 2002, reflected the general acceptance and implementation of this practice. Over the last fifteen years, it has become one of the most popular and conceptualized conservation land-management practices. It accepts the need for use and management of land, but with the proviso that any harvesting of produce or land-management practices should not reduce the long-term sustainability of the land. It should be noted that with sustainable development’s popularity there has also developed some misuse of the concept and application, providing justification for continued ‘sustained development’ of large businesses (Rowell 1996).

Although defined conceptually, sustainable development as a science and a practice faces many challenges. It must encompass at least six disciplines; conservation ecology, landscape ecology, restoration ecology, ecological economics, environmental law and environmental ethics (Aronson 2011), resulting in a necessary transdisciplinarity for which language and methods are still evolving (van Andel and Aronson 2012a). Equally, Aronson *et al.* (2010b) describe the need overcome three ‘great divides’ in the road to sustainability; between deep ecologists and fundamentalist neoclassical economists, the economic divide between the rich and the poor, and the information divide between ‘the environment’ and ‘the market’.

Whilst it would be ideal for land-management practices to follow the true principles of sustainable development from the start, the need for and relevance of these practices often become important or recognized only once the land is over-used, and the sustainability of the ES become a concern. Consequently, the successfully management and sustainable development of land often necessarily goes hand-in-hand with its restoration or rehabilitation (TEEB 2010, Costanza *et al.* 2006).

2.2.5 Turning to ecological restoration

By restoring degraded ecosystems, biodiversity and ES can be recovered (SER 2004, van Andel and Aronson 2012a). Crucially, ER also provides an opportunity to reassess the relationship between humans and the restored site (Turner 2005, Tongway and Ludwig 2011).

Land degradation generally occurs as a result of societies’ need or desire to develop the land (SER 2004, TEEB 2010); this can be a result of the local communities’ livelihood activities, land-owners wanting to make money from the land, or agricultural businesses wanting to develop the land. To place this land within the boundaries of a protected area does not deal with this issue, as the need or desire to develop the land still remains. Equally, to simply restore the previous ecosystem does not address the issues that led to the ecosystem becoming degraded in the first place, leaving the ecosystem open to degradation once more. Instead, the interdisciplinary approach of ER builds an understanding of the social complexities of the site, the needs of the local community, both for the land and themselves, resulting in an area they wish to care for and maintain (Tongway and Ludwig 2011, SER 2004, Turner 2005).

2.3 Learning to recover our lands: Restoration ecology

2.3.1 A brief history

Over the last 30 years ER has become one of the most dominant forms of conservation and over the last decade ER has been proposed by governments and scientists as a necessary step in recovering many of the ES losses suffered by ecosystems around the globe (Turner 2005, Clewell and Aronson 2006, Rodrigues *et al.* 2011).

The practice of ER is supported by the research science, restoration ecology (RE). Within its short history, this new science can already cite many success stories (see http://www.globalrestorationnetwork.org/, Nelleman *et al.* 2010). To date, however, the majority of ER projects and RE research studies have been focused in the temperate zone (e.g. Palmer 2006, Huff and Varley 1999). In this environment, restoration often takes on a very 'pure' form; an attempt to recover a site to its exact previous state (Gobster 2001). There are fewer restoration projects underway in the tropics, with most based in the neo-tropics (Rodrigues *et al.* 2009, 2011, Aronson *et al.* 2010a). Tropical projects commonly avoid visions of recovering pristine ecosystems, but instead focus on determining a path to co-existence between the communities and the landscape (Adams and Infied 2003, McManus 2006, Lele *et al.* 2010). This is necessary in countries where local communities still rely on the land for their livelihood, rather than as a retreat or escape from busy lives (Clewell and Aronson 2006, Lele *et al.* 2010, Rodrigues *et al.* 2011).

2.3.2 Classifications

Ecological restoration and its larger relevance to conservation, science, politics and sociology, has, in the past, been poorly defined (Higgs 2003, van Andel and Aronson

2012, SER 2004). It is a conservation method, a product of scientific research, a process through which communities engage and/or a political or consumerist product. It can take on multiple forms and objectives, even its purpose can be debated: Rosenzweig (2003) defines ER as an attempt to recover a site to its exact previous state, which he defines as having limited application and uses, associated with western values of land recovery. Higgs (2003) would argue that provided there is the recovery of land to a state which reflects its previous ecological integrity (the levels of previous biodiversity and ecosystem functions), and historical integrity (a reconstruction of the previous ecosystem, remaining true to native species and habitat), and works towards improving local livelihood, this is ecological restoration. In order to solidify and clarify the various terms, the Society of ER produced the 'Primer on ER' (SER 2004), which defined ER as 'the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed' (pp. 3). It then discusses what constitutes 'recovery' and also where 'rehabilitation', 'reclamation' and 'mitigation' fit within (or outside) of ER's definition.

Despite the clarifying nature of this document, the actual practice of ER often continues to be confused due to its interdisciplinary nature, and methods are often fractured and, in some cases, poorly justified (Higgs 2005, McManus 2006, Hobbs 2007, Clewell and Aronson 2013).

2.3.3. Ecological architecture

The resulting end-point of the restoration, the final form which the landscape takes, is dependent upon governmental views and support, scientific feasibility and local participation (Higgs 2005, Tongway and Ludwig 2012) (Fig 2.1). By thoroughly understanding both the ecology of the site and the local community's hopes and requirements from the ecosystem, a realistic restoration action plan can be developed and implemented by researchers and local people working together (McManus 2006, Palmer 2006, Tongway and Ludwig 2011).

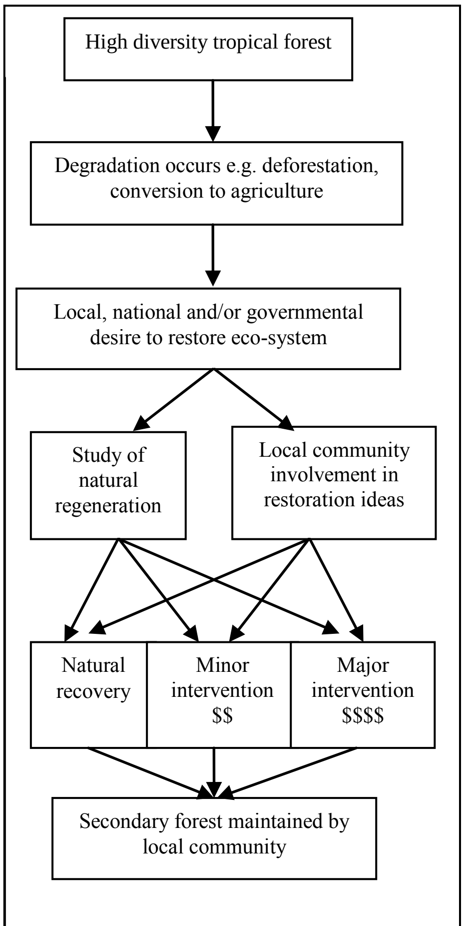


Figure 2.1: The stages involved during the process of forest restoration. Adapted from Aide *et al.* (2000).

During this process, there is no single answer as to what final form the land should take. Indeed the expectations and hopes at the start of the process may differ from those at the end of the process (Higgs 2003). Whilst at times, to include all social, political and ecological perspectives within one forum may seem difficult, and compromises may need to be made, the alternative, to ignore any of these aspects is unacceptable, and leads to restoration plans which are incomplete and inappropriate (McManus 2006, Palmer 2006, Tongway and Ludwig 2011). As Sheil and Lawrence (2004:636) remind us, 'Conservation is ultimately not a science but a societal goal – a normative and ethically motivated pursuit – that must include voices other than those of scientists alone.'

2.3.4 The components of ecological restoration

Restoration ecology is not simply the process of ecological understanding and recovery of an ecosystem. It is a multi-faceted, inter-disciplinary science, which requires the incorporation of all the factors that influence the landscape (van Andel and Aronson 2012, Clewell and Aronson 2013). These can be summarised by the following non-exclusive subjects; Restoration ecology, Social participation, local views and knowledge, Political influence and role of the institutions, and Economics. Each of these are discussed below. However, despite each subject being recognised within the literature as important and relevant to restoration, frequently ER projects are carried out without addressing all these factors, and rarely are they joined together to create a holistic view of the study-site (Turner 2005, Tongway and Ludwig 2011).

2.4. Tropical forest restoration ecology

To recover an ecosystem, the natural ecological processes that govern the ecosystem, and the extent and form in which they have been altered due to the disturbance and degradation must be understood (Holl 2012).

RE operates under the knowledge that ecosystems are constantly under a process of regeneration. This process of regeneration, as discussed by Wang and Smith (2002), is composed of certain ‘sub-processes’ such as, seed production, dispersal, predation and germination. Each of these sub-processes are interlinked and facilitate, as Wang and Smith have called it, the ‘seed dispersal loop’ (fig. 2.2). If any of these sub-processes are disrupted, a forest ecosystem’s ability to self-regenerate will be impaired.

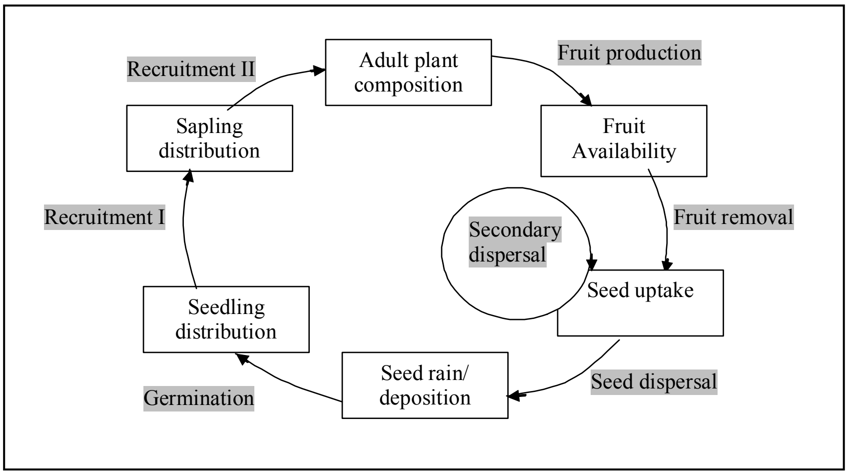


Figure 2.2: The seed dispersal loop, as proposed by Wang and Smith (2002), illustrates the stages of forest regeneration, and the series of sub-processes (highlighted in grey) facilitating forest regeneration.

For each of these sub-processes to proceed, the biotic and abiotic environmental conditions necessary at each stage must be operational, such as animal dispersers, and nutrient, water and light availability. After degradation, an ecosystem may be capable of self-recovery through self-regeneration. Indeed, most ecosystems are capable of some level of self-regeneration after degradation, as natural regeneration is often initiated through low-level disturbance (Aide *et al.* 2000, Corlett 2009). However, the more extreme and repeated the disturbance, the lower the ecosystem's resilience becomes to self-regenerate (SER 2004). As self-regeneration slows, or stops, the ecosystem will remain in its degraded state for a longer period of time.

RE becomes necessary when an ecosystem, after some form of disturbance, has become degraded and has lost its natural ability to regenerate, or is regenerating at a very slow-rate. In this environmental state, due to the changes in the environmental conditions brought about through the disturbance, some or even all of the 'sub-processes' of regeneration are unable to operate as normal. These altered environmental conditions that are impairing the 'sub-processes' of regeneration are termed 'regeneration barriers' (Holl *et al.* 2000, Zimmerman *et al.* 2000). If these are determined, it is possible to target these altered environmental states, and use methods to restore the previous environmental conditions, thus alleviating the barriers (Holl *et al.* 2000, Tongway and Ludwig 2012). This, then, facilitates the sub-processes of regeneration to re-establish, and the cycle of regeneration to begin, thereby restoring the ecosystem.

Ecosystems are extremely complex. The potential number of changed environmental conditions that become ‘regeneration barriers’ after an ecosystem is degraded are numerous. As RE has developed, however, the importance of certain key environmental conditions in the regeneration process have been noted, and when these conditions are altered, common regeneration barriers begin to emerge. In the tropics, studies across different ecosystems have shown that certain barriers re-occur, such as, limitations to seed dispersal (Holl 1999, Martinez-Garza *et al.* 2009, Zanini and Ganade 2005), competition with herbaceous vegetation (Holl *et al.* 2000), fire (Aide and Cavalier 1994, Hooper *et al.* 2005) and soil nutrient availability (Aide and Cavalier 1994, Tobon *et al.* 2011, Amazonas *et al.* 2011).

To investigate if a sub-process within the regeneration process is affected by an altered environmental state, the natural levels of the sub-process should be assessed within a healthy, operating ecosystem or ‘reference site’ (SER 2004), to determine normal levels, and compared to a degraded area of this ecosystem, to determine if the process has significantly altered. Significant alterations for each sub-process and the environmental features that are producing these alterations highlight the regeneration barriers.

Below is a discussion of the various sub-processes as described in Wang and Smith’s ‘seed dispersal loop’, and how each of these processes might be affected by altered environmental conditions that could develop into regeneration barriers. The stages shown in Figure 2.2 can be grouped into two categories: the process of seed dispersal, and the process of recruitment and growth.

2.4.1 The process of seed dispersal

The importance of seed dispersal for normal forest regeneration is explained through the Janzen-Connell ‘escape’ hypothesis: based on density dependence, predator and pathogen pressures decline further from the parent tree, thus increasing the survival chances of both seeds (Janzen 1970) and seedlings (Connell 1971). Howe *et al.* (1985) suggested that as well as this ‘escape hypothesis’, there is also the ‘colonization hypothesis’, the need to reach newly disturbed areas, and the ‘directed dispersal hypothesis’, the need to reach areas that the plant is particularly adapted to.

Depending on forest type, wind and animals tend to be the two main forms of seed dispersal. Animals may disperse seeds internally or externally, actively or passively (Stiles 2000). 50 – 90% of tropical tree species rely on animal dispersers, with birds, primates and rodents often being the dominant primary and secondary dispersers (Howe and Smallwood 1982, Forget 1990). Loss of animal-dispersal would lead to loss, both in the short- and long-term, of plant biodiversity (Chapman and Chapman 1995, Khan *et al.* 2005).

After an ecosystem becomes degraded, it not only loses much of its plant species diversity, but also its animal seed-dispersers, since animal populations decline, and those remaining will mainly stay within forest fragments (Howe and Smallwood 1982, Chapman and Chapman 1999, Cardoso da Silva *et al.* 1996). Unless dispersed by water, wind or chance animal behaviour, dispersal for most tropical forest tree species is disrupted after degradation (Janzen and Vázquez-Yanes 1991, Khan *et al.* 2005). Numerous studies have shown that both fruit and seed abundance and biodiversity, especially for animal-dispersed species, dramatically declines just a few meters beyond the forest edge (Zimmerman *et al.* 2000 – Puerto Rico, Aide and Cavalier 1994 – Colombia, Holl *et al.* 2000, Holl 1999 – Costa Rica, Martinez-Garza *et al.* (2000) - Mexico). Consequently, reduced animal seed-dispersal is frequently cited as potentially one of the largest obstacles to tropical forest regeneration and restoration (Aide *et al.* 2000, Florentine and Westbrooke 2004, Holl 1999).

Soil seed banks (the store of dormant seeds within the soil that have arrived by falling from the parent tree or by dispersal) build up over time in most ecosystems. In some ecosystems, such as temperate forests or savannahs, seed banks act as a crucial source of seedlings for re-colonization (Bakker *et al.* 1996). In tropical environments there are fewer seeds adapted for dormancy and most ecosystems have short-lived seed banks (Corlett 2009, Janzen and Vázquez-Yanes 1991). This may be due to the seedlings requiring moist conditions to ensure their survival, so although in seasonally dry environments dormancy is advantageous, in year-round humid conditions immediate germination is more optimal (Corlett 2009, Blakesley *et al.* 2002).

Following forest degradation, seed banks can act as important sources of new seedlings to re-colonize the area (FORRU 2008, Bakker *et al.* 1996, Daïnou *et al.* 2011). After disturbance, however, seed banks may become damaged, and if new seed banks are not built up from near-by trees or through dispersal, this source of seedlings may be lost (Janzen and Vázquez-Yanes 1991, Aide and Cavelier 1994). In degraded areas, the seed bank can be the same volume or higher than in the natural forest, but with a different composition, namely a higher proportion of herbs, shrubs and grasses, leading to further complications in the restoration process (Janzen and Vázquez-Yanes 1991, Bakker *et al.* 1996, Brearley *et al.* 2004, Daïnou *et al.* 2011).

2.4.2 The process of recruitment and growth

Even if tree seeds are dispersed to the degraded site, this still does not guarantee success for regeneration of the area. The second stage in the process of regeneration is that of recruitment and growth. The seed must successfully germinate and then grow through seedling, sapling and finally to mature, fruiting tree in order for the regeneration process to complete its cycle. The most delicate point in this cycle is the seedling; they have little reserves if resources become limited, and are susceptible to damage as they do not yet have protective structures (Florentine and Westbrooke 2004). Some plant species are adapted to tolerate more extreme environmental conditions, but in a degraded site, the resources required for growth, the environmental conditions which the plant can survive and the level of competition it must endure all differ from those conditions within a non-degraded site (Corlett 2009). The following section considers the changed environmental conditions likely to occur in a degraded site, which may influence the survival and growth of the seedlings, thus becoming regeneration barriers.

Altered pH and nutrient limitations

Plants require an array of nutrients taken up from the soil but the two that most commonly limit plant growth are nitrogen (N) and phosphorus (P) (Townsend *et al.* 2011). The carbon to nitrogen ratio (C:N) can be used as an indicator of nitrogen limitation for plants.

Overall, N forms the third most abundant element in plants and is incorporated into proteins (Corlett 2009). Plants which are N-limited show a decline in growth and overall mass, with a relative increase in below-ground biomass and a decrease in chlorophyll levels. The recycling of organic N by bacteria from decaying organic matter into inorganic N which can then be taken up again by plants is key to ecosystem survival

(Corlett 2009). The performance and abundance of these bacteria, *Nitrosomonas* and *Nitrobacter*, and other microorganisms, are heavily dependent on their environment. In dry, acidic or waterlogged environments their nitrification rates will decline. Young soils are frequently low in nitrogen availability as there has been little time for N to build up through these biochemical processes, whilst older soils are linked to higher N levels (Corlett 2009, Davidson *et al.* 2004, Townsend *et al.* 2011). Limitations in nitrogen have been shown to limit tropical forest primary productivity in Borneo (Paoli and Curran 2007), understorey seedlings in Panama (Santiago *et al.* 2012) and secondary forest tree growth in Brazil (Davidson *et al.* 2004).

Organic carbon (org-C) is a necessary component of nutrient recycling and soil health as it provides the energy source for the micro-organisms in the soil (Gomez-Pompa *et al.* 1991). The ratio of C to N can provide an indication of the 'value' of the organic matter to the micro-organisms, with a high C:N ratio being less amenable to soil decomposer organisms, indicating a slow nutrient turnover.

Phosphorus is used in plants as a metabolic regulator. P constitutes only 0.3% on average of a plant's dry weight; yet at one third of this concentration, the plant becomes P limited. In most soils, at least 99% of P is unavailable to plants. In young soils, phosphate is more available as less of it has been fixed, but in older soils, such as those commonly found in the tropics, most of this phosphorus has been fixed and is unavailable (Townsend *et al.* 2011). Bacteria in the soil, through secretion of acids and phosphatase enzymes, can increase the concentration of free P in the soil. Some plants can also release phosphatase from their roots, whilst most plants form a symbiotic relationship with mycorrhizae (soil fungi) which increases their P uptake (discussed in a subsequent section). Several studies have suggested that in some tropical ecosystems P is the most influential nutrient in controlling species composition, forest above-ground biomass and tree growth (Paoli *et al.* 2006, Paoli and Curran 2007).

Tropical environments are associated with high levels of productivity due to year-round photosynthesis, and also have correspondingly high rates of organic matter decomposition, except where there is frequent or prolonged water-logging. At high soil respiration levels, soils become more acidic (low pH), and the subsequent abundance of H^+ can result in replacement of the ‘nutrient-ions’, and their subsequent leaching, or in the case of phosphorus, fixing. This leads to a range of tropical soils being associated with high acidity and low nutrient availability. In such situations, plants are highly dependent on the below-ground ecosystem; the soil microorganisms and the recycling of organic matter (Gomez-Pompa *et al.* 1991, Corlett 2009). For the soil microorganism community to function effectively it requires a rich supply of organic matter, thus soil organic carbon levels must be maintained. Equally, the C:N ratio determines the ‘appealability’ of the organic matter, and there is a possibility that the respiratory activities of microorganisms also link to phosphate release (Chimner and Ewel 2005, Bragazza *et al.* 2007).

The levels of soil phosphorus, nitrogen and carbon are all carefully controlled by the micro-organism nutrient recycling process, which can be affected by changes in pH, temperature, light, water level, and plant species present (Bragazza *et al.* 2007, Sulistiyanto 2004, Corlett 2009). Habitat disturbance in tropical forests is often associated with changes in soil physical and chemical characteristics, including nutrient availability. Nutrients are lost from the environment through the removal of the organic vegetation (timber when logging) (Corlett 2009) and soil erosion (Pimental *et al.* 1995). This can lead to reduced abundances of microorganisms, reduced rates of decomposition and production of inorganic nitrogen and free organic phosphate (Glatzel *et al.* 2006). Furthermore, tropical forest degradation is associated with an increased risk of fire due to the influx of invasive grasses (Hooper *et al.* 2005, Zanini and Ganade 2002), the remaining dead timber associated with degraded sites and the drying of the exposed soil. Between 5 and 50% of fixed nitrogen is lost through burning due to nitrogen's low volatisation temperature (Toda *et al.* 2007). This loss of nitrogen through fire has been shown to limit secondary succession in evergreen broad forest in East China (Yan *et al.* 2006), in tropical Amazonian secondary forests (Davidson *et al.* 2004) and in secondary tropical forests in Sarawak, Malaysia (Tanaka *et al.* 2007), and it can take decades for soil nitrogen levels to recover to pre-fire levels (Amazonas *et al.* 2011).

Following tropical forest degradation, therefore, the levels of soil N and P may become disrupted. This has been illustrated by Aide and Cavalier (1994) in the lowland tropical forests of Columbia, and by Vierra *et al.* (1994) in abandoned pasture in the Amazon basin. However, findings from other studies are conflicting: Ganade and Brown (2002) and Zanini and Ganade (2005) found that nutrient availability was not a regeneration barrier in degraded Brazilian forest, since slow-growing, low-nutrient-demanding pioneer species returned to the site, and Hooper *et al.* (2005) found little difference in nutrient availability between degraded and adjacent intact tropical forest soils in Panama. In contrast, Holl *et al.* (2000) found that addition of NPK fertiliser improved plant growth rates in degraded Costa Rican forest.

Water levels

In plants, water provides the medium which transports other materials around the plant, it provides turgor and structure to cells and to plant organs including stems and leaves. Upon water limitation, plants lose turgor of cells and tissues, a change in cytoplasmic conditions affecting biochemical processes and a conflict in the need to continue photosynthesis yet reduce water loss (which occurs concurrently with photosynthesis in the process of transpiration) (Cao 2000, Tobin *et al.* 1999). During water limitation, a plant initially suffers dehydration, then desiccation and eventually mortality (Engelbrecht and Kasar 2003, Bunker and Carson 2005). Seedlings, with fewer reserve resources and less internal rigid structures, are very susceptible to dehydration and desiccation (Marod *et al.* 2004, Poorter and Markesteijn 2008).

The opposite extreme to water limitation is flooding. Flooding can be a transient occurrence, or a permanent or semi-permanent feature of the environment, such as in marshes or swamps. As plants are aerobic respirators they must have access to air, and potentially, in flooded environments, plants risk the threat of 'drowning' if their roots are without adaptations, such as pneumatophores or knee roots (Page and Rieley 2005).

Whether through high or low water-use strategies, plants must be adapted to the water conditions of their given environment in order to survive. Alterations to these water levels result in a plant's carefully evolved adaptations becoming redundant. Degradation of an ecosystem can be associated with changes in water levels, particularly in wetlands (Turner *et al.* 2000), and hydrological rehabilitation of the landscape is crucial to its restoration (Hopfensperger *et al.* 2006). Plants which are adapted to moist, forest environments may experience drought due to exposure, and desertification (Nepstad *et al.* 1996, Martinez-Garza *et al.* 2011), and equally degraded landscapes which flood can pose a difficulty for establishment of young seedlings (Giesen 2004, van Eijk *et al.* 2009). Survival of seedlings in degraded areas can therefore be dependent on the hydrological regime therein, and disruptions to the conditions they are adapted to can become regeneration barriers (Marod *et al.* 2004, Poorter and Markesteijn 2007, van Eijk *et al.* 2009).

Light levels

While plants depend upon light energy to power photosynthesis and produce the sugars they needs, they must also protect themselves from the dangers of too much light. Plant species display a wide spectrum of tolerance to light levels, in accordance with the niche they inhabit. ‘Shade-tolerators’ are adapted to low light levels, germinating and maturing under the shade of a dense forest canopy. Shade tolerant species tend to have larger, thinner leaves to capture as much light energy as possible; they have low photo-assimilation, growth and respiration rates, preserving the small amount of energy they capture. These species are adapted to competing for light, and invest in above-ground biomass (Corlett 2009, Marod *et al.* 2004). ‘Light-demanders’ have special adaptations to survive and grow under high light levels. Their primary adaptation is their high photoassimilation, respiration and growth rates. They also possess physical adaptations, such as small leaves and specialised leaf hair cells, trichomes, to reflect sun light. These species, instead, must compete for below-ground resources such as water and nutrients, and, invest more in below-ground rather than above-ground biomass (Bazzaz 1991, Khurana and Singh 2001, Marod *et al.* 2004).

Specific adaptations restrict the range of light levels that a particular plant species can tolerate (Marod *et al.* 2004). Sun-loving plant species can ‘respire themselves to death’ if put in shade conditions, as the growth rate they adopt, achievable in high light conditions, cannot be sustainably maintained in low light levels (Sack and Grub 2002). Equally, studies into the effects of sun-flecks on shade-tolerators under the forest canopy have shown that extended high intensity light-levels for plants un-adapted to these conditions can lead to overheating, leaf death, and desiccation (Lambers *et al.* 1998).

Fire or logging, leads to increases in light levels. Appropriate light levels for each species are crucial to seedling germination, growth and survival (Corlett 2009): seedlings which are shade-tolerant can no longer survive due to the increase in light energy. Equally, sun-lovers may be inhibited if other conditions are altered such as water or nutrient levels, which they previously relied upon to maintain their high levels of photosynthesis and growth (Marod *et al.* 2004, Cabin *et al.* 2002). Disturbance and degradation in a forest ecosystem can alter light levels, which may then restrict many species from regenerating in the degraded area (Loik and Holl 1999).

Competition with herbaceous vegetation

The environmental factors described in the previous sections (nutrients, water and light) are key to plant survival and are consequently competed for. In nutrient-rich ecosystems, plants are able to grow quickly and rapidly and compete above-ground for light. In nutrient-poor ecosystems, or those with low water levels, below-ground competition becomes more important. Whether plants are adapted to quickly draw-down the available resources, or are adapted to tolerate low resource availability, each species has evolved a specific competition strategy that facilitates its survival (Wright 2002).

Changed abiotic factors post-disturbance may themselves prevent natural regeneration, or they may facilitate new species to move in: after degradation, invasive species, typically sedges, grasses and ferns that tolerate high levels of disturbance, frequently become dominant in disturbed tropical forest ecosystems (Wilson 1999, Corlett 2009, Cabin *et al.* 2002). Their presence draws down further the already depleted nutrients, and water sources can become limited (Nepstad *et al.* 1996, Calloway and Walker 1997) and they can also trigger a positive-feedback for fire (Hooper *et al.* 2005, Cabin *et al.* 2002). Seedlings from the adjacent forest are subjected to environments for which they do not have competitive strategies (Elliot *et al.* 2006). In a degraded area of Costa Rican forest, after clearing and monitoring for six months, it was found that species-richness and cover of broad-leaved species was five times greater in grass-cleared plots than in non-cleared grass area, and transplanted seedlings had higher survival under shrubs (24% grass cover) than those transplanted into purely grassy plots (Holl *et al.* 2000). Similarly, in an area of previously tropical forest, and subsequently abandoned agricultural land in Panama, seedling growth improved in invasive vegetation removal trials (Hooper *et al.* 2005). Weeding is often recommended, therefore, to remove the regeneration barrier caused by competition with invasive species (Elliot *et al.* 2006, Cabin *et al.* 2002).

In other instances, however, it has been shown that invasive vegetation can act as a first stage of succession, facilitating the return of tree seedlings and providing a path to natural regeneration (Gomez-Aparicio 2009). As the invasive species are able to tolerate the extreme conditions, they stabilise the environment for the establishment of tree seedlings. Zimmerman *et al.* (2000) showed that in an, once forested, abandoned pasture dominated by ferns and sedges in Costa Rica, that upon vegetation removal, surface temperature rose and fluctuated more, and one of the tree species previously present in the area was lost. Furthermore, overall germination across all species was lower, but survival was no different between ‘invasive vegetation cleared’ and ‘non-cleared’ areas. Equally, germination of forest tree species under grass was shown to be higher than in areas without grass on the degraded abandoned pasture in Costa Rica (Holl 1999). Aide and Cavalier (1994) found a similar germination effect in Colombia, and also growth and survival of six species of transplanted seedlings was greater in grass plots compared to cut plots and burnt plots.

Mycorrhizae

Mycorrhizae are fungi that form symbiotic relationships with plant roots. In exchange for sugars produced by the plant, the mycorrhizae provide additional phosphates, nitrates, and other micro- and macro-nutrients; they can also increase water supply to the plant during periods of drought, and reduce susceptibility to soil-borne pathogens (Dell 2002, Rillig 2004). The symbiosis is controlled by the seedling; given the cost of sugars to the plant the symbiosis will only be permitted if some required benefit is attained (Garcia-Garrido and Ocampo 2002). The relationship is, however, highly specific. Different species and groups of mycorrhizae form different associations (Kiers *et al.* 2000, Lovelock and Ewel 2005).

Studies on the relationships between mycorrhizae, their plant hosts and their ecosystems have been under-studied in the tropical zone (Janos 1980a), although in recent years this has begun to be remedied (Kiers *et al.* 2000, Allen *et al.* 2003, Tawaraya *et al.* 2003, Lovelock and Ewel 2005). These studies have shown mycorrhizae are just as important in tropical as in temperate forest biomes.

Mycorrhizae interact directly with both the biotic and abiotic components of an ecosystem; they can affect environmental conditions such as soil structure, pH, salinity and nutrient abundance and also affect the composition of soil microbial and plant communities. These interactions also operate in the reverse direction, with changes to abiotic and biotic conditions impacting on mycorrhizal composition and abundance (Janos 1980b, Allen *et al.* 1995, Dell 2002, Rillig 2004). During disturbance, plant and soil community composition and abiotic conditions alter rapidly, and this in turn can impact upon the mycorrhizal community (Allen *et al.* 1998). In some cases this can lead to a reduction in mycorrhizal abundance, as observed in various types of degraded tropical forest in Costa Rica (Fischer *et al.* 1994), but more often, the disturbance facilitates a change in mycorrhizal composition, as observed in tropical forest of Nicaragua and degraded areas of dry tropical forest in Costa Rica (Johnson and Wedin 1997, Picone 2000). The spores of mycorrhizal species adapted to disturbance move into the degraded area, and form relationships with the pioneer plant species. This can then make it difficult for the previous tree species to return, as their corresponding mycorrhizae are no longer available (Allen *et al.* 2003).

2.4.3 Transplanting seedlings

Given the above regeneration barriers that commonly occur in degraded tropical forest sites, which impact on seedling recruitment and survival and growth, a common method of ER is transplanting mature seedlings to the site of disturbance (Holl 2012, FORRU 2005, Kettle 2010). By transplanting plants as mature seedlings, the barrier of reduced seed-dispersal is removed, and the delicate stage of sprouting and immature seedling growth is avoided. Furthermore, if appropriate species are chosen they can help to encourage animal seed-dispersal, create shade – reducing invasive grass, herb and sedge cover, and reducing the stressful microclimate conditions, and sometimes improving soil structure and nutrient availability (Florentine and Westbrooke 2004, Holl 2012, Cusack and Montagnini 2004). Preferentially, native species should be selected, and those that possess the appropriate traits to tolerate the degraded conditions and meet the above requirements (e.g. attract animals, fast-forming canopy, nutrient-fixation). These necessary traits are summarized in the Framework Species Method, which proposes planting a mixed array of species that will help to 'short-cut' succession and quickly re-establish a mixed diversity forest (FORRU 2005, Blakesley *et al.* 2002). To carry out this method, however, requires detailed silvicultural knowledge of the ecosystem and its tree species which is not always available, and often a smaller sub-set of species must be used (Florentine and Westbrooke 2004, Lamb *et al.* 2005).

The previous section described the ecological aspects that are commonly linked to potential regeneration barriers in forest RE. The community and stakeholders also influence a landscape's health, degradation and restoration. The following sections address the social science components of RE.

2.5 Social participation, local views and knowledge

Restoration of a piece of land is a value-based process, as discussed above (2.3.3 Ecological architecture). It is not simply an ecological process of land recovery, as the land's final form must be chosen, and should represent the needs and hopes of those who use the land (Tongway and Ludwig 2011, 2012). Furthermore, social, economic and political knowledge of the site may reveal further barriers obstructing restoration, highlighting factors which must be addressed to enable successful land recovery (van Andel *et al.* 2012, Tongway and Ludwig 2011).

Studies of restoration projects have shown that when the values of the local communities are fully included in a forum within which they can express themselves, there has been better recovery of aspects of the environment to which they attach social, political or symbolic relevance (McManus 2006, Palmer 2006, Tongway and Ludwig 2011). In addition, this can result in an increase in personal income and empowerment (Murombedzi 2003, Palmer 2006, Higgs 2005). Furthermore, studies indicate that inclusion of local views and perceptions, and the use of local knowledge in locally-based land-use planning, leads to more achievable plans and successful outcomes. This may be in the form of scientists engaging and learning from the local community, allowing the views of each respective group to be clarified, and the needs of all stakeholders to be more closely met (Sheil and Lawrence 2004, McManus 2006), or that, as a result of close-collaboration and participation, trust relationships between scientists and local people are improved and tensions and conflicts are ameliorated (Moller *et al.* 2004, Berkes 1999).

Consequently, land-planning and management now tries to incorporate the views and knowledge of local communities (Walsh and Mitchell 2002, Stewart *et al.* 2005). Traditional ecological knowledge (TEK) is being applied in land-use management and environmental decision-making, especially in developing nations (Moller *et al.* 2004, Sheil and Lawrence 2004). Solutions to land-development, resource-use, conservation of biodiversity and sustainability can be found within indigenous land-use practices, and guide the form that restoration projects should take (Berkes *et al.* 2000).

Despite demonstrations of the benefits that local contributions can bring to ecosystem restoration, case-studies incorporating community-based participation and applied-TEK into local land-use decision-making, such as restoration work, remain isolated, rather than a standard approach (Sheil and Lawrence 2004, Shackelford *et al.* 2013). Reasons for this might be explained through two issues. Firstly, issues associated with participation remain contested (Hickey and Mohan 2004); some argue participation practices can lead to misrepresentation (Serje 2003, Palmer 2006, White 1996), whilst others see it as a necessary and achievable method to attaining equitable and appropriate land-use practices (Moller 2004, Craps *et al.* 2004). The second issue is whether the views and local knowledge developed through participation in TEK are compatible with the more westernized approach to science, or in this instance, to restoration. These two issues are discussed below.

2.5.1 Problems with participation

Ironically, one of the main constraints on community participation in recent years is its popularization (White 1996). Organizations have become so determined to include 'participation' within the planning stages of a project, that its actual relevance or appropriateness has become obscured. As a Cameroon official described, during the planning for a community-participation workshop, 'if they don't have a community we'll make them form one, and then we'll order them to participate' (Sharpe 1998). The use of participation has become such a necessary tick-box for project proposals that the methods employed can often be inappropriate, reflecting western planning and procedures rather than accommodating the cultural preferences of those involved (Walsh and Mitchell 2002, Serje 2003).

A further result of the mainstreaming and popularization of participation is that its meaning and intent has become muddled, and ulterior motives may be practiced, hidden within 'seeming transparency' of 'inclusive participation'. White (1996) describes that 'participation' now holds multiple meanings, outlined in four separate, non-mutually exclusive, groups. These are: 'Nominal participation' which displays some form of participation, allowing local people to feel included and provides legitimization to the work. 'Instrumental participation' which increases efficiency and provides a means to an end, such as local people providing a work-force so that funding is sought only for materials. 'Representative participation' can provide a voice and leverage for the local community and, through this, make the work more sustainable. Finally 'transformation participation' empowers all those involved, bringing about confidence and change. Whilst each of these groups provides some form of benefit to local people and facilitators, each has different objectives and achieves this through different means. To continue to frame them all under the single-heading of participation muddies our understanding and creates room for exploitation of local knowledge. Furthermore, in considering nominal participation, the need to 'legitimize' work through participation raises a further important concern. Participation has become such a feature of popular environmental decision-making, that in order to legitimize ones' work in this field, participation must be included (White 1996, Sharpe 1998). Equally, to gain funding and support for the work, participation legitimizes the request. The outcome of this is two-fold: firstly, participation becomes reduced to a necessity of process rather than something to be cultivated and supported. Higgs (2003) describes the *process* of restoring a site as being as pivotal as the actual outcome, as it allows participants to develop a sense of community and understanding in relation to the site, and the site itself becomes a feature of their identity. To exclude this process puts at risk the success of the final product. Secondly, the method and objectives become dictated by Western funding bodies and agencies, which may not include the cultural preferences or interests of the stake-holders. Objectives and outcomes may often be defined before the participation begins, in order to meet desires or expectations of the funders, creating conflicts of interests, and removing the importance of the knowledge which emerges through the participation process (Walsh and Mitchell 2002, White 1996). An obvious example for this is the recent development of the carbon-market and systems such as REDD+ which opens many opportunities regarding funding for ER, but has a number of pre-determined objectives that means the participation is more likely to be 'representative' (i.e. to have a participative and contributive voice' rather than 'transformative' (i.e. empowering the participants to achieve their goals) (van Noordwijk *et al.* 2008, Wright 2011, Alexander *et al.* 2011).

The second stage at which problems arise is during the actual process of participation, and the practical social issues that must be contended with. These can be expressed as: Who has a right to participate? Whose views count? And, is there true representation? These questions are each discussed below:

Who has a right to participate? A logical argument might nominate all stakeholders involved with the land. However, this level of participation is rarely attainable. Large-business stakeholders rarely participate, whilst indigenous communities or small-scale organizations may be overlooked (Craps *et al.* 2004). Furthermore, those perceived to have rights to the land, the stakeholders, may be under dispute. For example, recent immigrants to areas may be considered to have less claim (Sharpe 1998, O'Connor 2004). Equally, women can be excluded from the participation process, as it is considered their views can be represented by the men. Young people can often feel it is not yet their right to participate, being too 'immature' or 'inexperienced', whilst in other instances, the misuse of land by elders can leave the young feeling that elders no longer have a right to participate (Walsh and Mitchell 2002, Sharpe 1998).

Whose views count? A frequent misconception of indigenous community views is that they share one voice. Immigration, changes to land and social structures and movement from rural to urban areas have resulted in fractured communities with contested views of the future (Sharpe 1998), yet these diverse views within one community are often not fully recognized (Craps *et al.* 2004). Furthermore, as discussed above, funding-agencies, large-business stakeholders and government may hold more sway due to their positions of higher authority, which can result in a weighting of their views, leaving the local land-users feeling marginalized (White 1996).

Is there true representation? Social and political tensions, and struggles for power often mean certain groups may not be heard, or, even if included, may not speak out. As

White (1996) points out, participation does not guarantee views will be heard, and that even ‘sharing through participation does not necessarily mean sharing in power’ (White 1996:6). Social and cultural structures may mean women or young do not express their views, even if they are included. Equally, those better educated, or with some Western language skills or knowledge may, often unintentionally, get preferentially-treated (Walsh and Mitchell 2002).

2.5.2 Using the results: Traditional Ecological Knowledge

A crucial, recent development in the on-going discourse of participation is the potential value and use of the knowledge of the local land-users. Indigenous or ‘traditional ecological knowledge’ (TEK) is now being viewed as a valuable resource to direct or guide environmental decision-making (Walsh and Mitchell 2002, Wangpukapattanawong *et al.* 2010); for a review of the applied uses of TEK see Sheil and Lawrence 2004). TEK, in practice, can establish agroforestry systems which provide agricultural income to the land-users whilst preserving ecosystem function and biodiversity (Tynela *et al.* 2000, Lawrence 1996). Parabiologists (people who lack formal higher education, but are trained in biological tasks/work), often local people with inherent knowledge about study sites, are being employed in conservation and environmental work (Sheil and Lawrence 2004).

Is TEK compatible with westernized methods of land planning?

Defined as ecological knowledge derived through societal experiences and perceptions accumulated within traditional societies during their interaction with nature and natural resources (van Andel and Aronson 2012a); it is shared orally and learned through practice and experience. Berkes (1999) defines this as the ‘knowledge-practice-belief complex’. ‘Western’ science develops in a more abstract form, through meticulous recording and theoretical experimentation. Some would therefore argue that to join the two is impossible, as they are rooted within separate knowledge structures (for discussion see Berkes *et al.* 2000), and are often categorized through dichotomies; urban and rural, modernity and tradition, progressive and conservative tendencies (Craps *et al.* 2004). Recent work shows, however, that through these different approaches to the formulation of knowledge about the ecosystem, there is much room for compatibility and complementarity. Yet, due to their fundamental differences, there also remain obstacles which must be negotiated. The advantages and problems of combining the two approaches are discussed below.

A review by Berkes *et al.* (2000) illustrates the potential overlap between TEK and Modern or Western science, and also highlights where they diverge, and how this may be complementary. It is argued that ‘probably none of the examples is purely traditional but incorporate both Western science and local practice’ (Berkes *et al.* 2000:1252). For example, in both TEK and Western science, monitoring, protection and restrictions all play a crucial role. Shamans conduct field observations of numerous local species, ascertaining their abundances, and determining the numbers which can be sustainably hunted. Equally, through temporal or spatially enforced restrictions, habitats and species are protected, providing them with ‘resting periods’ when numbers can recover, or having ‘sacred groves’ or other off-limit areas that provide breeding and living ground (Warren and Pinkston 1998). These practices resonate strongly with guidelines for sustainable land-use within Western science practices.

Equally, many land-use practices that were once used globally, such as resource rotation in agriculture, and multiple-species management which promotes biodiversity and supports ecosystem function (Tyson *et al.* 2000), have lost favor in Western countries, due to production inefficiency. However, monoculture agriculture is now having worrying effects on biodiversity and ES. Western governments are thus promoting and subsidizing farms that reintroduce crop-rotations, hedge-rows, and other more ‘traditional land-use practices’. Meanwhile, these practices are still continued through TEK across the world (e.g. Mexico - Alcorn and Toledo 1998, Nigeria - Warren and Pinkston 1998).

Finally, land-use practices developed from TEK can offer benefits, which, through the use of conventional Western science, are difficult or impossible to achieve. For example, land practices based on TEK often involve both long- and short-term planning (Berkes *et al.* 2000). Due to the historical and cultural associations of TEK, and the necessity for TEK to be passed through the generations, long-term foresight is more frequently implemented than in practices associated with Western science. For example, African herders develop their herding routes in two rotations, ‘macro-mobility’ and ‘micro-mobility’, related to the scale of the route and the time consumed to complete the route (Walker 1993). With this appreciation of ethnohistorical information, there is the opportunity for long-term monitoring. Through a life-time of practical experience and oral histories, important ecological events or trends which have a longer cycle may be detected, which short-term scientific monitoring may miss (Moller *et al.* 2004). Traditional management systems are usually rapid and low-cost, requiring less complex equipment (Moller *et al.* 2004). Though they may attain a lower precision of accuracy, they can dramatically increase the data sample size. Furthermore, as it operates at a lower degree of accuracy, TEK, in practice, often follows ‘rule of thumb’ guidelines, which are often more transferable and robust than intricate and complex models (Gadgil *et al.* 1993).

Despite these positive features and similarities, there are practical physical barriers to integrating TEK into Western science. Most TEK is specific to the region or habitat it is developed in, and therefore may only have limited application beyond these locations (Berkes *et al.* 2000). There can be language and cultural barriers, which take time to understand, such that transmission of knowledge is slow and time-consuming (Sheil and Lawrence 2004, Walsh and Mitchell 2002). Furthermore, to spend time learning from, and working with, indigenous communities is not only time-consuming for the scientists, but also for the local people involved. With other time-demands, such as family and work needs, participation levels can be low or tail-off (Walsh and Mitchell 2002, White 1996). Often, work within indigenous communities is carried out by social scientists. However, appreciation of certain land rituals or traditions can require ecological knowledge, and so biologically-relevant information may get overlooked (Berkes *et al.* 2000). A further practical issue to contend with in the use of TEK is the complexity of ethical issues and intellectual property rights (Walsh and Mitchell 2002, Sheil and Lawrence 2004). An appreciation of social science methods is needed for appropriate participation, a feature lacking in most biological scientists through lack of experience (Hickey and Mohon 2004, Higgs 2005).

Whilst TEK and its related land-practices often results in win-win situations for the land-users and the ecosystem, these are merely a by-product or consequence of the land-practice, rather than its objective (Berkes *et al.* 2000). Should the most cost- and energy-efficient land-practice alter, for example, with high biodiversity lowering potential productivity, then these environmentally-friendly practices may be lost (Beukema 2004).

TEK relies upon an oral and practical transmission of knowledge. It must pass down the generations, and as such is heavily dependent on the social structures (Berkes *et al.* 2000). Dramatic social upheaval, political change and environmental degradation across many of these local communities is leading to a loss of traditional social structures

(O'Connor 2004, Sharpe 1998). Knowledge is no longer being passed from elders to the young, migrants to the area do not receive the benefit of ethnohistorical information, and as tropical forests become an increasingly more difficult place to live, the continuation of this knowledge is under threat (Sharpe 1998).

2.5.3 Successful participation

Developing planning ideas and making land-based decisions with a diverse group of stakeholders inevitably brings challenges and conflicts. However, through past experiences the obstacles that transpired, and how they were negotiated, can be learnt from. In the section below, some of the successes of participation are described, in which projects have sought to include indigenous communities and TEK in the environmental decision-making process.

A study in a mangrove swamp in Banawa District of north-west Sulawesi, Indonesia, was carried out to ascertain the local peoples' views and attitudes in relation to the real and perceived benefits of land-use change (conversion from fishing and resource harvesting to aquaculture (Armitage 2002)). A 'participatory appraisal approach' was used, including participatory mapping, seasonal calendars, interviews, focus groups and workshops. From this, it was possible to develop social and personal narratives reflecting the negativity and marginalization local people felt in relation to the conversion.

A large collaborative project was initiated in southern Ecuador, in an attempt to bring together the numerous stakeholders involved in developing a sustainable rural drinking water plan. A review of this project discussed the use of 'multi-party collaboration', with an emphasis on a 'social-constructivist perspective'. This method, carried out in 'search workshops', allowed stakeholders to bring together and discuss their converging and diverging views, and, through close collaboration with the facilitator, there has since been the creation of a legal charter, and six years into the project, the creation of a service centre with more planned. It is suggested in this review that the key issue was to determine a ‘common vision’, which was achieved through ‘face-to-face contact’, where previously there was large ‘fragmentation’ across the different stakeholders (Craps *et al.* 2004).

The Social Forestry Development Project (SFDP) established in 1992, in West Kalimantan Indonesia, with organizers from the German agricultural agency, GTZ, together with the Indonesian Forestry Department, worked to encourage and facilitate smallholders in traditional Dayak land-management, which would support local livelihoods and protect the surrounding forests. Through close-collaboration and integration of western science with TEK, a number of land-use practices were developed which could increase land-use efficiency and generate capital whilst decreasing the pressure on the forest (Potter and Lee 1998).

Of the participation examples above, there have been things to learn and experience which can transform and construct ideas and decisions, for facilitators and participants alike. It is this method of reflection and construction that is most important, and most likely to bring more successes in the future. From this constantly growing set of experiences, we can hope to develop more appropriate methods for participation, which can anticipate the hurdles, and hopefully move towards fair and just inclusion of all stakeholders.

2.6 Political influence and role of the institutions

The process of globalization, and the pressures and developments associated with it, has led to rapid evolution and change in the social, political and environmental conditions in many developing countries (Mertz *et al.* 2005). Governments and large businesses in developing nations have supported massive programs of deforestation and land-use change, leading to land degradation, in a bid to join the expanding world markets. Mertz *et al.* (2005) call this the 'globalization of poverty', with strengthened state power increasing the constraints on local people's lives and decentralization generating a higher risk of resource exploitation from external forces (Tsing 2005). At the same time, with changing conditions and influences from the west, indigenous communities and authorities are becoming fractured (Sharpe 1998, White 1996, Craps *et al.* 2004). These changes have also led to a global awareness and need for the sustainable use of global resource management. As land-tenure, land-use and political conditions rapidly change, there is a need to address the long-term sustainability of these practices, and governments and authorities have to become more accountable for control and use of their natural resources (Walsh and Mitchell 2002, Tsing 2005).

Those with rights and ownership of the land also determine how the land is used and developed. Local land management can become dominated by external structures, such as the government, businesses or conservation bodies. It can lead to conflict of ownership rights and, in numerous instances, across the globe, and particularly in countries which are in the process of rapidly developing, lead to marginalisation and injustice (Mertz *et al.* 2005, Hillman 2006, Williams and Mawdsley 2006). It can cause the poor or local landowners, who have claimed ownership through traditional, local cultural processes, rather than having legally-recognised ownership, to lose their land rights. It allows the rich, or those with more access to legal processes and information, the ability to exploit both the land and the local people (Armitage 2002, McCarthy 2005, Peluso 2009).

Governments, local authorities and institutions are crucial to the success of land restoration. Based on past examples, the support and expectations of local and national authorities determine the level of action and participation possible (Clewell and Aronson 2013, Aide *et al.* 2000, fig 2.1). There are now both governmental and NGO movements to return land rights to those who had legitimate but 'non-legal' claims to their land at the time their land was removed from them (Walsh and Mitchell 2002, McCarthy 2005, Moeliono *et al.* 2012). However, with much of this land now degraded, restoration becomes a necessary process in facilitating owners to recover use of their land. Cooperation, involvement and participation of the institutions and authorities that are stake-holders or land-owners of the degraded land are essential features of ER (Williams and Mawdsley 2006, Clewell and Aronson 2013, Tongway and Ludwig 2011). Furthermore, issues of procedural and distributive justice in terms of the institutions and authorities marginalizing the rights or access of the local land-users, both in the past and present relationship may generate conflict and tensions which, as a barrier, must be addressed and resolved before successful restoration can occur (Hillman 2006).

2.7 Economics

The science of socio- and environmental-economics is vast and complex, and is not something this study explores directly. However, as with any social land-management investigation, the social and economic aspects cannot be separated. The following section provides an overview of the importance of economics in restoration. None of the subsequent data or results feature economic analysis, instead they discuss the understanding and attitudes of the community to the economic situation.

The economics of the site and the stakeholders greatly influences the feasibility and success of ER (Clewell and Aronson 2006, Aronson *et al.* 2007). Although it has been shown in a meta-analysis that restoration activities most often have a positive benefit-cost ratio (Neβhöver *et al.* 2011), short-term economic payoffs can often provide the greater incentive (Schuyt *et al.* 2007, Williams and Mawdsley 2006). The availability of monetary funds to support the restoration activities is important and often essential in developing countries (Metz *et al.* 2005, Holl 2012), where local communities must receive real and immediate benefits in order to support and participate in sustainable land-management practices (Rodrigues *et al.* 2011, Adams and Infield 2003, Tynela *et al.* 2000). Recent research and policy developments now work to incorporate the importance of market-values into restoration activities, in order to facilitate countries and communities to protect and restore with immediate economic benefits (TEEB 2010, Alexander *et al.* 2011).

2.8 <u>The problems facing ecological restoration</u>

With ER recent dramatic increase in application, and its complex interdisciplinary nature, this practice faces several challenges that must be addressed.

2.8.1 Gaps in the knowledge

ER in developed countries serves to restore ‘wild landscapes’ - a retreat from busy life, a recreational area, an area to recover a ‘natural ecosystem’ (Gobster 2001). However, in developing countries, rural communities are often still dependent upon natural resources, and ER must meet the livelihood needs of the community (Mertz *et al.* 2005, Rodrigues *et al.* 2011). Little has been written on ER as a means to serve the greater needs of poorer countries, and the potential opportunities it creates, yet at the same time international politics and activities move ahead on this (Clewell and Aronson 2006) and large-scale rehabilitation programs, such as those under REDD+, have been introduced often without the necessary social-science knowledge to support the activities (van Noordwijk *et al.* 2008, Wright 2011, Alexander *et al.* 2011).

2.8.2 Site individuality versus landscape-management

A crucial concern facing RE is the transferability of knowledge gained at any particular site. Each site is unique and has an individual history; the ecological, social, historical and institutional barriers obstructing recovery at one site can rarely be extrapolated to other sites, even those of near proximity or which share the same natural history (Curran *et al.* 2012, Holl *et al.* 2000, van Andel and Aronson 2012b). This opens the debate as to the use of ER: can we physically develop an appropriate restoration plan for each degraded area across the globe? Should RE support 'mega-projects' that are technically adept, applying scientific knowledge but which lack the opportunity for community engagement and participation (Higgs 2005)? There is no easy answer. However, guidelines and approaches can be developed, which still allow for site individuality but provide a pathway to more efficient landscape-scale site restoration (Manning *et al.* 2006, Tongway and Ludwig 2011, 2012, Aronson and Le Floc'h 1996).

2.8.3 The 'socio-ecological gap'

RE necessarily encompasses numerous sciences (social, political, biological, physical), as described in the preceeding sections (van Andel and Aronson 2012a). However, RE sometimes focuses efforts on the ecological, biological and physical aspects, neglecting the human components (Higgs 2005, Shackleford *et al.* 2013). As a consequence, the restoration plans, or the social constructions of nature as McManus (2006) calls them, can be heavily influenced by biological and environmental values, and lose their understanding of the local community's needs, expectations and interpretations of nature (Willams and Mawdsley 2006, Hickey and Mohon 2004, Tongway and Ludwig 2011), which can lead to disharmony. Those with rights to the land, i.e. the landowners and indigenous people, end up with land that they do not relate to, and which they neither want nor need (Palmer 2006). Studies without local participation have shown local people have created problems and obstacles during the restoration process due to a lack of agreement on the aims of the restoration (McManus 2006, Collier 2011). Furthermore, in restoring land to a form undesired by the local community, causes of degradation can re-emerge (Collier 2011). Restoration ecologists should develop and implement restoration action plans through a sound understanding of the local, social pressures and polities, to facilitate local participation and work towards not just land recovery, but a long-term coexistence that meets the needs of the people and the ecosystem (Higgs 2005, McManus 2006, Clewell and Aronson 2013, Tongway and Ludwig 2011).

Established methods of public participation in restoration projects are lacking and the gap between RE and other features of ER continues to exist (Higgs 2005). As restoration projects become ever more popular, it is essential that methods are established and projects developed based on the integration of social and ecological knowledge (Rodrigues *et al.* 2011, Tongway and Ludwig 2011, Clewell and Aronson 2013).

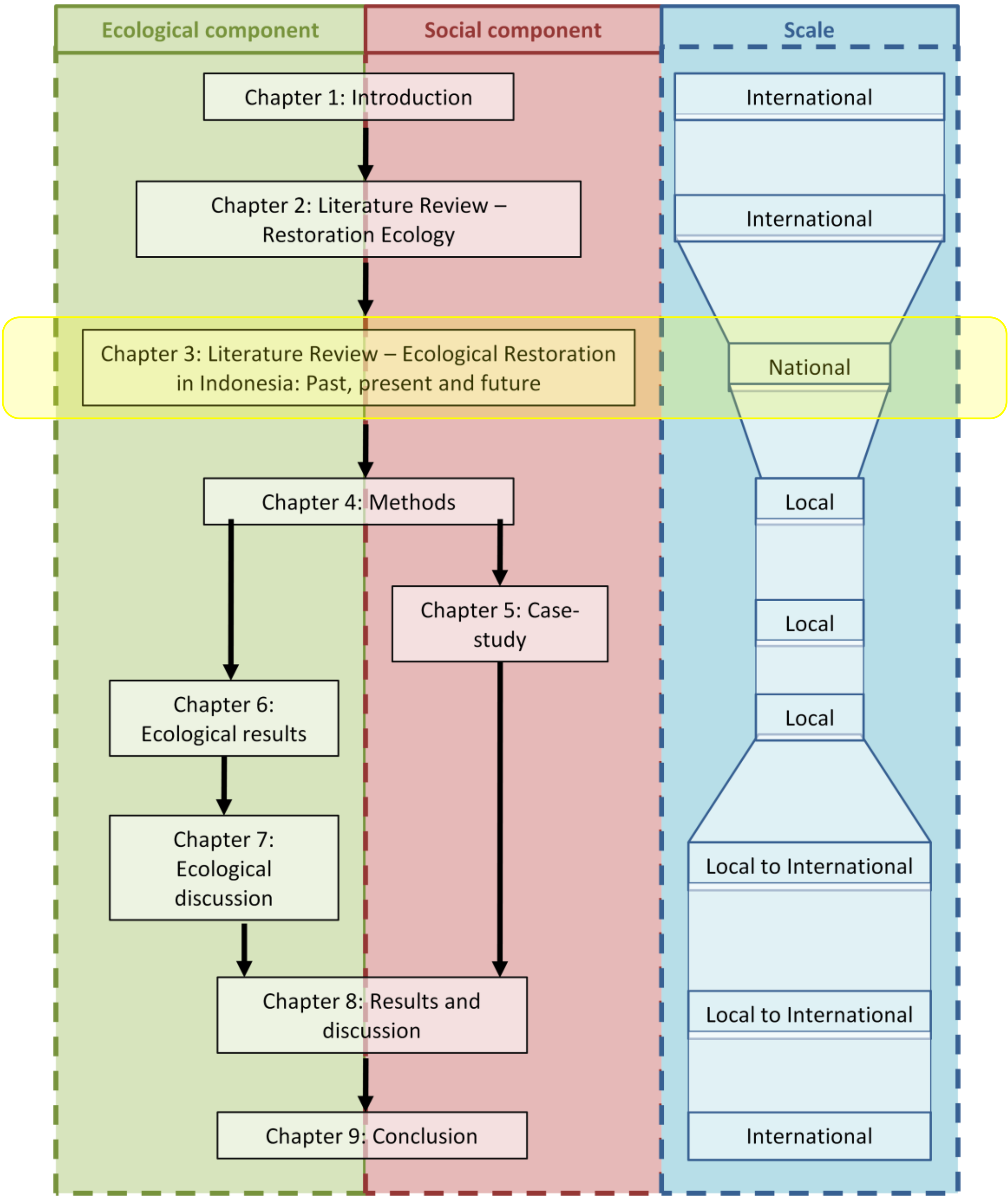
2.9 Conclusions

This chapter has given an overview of RE, particularly its ecological and social components. It also addressed the challenges currently facing this science; the gaps in the knowledge, the need to bridge the social and ecological disciplines and the issues of transferability of data and of scale. Whilst there was an emphasis on tropical regions, this chapter aimed to be non-specific in terms of region and ecotype. However, as described above, site-specificity is key to successful restoration. The next chapter, Chapter 3, addresses this, presenting the second literature review of this thesis, focusing on the region and ecosystem under study: Indonesia and tropical peat swamp forest. These two chapters combined then provide the necessary background to this study, and at the end of Chapter 3, the research objectives, based on the gaps in the literature and the challenges facing this science, this country and this ecosystem will be outlined.

3. Literature Review 2

Ecological restoration in Indonesia:

Past, present and future perspectives



3.1 <u>Introduction</u>

The practice of ER is specific to place. The ecology of the ecosystem to be restored must be known, but this is only one factor. The history of degradation can also increase ecological understanding and guide selection of appropriate restoration measures. Understanding the history of degradation also explains social, economic and political factors that are impacting upon the landscape, the stakeholders involved in the site, and their attitudes towards the area. Chapter 2 dealt with the science of RE, in its broad context, with an emphasis on tropical conditions. This chapter now provides the context for the location chosen for this study; a degraded area of tropical peat swamp forest (TPSF) in Central Kalimantan, Indonesia. This chapter will detail the geographical information about the country and the ecosystem, including TPSF ecological conditions, the social history of the country, particularly the political regime (the New Order) that impacted most heavily on Indonesia's development, social situation and environment, including TPSF. It explores the current state of Indonesia's TPSF, and the challenges TPSF faces. Finally, the chapter will discuss the current political and social climate, with reference to ecological restoration in general, and specifically restoration of TPSF.

3.2 <u>Indonesia: the land mass</u>

Indonesia consists of 17,508 islands. The largest islands are Java, Sumatra, Borneo (shared with Brunei and Malaysia), New Guinea (shared with Papua New Guinea), and Sulawesi. Lying along the equator, Indonesia has a tropical climate, with two distinct wet and dry seasons.

Indonesia supports 6% of the world's tropical forest (FAO 1993). The country hosts over 2,800 known species of amphibians, birds, mammals, fish and reptiles, of which 47% are endemic, and supports 25,000 species of vascular plants, of which 60% are endemic (Conservation International 2006), giving it the world's second highest level of biodiversity after Brazil (Brown 1997).

For thousands of years, Indonesia's land has been used and managed by its local communities (Taylor 2003): In West Kalimantan, traditional farmers practice diverse farming systems, creating rice swiddens, forest gardens (in which fruit trees are cultivated within bio-diverse habitats) and rubber gardens (equivalent to forest gardens, but where rubber trees are cultivated) (Potter and Lee 1998). In the Aceh region of Sumatra, pepper and nutmeg are produced locally, along with other cash-crops, cultivated as forest-gardens (McCarthy 2005). In the mangrove swamps of Sulawesi, the natural resources are used for local fishing and harvesting (Armitage 2002). These methods of land practice date back thousands of years, and on the local-scale have been sustainable forms of livelihood for the communities (Taylor 2003, Tsing 2005, Peluso 2009).

In order to control and oversee the land-management and land-rights for each area, and, given the spatial separation of each community, land control and management was overseen for each local community ('*seuneubok'*) by a locally elected 'head of the community' (*'ketua seuneubok*'). The ketua seuneubok would oversee the laws and rules for their specific seuneubok, based on *Adat* laws (McCarthy 2005). Whilst *adat* laws were not police enforced or uniform across regions, they reflected culturally-appropriate forms of control, and were enforced through a sense of obligation and respect (McCarthy 2005). These laws allowed people to claim areas of land, and these claims were recognized and respected within the region, despite the land not being in continual use (Potter and Lee 1998).

3.3 Indonesia's tropical peat swamp forest

Tropical peat swamp forest (TPSF) is the natural state in which tropical peatlands exists. Tropical peatlands are found in the Caribbean, South and Central America, Africa and mainland Asia, but the majority (56% by area) are in Southeast Asia, with 47% of the total area (206,950 km^2) occurring in Indonesia (Page *et al.* 2011). Peatlands are formed when the rate of input of organic material exceeds the rate of decomposition under waterlogged, anaerobic conditions. This leads to the accumulation of partially-decomposed organic matter, i.e. peat, which in the tropics can sometimes reach a thickness in excess of 15 m (Page *et al.* 2011). Tropical peatlands cover 0.3% of the Earth's land area, but owing to the thickness of many deposits, they contain a large carbon store of 82-92 Gt (Page *et al.* 2011), equivalent to 3.5% of the global vegetation and soil carbon pool (Amthor *et al.* 1998) and 15-19% of the global peatland carbon store (Gorham 1991, Immirzi and Maltby 1992).

Indonesia's peatlands are found mainly in Sumatra, Kalimantan and West Papua, where they form extensive domes in coastal and sub-coastal lowland locations, and the vast majority is ombrotrophic, i.e. rain-fed and thus very low in available plant nutrients. They contain a carbon store of 57 Gt, which comprises 74% of Indonesia's total forest soil carbon pool (Page *et al.* 2011). In addition to carbon storage, they also provide a range of other ES: support floral and faunal biodiversity, including several habitat endemics (Posa *et al.* 2011); stabilize hydrological and nutrient cycling systems (Wösten *et al.* 2006, 2008); and provide a means of livelihood for local communities (Sjarkowi 2002).

3.4 Indonesia: the country

Six-thousand of Indoensia’s islands are populated, with over 700 languages spoken across them. Indonesian is the national language. The population numbers approximately 240 million, split across numerous ethnic groups, including Javanese, Batak, Dayak and Madurese. Indonesia is the world's most populous Muslim-majority nation, although it also recognizes Protestant, Roman Catholic, Hindu, Buddhist and Confucianism faiths. Indonesia has a democratic government, and is developing strong trade relations both within Asia and the West. The central government resides in Jakarta, but the country is divided into provinces and regencies, which are then further divided into districts. Each of Indonesia’s 33 provinces has its own political legislature and governor.

3.5 The Dutch colonisation

Indonesia’s history has been marked by occupancies and colonizations, including India, Holland, Britain, Japan and Portugal, all eager to acquire the wealth Indonesia’s export of spices, metals and rubber could provide (Tsing 2005). The longest occupancy was by the Dutch, beginning during the 17th century, driven by their desire to monopolise the spice market (Ricklefs 2008). Until 1800, the colonial occupancy mainly rested in Java (Taylor 2003). In the 1860’s, the Dutch expanded into non-Javan Indonesia, in response to British colonists establishing themselves in some of Indonesia’s more eastern islands (de Jong 1997). This period of Dutch colonial rule continued from 1870-1940, with only superficial control exerted on Indonesia’s ‘outer islands’ to ensure occupancy (Ricklefs 2008). The eastern islands offered less by way of spice cash crops, being richer in timber and rubber, which were less profitable at that time. Indeed, in many of the outer islands, the legacy of Dutch presence is negligible, with customary *adat* laws, overseen by *seuneubok ketua* continuing instead (McCarthy 2005).

3.6 The New Order (1966-1998)

3.6.1 Creation of an authoritarian regime

In 1942 the Japanese occupied Indonesia, over-throwing the Dutch colonists (de Jong 1997). From 1942 to 1945 their control was severe, resulting in the Indonesian independence movement (Ricklefs 2008). During the National Revolution Sukarno declared Indonesia's independence in 1945 (de Jong 1997). There then followed five-years of armed and diplomatic struggle with the Dutch, before they recognized Indonesia's independence in 1949, after much international pressure (Taylor 2003).

Sukarno governed Indonesia from 1945-1965, in a democracy that leaned towards authoritarianism. In 1965, in a coup d'etat, Sukarno was ousted from power by General Suharto, the head of the military (Ricklefs 2008). In 1968 Suharto was officially declared President, and he ensured that uprisings from leftist-Communist factions were strongly oppressed (de Jong 1997). He increased the status and power of the army, giving them superior control over any civilian officers (de Jong 1997). This new administration, the New Order, a hierarchical, authoritarian regime, was to bring three decades of economic growth to Indonesia but was also strongly associated with corruption and political suppression (Tsing 2005).

3.6.2 Principles of the New Order for land-use and economic growth

During Suharto's leadership, every attempt was made to boost Indonesia's position within the world market, through the rapid and large-scale export of many of its natural resources, including gas, gold, timber, spices and rubber (Potter and Lee 1998, Furniss 2006). Suharto declared all forested land under the control of the state, and divided land into three main categories under the Forest Use by Concensus Act: nearly a third of Indonesia's land (49.2 million hectares, MHa) was classified as protected land (not to be used in resource extraction or agriculture), 64.4MHa was classified as Production Forest; forest which could be clear-fell logged, or selectively logged. Finally, 30.5Mha was classified as Conversion Forest, which could be used for agriculture, etc. Under these headings, vast areas of forest were perceived as 'idle' until they were put to some form of economic and social use; plantation, agriculture, etc. (Muhamed and Rieley 2001, McCarthy 2000).

3.6.3 Impacts of the New Order on the land

Changes to recognized land-ownership and land-use

During the reign of the New Order, the Forest Use by Consensus Act enabled huge areas of land to be 'given over' by the local communities to government through pressure, intimidation, lack of rights and confused legislature. It was then exploited for its commercial resource potential (Potter and Lee 1998, O'Connor 2004, Tsing 2005, Peluso 2012). Furthermore, the government implemented state-led authority in the rural regions (Tsing 2005, Peluso 2009). The *seuneubok ketua* were replaced by *kepala desa*, government-instated official village heads (McCarthy 2000, 2005). Logging and extraction privileges were awarded to timber and plantation companies (oil-palm, pepper and paper). At the start of the New Order (late-60's) Production Forest covered 80% of Indonesia's forests, and numerous indigenous communities lost their forest and livelihoods (O'Connor 2004, McCarthy 2000, Tsing 2004).

‘Population redistribution’ was established, first by the Dutch, and continued under Suharto’s control (Fearnside 1997). Now commonly known as the Transmigration Program, it has moved hundreds of thousands of people from over-populated cities, often in Java, to areas with relatively low population density, for example, Sumatra and Kalimantan (Hardjono 1989). The government distributed land to the migrants with little regard for *adat* land laws. The migrants were given subsidies and funding to establish themselves on the land, whilst none were given to their adjacent indigenous neighbours. The Transmigration Program goal was claimed to be ‘integration and unification’, however it instead led to issues of marginalisation, notions of Javanese imperialism, and increased land pressures and poverty levels in areas which did not have the resources or infrastructure to support the increased population (O’Connor 2004, Potter and Lee 1998).

The Mega Rice Project (MRP) began in 1995 and aimed to convert more land into paddy fields, to make Indonesia self-sufficient in its rice needs. To do this, 1 MHa of Central Kalimantan, much of which was TPSF, were designated as land to be drained, through the construction of canals, channeling water into the rivers to flood areas downstream to make them suitable for rice production. The drainage of the peat led to excess drying, and in 1997, exacerbated by an extended dry season driven by an ENSO (El Niño Southern Oscillation) event, extensive wildfires spread through the area, affecting 1.45 million hectares (Page *et al.* 2002). By 1999, the MRP was officially abandoned, however by this time, all the canal excavations had occurred, and 15,000 migrants had been brought from over-populated areas in Indonesia to work the land that was now unable to support them (Muhamed and Rieley 2001).

3.6.4 End of the New Order

Support for Suharto and the New Order began to wane in the 1990s, with greater demands for democracy from within Indonesia's political parties. The New Order's authoritarianism and human rights abuses led to national and international criticism. These factors culminated in the Indonesian Revolution of 1998 and the resignation of Suharto as president (Ricklefs 2008).

3.7 Indonesia’s current state

3.7.1 The new government

After the fall of the New Order, priorities were made for democratic reform, removal of corruption, media freedom, and reduction of poverty and unemployment (Ricklefs 2008). The following 15 years saw four presidents and gradual progression in these goals (Table 3.1).

Table 3.1: Overview of presidents in Indonesia since the fall of the New Order to present, and their main activities.

Period	**President**	**Election proceedure**	**Activities**
1998-1999	Habibie	Previously, vice-president, appointed by Suharto	Released the limit on the number of recognized political parties (increased from 3 to 48), developed the decentralisation process (shifting power to the provinces), worked to liberate the press (all under much international pressure)
1999-2001	Wahid	Appointed by elected representatives	Formed a cabinet from numerous different parties, pushed for democratic freedom, worked towards media freedom, reduction of corruption and military control
2001-2004	Megawati (daughter of Sukarno)	Elected	Democratic reform became a reality and the economy saw further improvement, however issues of corruption, poverty and unemployment still dominated
2004-2009	Susilo Bambang Yudhoyono (SBY)	First democratic election	Increased economic growth, reduced poverty, increased welfare support, continued to challenge corruption, empowered the decentralisation process, led developing countries in becoming engaged in the climate-change debate - Indonesia hosted the United Nations Framework Convention on Climate Change (UNFCCC) meeting in Bali, 2007.
2009-present	SBY	Democratically re-elected	

(Ricklefs 2008, Taylor 2003, Barton 2002, Schütte 2012, DNPI 2010)

Through the process of decentralisation, power and authority shifted. Each province elects their own Governor. The Governor and their party, which can differ from the President’s party, oversee much of the poltics and law of the province. In some cases this has led to a greater voice for the communities (Engel and Palmer 2006, McCartly 2005), whilst in other cases it has led to greater freedom for the local governments, where corruption is still rife, leading to increased land-exploitation (O’Connor 2004, Tsing 2005).

3.7.2 Addressing land-ownership and management

The liberation of the press and the instigation of democracy have meant that the government is now much more accountable for its actions regarding land-use, and fairness and equity to the local communities (Engel and Palmer 2006). In some cases, *adat* law regarding land-ownership and management have been successfully reinstated (McCarthy 2005, Peluso 2012), and communities can have a stronger voice in controlling how their land is used (Engel and Palmer 2006, Mertz *et al.* 2005). However, perhaps more commonly, a confused, ill-defined legal framework has allowed the decentralized governments to appear to protect forest whilst continuing to clear vast areas of land (O'Connor 2004, Mertz *et al.* 2005, Sikor and Lund 2009). Large-scale business in illegal logging remains unchecked (Jepson *et al.* 2001), and communities remain disempowered to bring about the control they desire (Engel and Palmer 2006, Timmer 2010, Peluso 2009).

3.7.3 Current state of Indonesia's land: focus on tropical peat swamp forest

Poverty and employment remain high in Indonesia, and the priorities are still the improvement of welfare and the economy (Ricklefs 2008). In light of this, land exploitation, although to some extent more transparently and equitably governed, still continues (Tsing 2005, Mertz *et al.* 2005). In the last thirty years, Indonesia has lost 40 MHa of its forest, equaling 30% of the total area, and projections for potential oil palm plantation increases range from 1-28 MHa (Wicke *et al.* 2011), with annual deforestation rates ranging between 1-2.2% (Miettinen *et al.* 2011).

TPSF has been logged for timber, or drained and converted to palm oil and pulpwood plantations or used for other agricultural projects, for example, the failed Mega Rice Project (Muhamad and Rieley 2001, Furniss 2006, Potter and Lee 1998). Between

1985 and 2006 about 47% (121,000 km^2) of SE Asia's TPSF became degraded through logging, drainage and/or fire (Hooijer *et al.* 2006, 2010) and at the current time only 4% of the TPSF in Sumatra and Kalimantan is still in a pristine condition (Mietinnen and Liew 2010). In TPSF, the forest vegetation and the peat are strongly inter-dependent (Page *et al.* 1999). Logging and drainage cause direct changes to forest structure and composition (van Eijk *et al.* 2009); but also enhances aerobic decomposition of the peat and increases the risk of wildfire. Fires combust both the aboveground biomass and also, where the peat is sufficiently de-watered, the surface peat to depths of 30 – 50 cm (Page *et al.* 2002, Ballhorn *et al.* 2009). Drainage increases the risk of dry season drought, whilst surface subsidence can increase the risk of semi-permanent (wet season) or permanent flooding (Page *et al.* 2009).

The net result of TPSF degradation is that species-diverse forest is replaced by a variety of less biodiverse secondary communities. Following low levels of disturbance, forest re-growth will occur, but following more severe and/or regular disturbance, the re-establishment of woody species is retarded, whilst at extreme levels of degradation (severity and frequency), woody vegetation is indefinitely replaced by sedges and ferns (Hoscilo *et al.* 2011). In addition to a reduction in biodiversity, TPSF degradation also leads to the loss of most, if not all, ES, including carbon storage and hydrological regulation (Page *et al.* 2009). Hooijer *et al.* (2006, 2010) estimated that the CO_2 emissions arising from peat oxidation in drained peatlands in Southeast Asia are in the range 355 – 874 Mt CO_2 yr^{-1}. At least one-third of these emissions are associated with degraded TPSF. Additional emissions of a similar magnitude are associated with wildfires, with degraded TPSF, particularly in Indonesia, identified as the foremost source (Langner *et al.* 2007, Langner and Siegert 2009, Page *et al.* 2002).

3.8 Restoration for Indonesia's degraded land?

Given the current state of Indonesia's land, its rapidly evolving government, and the government's desire both to empower local people to reclaim their land rights and livelihoods and enter into the carbon market, there has recently developed much potential for restoration of Indonesia's forests.

3.8.1 New social and environmental climate

In recent years forest restoration has gained much global attention, particularly in relation to recapturing ES and addressing climate-change (Alexander *et al.* 2011, van Andel and Aronson 2012a). With Indonesia's high rates of land exploitation in the last 50 years, and the advent of a new democratic government focusing on both developing economically and addressing climate change, a new arena has opened up for land restoration. As a result of excessive land exploitation, communities who have relied on natural resource management and services for their livelihoods have found their way of life threatened (Armitage 2002, Tynela *et al.* 2002, Moeliono *et al.* 2012). With the new democratic government, communities are finding a stronger voice to reclaim land-rights and land-use (Mertz *et al.* 2005, Engel and Palmer 2006, Moeliono *et al.* 2012). As many of these traditional livelihoods followed more sustainable land-practices, with diverse crops and cultivation of forest gardens (Tynela *et al.* 2002, Tsing 2005, Mertz *et al.* 2005), this opens opportunities for restoration and rehabilitation to feature as part of their land reclamation (van Noordwijk *et al.* 2008). Furthermore, the loss to Indonesia's ES is being felt at the local, national and international scale, leading to pressure and support of numerous stake holders and investors in seeing these services restored (Spracken *et al.* 2008, van Noordwijk *et al.* 2008).

3.8.2 Availability of new funds: the carbon-market

In order for ER to proceed successfully, it needs the support and involvement of numerous stakeholders, from local communities to national government, but also, funding to support the activities (Aide *et al.* 2000). Reducing greenhouse gas emissions from deforestation and degradation (REDD+) has become an important part of the negotiations under the United Nations Framework Convention on Climate Change (UNFCCC). REDD+ is a mechanism to provide positive incentives to promote protection and restoration of tropical forests. With respect to SE Asian forests and, in particular, those in Indonesia, initiatives to reduce greenhouse gas emissions have been given added impetus by recent studies showing that ecosystem restoration could be one of the most cost-efficient measures for reducing peatland CO_2 emissions (Spracken *et al.* 2008, van Noordwijk *et al.* 2008). In response to this, the Indonesian Government is now collaborating internationally to initiate large-scale restoration programmes on Indonesia's degraded lands (van Noordwick *et al.* 2008, KFCP 2009). Alongside these government initiatives, some NGOs are developing similar programmes, whilst further opportunities are being provided by the fast-growing carbon trading market for privately-funded initiatives. Work has already been published describing the important potential link between REDD+, funding opportunities and ER (Alexander *et al.* 2011, Sasaki *et al.* 2011), and has mentioned the potential for countries such as Indonesia to be involved.

3.9 Restoration for Indonesia's tropical peat swamp forest?

Due to the large amount of carbon that could be potentially saved, one key area of interest in Indonesia is initiating peatland restoration/rehabilitation (Spracken *et al.* 2008). The largest REDD+ demonstration project to date, the Kalimantan Forest and

Climate Partnership (KFCP), within the Indonesia Australia Forest and Carbon Partnership (IAFCP), is already underway in Central Kalimantan, Indonesia, tackling an area of 120,000 Ha of degraded peatland within the former MRP area, with at least Aus$30 million invested in the activities (KFCP 2009).

3.9.1 Challenges and barriers to be overcome

Limited scientific knowledge of TPSF ecosystem dynamics and post-disturbance forest regeneration has only become available relatively recently and, at present, little of that knowledge has been applied to ecosystem restoration (Page *et al.* 2009, Giesen 2004, van Eijk *et al.* 2009, Ismail and Shamsudin 2003). Often TPSF degradation is linked to logging and drainage, leading to flooding in the wet season and fires in the dry season. Thus, hydrological rehabilitation and fire management have been targeted as the primary TPSF restoration tools. Whilst some progress has been made, there remain many challenges to overcome these two barriers (Page *et al.* 2009). Furthermore, even if fire prevention and hydrological recovery are achieved, this still does not guarantee TPSF recovery, as a suite of forest regeneration barriers then come into play, such as limited seed dispersal and nutrient availability, invasive species competition, etc. (as described in Chapter 2). Finally, an ecosystem cannot be restored without the support and involvement of its respective stakeholders. As described above, Indonesia's recent history is rife with issues of land-ownership, land-use, and tensions between local communities and the government. The likely barriers facing TPSF restoration based on current available literature are described below.

Disrupted hydrology

Disrupted hydrology has the potential to become a regeneration barrier in some degraded ecosystems, as observed by Nepstad *et al.* (1996), but it is not a common. For disturbed wetland ecosystems, especially degraded TPSF, however, a disrupted hydrology is perhaps the most frequent and problematic regeneration barrier.

Tropical peatlands are entirely dependent on their high water levels (Chimner and Ewel 2005, Wösten *et al.* 2008); the peat being submerged for up to 9 months of the year with only the upper peat surface; to a depth of 40 cm, exposed to aerobic conditions during the dry season (Page and Rieley 2005). However, nearly all peatland uses require drainage (Page and Rieley 2005): e.g. canals to remove logged timber, and to support the growth of nearly all crops (Wösten and Ritzema 2002). Construction of canals results in exposure of a greater depth of the upper peat to air, resulting in enhanced rates of aerobic decomposition (Hooijer *et al.* 2010). This reduction in year-round water level, coupled with the increased risk of flooding in the wet season (due to peat subsidence) and fire in the dry season (due to the loss of water storage facility) (Page and Rieley 2005) leads to a change in species composition; towards invasive sedges and ferns (Wösten *et al.* 2006, van Eijk *et al.* 2009).

Fire

The other main barrier facing TPSF restoration is fire (Page *et al.* 2009). Forest fires between 1997 and 2003 led to a 28% forest-cover loss in the former MRP (449,000ha) (Page *et al.* 2009). Only 12% of Kalimantan's peatlands remain covered by pristine TPSF (or show only slight signs of degradation), the rest of the TPSF in this region show signs of degradation, disturbance, cultivation and drainage (Miettinen and Liew 2010), leaving them susceptible to fire (Hoscilo *et al.* 2011). Fires on TPSF are triggered by land-use change, especially linked with peat drainage. Fires lead to further forest loss (Hoscilo *et al.* 2011), further complications of flooding (Wösten *et al.* 2006), human health problems due to smoke inhalation (Harrison *et al.* 2009) and the release of carbon (Page *et al.* 2002) and associated climate change (Hooijer *et al.* 2006). For TPSF restoration to be successful, and for carbon loss from the system to be reduced, fire management and prevention is essential.

Lack of ecological knowledge

Whilst initial restoration efforts have focused primarily on hydrological rehabilitation and fire prevention, restoration of a closed forest canopy is also necessary as it will ameliorate the microclimate and stabilize the peat surface, reduce the risk of fire and thus contribute to the protection of the remaining peat carbon stocks, as well as restoring the capacity for biodiversity support (Page *et al.* 2009).

In forest restoration projects globally, there is a tendency to focus on 'tree planting' (Florentine and Westbrooke 2004, FORRU 2008, Corlett 2009). This activity can, however, be extremely expensive (Corlett 2009, Lamb *et al.* 2005) and without researched ecological, forestry and silvicultural practices, seedlings may be planted, only to subsequently die (Florentine and Westbrooke 2004, Holl *et al.* 2000). Degraded TPSF is no exception and, whilst several thousand hectares of deforested peatland have already been planted, there is little information on the silviculture or success rates of the methods used, although it is known that in some reforestation projects, few seedlings have survived (Giesen 2004, van Eijk *et al.* 2009, Ismail and Shamsudin 2003). Alternative methods such as regeneration barrier alleviation (Holl *et al.* 2000, Aide *et al.* 2000), seed sowing (Florentine and Westbrooke 2004) and assisted natural regeneration (FORRU

2008) can also be used, but again, the ecological knowledge to support these activities in degraded TPSF is lacking (Page *et al.* 2009).

Seed dispersal

In the forests of Kalimantan bats, rodents, gibbons, orangutans and other primates, pigs and deer play a role in animal-dispersal of tree seeds (Corlett 1998, 2009). Webb and Peart (2001) found that over 60% of tree species in a mixed dipterocarp forest, in West Kalimantan, were dispersed rather than falling to the ground and remaining in situ. There are no published studies to date on the effect of disturbance and degradation on seed-dispersal in TPSF, however it has been suggested as an important barrier in this ecosystem (Page *et al.* 2009). In addition, Giesen (2004) observed that in degraded peatland areas of Berbak National Park (Jambi, Sumatra) the tree flora was dominated by wind-borne species, while Tomita *et al.* (2000) made a similar observation in degraded TPSF in Thailand. In a study of seed-dispersal by birds using artificial bird perches, Graham and Page (2011) showed that most bird seed-dispersers present in degraded TPSF areas only dispersed seeds of tree species already present in that zone, with very low seed dispersal from species growing in the adjacent forest. These findings suggest that, similar to many other degraded tropical forest ecosystems, degraded TPSF may experience low levels of tree regeneration through a lack of seed dispersal.

Seed banks

To date there are no published studies of the soil seed bank in TPSF under natural conditions. One study considered the soil seed bank in a fire-degraded peatland area in Central Kalimantan and found only one wind-dispersed species emerging post-fire. It was assumed that fire had destroyed the seed bank (Simbolon *et al.* 2003). Other authors have also commented that disturbance probably leads to the loss of the TPSF seed bank (Page and Rieley 2005, Giesen 2004). Some caution needs to be applied in this interpretation, however, as it is widely accepted that in wetter environments, such as tropical rain forests, there is a strong tendency for short seed dormancy and, consequently, for the soil seed bank to be small. Under these situations, seed dispersal becomes the most important mode for seedling recruitment (Janzen and Vázquez-Yanes 1991, Corlett 2009, Bakker *et al.* 1996).

Nutrient availability

Peatlands develop when there is an imbalance between organic matter production and organic matter decay (Brady 1997). Ombrogenous peatlands (i.e. peatlands which have developed only under the influence of rainfall) are highly acidic and low in nutrients, thus efficient nutrient cycling is crucial in order to maintain forest productivity (Sulistiyanto 2004). Peat soils can be classified according to their percentage organic matter (OM) content; those with greater than 66% OM are 'fibric' and have a higher nutrient availability, as compared to hemic peats with 33-66% OM and sapric peat with less than 33%. Decomposition, or 'humification' of the peat, as may occur under cultivation, leads to mineralization of the OM, releasing N and P in the process. As the forest vegetation is no longer there to absorb this nutrient flush, this release of nutrients is lost either into water ways or the lower peat levels (Page and Rieley 2005, Notohadiprawiro 1997).

Light intensity

There is little published information on light-tolerances of TPSF tree species, or the impact increased light levels (post-disturbance) have on seedling regeneration. Native TPSF tree species are adapted to low-light levels in the understorey, competing for light with their neighbours, and can utilize gaps to serve as regeneration foci. It is unlikely many species are adapted to cope with the extremely high light levels of cleared forest areas. Regeneration studies have, however, highlighted that several TPSF species can behave as pioneers indicating high-light tolerance (Lee 1979, Kessler 2000), such as *Tristaniopsis obovata*, *Combretocarpus rotundatus* and *Shorea balangeran.*

Competition with invasive vegetation

TPSF degraded through repeated fire and flooding quickly becomes dominated by ferns (species of *Stenochlaena*, *Lygodium*, *Polypodium* and *Pteris*) and sedges (*Cyperus* and *Scleria* spp.) (Page *et al.* 2009, Giesen 2004). This has been suggested as a regeneration barrier to tree seedling establishment and growth (Page *et al.* 2009) although there is little published work that has explored the impact of these invasive species on TPSF regeneration. A few studies have shown that the effect may be dependent on the tree species and the environment; Whitmore (1984) found some species did well under competition in degraded TPSF areas such as *Cratoxylon* sp. and *Litsea* sp. whilst slow growers such as *Shorea albida* did poorly. Ibrahim (1997) found that clearance of invasive species which reduced competition for sunlight and nutrients was required to encourage native TPSF species, and if this was not done fast-growing species such as *Macaranga* sp. would dominate. However, Nuyim (2000) showed that whilst weeding around transplanted seedlings in degraded tropical peatlands did improve stem diameter, stem biomass and branch biomass, it did not affect survival, height or crown width. Interestingly, *Melaleuca leucodendron*, a known woody invasive in other ecosystems, is the only *Melaleuca* native to Central Kalimantan (AFTree database 2013), and is actually used as a reforestation species in some restoration projects (Graham 2009).

Mycorrhizal availability

Tawaraya *et al.* (2003) established that in natural TPSF, 17 of a total of 23 tree species investigated hosted either vesicular arbuscular mycorrhizae (VAM) or ectomycorrhizae. Under nursery conditions, once the correct mycorrhizal species was established for a given host species, the symbiosis was shown to increase seedling biomass, height, leaf production and nutrient assimilation of various TPSF tree species (Turjaman *et al.* 2005, Turjaman *et al.* 2006, Turjaman *et al.* 2008). It is possible that degraded TPSF areas no longer support the right mycorrhizal composition to support transplanted seedlings, as shown in other degraded ecosystems (Fischer *et al.* 1994, Johnson and Wedin 1997, Picone 2000). A solution to this is that seedlings can be inoculated with their mycorrhizae during cultivation in seedling nurseries, so upon transplantation the mycorrhizae are already associated with the plant roots, and the plants can immediately accrue the benefits, allowing them to tolerate better the degraded conditions. One study has already explored this potential restoration tool, and showed there was some advantage (increased survival and growth rates) to transplanted *Shorea balangeran* seedlings in a degraded area of TPSF in Central Kalimantan (Turjaman *et al.* 2011). This study did not, however, examine the actual mycorrhizal colonization percentages once in the field, to better explain the effects, or monitor the effect on seedling nutrient content.

Land-ownership and land-use

Tropical peatlands were no different to the rest of Indonesia with regard to local communities claiming land-rights and cultivating land under *adat* law (Page and Rieley 2005) which were then, in one form or another, relinquished to the government, and used for logging, transmigration and agriculture (Byron and Shepherd 1998). Who owns land and has the right to undertake or manage any restoration activities could be disputed and become an area of conflict. Added to this is Indonesia's confusing and contradictory land-ownership laws (O'Connor 2004), resulting in potential barrier to forest restoration.

Traditionally much of the TPSF along the banks of rivers has been cleared and cultivated by indigenous communities for rice and vegetables, with the surrounding resources being used for natural produce harvesting (Page and Rieley 2005, Smith 2002). This was succeeded by commercial, concession-based logging, removing a small number of commercially valuable timber species under selective-logging practices (Page and Rieley 2005). The land has also been exploited through intense (and unsuccessful) agricultural ventures, such as the MRP, resulting to peat drainage and burning (Muhammed and Rieley 2001), and illegal logging companies taking smaller trees across a greater range of species (Page and Rieley 2005, Casson and Obidzinski 2002). Communities grew up around these logging and agricultural ventures, which in addition to transmigration settlements, increased the pressure on the forest and land (Fearnside 1997, Page and Rieley 2005, Casson and Obidzinski 2002). These communities now often participate in these non-sustainable activities with few alternatives. These land uses must be addressed and alternative livelihoods provided if restoration is to become a feasible option.

Relationship of local communities with government and other external stakeholders

Whilst the last fifteen years have seen remarkable changes to the structure and accountability of Indonesian government, these were preceded by years of inequality and unaccountability (see above). Furthermore, whilst changes are being made, they are slow across such a large country with decentralization providing routes and opportunities for further confusion and unfairness (O'Connor 2004, Tsing 2005). Local communities have mixed and complex views towards their government, often relating to a history of confusion and mistrust (Tsing 2005, Timmer 2010). Restoration or any land-management practice requires the collaboration of local communities and the local, regional and national government, and these issues would need to be addressed.

Economics

Of the 234 million people living Indonesia, more than 32 million currently live below the poverty line, and approximately half of all households remain clustered around the national poverty line of $22 per month (World Bank 2013). Under the governance of the New Order, local community and individuals often lost land claimss, as described in 'Land-ownership and land-use' above. In a country still affected by corruption (Schulte 2012), and with the voices of the local community only recently being recognized (Engel and Palmer 2006, Moeliono *et al.* 2012), many people in rural communities struggle to find successful livelihoods (Tsing 2005, Timmer 2010).

TPSF has low productivity due to its low nutrient availability (Page and Rieley 2005). Consequently, peatland areas in Indonesia tend to support low density communities with few livelihood options (Fearnside 1997). In these less developed regions, the economies of these rural communities are often low, restricting their options and voices in engaging in land-use issues (Tsing 2005, Moeliono *et al.* 2012).

3.10 Research gaps

The previous two chapters aimed to review: the science of RE; its process – both social and ecological; the difficulties and barriers associated with restoration in regard to these two disciplines, especially in their interdisciplinary nature; a background to the country of study – Indonesia, its current government and policies, particularly in relation to land-use and TPSF restoration; and the challenges associated with this. In light of this review, the following research gaps have been highlighted:

A need for greater understanding of the regeneration barriers facing degraded TPSF, both the ecological and social aspects.

A need to better understand the most efficient and successful routes to over-come these regeneration barriers.

A need to explore methods for combining and linking social and ecological factors that influence a landscape in both its degradation and restoration.

A deeper understanding of the barriers facing TPSF restoration in the wider context of the current political, social and economic situation in Indonesia.

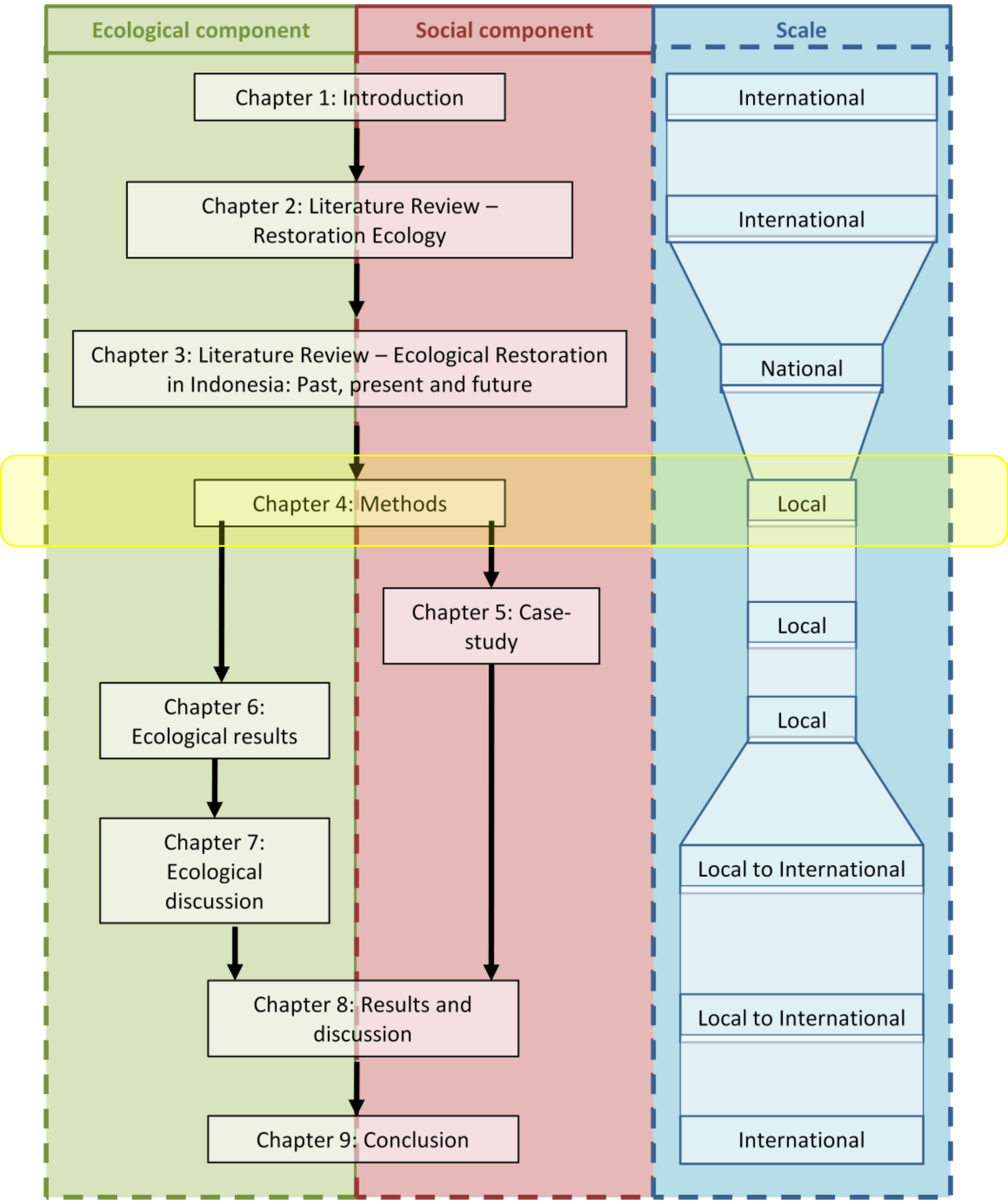
3.11 Research objectives

The research objectives for this study, based on the gaps in the research as described above and the previous chapter are:

- At a given degraded tropical peat swamp forest study site in Indonesia, identify and explore the active regeneration barriers (covering both the social and ecological aspects of RE) that are affecting the site's recovery.
- Explore routes as to how these regeneration barriers might be addressed or alleviated to facilitate restoration, specifically for this site and more generally for the TPSF ecosystem and for other ecosystems.
- During this process, explore methods as to how the socio-ecological gap facing RE might be addressed.

- Make observations and address the larger debate of how appropriate ER is with regard to Indonesia's TPSF.

4. Methods


Ecological component
Social component
Scale
Chapter 1: Introduction
Chapter 2: Literature Review – Restoration Ecology
Chapter 3: Literature Review – Ecological Restoration in Indonesia: Past, present and future
Chapter 4: Methods
Chapter 5: Case-study
Chapter 6: Ecological results
Chapter 7: Ecological discussion
Chapter 8: Results and discussion
Chapter 9: Conclusion
International
International
National
Local
Local
Local
Local to International
Local to International
International

4.1 Introduction

A research programme was designed to investigate the social and ecological barriers preventing forest regeneration in an area of degraded tropical peat swamp forest (TPSF), Central Kalimantan, Indonesia. The research setting offered an ideal environment since it was possible to investigate these two aspects at two study sites in close proximity. At the ecological study site the regeneration barriers that were preventing natural regeneration were assessed by comparing a degraded area of TPSF with the adjacent intact forest (April 2007 – March 2009). The neighboring village provided the community study site, where the social issues or barriers that were associated with the forest's regeneration were explored through working closely with the local community, using interviews and focus groups (Oct 2007 – March 2008, April 2009 – May 2009). This chapter describes the two study sites, with a detailed review of the forest types, and the methods employed to investigate the potential regeneration barriers. Finally, this chapter reviews the methods used in bridging the socio-ecological gap. Chapter 5 provides a more in-depth discussion of the community study site, the stake-holders and participants, to complement and provide context both for this chapter and the subsequent results and discussion chapters.

4.2 The ecological study site

The ecological study took place in the TPSF of the Natural Laboratory of Peat Swamp Forest (NLPSF) (02º18' S, 113º50' E, elevation a.s.l. 30 m), located within the Sabangau peatland, and is under the management of CIMTROP (see 5.2.2) in Central Kalimantan, Indonesia. The site is located within the northern part of the Sungai (River) Sabangau catchment and forms part of 5000 km^2 of TPSF located between the rivers Sabangau and Katingan (fig. 4.1). These forests were previously continuous and undisturbed but during recent years concessional logging, illegal logging and fires have resulted in large areas being degraded (Rieley and Page 2005). The climate is humid tropical, with a mean maximum temperature of 28.9ºC, a mean minimum temperature of 22.0ºC, and an annual rainfall of 2912 mm yr^{-1} (2003-2007 average), with a wet season from October/November through to May/June (Harrison 2009). The study site is approximately 15 km south-west of Palangka Raya, the largest city and regional capital of the province of Central Kalimantan. The surrounding land is populated with small villages mostly located along rivers and canals. These include Kereng Bangkirai; the closest village to the ecological study site, and the location of the community study (fig. 4.2) (Smith 2002, Rieley and Page 2005).

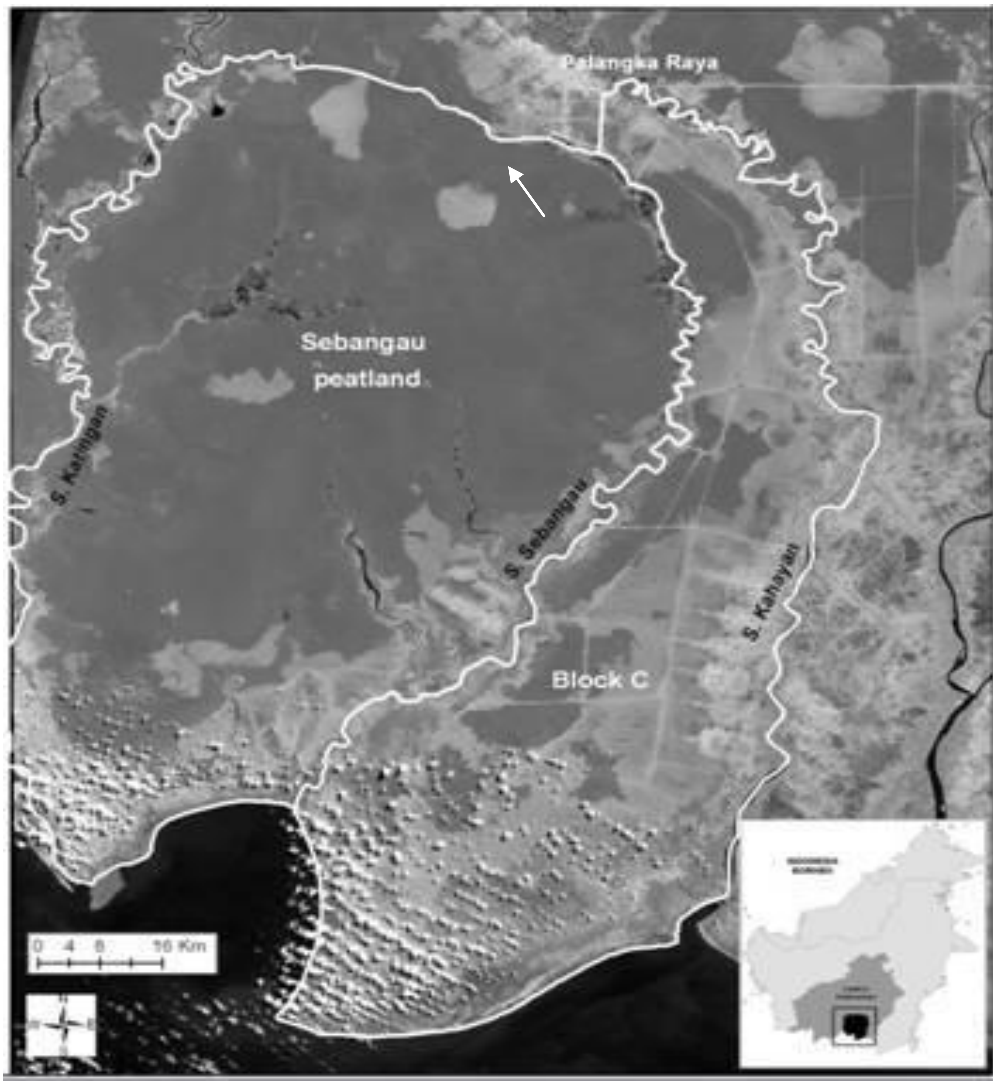


Figure 4.1: A map showing the study site area, insert) Central Kalimantan in relation to the island Borneo, large) the Sabangau peat dome; the NLPSF, depicted by a white arrow. Photo courtesy of Agata Hoscilo

The NLPSF covers an area of land adjacent to the River Sabangau, which encompasses degraded riverine forest and mixed peat swamp forest, and further onto the peat dome, low pole forest and tall pole forest communities occur. Between each of these forest types, there is a ‘transitional forest zone’, described as the transition between, and sharing the characteristics of, the two adjacent forest types, for example ‘mixed peat swamp forest – low pole transition zone’ (Page *et al.* 1999) (fig. 4.2). These forest types are distinguished by forest structure and species composition (Shepherd *et al.* 1997, Page *et al.* 1999).

At this location, the riverine forest is degraded, as is much of the ‘riverine – mixed peat swamp forest transition zone’. The mixed peat swamp forest (MPSF) and other forest communities remain relatively intact, although there has been some disturbance from logging activities. Due to the structure of the peat dome, natural water tracks have developed from the run-off of rain-water, and in the wet season the water table is so high, that water can flow freely over the peat surface (Page and Rieley 2005). This location also has man-made canals (1-2 m wide and deep), used during the time of illegal logging, cut in from the river to the forest. The ecological component of this study focused on the MPSF and the degraded forest zone; which covered parts of the MPSF and the riverine-MPSF transition zone (fig. 4.2).

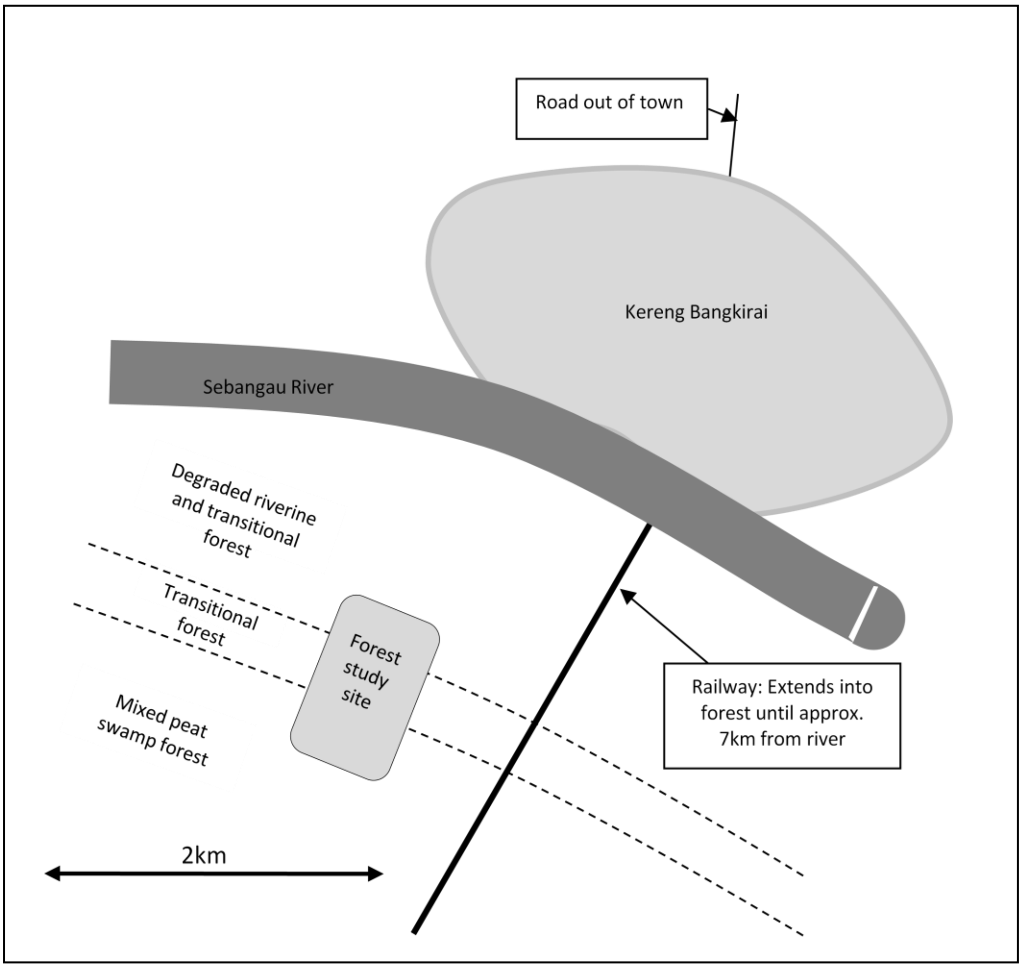


Figure 4.2: Map of the forest study site, river, access railway and Kereng Bangkirai.

4.2.1 Characterizing the forest zones

In order to determine if altered environmental conditions had resulted in the development of regeneration barriers (see 4.3.1), the environmental features or ‘potential regeneration barriers’ were assessed in the degraded site (‘Degraded Forest’ - DegF) and compared to inside the forest, where regeneration was operating naturally (‘Natural Forest’ - NF); this location may be considered as the reference site. To determine how far these barriers penetrated into the forest, three further forest zones (FZ) were studied; ‘Open-Canopy disturbed forest’ (OCDisF), ‘Forest Edge’ (FE) and ‘Closed-Canopy disturbed forest’ (CCDisF) (see Table 2.1). In each FZ 600 m transects were established, running parallel to the forest edge (fig. 4.3). Having assigned these FZ, data were collected in order to provide a full ecological description of each zone: Vegetation study plots were established in each FZ to provide plant species composition and tree density, basal area, biomass, average height and canopy cover. Litterfall traps were also established to provide litterfall biomass data. This work was done to provide a more detailed classification and description of each FZ as opposed to part of the subsequent investigation, hence these data are presented here as part of the research method rather than in the subsequent results chapter.

Within each FZ, four 20 x 20 m plots were established, with smaller 5 x 5 m and 2 x 2 m plots nested in the North-East corner of each large plot. In each 20 x 20 m plot every tree (DBH $\geq$5 cm) had height, diameter at breast height (DBH, at standard height of 1.3 m) and species recorded. In every 5 x 5 m plot the same attributes were recorded for tree saplings (5 cm $\geq$ DBH $\geq$1 cm), and in the 2.5 x 2.5 m plots the number and species of seedlings (DBH $\leq$1 cm) were recorded (Nascimento and Laurance 2002, also following Hoscilo 2009).

Eight litter fall traps were established at randomly selected points along each transect. These collected all falling litter, and trap contents were collected monthly for one year. The litter was separated into: leaves, fruits and flowers, small branches (diameter less than 2cm), large branches (diameter greater than 2cm, excluded in analysis; over a short period large branch weight can skew data), bark, and miscellaneous. These separate components were dried in a drying oven until constant dry weights were obtained. The canopy cover above each litter fall trap was measured using a densitometer.

For statistical analysis of these data see 4.3.5 Analysis.

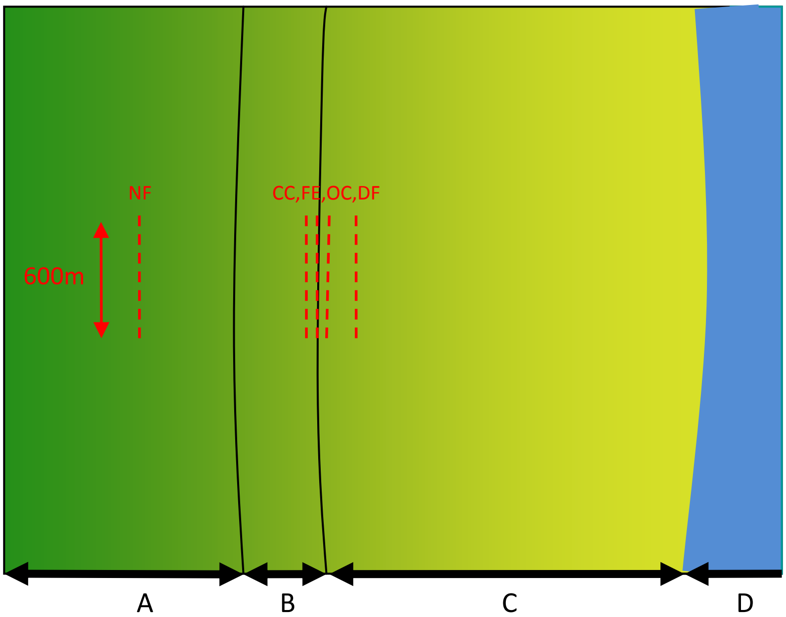


Figure 4.3: The forest study site. The area of sedge swamp (C) was previously riverine forest that had been extensively logged sometime prior to the study. The area of transitional forest (B) had probably receded further from the river (D) due to edge effect pressures. The study transects are shown as dashed lines; each 600 m long. Transects were positioned in the different FZ; 200 m outside of the forest (DegF), 50 m outside of the forest (OCDisF), at the forest edge (FE), 50 m inside the transitional forest (CCDisF), and 1 km within the undisturbed peat swamp forest (NF) (mixed peat swamp forest, A).

Table 4.1: Definitions of each FZ used in the ecological study, showing name, abbreviation and distance from forest edge (see also fig. 4.3).

Forest zone	**Abbreviation**	**Distance from forest edge**
Natural forest (or reference site)	NF	Approx. -1km
Closed-canopy disturbed forest	CCDisF	-50m
Forest edge	FE	0m
Open-canopy disturbed forest	OCDisF	+50m
Degraded forest	DegF	+200m

The average number of species of trees, saplings and seedlings recorded in the plots was calculated for each FZ (Table 4.2). Species number was highest for trees (47.3 species) and saplings (21.8 species) in the NF, and highest for seedlings in the CCDisF (14.8 species), these being the two least degraded FZ. The three most degraded FZ (FE, OCDisF and DegF) had progressively lower species numbers, in all cases significantly lower than the NF (apart from FE saplings).

Table 4.2: The average number and SD of tree, sapling and seedling species found in each FZ, and the corresponding p-values for these number of species as compared to the NF, n = 4.

		NF	**CCDisF**	**FE**	**OCDisF**	**DegF**
No. of tree species per plot (20 x 20 m)	**Average**	47.3	35	16	1.3	1
	SD	7.8	3.4	3.7	1.3	0
	p-value*	-	0.028*	<0.001**	0.029*	0.029*
No. of sapling species per plot (5 x 5 m)	**Average**	21.8	19	15	1.3	0.5
	SD	3.1	6.1	6.8	1.9	0.6
	p-value*	-	0.450	0.120	<0.001**	<0.001**
No. of seedling species per plot (2.5 x 2.5 m)	**Average**	7	14.8	12.8	1.5	1.5
	SD	2.9	9.1	3.3	1	0.6
	p-value*	-	0.343	0.041*	0.029*	0.029*

* as compared to NF

The dominant species in each FZ was calculated for trees, saplings and seedlings (Table 4.3). In the NF, CCDisF and FE, tree species dominance was highly variable; across the FZ and across seedlings, saplings and trees – with dominance of an individual species never exceeding 20%. It was only in the two most degraded FZ, OCDisF and DegF, that the same species dominated from seedling through to tree, with dominance reaching 70-100%. Dominant species in these zones include *Combretocarpus rotundatus, Syzygium* sp., and *Ploiarium alternifolium*.

Table 4.3: The five most dominant species found in each FZ, for trees, saplings and seedlings, and their percentage dominance. Some species could only be identified to genus, however, different species within these genera were recognized separately as morpho-species (using local names).

		NF		CC disturbed		FE		OCDisF		DegF	
		Species	**%**	**Species**	**%**	**Species**	**%**	**Species**	**%**	**Species**	**%**
Tree	1	*Neoscortechnia kingii*	6	*Licania splendens*	17	*Tristaniposis sp.* 'Blawan merah'	18	*Combretocarpus rotundatus*	73	*Combretocarpus rotundatus*	100
	2	*Shorea teysmanniana*	6	*Elaeocarpus mastersii*	8	*Calophyllum sp.* 'Mahadingan'	13	*Syzygium sp.* 'Hampuak'	3	-	
	3	*Blumeodendron tokbrai*	4	*Shorea balangeran*	5	*Syzygium sp.* 'Hampuak'	10	*Tristaniopsis sp.* 'Blawan'	3	-	
	4	*Calophyllum hosei*	4	*Combretocarpus rotundatus*	5	*Licania splendens*	10	-		-	
	5	*Palaquium leiocarpus*	4	*Syzygium sp.* 'Jambu'	4	*Garcinia sp.* 'Manggis'	8	-		-	
Sapling	1	*Gonystylus bancanus*	14	*Palaquium cochlearifolium*	10	*Ploiarium alternifolium*	20	*Ploiarium alternifolium*	31	*Ploiarium alternifolium*	25
	2	*Cephalomappa sp.* 'Kerandau merah'	8	*Ilex cymosa*	6	*Calophyllum sp.* 'Mahadingan'	16	*Calophyllum sp.* 'Mahadingan'	11	*Combretocarpus rotundatus*	25
	3	*Syzygium sp.* 'Jambu'	7	*Syzygium sp.* 'Jambu'	6	*Garcinia sp.* 'Mahalilis'	11	*Elaeocarpus acmocarpus*	7	-	
	4	*Tetractomia tetrandra*	5	*Tetractomia tetrandra*	5	*Ilex cymosa*	8	*Tristaniopsis sp.* 'Blawan'	1	-	
	5	*Syzygium havilandii*	3	*Elaeocarpus mastersii*	5	*Syzygium sp.* 'Hampuak'	6	-		-	
Seedling	1	*Pternandra* sp. 'Kamuning biasa'	11	*Syzygium sp.* 'Jambu'	16	*Syzygium sp.* 'Hampuak'	19	*Ploiarium alternifolium*	76	*Ploiarium alternifolium*	53
	2	*Antidesma phanerophleum*	11	*Ilex cymosa*	12	*Licania splendens*	12	*Elaeocarpus acmocarpus*	20	*Combretocarpus rotundatus*	47
	3	*Diospyros bantamensis*	11	*Syzygium sp.* 'Tampohot'	8	*Ilex cymosa*	10	*Calophyllum sp.* 'Mahadingan'	4	-	
	4	*Ardisia* sp. 'Kalanduyung himba'	10	*Tristaniopsis sp.* 'Blawan'	7	*Syzygium sp.* 'Tampohot'	9	-		-	
	5	*Syzygium sp.* 'Jambu'	9	*Calophyllum hosei*	6	*Syzygium sp.* 'Jambu burung kecil'	6	-		-	

Tree, sapling and seedling densities were calculated for each FZ (Table 4.4). Tree density was highest in the NF (2831.3 individuals ha^{-1}), and was similar in the CCDisF (2731.3 individuals ha^{-1}), but significantly lower in the FE (1500 individuals ha^{-1}), OCDisF (137.5 individuals ha^{-1}) and DegF (68.8 individuals ha^{-1}). Saplings and seedlings did not follow this pattern; instead the highest densities were found in the FE (18,300 individuals ha^{-1} saplings and 55,600 individuals ha^{-1} seedlings). Sapling individuals ha^{-1} in the FE were not significantly higher than in the NF (15,600 individuals ha$^{-1)}$, but seedlings, both CCDisF and FE had significantly higher densities than the NF (55,600 individuals ha^{-1} for FE and 45,200 individuals ha^{-1} for CCDisF compared to 15,600 individuals ha^{-1} for NF). Only in the DegF was seedling density significantly lower than in the NF (6000 individuals ha^{-1}). In the FE, higher densities of seedlings and saplings but lower densities of trees suggest that the disturbed forest is regenerating. A similar result was obtained for the CCDisF, but the higher tree density indicates a lower level of disturbance. In the DegF, the much lower tree, sapling and seedling densities suggest high levels of disturbance with little evidence of regeneration, whilst the OCDisF shows some evidence of regeneration with low tree and sapling numbers but comparable seedling numbers to the NF.

Table 4.4: The average densities and SD of trees, saplings and seedlings found in each FZ calculated per hectare, and the corresponding p-values for these densities as compared to the NF, n = 4.

	Measurement	NF	CCDisF	FE	OCDisF	DegF
Density of trees (individuals/ha)	**Average**	2831.3	2731.3	1500.0	137.5	68.8
	SD	457.1	208.5	273.9	131.5	42.7
	p-value*	-	0.704	0.002**	<0.001**	<0.001**
Density of saplings (individuals/ha)	**Average**	13000.0	14000.0	18300.0	3200.0	200.0
	SD	4761.0	4963.9	7514.4	4182.5	230.9
	p-value*	-	0.781	0.278	0.021*	0.002**
Density of seedlings (individuals/ha)	**Average**	15600.0	45200.0	55600.0	25200.0	6000.0
	SD	4953.1	28929.3	9454.5	18072.5	2400
	p-value*	-	0.057*	<0.001**	0.345	0.013*

* as compared to NF

Basal area of trees and saplings, and total basal area (trees plus saplings) was calculated for each FZ (Table 4.5). The basal area of trees decreased from the NF (35 m^2 ha^{-1}) to the DegF (0.4 m^2 ha^{-1}), with significantly lower basal areas for the FE, OCDisF and DegF. However, the sapling basal area per hectare increased from the NF (5.6 m^2 ha^{-1}) to FE (8.5 m^2 ha^{-1}), although not significantly, but then significantly reduced in the two most degraded FZ, OCDisF (0.9 m^2 ha^{-1}) and DegF (0.03 m^2 ha^{-1}). The total basal area followed the trend of the tree basal area with FE (21.0 m^2 ha^{-1}), OCDisF (2.6 m^2 ha^{-1}) and DegF (0.4 m^2 ha^{-1}) all having significantly lower total basal area per hectare than NF (40.7 m^2 ha^{-1}).

Table 4.5: The average basal areas and SD of trees, saplings and seedlings found in each FZ, and the corresponding p-values for these basal areas as compared to the NF, n = 4.

		NF	**CCDisF**	**FE**	**OCDisF**	**DegF**
Basal area of trees (m^2/ha)	**Average**	35.0	29.5	12.5	1.7	0.4
	SD	4.2	9.9	2.9	1.2	0.1
	p-value*	-	0.343	<0.001**	<0.001**	<0.001**
Basal area of saplings (m^2/ha)	**Average**	5.6	6.2	8.5	0.9	0.03
	SD	2.5	0.9	3.6	1.5	0.04
	p-value*	-	0.670	0.242	0.018*	0.004**
Total basal area (m^2/ha)	**Average**	40.7	35.7	21.0	2.6	0.4
	SD	4.3	9.1	3.1	0.6	0.2
	p-value*	-	0.365	<0.001**	0.029*	0.029*

* as compared to NF

The biomass of trees and saplings and total woody biomass (TWB; tree and sapling biomass combined) followed the same pattern as observed for basal area. Tree biomass decreased from the NF (161.9 t ha^{-1}) to the DegF (0.5 t ha^{-1}), with significantly lower biomasses for FE, OCDisF and DegF. Sapling biomass increased from NF (8.0 t ha^{-1}) to FE (10.7 t ha^{-1}), but not significantly, but then significantly decreased for OCDisF (0.6 t ha^{-1}) and DegF (0.00 t ha^{-1}). The TWB followed the same trend as the tree biomass with the FE (44.5 t ha^{-1}), OCDisF (2.7 t ha^{-1}) and DegF (0.5 t ha^{-1}) all having significantly lower biomass than the NF (169.9 t ha^{-1}) (Table 4.6).

Table 4.6: The average biomass and SD of trees, saplings and seedlings found in each FZ, and the corresponding p-values for these biomasses as compared to the NF, n = 4.

		NF	CCDisF	FE	OCDisF	DegF
Biomass of trees (t/ha)	**Average**	161.9	124.7	33.7	2.1	0.5
	SD	22.5	64.5	10.4	2.2	0.4
	p-value*	-	0.318	<0.001**	0.029*	0.029*
Biomass of saplings (t/ha)	**Average**	8.0	9.3	10.7	0.6	0.00
	SD	4.0	0.9	4.7	1.0	0.01
	p-value*	-	0.555	0.413	0.012*	0.008**
TWB (t/ha)	**Average**	169.9	134.0	44.5	2.7	0.5
	SD	22.2	64.0	6.8	1.7	0.4
	p-value*	-	0.331	<0.001**	<0.001**	<0.001**

* as compared to NF

The average tree height and canopy cover (CC) declined from the NF (height 13.33 m, CC 76%) to the DegF (height 5.14 m, CC 23%), with FE, OCDisF and DegF being significantly lower in height, and OCDisF and DegF having significantly lower CC (Table 4.7).

Table 4.7: The average tree canopy height and canopy cover (and SD) of trees, saplings and seedlings found in each FZ, and the corresponding p-values for the heights and canopy cover as compared to the NF, n = 4.

		NF	CCDisF	FE	OCDisF	DegF
Tree canopy height (m)	**Average**	13.33	12.64	9.66	7.71	5.14
	SD	0.42	0.96	0.22	1.94	2.87
	p-value*	-	0.238	<0.001**	0.057*	0.029*
Canopy cover (%)	**Average**	76	79	70	28	23
	SD	13	14	14	31	25
	p-value*	-	0.667	0.433	0.006**	0.001**

* as compared to NF

The average litter fall for non-reproductive litter (NRL - leaves, bark, and small branches) and reproductive litter (RL - fruits and flowers) for each FZ was calculated (Table 4.8). In the NF litter biomass was 5956.43 kg^{-1} ha^{-1} yr for NRL and 545.03 kg^{-1} ha^{-1} yr for RL, contrasting with the DegF, 223.21 kg^{-1} ha^{-1} yr for NRL and 8.74 kg^{-1} ha^{-1} yr for RL. The biomass of NRL was significantly lower in the OCDisF and the DegF compared to the NF, with the total combined litterfall weights following this pattern. RL was significantly lower in the FE, OCDisF and DegF zones compared to the NF.

Table 4.8: The average litterfall weights of NRL and RL and their combined totals (with SD) of trees, saplings and seedlings found during one year in each FZ, and the corresponding p-values for data as compared to the NF, n = 8.

		NF	**CCDisF**	**FE**	**OCDisF**	**DegF**
NRL (kg/ha/yr)	**Average**	5956.43	6340.04	7049.54	1099.23	223.21
	SD	1245.66	1595.46	2183.51	1563.72	554.16
	p-value*	-	0.600	0.239	<0.001**	<0.001**
RL (kg/ha/yr)	**Average**	545.03	436.60	150.00	15.59	8.74
	SD	405.75	356.14	154.40	17.28	17.83
	p-value*	-	0.579	0.065*	0.001**	<0.001**
Total litterfall (kg/ha/yr)	**Average**	6545.74	6847.91	7220.86	1125.39	234.89
	SD	1328.43	1626.93	2182.01	1598.63	570.77
	p-value*	-	0.690	0.467	<0.001**	<0.001**

* as compared to NF

Based on the above data it was possible to describe in more detail the vegetation characteristics of, and differences between, the five FZ (Table 4.9) This information confirms the presence of a gradient of increasing environmental degradation, as reflected in all recorded attributes, from the intact NF to the highly degraded zone beyond the forest edge.

Table 4.9: Summarizing the FZ's vegetation characteristic data.

FZ	Species diversity and composition	Forest dynamics	Forest structure	Productivity	Comment
NF	High number of tree and sapling species, fewer seedling species. Low species dominance with much variance	High tree density, moderate sapling density and low seedling density, with high basal area and biomass	High canopy height and canopy cover	High litterfall production	Normal forest
CCDisF	High number of tree, sapling and seedling species. Low species dominance with much variance	High tree density, moderate sapling density and high seedling density, with high basal area and biomass	High canopy height and canopy cover	High litterfall production	Similar to NF, but some disturbance
FE	Lower number of tree and sapling species, but high number of seedling species. Slightly higher species' dominance with lower variance	Lower tree density, high sapling density and very high seedling density, with lower basal area and biomass	High canopy cover, but reduced canopy height	High litterfall production	Disturbed and showing signs of high regeneration
OCDisF	Low number of tree, sapling and seedling species. Low species variance with high species dominance	Very low tree density, low sapling density and high seedling density, with very low basal area and biomass	Reduced canopy height and low canopy cover	Low litterfall production	Further disturbed but still showing some signs of regeneration
DegF	Low number of tree, sapling and seedling species. Low species variance with high species dominance	Very low tree density, very low sapling density and low seedling density, with very low basal area and biomass	Reduced canopy height and low canopy cover	Very low litterfall production	Highly disturbed showing little sign of regeneration

4.3 Establishing the ecological regeneration barriers

4.3.1 Barriers investigated

A site can remain in a degraded state due to some or all of the sub-processes of regeneration being unable to operate, due to alteration of biotic or abiotic conditions (section 2.3.4). Based on a knowledge of the most commonly cited forest regeneration barriers found in the tropics and a specific understanding of the TPSF ecosystem (Chapters 2 and 3), the following potential ecological barriers were selected for investigation in this study:

i) a disruption of the process of seedling recruitment through a reduction in the level of
   a. seed rain
   b. seed dispersal
   c. soil seed bank

ii) a disruption in the process of seedling survival and growth through altered
   a. nutrient availability
   b. water level
   c. light intensity
   d. competition with non-tree vegetation
   e. mycorrhizal availability.

4.3.2 Seedling trials

In order to determine the effect these potential barriers weer having on natural regeneration, seedlings were cultivated for five months in a nursery and then transplanted into each FZ, under three different treatments; nutrient additions (NA), shade cover (SC) and herbaceous vegetation competition removal (CR) (methods below). Three tree species were selected to be used as transplant species for these trials; *Dyera polyphylla* (Apocynaceae), *Shorea* *balangeran* (Dipterocarpaceae) and *Combretocarpus rotundatus* (Anisophyllaceae). These species were selected based on a review of published and grey literature which revealed their suitability for TPSF restoration trials:

Combretocarpus rotundatus is a known stress-tolerant species, tolerating low-nutrients (Matsubara *et al.* 2003), fire (Wibisono *et al.* 2005), high light levels (Wibisono *et al.* 2005), and flooding (Van Eijk and Leenman 2004). It is dominant in secondary TPSF successional communities and classed as a fast-growing pioneer (van Eijk and Leenman 2004, Giesen 2004, Whitmore 1984). It has met with success in previous restoration trials (Giesen 2004, 2009). It grows quickly, quickly closing a canopy (Saito *et al.* 2003).

Shorea balangeran is an important timber species, found in primary and secondary TPSF and is described as a pioneer species (Rachmanadi and Lazuardi 2007). It known to tolerate high light levels (Giesen 2009), flooding (Simbolon and Mirmanto 1999), and it has been successfully used in TPSF transplant trials (Wibisono and Gandrung 2008, Lazuardi 2004).

Dyera polyphylla is an important commercial species; its sap is tapped and collected for latex production. Although commonly nominated as a suitable species for TPSF restoration, it has achieved mixed success (Wibisono and Gandrung, 2008, Giesen 2009). It hassome tolerannce to high light levels and grows in open areas (Wibisono *et al.* 2005, Rachmanadi and Luzuardi 2007).

All three species are known to be native pioneer or early-succession species. Based on the framework species method (see 2.4.3), each contributes different attributes, described above, yet all are likely to survive in the degraded area.

4.3.3 The process of recruitment

To assess whether seedling recruitment had altered following disturbance, three factors were considered: seed rain, seed dispersal and soil seed bank.

Level of seed-rain and seed-dispersal

To assess the level of seed rain and seed dispersal, eight seed-fall traps were constructed in each FZ, comprised of 1 m^2 table-like structures, with frames of plastic piping and tops of sagging nylon-netting. Traps placed outside the forest also included a 20 cm ‘wall’ of nylon around the plastic piping frame to prevent loss of seeds by wind. The eight traps were positioned along each transect using stratified randomization (no more than two traps per 100 m; stratified random placing was also used for all other methods described below), 2-5 m from the transect, to the left or right. Ground vegetation beneath the traps was cleared.

All trees with overhanging vegetation that could drop fruits and seeds into the traps were identified and tagged. Overhanging vegetation was checked every six months, to record new recruits and mortalities. Fruits and seeds found in a trap with species present in the over-hanging vegetation were assumed to have arrived in the trap through seed rain, whilst fruits and seeds of other species were assumed to have arrived in the trap as a result of seed dispersal. Based on these assumptions, dispersal rates may have been underestimated as seeds of the overhanging species could also have arrived in the trap as a result of dispersal (Webb and Peart 2001).

Every month (following Zimmerman *et al.* 2000), the contents of the fruit and seed fall traps were collected into cloth bags, and labeled accordingly. The contents were sorted into seeds/fruits, and other leaf litter (see 4.2.1), and the species and abundance of the seeds or fruits were recorded. Each species was further classified as being either wind-dispersed or animal-dispersed based on the seed form and personal observation; being either light-weight and/or winged for wind-dispersed and fleshy for animal-dispersal. The seeds and fruits of each trap were then placed in separate envelopes, dried at 40-50 ºC for 14 days, and the dry weight recorded.

Abundance of seed banks

Surface peat samples (five samples per transect (Duncan 2006), 12.5 cm x 12.5 cm x 5 cm depth (Zimmerman *et al.* 2000) were collected from five stratified random locations in each FZ during the months of September and December 2007, and March and June 2008. In most seed bank studies, leaf litter is removed from the soil surface before the sample is taken. However, in TPSF, the point of definition between litter and peat is unclear, especially as roots come right to the surface of the litter. Thus dry, fully-formed leaves were removed from the peat surface but any litter below this was taken as part of the sample. The samples were transferred to a seedling nursery, which provided natural forest conditions, i.e. shade, water, and protection from direct rain-fall. All samples were spread out on germination trays to a thickness of 1 cm (Duncan 2006), the number of seeds visibly present in each sample, and corresponding species (where known, if not known morpho-species used), was recorded immediately and the germination and survival of seedlings over a six month period was recorded monthly (Zimmerman *et al.* 2000).

4.3.4 The process of seedling survival and growth

To assess whether environmental conditions had significantly altered in the disturbed and degraded forest zones, compared to the NF, and if these significantly influenced seedling survival and growth, the following variables were measured; nutrient availability and other peat soil properties, light intensity, height of water table, competition with non-tree vegetation and mycorrhizal availability.

Nutrient availability and peat soil properties

Peat samples (10 x 10 x 10 cm) were collected during the peak of the wet season (February 2008) and the peak of the dry season (September 2007) from the peat surface (top 20cm) at five stratified random points along each of the transects. The peat samples were analysed for pH, organic carbon content (%org-C), percentage nitrogen (%N) and total phosphorus (P-Total). The peat analyses were conducted in the laboratories of the Geography Department, University of Palangka Raya, using their standard protocols (Table 4.10).

Table 4.10: The laboratory methods used to assess the peat properties: %-Org.C, %N, P-Total and pH.

Soil property	**Procedure**
All	There was an initial drying of all samples under natural conditions for one week.
pH	10 g of peat combined with 5 ml of distilled water, centrifuged for 30 minutes, pH measured and calibrated against known solutions of pH 4 and pH 7.
% C	5 g of peat, oven-dried (105 ºC) for 24 hours, cooled, and the mass recorded. The sample was placed in an oven (900 ºC) for a further 5 hours, until ash formed. The sample was cooled and mass recorded: % C = ash mass / dry mass x 100.
% N	0.05 ml of NaOH were combined with 0.05 g of peat. The solution made up to 50 ml by addition of $K_2O_8S_2$ (Potassium peroxydisulfate), heated for 2 hours using a pressure steam sterilizer, then cooled. 2 ml of solution was mixed with 0.8 ml of H_2SO_9 (Salycilic acid), then made up to 20 ml by addition of NaOH. The N concentration was then determined using a spectrometer (λ = 410nm).
C:N	% C / % N
Total P	0.25 g of peat was combined with 257.2 ml of perchloric acid. The solution was made up to 1 litre with distilled water. 15 ml of solution was twice filtered through filter paper (hole size 42). This solution was then made up to 25 ml in a conical flask with the addition of distilled water. This solution was prepared for analysis in a spectrometer using the Scheel method (2ml solution used with Scheel method 1, a further 2ml of solution added, and Scheel method 2 used. Left to settle for 15 minutes then Scheel method 3 used. The 4 ml of solution added to 5 ml of distilled water and left to settle for 15 minutes. Wavelength of 700 nm used in the spectrometer calibrated against standardised solutions of known phosphorous concentrations.

To determine the potential effect of limited nutrient availability on seedling growth, eight 2 x 2 m seedling plots were established along each transect. All non-mature tree vegetation was removed from these plots. Three *Combretocarpus rotundatus*, three *Shorea balangeran* and three *Dyera polyphylla* seedlings were transplanted into each plot. 5 g of slow-release nutrient tablets, 'Dekaster Plus', were added to the surrounding soil at the time of seedling planting. Each nutrient addition contained 0.9 g nitrogen (N), 0.45 g phosphorus (P_2O_5), 0.5 g potassium (K_2O) and 0.1 g magnesium (MgO) with trace amounts of boron, copper, iron, manganese, molybdenum and zinc. Each seedling was tagged, and their height, basal diameter (BD) and leaf number (LN) were recorded monthly for seven months. The plots were weeded monthly.

Water level

At eight randomly selected positions along each transect, a flood-level measure for measuring water-level above the peat surface, and a dip-well water-level measure, for measuring water table level beneath the peat surface, were erected. Each flood-level measure consisted of a 3 m plastic pole. The lower 1 m of this pole was inserted into the peat, at a position which was neither a distinct hummock nor a hollow, and the remaining 2 m above the peat was marked at 2 cm intervals. When the water-table was above the peat-surface, the level was recorded. Each dip-well consisted of a 2 m piece of plastic piping with holes drilled along its length (Chimner and Ewel 2005). This piping was inserted into the ground, adjacent to the flood-level measure. When the water-table was below the surface of the peat, a 1m long, thinner rod, marked at 2 cm intervals was inserted into the pipe. When removed, the depth of the water table beneath the surface could be measured.

Light levels

Light levels were measured indirectly. A quantitative light-intensity reading can be attained for an individual point, and several points within close proximity of each other, using a light meter. However, over different times, days, and weather conditions light intensity will vary, and it becomes difficult to compare over a wide-range of positions. Instead, the percentage canopy cover at each position was recorded as a proxy for light intensity. A digital camera was set-up horizontally on a flat surface (using a tripod with spirit-level) and photographs were taken of the canopy, first 1 m above the ground surface, and then at ground level in order to record the additional shading from any ground vegetation; pandans etc. This was carried out at eight stratified random positions along each transect. Photographs were then converted to percentage of black and white pixels using Photoshop, and the percentage of white pixels, which indicated percentage of open canopy, was used a proxy for light intensity.

To determine the impact of light intensity on seedling growth, eight 2 x 2 m seedling plots were established along each transect. Over these plots, shade covers (70% shade, comparable to TPSF natural canopy shade; personal data) were constructed out of banana leaf matting. All non-mature tree vegetation was removed from the plots. Three *Combretocarpus rotundatus,* three *Shorea balangeran* and three *Dyera polyphylla* seedlings were transplanted into each plot. Each seedling was tagged, and height, BD and LN were recorded monthly for seven months, and the plots weeded monthly.

Competition with herbaceous vegetation

At this study site many sedges (*Cyperaceae), Pandanus* species and a woody species 'asam-asam' *Ploiarium alternifolium* have invaded the disturbed and degraded area; all of these rarely occur in the closed forest. To establish the percentage cover of this invasive herbaceous vegetation in each of the forest zones, eight 1 x 1 m plots were established at randomly-stratified positions along the transects, and the ground cover was recorded according to floral group/growth form, namely: pandan, sedge, liana, tree (greater than 3 cm DBH), sapling (greater than 1.3 m in height, less than 3 cm DBH), seedling (less than 1.3 m in height), and other. Vegetation was only recorded if the base of the plant was inside the plot. This was repeated every three months for one year.

To determine the impact of competition with herbaceous vegetation on seedling growth and survival, sixteen, stratified randomly-placed, 2 x 2 m seedling plots were established along each transect. In eight of the sixteen plots, all the herbaceous vegetation was removed, in the other eight plots, the herbaceous vegetation remained. Three *Dyera polyphylla*, three *Shorea balangeran* and three *Combretocarpus rotundatus* were planted into each plot. Every month for seven months, survival, height, BD and LN of each seedling was recorded. Weeding in the vegetation-removed plots occurred monthly.

Mycorrhizal availability

Mycorrhizal availability and the related impact on seedlings in the different forest zones compared to the NF was investigated. The tree species were selected based on the reasoning described in 4.3.2. The mycorrhizal species which form mutualisms with *S. balangeran* and *D. polyphylla*, namely *Scleroderma columnare* for *S. balangeran* and *Glomus clarum* and *Gigaspora decipiens* for *D. polyphylla*, were already established and available in prepared tablet form for seedling inoculation. This was not the case for *C. rotundatus*, and so this species was not included in the mycorrhizae study. 800 seedlings of *S. balangeran*, half inoculated with ectomycorrhizal spores of *Scleroderma columnare,* half as the control seedlings, and 900 *D. polyphylla*, one third inoculated with endomycorrhizal spores of *Glomus clarum,* one third inoculated with endomycorrhizal spores *Gigaspora decipiens,* and one third as the control seedlings were cultivated in the nursery. These were transplanted into seedling plots in each FZ, and their survival, BD, height and LN were recorded monthly for one year. Sample seedlings from each mycorrhizal treatment and FZ were harvested during the peak wet season and the peak dry season. Roots were analysed for percentage of mycorrhizal colonization, and leaves for nitrogen and phosphorus content. Dry weights for roots and stems plus leaves were recorded. For complete methods refer to the publication, on the attached CD.

4.3.5 Analysis

All the environmental factors were assessed across five independent transects located in five FZ. Assessment of each environmental factor was replicated within each FZ. Each environmental factor was first considered across seasons within each FZ, to determine whether time of year affected the environmental condition. If there was no seasonal effect, an average for the year was calculated: if there was a seasonal effect, seasons were analysed separately with regard to each FZ. The environmental conditions from each FZ were then compared to the NF (control).

Transplanted seedlings were subjected to different four different treatments (Nutrients Added – NA, Shade Covered – SC, Competition Removed - CR and Control - Con) across the five FZ. The impact the treatments and FZ had on the seedlings' of each species survival and growth was assessed through: averaging the survival, increase in BD, increase in height and change in LN of the seedlings in each plot. The data from the eight seedling plots for each species on each transect was analysed, looking at effect of FZ in comparison to the NF and the effect of each treatment within each FZ in relation to the Con seedlings.

The statistical tests used for each stage and the decisions made regarding the statistical analysis are summarised in figures 4.4 and 4.5 and table 4.11. Where results were in the form of a percentage the data were converted using the Arcsine Square Root Transformation.

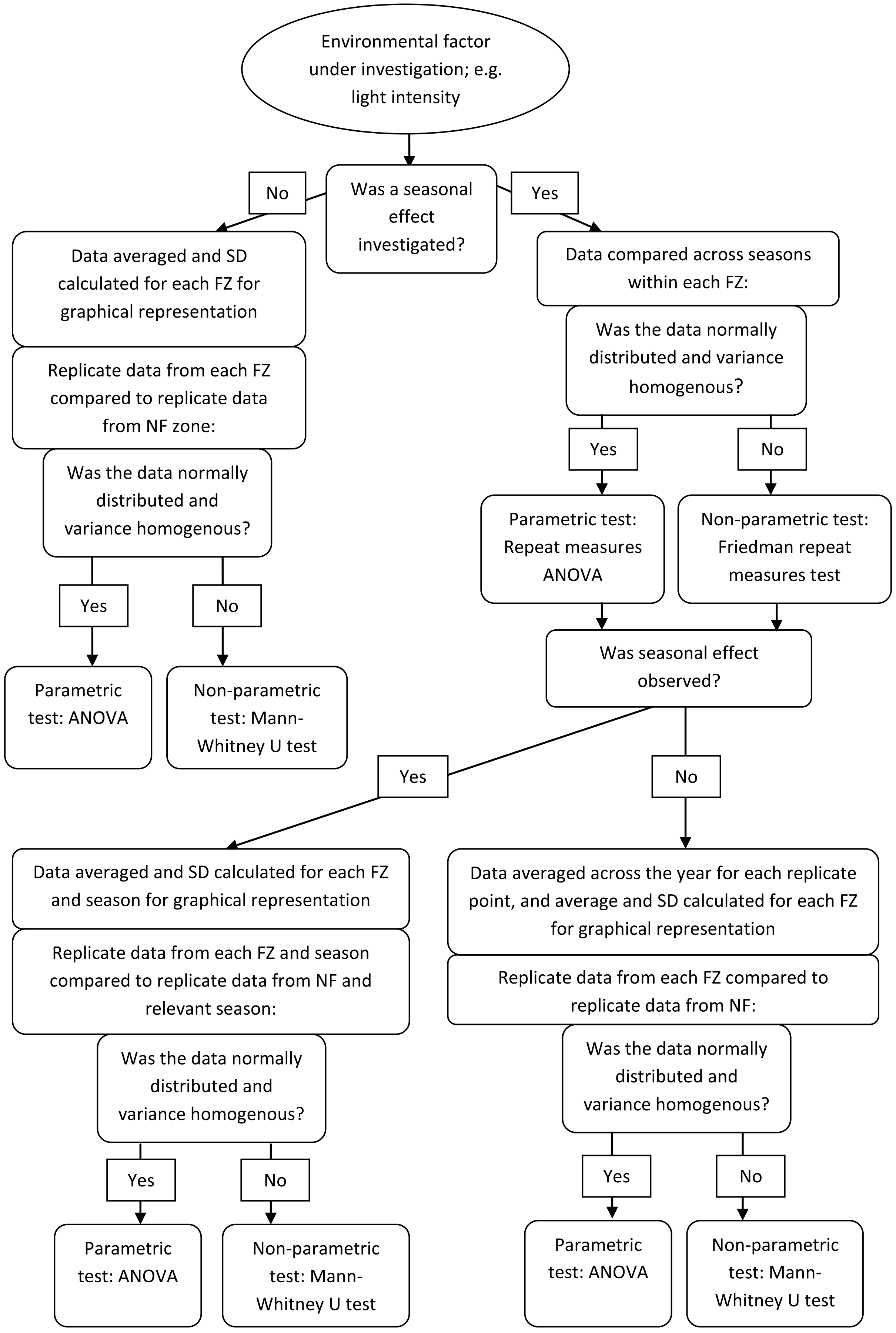


Figure 4.4: Decision diagram and analysis route to determine the statistical tests used for analysing the environmental conditions.

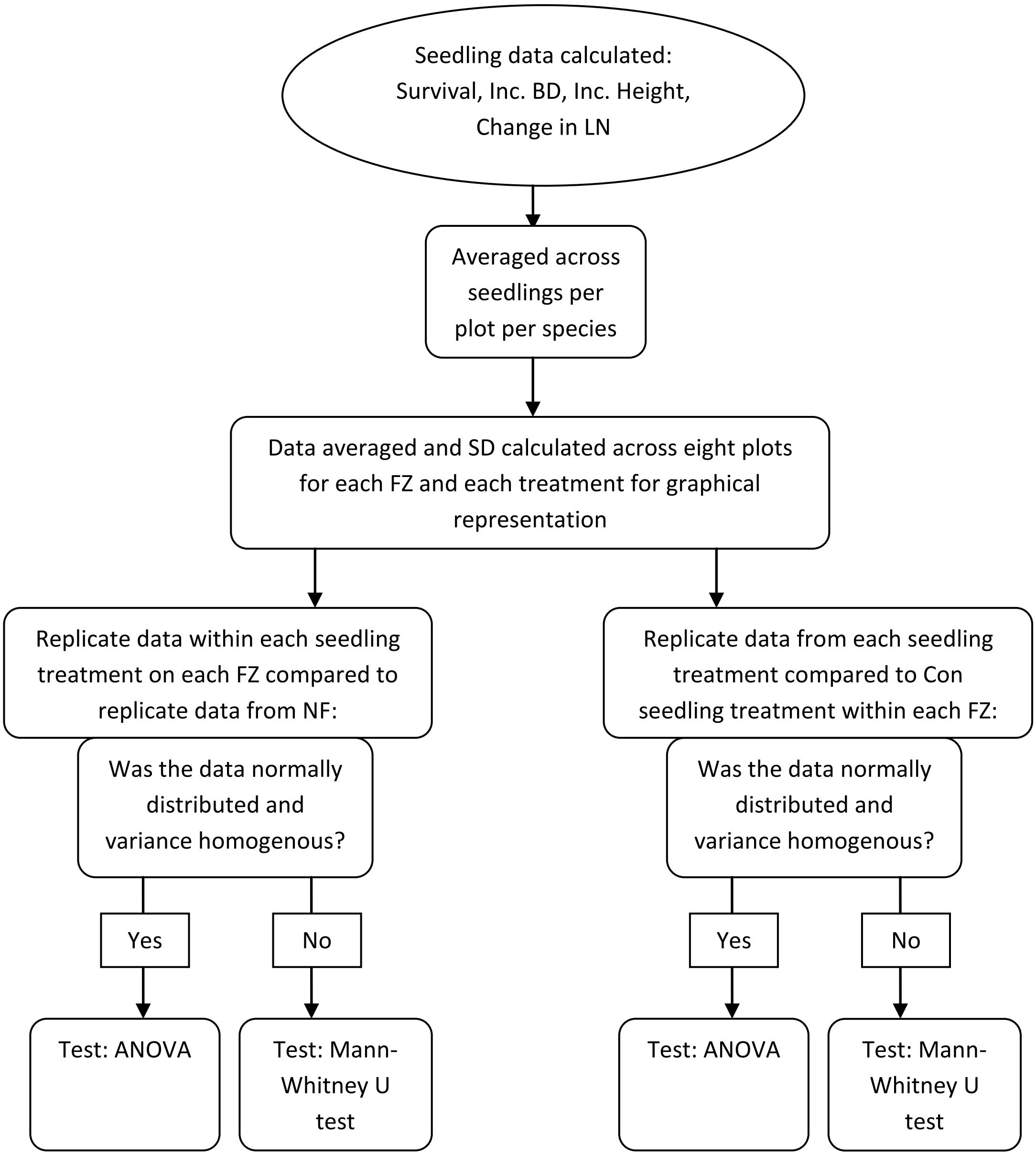


Figure 4.5: Decision diagram and analysis route to determine the statistical tests used for analysing effect of treatment and FZ on the seedlings of each species. BD – basal diameter, LN – leaf number, SD – standard deviation, FZ – forest zone, NF – natural forest, Con – control.

Table 4.11: The environmental conditions that were analysed using the above statistical decision diagram, and the relevant seasonal data corresponding to each condition.

	Environmental condition	**Seasonal effect investigated?**	**Effect of season observed**
Forest characteristic	Species number	No	-
	Tree density	No	-
	Basal area	No	-
	Biomass	No	-
	Canopy height	No	-
	Canopy cover	No	-
	Litterfall	No	-
Potential regeneration barrier	Seed rain	No	-
	Seed dispersal	No	-
	Soil seed bank	Yes	No
	Nutrients	Yes	Yes
	Light	No	-
	Water	Yes	Yes
	Competition	Yes	No
	Mycorrhizae	Yes	Yes

The only exception to the above statistical analysis route was the analysis of species composition. For each forest plot and for each stage of tree maturity, the number of individuals recorded for each species was calculated as a percentage of the total number of individuals giving percentage dominance for each species at each stage of tree maturity. These were averaged across the four forest plots on each FZ. The five most dominant species and their averaged dominance for each FZ were presented.

4.4 Social participation: Knowledge and views of the local community

Involving the local community in the process of restoration of a degraded site is an essential feature of RE, as discussed in 2.5. The aim of the social component of this study was to understand from the 'local community' what were, and what they saw, as potential barriers preventing natural regeneration, and how these might be alleviated. To do this, focus groups and interviews were conducted with participants from the community, discussing past, present and future uses, changes and concerns about the land and forest surrounding their village.

Adams and Infield (2003) defines local community as those with either/both a proximity or historical right to the land. The key element was to work with participants that were not only the 'geographical local community' (Gusfield 1975) to the degraded site but also those which, as McMillan and Chavis (1986) describe as having membership, influence, a fulfillment of need, and a shared emotional connection to the relevant topic, in this case, the land, which is what creates a distinct community.

This study only worked with participants from the village of Kereng Bangkirai. Only members of Kereng Bangkirai regularly use the adjacent degraded study site, therefore they had most knowledge and invested interest in the land. Including other villages would have increased the transferability of this study, but given the time limitations, working at one study site and only with individuals directly related to that site was all that could be achieved. If the research had been scaled up to include more villages and more study areas, it would have risked losing the elements of depth and understanding which are so important to RE.

4.4.1 Participation and expectations

The primary focus of this research was to determine the barriers which were preventing recovery of the degraded study site. The barriers could have been ecological, institutional, procedural, or rooted in attitudes and concerns of the local community. Many ER projects document the participation of the local community in developing a RAP (Tongway and Ludwig 2011). However, this stage of restoration is only done after the barriers are determined. Thus I aimed to engage with and share the knowledge and experiences of the local community with regard to this study site at the same time as investigating the ecological barriers, in order to build up a more complete picture of the factors influencing the landscape.

It was hoped that, subsequent to this study, some of the information might be used in the restoration of the land. However, at the time of research, there was no guarantee or certainty of actual restoration; lack of money, human resources and local and governmental support all potentially creating barriers. Given this, it was essential that no false hopes be fostered within the community and that my presence in the community was perceived only with the purpose of learning from and sharing their knowledge. Given this, the style of participation and the topics to be discussed were modulated to ensure no false promises were made.

There was the need for honesty and trust between myself and respondents (Flowerdew and Martin 2005). Therefore, I classified the level of participation (based upon White's (1996) participation classifications), that of representative participation, one which can provide a voice for the local community, and give them some element of leverage, yet without making claims to empower or hand over decision making to the local community (which was not a possibility due to the fixed power relations between the community and CIMTROP, see 5.2.2).

Given my own personal stand-point is pro-restoration, I was especially careful not to appear to the local community as an 'activist' able to bring about this change. In particular, when discussing Topic 3: The future of the area, there was room for the local community to misinterpret the discussion and understand that it was 'action-planning'. In fact, at the end of Topic 3, in three of the four focus groups, I was asked to assist them in bringing about these 'hopes' they had been discussing, by 'getting the government to pay attention', by 'making a proposal' and 'organising the local community'. The fact I was asked and the response I gave made me proud and sad respectively: I explained that 'I am still a student', 'I am just here to learn about the community', 'I will try to publicise my findings, but as a researcher, not someone working directly with the government'. I felt that through these final discussions, my role was clear to the local community.

4.4.2 Social structure

From personal observations within Dayak communities in Central Kalimantan, their social structure operates, firstly, through an informal class system, and secondly, as non-confrontational. The class system, rather than being based upon position of birth seems in relation to the level of education gained (and subsequently, station of job). Qualifications in Indonesia are gained at the ages of, approximately, 11 (SD), 16 (SMP), 19 (SMA), and university (S1). Gaining a university degree in Central Kalimantan is still relatively rare and prestigious, largely due to expense. Given the lack of good education facilities in the more rural areas, and the associated costs (all education in Indonesia must be paid for), many villagers in this region did not attain SMP or SMA, and have poor literacy (Smith 2002). Having good qualifications and subsequently being in a good job and position of authority tends to place this individual in a position of superiority. These people might be referred to as '*orang besar*' (big person), and those in less prestigious positions will often say they don't feel comfortable to approach this person, or speak out in front of them as they are '*tidak berani*' (not brave), referring to themselves as '*orang kecil*' (small person). Low income can restrict families from increasing their children's 'positions', and equally, marriages usually occur across similarly educated individuals.

The effect of being a non-confrontational people further exacerbates this issue. Whilst on the whole people are very chatty and friendly, they rarely will exert a definite opinion when asked directly, especially if it is to someone they feel is 'above' them. They will far rather hear the opinions of the persons 'above them' and concur, or at least, follow on these instructions, rather than make their own opinions known. This structure can be broken by cultivating trust and friendship, but is a slow process. As such, in all the participatory activities it was essential I considered the age range and occupations of the participants.

4.4.3 Facilitators

Working alongside me, as facilitators in the participatory activities and to assist in translations, were three of CIMTROP's Patrol Team. These people were selected as facilitators as, primarily, being with CIMTROP they were the gatekeepers that allowed me 'research access' to the community. Furthermore, they were skilled staff, familiar with working with this community and placed within it. All were males in their late-twenties, all born in Kereng and had worked in the Patrol Team for several years. Initially I was assigned Idrus and Marta Bina. Idrus was the head of the Patrol Team. I knew him to be courteous, intelligent, and we already had a good rapport; he took the role as lead facilitator. I knew Marta Bina less well, but knew him to be a hard-worker who was well thought of; he took the role of assistant facilitator. Unfortunately, half-way through the activities Idrus' father became ill, and so Idrus could no longer help. He was replaced by Hendri, who used to be head of the Patrol Team and was now a free-lance research assistant to CIMTROP. I knew Hendri well; he was similarly dynamic and sensitive as Idrus and filled the same role.

Hendri was the youngest of 13 siblings, and his father and mother (both now very old) were both from the first families to settle in Kereng. His family held several key positions in the village, and were very well respected. Whilst I knew less of Idrus' family history, I knew they were also a dominant family, having settled here a long time ago, living in a house on the main street. I felt that their personalities plus their 'presence' gained us lots of access and trust within the village and the participants.

Given all the facilitators were members of CIMTROP's Patrol Team, they already had a close relationship with the people of Kereng Bangkirai; serving as an intermediary and in a educational role between the community and CIMTROP, NLPSF and researchers. As such, their cultural and local knowledge, appreciation of potential conflicts, and their established relationship with the community were vital. Despite these benefits, the Patrol Team also held an official role within CIMTROP, and consequently the participants may have felt inhibited to speak openly on views regarding land management. Equally, the Patrol Team had been working to reduce illegal activities at NLPSF, such as logging and hunting, some of which was conducted by the local community, which could have fostered tensions and resentment. I remained sensitive to these potential issues, however did not witness any problems. Whilst the facilitators acted as the gate-keepers for me to the community and set-up the focus groups and interviews, once underway they spoke very little. They would only help me understand a phrase or word, better explain my meaning to the participants (when language got in the way) or translate from the local language to Indonesian.

At the start of this study I had spent approximately five years living and working in Central Kalimantan, and would class my Bahasa Indonesia language level as highly conversational but not fluent. Furthermore, given the high level of transmigration into

Central Kalimantan, Javanese, Banjarese and at least three Dayak languages were all spoken by different members of the community. Whilst in most instances participants would talk only in Bahasa Indonesia when with me, given that I wished to encourage free-flow of informal conversation, I did not insist people use Bahasa Indonesia at all times. As such, and given the limitations of my language skills, the facilitators were always ready to assist with my understanding, and translate any conversations from the local languages.

4.4.4 Personal perspective

During social research, the differences of background, race, gender and age between the researcher and the participants (the positionality), and how this is likely to affect the relationship or power relations between the researcher and participants must be considered (Kitchin and Hubbard 1999, Twyman *et al.* 1999). Lack of openness and trust can arise through these differences, and these differences can be increased when researching in developing countries (Howard 1994, Sharpe 1998).

Fortunately, there is not resentment, locally, of white people in this once colonised area (perhaps due to the Dutch colonisation having little effect in Central Kalimantan, see 3.5). Despite this, there were other perceptions associated with white people, and particularly white women, which I had to negotiate. White people are perceived as very wealthy, and whilst begging or expectations of charity was not usual, if a white person claimed lack money, they were often assumed to be lying. I found being honest about money and explaining that as a student I did not receive a wage, only funding which was spent on subsistence and paying my research assistants, was usually met with understanding.

Given that I was a PhD student (S3 in Indonesia), this was perceived as highly prestigious, as very few people attain this qualification in Kalimantan. To have an S3 is usually associated with someone of age, high standing and authority. I found that, given my young age, and being friendly often quickly dispelled any connotations of being of a ‘superior status’.

Generally, if Indonesian women drink or smoke they are often perceived poorly and assumed to be engaging in inappropriate activities. Unfortunately as many white women do drink or smoke, as well as sometimes wearing inappropriate clothing (in public from shoulders down to thighs should be entirely covered by men and women) they have gained this local stereotype. This is further exacerbated by the image the media creates of white women: American movies and celebrity life-style. However, I found it is relatively easy to dispel this character by not drinking or smoking, wearing appropriate clothes and learning the cultural manners of politeness.

Moser (2008) describes how the Indonesian village community she worked with only initially engaged with what she calls the ‘mega-categories’ or her positionality. Once the community knew her better, however, her personality or social skills were much more important. I feel this is very true, probably of most societies, but particularly in Indonesia where there are lots of issues of race and religion, and subsequent stereotyping. However, due to migration and trans-migration, everyone is mixed in together and as they must find routes to live comfortably and non-confrontationally, they are very good at separating their formulated stereotypes from the actual people around them.

I worked in this area for over five years, and during that time built up strong relationships within the community. I developed a personal relationship with a member of the village, and we were married in 2008. This relationship was warmly received by the community, and the wedding was celebrated with a large reception in my husband’s family home, which many members of the village attended. People then perceived me more as a member of their community, joking about my ‘becoming brown’ and referring to me as ‘a Dayak’.

There were risks associated with this closer connection to the community - ‘going native’ (Fuller 1999): taking on the community’s voice, rather than presenting their views as a neutral researcher (Kitchin and Hubbard 1999). However, I would argue, any social research in which there is prolonged engagement in a community leads to close friendships forming, and by its nature, ethnography leads to the researcher becoming involved and integrating into the culture and community (Kitchin and Hubbard 1999, Fuller 1999). As Schoenberger (1992:218) describes it is not that we need to ‘… do away with these things, but know them and learn from them’. Through documentation and discussions both with the community and my supervisor (creating a research audit) I hope I have been ethically and personally fair to all members of the village, whilst still conducting my research in a rigorous manner. To avoid conflict between my persona and research, my close Indonesian friends and family did not become ‘active participants’.

The second potential issue was through my personal bias towards restoration of degraded land. However, at this stage of the restoration process it would have not only be unfair and unethical to attempt to sway or edit representations of the participant’s views, but it would also obscure potential social barriers present in the village, which must be appreciated for restoration activities. Interestingly, I found most of the community’s views very much in line with my own, but given their in-depth level of insight and understanding of the forest and restoration, this hopefully showed that it was their own voice, not mine.

4.4.5 Participants and participatory methods

Kereng Bangkirai has a population of approximately 5550. The total number of participants involved in the activities was 154, or 2.8% of the village. Many of the participants participated in two or three of the topics. For an in-depth description of the participants, their gender, age, religion, occupations etc. see 5.3.

Focus groups were used as the participatory activity with the men. This method was selected as it provided a forum for the many views and attitudes of the community to be discussed in an open-forum, and to see how these views related and conflicted. It allowed themes to be addressed fully in a friendly semi-formal environment (Flowerdew and Martin 2005).

‘Conversational interviews’ were selected as the participatory activity with the women and elders. This method was selected due to being less formal in nature than the focus groups and I was better able to guide the conversation based on the participants responses (Flowerdew and Martin 2005). Yet it was still able to generate a multi-layered, deeper picture, in which the sub-themes could be addressed.

Smith (2002) observed that when being interviewed about forest conservation issues, women often chose to opt out of the interview, preferring to let their husbands answer for them, creating a 60:40 ratio of men to women participants. The facilitators working with me also felt that women might not feel as comfortable as men to attend the more formal focus groups, but instead suggested conducting more informal group ‘conversational interviews’ (Flowerdew and Martin 2005) in the women’s homes.

After conducting the interviews, I was able to observe better the male-female dynamics, and felt the right decision was made. Women were often more comfortable talking in the local language; Ngadju, and being translated, which would have made the dynamics of the focus group difficult. They often gave clauses to the information they gave: ‘I’m not sure but…’, ‘maybe it’s like this…’, etc., showing that whilst they did have knowledge to share, they felt less sure in themselves to provide it, and a formal environment might have decreased their comfort and willingness to share this knowledge. They were also able to attend to their children or duties at home whilst participating.

The information attained from the women often differed from the men, being more personal and family based. The men remembered detailed specifics of the logging companies; what species were taken at what dimensions, whilst the women would remember the impact it had on food availability and school quality, for example. Had there been mixed-gender focus groups, in which women were happier to let the men answer, these perceptions may have been missed.

4.4.6 When and where

The participation activities, which involved focus groups and interviews were all conducted over short periods of time (maximum length of sessions two-and-a-half hours). To coincide with natural times of socialising and relaxing, rather than work, the focus groups were conducted in the late afternoon for the men, and the interviews in the morning (when children are at school) for the women. The Patrol Post, which is a small office in Block D served as a good meeting room for the focus groups, and for the women, we travelled to different blocks on different days, and would visit between 2-4 homes in one morning.

Figure 4.6: The focus groups with the male participants (a and b), interviews with the female participants (c and d) and with the elders (e and f).

In order to gain access to the participants, for the male participants, the facilitators invited people the day before, telling them of the planned activities. The facilitators went alone to do this as it was felt it would be less ‘confrontational’ (a key aspect to Indonesian society) if I did not go. The participants could ask about the activities, and if they did not want to participate they would not have to feel embarrassed (a society taboo is to put someone in an embarrassing situation) in turning me down. I prepared a short information sheet describing myself and my activities, which the facilitators took to potential participants to discuss. The facilitators would invite 10 men to each focus group, and 7-10 would turn up.

With the women a similar process was adopted. The facilitators would take me to houses with likely participants, explain our intentions and ask for an interview. As we moved on to later topics and we re-visited the same houses, it was easier and often larger groups formed as they knew the process and seemed to prefer to be interviewed in groups rather than in ones or twos. Very occasionally we were told they did not want to participate. As such my first ‘presentation’ to all the participants was through the facilitators.

This process meant I had less to do with selection of the participants. The facilitators understood that I wanted to recruit people from all four blocks, of all ages, religions and occupations. They biased their selection to people they thought actually knew something about the topics we wanted to discuss. Although it may have been useful to hear views of those not so involved in the surrounding land, when I requested the facilitators to prioritize a particular group, for example Block A, the result was often participants who contributed little to the issues or the debate, having little knowledge or opinion on the topics.

Regionally, it is customary to reward people for their time or work discreetly. The men were given, in envelopes, the equivalent of half-a-days standard salary, 25,000Rp (or approximately £1.50), given they would spend often a large portion of their afternoon with us, and might need to cover transport costs as well. The women, as we wished to create an informal environment, were given a box of tea, a bag of coffee and a bag of sugar, amounting to about 10,000Rp value (70p). Again this reflected the amount of time and effort needed for them to participate, and was in a form that they were comfortable with.

4.4.7 Topics and activities

Three main topics were covered:

Topic 1: History of the land - historical uses, events, ownership and access, in particular which led to the land's degradation.

Topic 2: Present uses of the land, both degraded and non-degraded

Topic 3: Future of the land: concerns and hopes

Within these topics, sub-themes were addressed; physical barriers to recovery of the land, issues relating to land ownership, land rights and access, issues of social tension, and conflict over land-use. These topics and the methods described below were flexible to respond to new directions as the discussions proceeded. The topics and their starting points were chosen such that, in the immediate they could be discussed without addressing the more delicate sub-themes, which only developed if the groups were comfortable. The potentially most emotive topic, the future of the area, was left to the last, as a logical sequence, but also, as many of the participants re-attended Topics 1, 2 and 3, it was hoped that by this stage, trust would have been established, leading to more honest discussions.

In all the focus groups the activities required some degree of writing or drawing (see below). Whilst nearly all the participants were literate, they preferred to direct me and I did most of the writing, based on what they told me to write. I did not lead their answers, for example, on numerous occasions if I spelt something wrong, they would correct my spelling, thus I felt I was merely a tool they felt comfortable using.

At the start of the focus groups and interviews I introduced myself, and reading from a prepared sheet, described what my interests were, my motives for this research, how it might be used, then described the activity. I requested permission to record them, adding other requests such as for them to try to only speak in Indonesian.

In the interviews, the women were provided with a visual aid based on a synthesis of the information gained by the men in the focus groups (fig. 4.7). The women were happier for me to describe aspects of the visual aid and ask them questions in relation to it, rather than they themselves view it. This allowed me to gage if the views provided by the men were similar to the knowledge-base of the women. For example, rather than the women reading that the men had said 'the logging company PT Katunen worked from approximately 1971-1976, taking ramin (*Gonystylus bancanus)*, alau (*Dacrydium pectinatum*) and agatis (*Agathis borneensis*) wood measuring 40cm wide and 4m diameter', I could ask 'Who was the first logging company?', 'What were they like?', 'What would did they take?' etc. Thus the visual aid served as a base to guide the questions and to allow the women to appreciate the concept, but did not 'put words in their mouths'. This sequential route also allowed me to triangulate knowledge (Baxter and Eyles 1997), to see if the views and perceptions of the men were recognized and agreed with by the women and elders, to which they would then add their own perceptions.

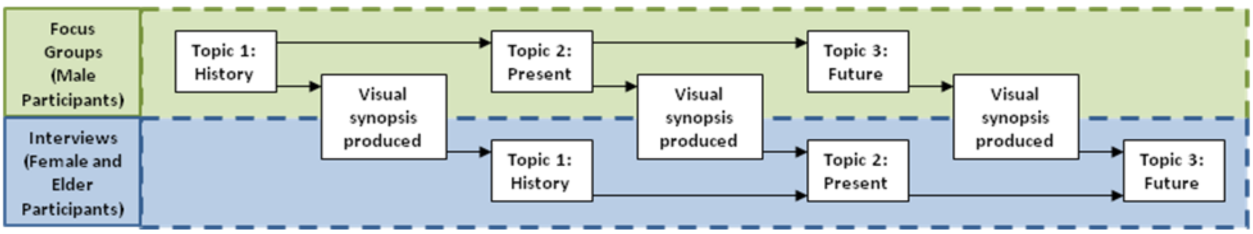


Figure 4.7: A flow diagram representing the order and flow of discussions for the focus groups and interviews

Questionnaire

At the start of each focus group or interview, each new participant was asked a short series of questions to establish the socio-demographics of the participants (Table 4.12). The questions were read aloud, and the answers written down by me, to avoid issues regarding literacy.

Table 4.12: Questionnaire given to each new participant at the beginning of each activity.

1. Age	2. Sex
3. Religion	4. Address (Block)
5. Have you always lived here? If not, where previously?	6. Occupation
7. Final level attained in education	8. Do you collect any natural resources?
9. If you could not collect those natural resources how would that affect you?	

Topic 1: History of the land

To build up an understanding of the uses of the study site before it became degraded, who had ownership and access rights to the land, what events occurred that altered this and brought it to its present state, the following activity was used.

Time-line diagram: Participants of the focus groups were asked to create a time-line on a large sheet of paper, representing the history of the study site (following methods in Walsh and Mitchell 2002). They were asked to mark on important events that occurred at the site, giving approximate years as to when they happened. They were encouraged to illustrate and annotate the events with further information, such as the impacts of each event, socially or ecologically, feelings associated with the event, and reasons for the event. They were questioned about changes in management and access rights after each event, and how the land-use and value of the land changed during each period. After completion, the diagram was ‘interviewed’; I asked the participants to discuss and explain the various events on the timeline in more detail.

This activity was repeated in four different focus groups with different participants, after which saturation of the historical events across the different groups was reached. From the diagrams produced (fig. 4.8), I created a synthesised time-line (fig 4.9), highlighting the findings across the groups. This was then taken to the women, and the older members of the community, and the diagram was ‘interviewed’ again.

Figure 4.8: Photo of a time-line diagram produced from a focus group meeting; Topic 1.

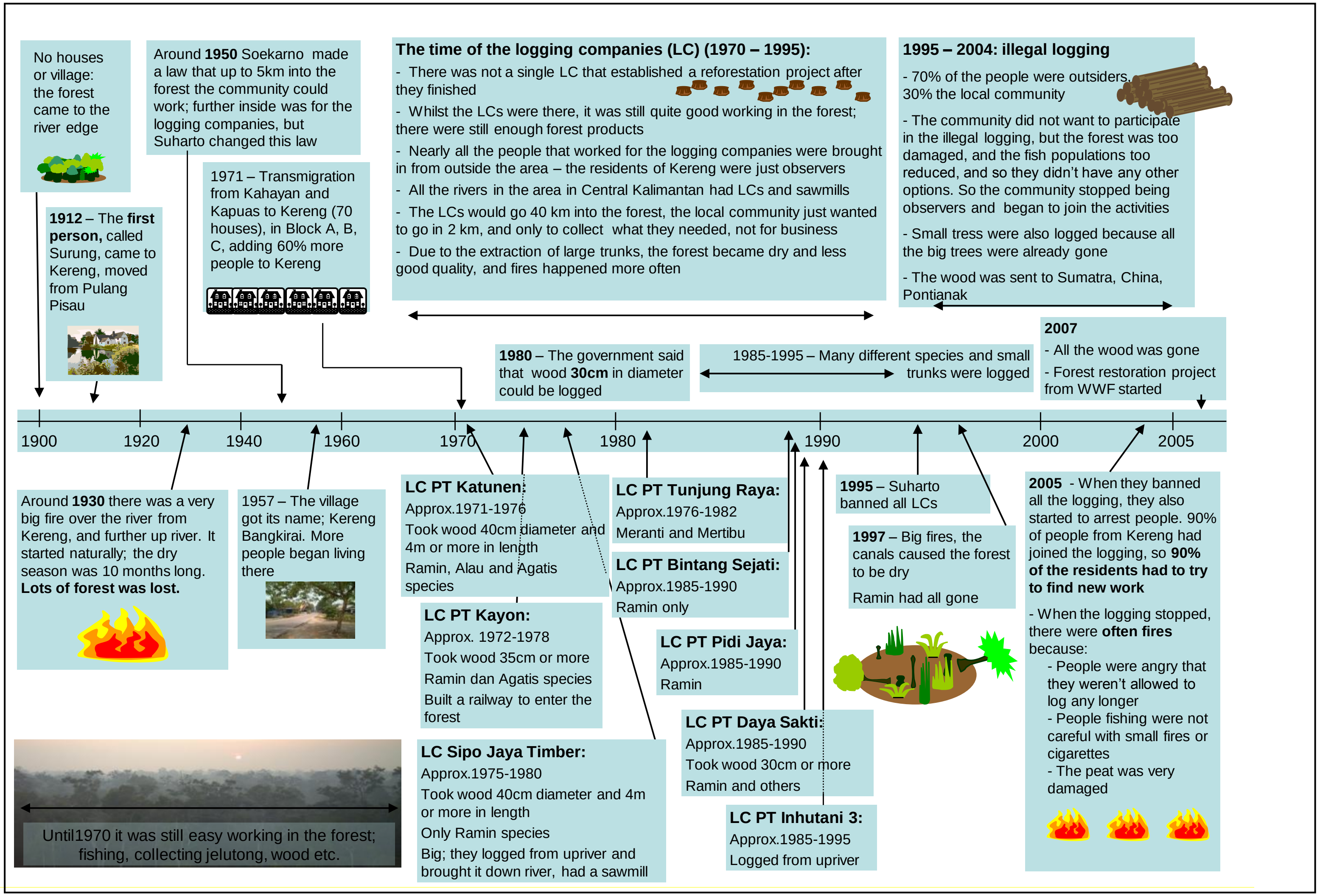


Figure 4.9: Synthesised timeline produced from the data of four focus groups, Topic 1, used as a visual aid in the interviews with women and elders (translated).

Topic 2: Present uses of the land

Despite its degradation, the disturbed land still served some purposes to the local community. It was important, therefore, to appreciate how this compared to the functions of the non-degraded land.

Reviewing past surveys: Present uses and activities: Two surveys were previously carried out in this region, and both surveys interviewed respondents from Kereng Bangkirai. As views may have changed in the 7-8 years since the surveys were taken, and as these surveys considered a larger area, covering 5 villages along the Sabangau River (Lyons 2003), and 25 villages along the Sabangau and the Kahayan Rivers (Smith 2002), this activity acted as a starting point to discuss present day uses. I constructed a large table, describing the findings of the two surveys, with regard to present land-uses (fig. 4.10). Focus groups were structured around this table, and the participants discussed the surveys' findings. All aspects of the table were read aloud to the participants. The table were drawn on, amended and added to. After reaching saturation (four focus groups) these findings were synthesized into another table (fig 4.11), which was used as a discussion stimulus when interviewing the women and elders.

Visions of nature: Based on Gobster's 'visions of nature' (Gobster 2001), focus groups were carried out to explore the 'views' on the surrounding landscape. This method was chosen as an already successful route to explore the different ways a community related to nature, not just for its economic uses, but how it seen, how it made them feel, what symbolic relevance it had etc. Diagrams were prepared on large posters, one depicting a healthy forest, and one depicting degraded forest. Behind the images the poster was split into five headings; Use (how the land is used), Icons (any cultural or symbolic features), Value (aspects of the land with meaning or significance), Function (the functions the land provides for us), and Structure (the vegetation and appearance of the land). At the bottom were the questions ‘Why is nature important? What do we need the forest for?’ (fig. 4.12). The five headings were explained to the participants, who were then asked to fill in any comments under the headings, in relation to non-degraded and degraded forest. This was done by asking questions that related to the headings, such as: ‘What does the forest provide for the community?’, ‘How does the forest help the environment?’, ‘How do you feel about the forest? Why?’, ‘What are important symbols from the forest for your community and your culture?’, ‘If you had to describe the forest to someone who had never seen peat swamp forest, what would you tell them?’, ‘When you enter the forest, what do you see?’, ‘Of the above questions, when the forest becomes degraded, how does this alter?’ Once this reached saturation (four focus groups), the outputs were synthesized into a single diagram showing all the data in relation to the two forest types (fig. 4.13). These were then used as discussion points with the women and elders in the village.

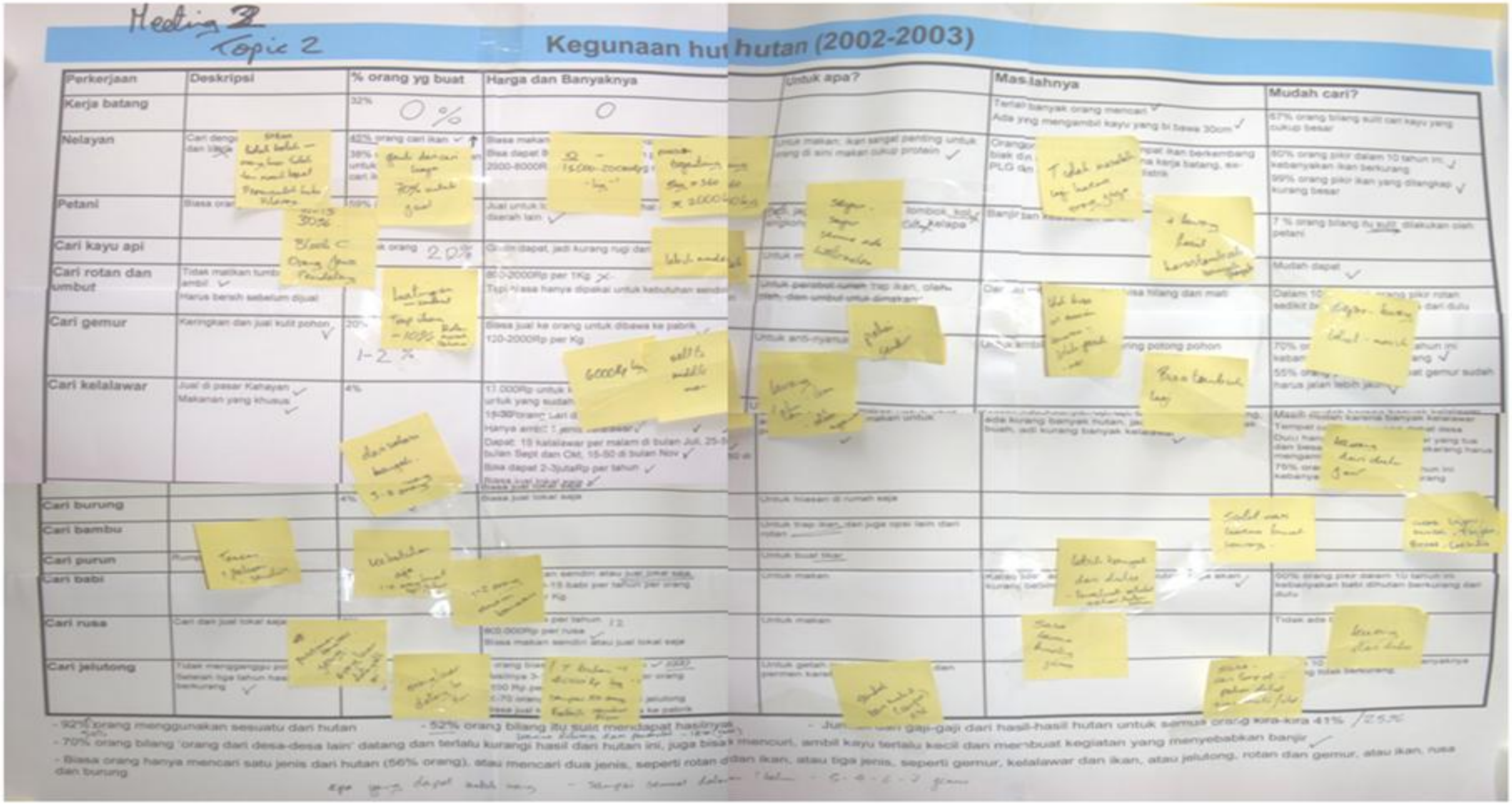


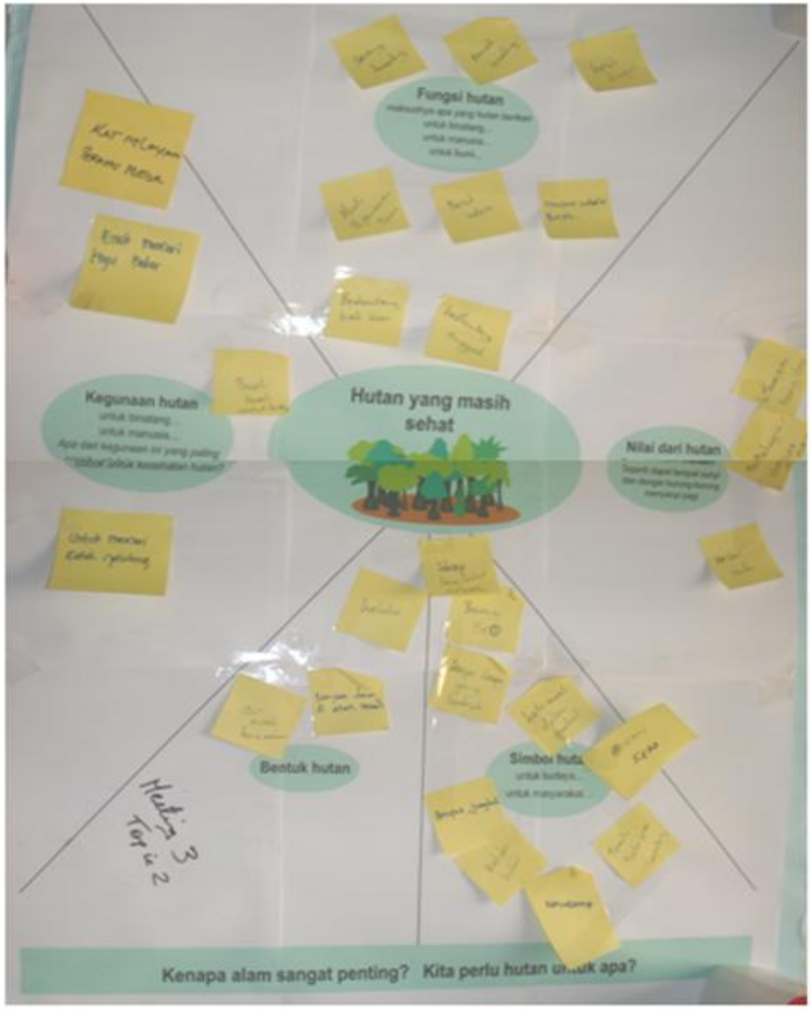
Figure 4.10: The ‘uses of the forest’ table, with data from the 2002-2003 surveys, added to and amended in the focus groups by men.

Uses of the forest in Kereng Bangkirai (2009)

Activity	Description	% people doing activity	Price and Quantity	Used for what?	Problems	Easy to collect?
Logging	No longer active – just for one's own needs	0%		Just for one's own needs – houses etc. There are still lots of uses for this, but people no longer brave enough to log	The government has banned it because it had nearly all gone – too many people were taking it before	Not allowed to log anymore Only the small trunks are left
Fishing	Fish with traps, nets and rods. No longer allowed to use electricity; banned by the government, and the community in agreement	60% people fish Nearly everybody sells the fish – not just for one's own needs	Can catch between 3-5kg per day – depending on the season Can catch 1.5t per year per person 5000-20,000Rp per Kg (seasonally-dependent)	For eating; Fish is extremely important for people here to eat enough protein – not often eating other meat	'Outsiders' still use electricity – and wipe out the small fish. There are outsiders that catch the baby fish	People thought that in 10 years the quantity of fish would be greatly reduced and the fish caught would be smaller There are now enough places for breeding and laying eggs, because people have started to look after these places
Farming	Normally people from the transmigration, in Block C	5-30%	Just sold locally; too expensive to transport to other areas. Also for personal needs.	Rambutan, corn, beans, leaves, chillies, cabbage, cassava, tomatoes, mangoes, oranges and coconut. Rubber and palm oil fields	Flooding and soil acidity.	People described farming as hard
Collecting fire wood	From wood that is already dead, for personal needs	Lots	Free to collect, so more profitable than buying cooking gas Cooking gas is only bought because it is easy to find	For cooking		Easy
Collecting dahanen	Collection does not kill the plant Before selling a cleaning process was involved	Depending on people's needs,10%	Not sold, people collect for their own personal needs only	For making fish traps	Fires cause a reduction in the available dahanen In the dry season, can't be collected – too far	In 10 years it was thought that the rattan would be about the same or slightly reduced The roots can re-sprout so it's not a problem.
Collecting gemur	The tree bark is dried and sold	2 - 20%	Normally sold to the middlemen who take it to the factory Can collect up to 25kg (dry weight) per day Price sold: 4500-6500Rp per Kg	Not really sure – just sold in raw form For mosquito repellant and glue	In order to collect the bark, people often cut down the trees, then have to wait for the tree to grow back (5 years to reach 10-20cm in diameter)	People thought that in 10 years the gemur would be reduced and that to find the gemur, they would have to travel further
Bat hunting	Sold in the Kahayan market and next to the Governor's office Food specialty	3-15 people in Kereng	17,000Rp for a live bat, 12,000Rp for a dead bat Only one species of bat collected Collected: 15 bats a night in the month of July, 25-50 the months of Sept and Okt, 15-50 the month of Nov Can make 2-3jutaRp per year Normally just sold locally	For food; the liver is eaten as asthma medicine, and the meat for other illnesses	Because there were lots of fires, and more people, there is less forest, resulting in less fruit, and consequently less bats	Have to go further to reach good hunting sites Before only large, older bats were caught but now often the small ones are caught too People thought that in 10 years the bat population would be reduced
Hunting birds	Species collected - cecak hijau, burung beo, murai, tinjau, betet, sarindit Hard to find, can find 1 in 3 days	2-5 people in Kereng	Normally just sold locally	As pets	The seasons are strange – there is less fruit, and lots of fires	People thought there were fewer birds, and they have to travel further to find them
Collecting purun	Long grass	1-10 people in Kereng	One mat – 15,000-25,000Rp	To make mats, hats and bags		There is more than there was before, because it grows lots after the forest burns
Hunting pigs	Hunted in the dry season – pigs don't like the wet	5 people in Kereng	Normally just for personal consumption or sold locally Between 20 pigs can be caught per year per hunter 10,000 – 30,000 Rp per Kg	For food	If there is not enough fruit in the forest, then the pigs will also decline	Still easy to find
Deer hunting	Collected and sold locally Only hunted in the dry season	10 people in Kereng	Can catch 6-20 deer per year 1,600,000 – 2,000,000 Rp per deer (40,000 Rp per kg, 40-50Kg per deer) Either for personal consumption of sold locally	For food		Because the forest is burnt, the hunters have to go further into the forest to hunt People though there are less hunters than before
Collecting jelutong	Doesn't harm the tree After three years the volume collected can reduce	20 people in Kereng, up to 10% But they have become the bosses and they bring in people (more than 100) to do the collecting	One person normally has1500 trees (10 rows, 100 trees per row) Results in 10-18 ton per year per owner 3000 - 4000 Rp per 1 Kg, 500kg – 1.5t per month, resulting in 1,5000,000 – 6,000,000 Rp per month Normally sold to a middleman who takes it to a factory	The sap is made into electricity cables , sandals, car tyres and chewing gum	Lots were cut down during the illegal logging, and also lots of trees are now old.	It was felt that in 10 years the population of jelutong would still be ok, but that the near by trees would be old, and they would have to go further to collect enough sap.

- 90% of people collected something from the forest - 50% of people said it was hard to find the produce - 90% of people from Kereng collected from or made their salaries from the forest or nature
- People said that people from other villages come and deplete the products of the forest - Normally people collect more than one type of produce from the forest, over 1yr; a rolling system dependent on season

Figure 4.11: The 'uses of the forest' table created from the synthesised data from the focus groups, to be used as a discussional aid in the interviews with women and elders (translated).



a)

b)

Figure 4.12: The annotated visual aid used in the focus groups with men for Topic 2, to promote discussion on views of the forest, both non-degraded (a) and degraded (b).

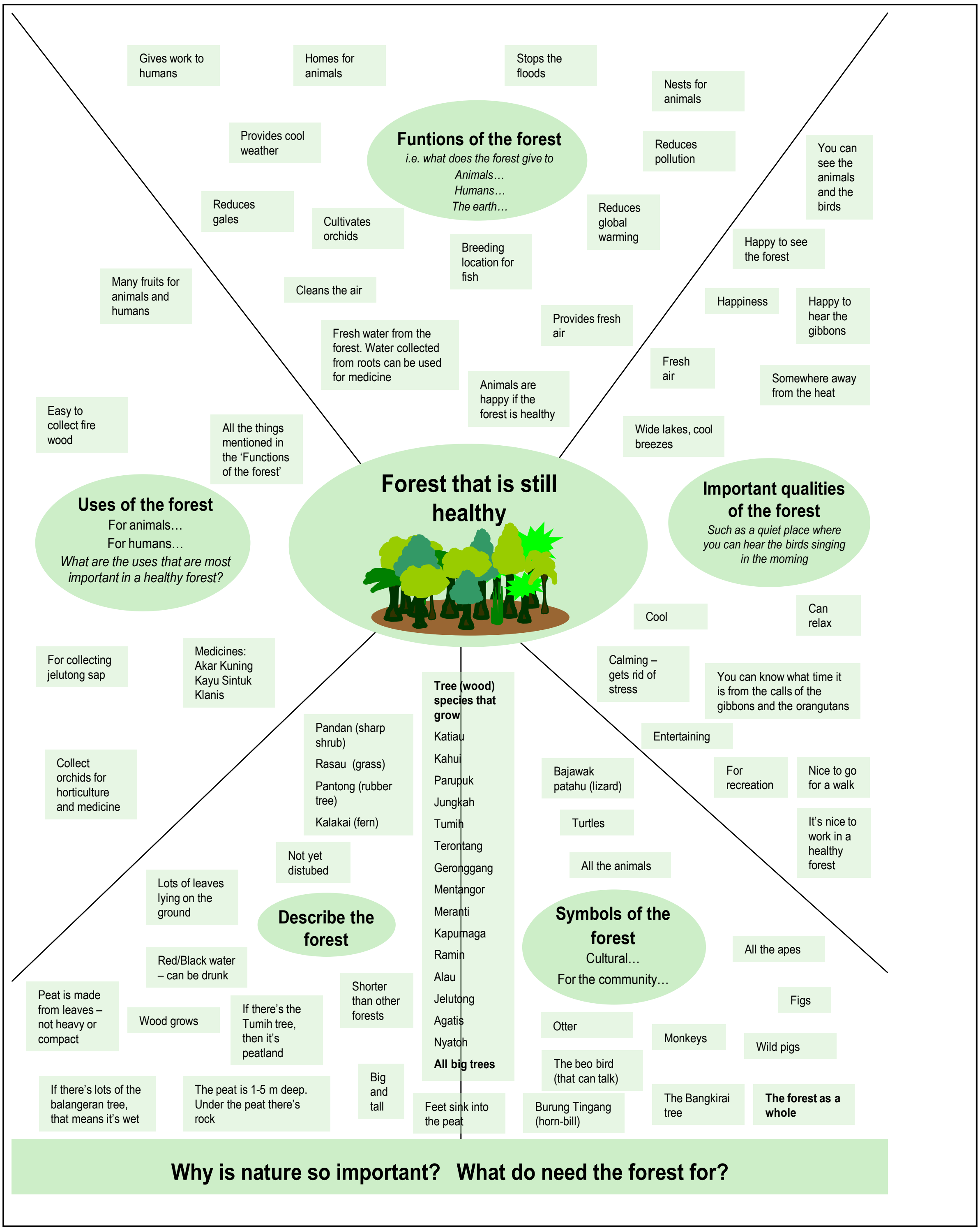


Figure 4.13a: The discussional aid on the views of the healthy forest, produced from the synthesised data gathered in the Topic 2 focus groups, used in the interviews with women and elders (translated).

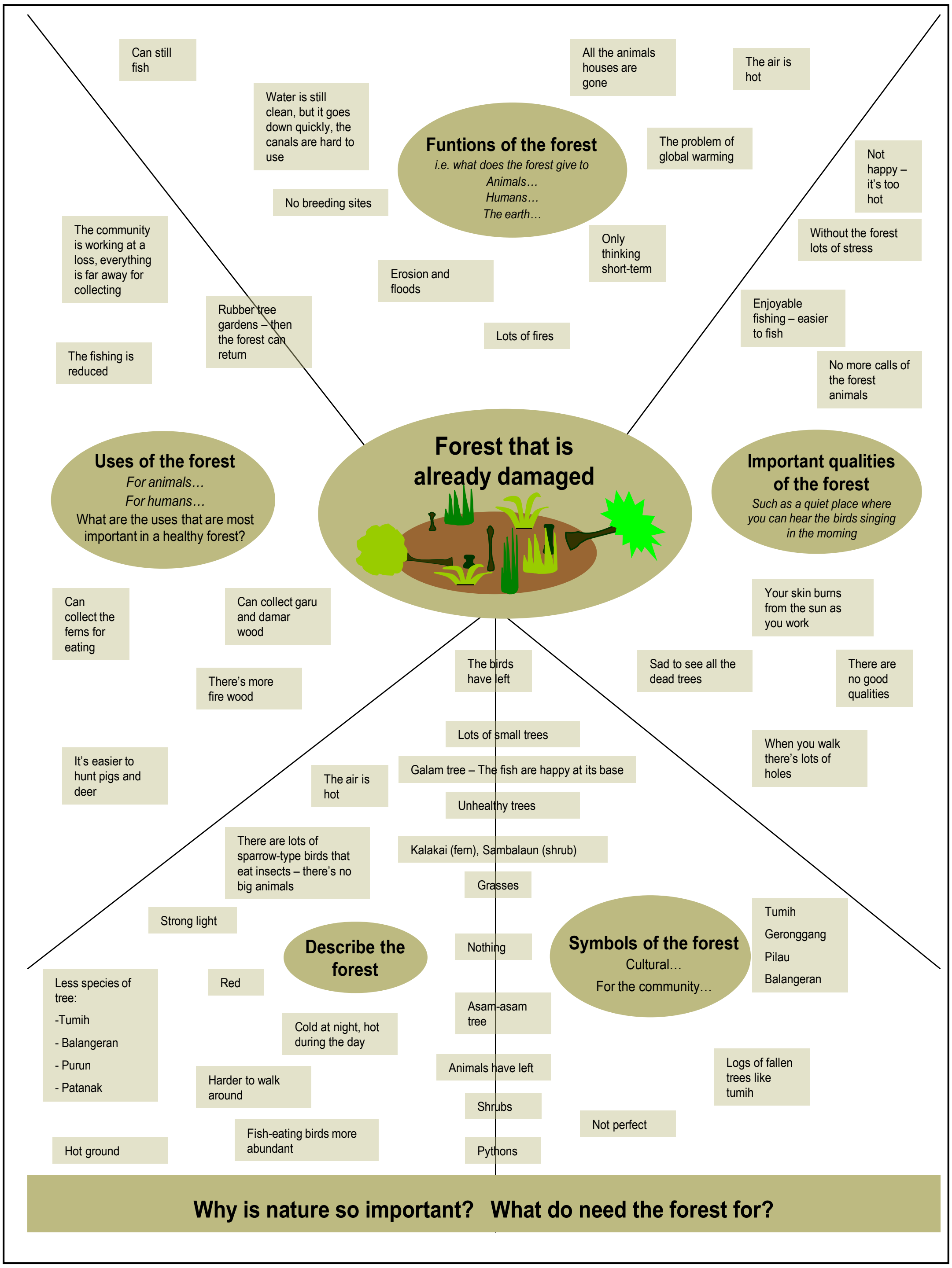


Figure 4.13b: The discussional aid on the views of the degraded forest, produced from the synthesised data gathered in the Topic 2 focus groups, used in the interviews with women and elders (translated).

Topic 3: Future of the land

This focused on how the community perceived the future of the land, both their desires and aspirations, and also their concerns.

Reviewing past surveys: Future concerns and sustainability for the area: The surveys of Smith and Lyons not only focused on present uses and activities of the forest, but also questioned perceived sustainability of these respective resources, and concerns about the future of the land. Thus, as described for understanding present uses and activities, a similar poster was designed summarising Smith's and Lyon's findings on future uses and concerns. These were discussed in focus groups and interviews as described in the above section (fig. 4.14.a).

Stepping stones: This diagramming method was used in the focus groups to establish what the participants saw as the major barriers or reasons that the site has stayed as a degraded site, rather than returning to healthy forest, and how they would overcome these barriers. This topic was designed to display some of the participants' attitudes and knowledge-base regarding land recovery and restoration, without obviously requesting them to design an 'action plan'. Also, the metaphorical nature of this diagramming technique appealed to the participants, given they live along a river.

A large poster was displayed to the focus group, in which a river ran across the empty centre. On one bank of the river was degraded forest, with the notation, 'this is where we are now', on the opposite river bank was a picture of 'healthy forest' with the notation 'this is where we want to be' (in the previous sessions it had become apparent that all participants wished to see the return of the forest, though the reasons and degree of need differed, and thus I felt I was not instructing them that 'this was I felt where they wanted to be' but instead felt this was truly 'where they wanted to be'). It was described that we were to find a route across the river; to transfer the forest from degraded to healthy. However, there are lots of crocodiles in the river (drawn on cards) which prevented us crossing the river easily. Fortunately there were also stepping stones (also drawn on different cards) which could help us get around the crocodiles (fig. 4.15). I described that the crocodiles represented all the problems and difficulties they would face in reaching healthy forest again, and the stepping stones represented their solutions to how they could get around these problems. They were encouraged to take the crocodile cards and write or draw on the problems, and for every problem to try and write a solution on the stepping stone cards. We would stick each card to the board and the exercise was complete when they had exhausted all problems (method adapted from Walsh and Mitchell 2002).

After four focus groups, the problems and solutions being discussed had reached saturation, and were compiled into a single poster (fig. 4.16), along with a second poster detailing the concerns from the future (fig. 4.14.b), regarding the first exercise. I then visited the homes of women and elders in the village and worked through each poster, discussing if they agreed with the findings, and had further interpretations.

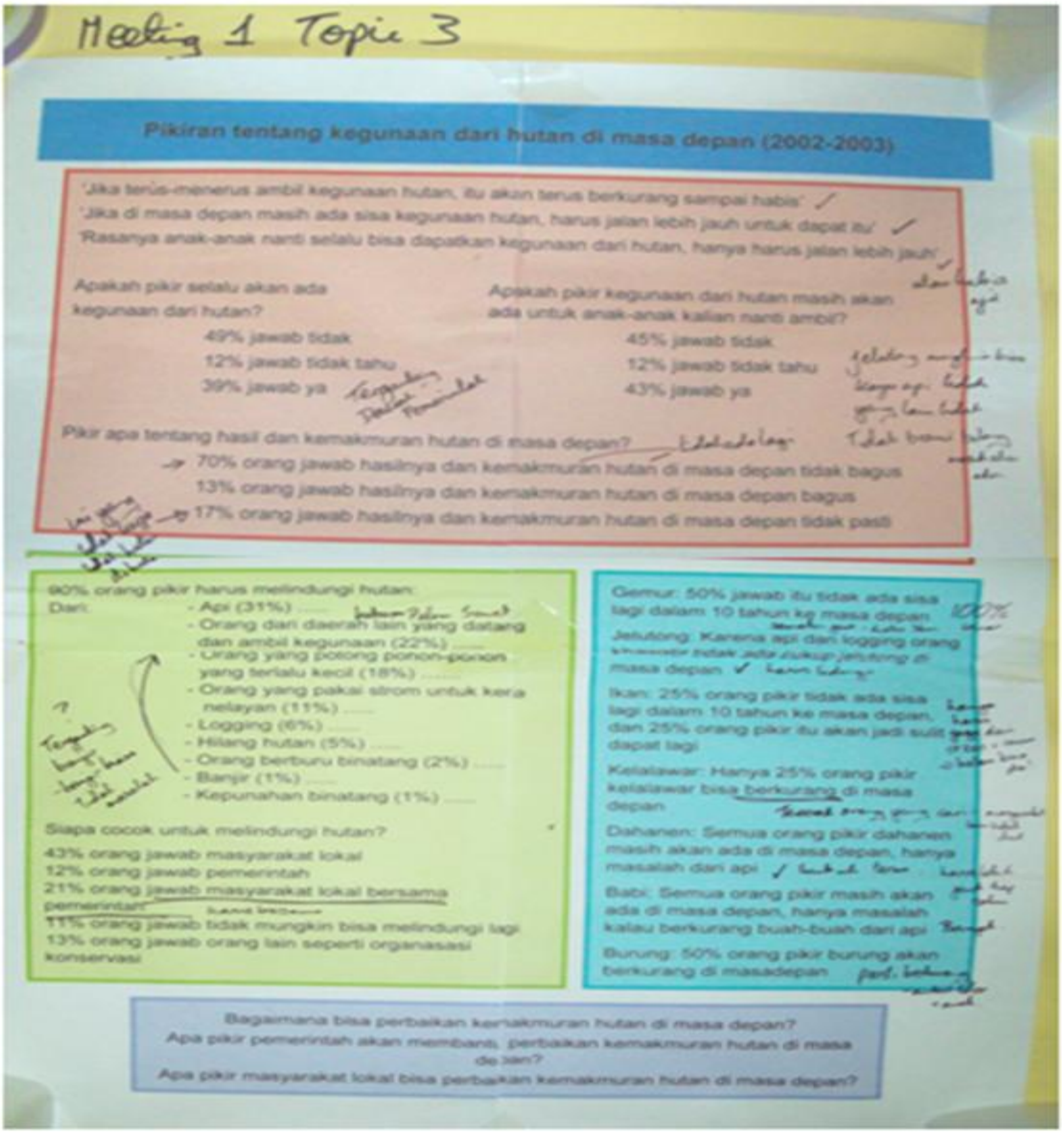


Figure 4.14.a): An annotated discussional aid used in Topic 3 to discuss the concerns for the future of the land in the focus groups.

Questions about the uses of the forest in the future (2009)

- Do you think you will always be able to use the forest? Or do you think things will reduce or run out?
- Do you think, to collect forest produce, you will have to travel further in the future?
- Do you worry that in far away places, the forest produce can also run out there? Or do you think in further away locations there will always be forest produce?
- Do you think your children and grandchildren will one day also be able to collect the forest products?
- Do the you think the quality of the forest in the future will still be good or less so?

Do we need to protect the forest?

From what?

1. Fires
2. Illegal logging
3. Fishing with electricity
4. Flooding
5. Hunting
6. Oil palm plantations

Who should protect the forest?

- The local community
- The government
- The local community together with the government
- Some other group, such as local conservation groups
- It can't be protected any more

Do you think the government will help to restore the forest in the future?

Do you think the local community can restore the forest in the future?

Gemur : Do you still think there will be gemur to collect 10 years from now? Why?

Jelutong: Do you still think there will be jelutong to collect 10 years from now? Why?

Fish: Do you still think there will be fish 10 years from now? Why?

Bats: Do you still think there will be bats to hunt 10 years from now? Why?

Dahanen: Do you still think there will be dahanen to collect 10 years from now? Why?

Pigs: Do you still think there will be pigs to hunt 10 years from now? Why?

Birds: Do you still think there will be birds to hunt 10 years from now? Why?

Does this community want to see the forest restored in this area?

Figure 4.14.b): The synthesized discussional aid used in Topic 3 to discuss the concerns for the future of the land in the interviews (translated).

Figure 4.15: The diagramming technique ‘stepping stones’ used in the focus groups to discuss barriers and solutions to forest restoration.

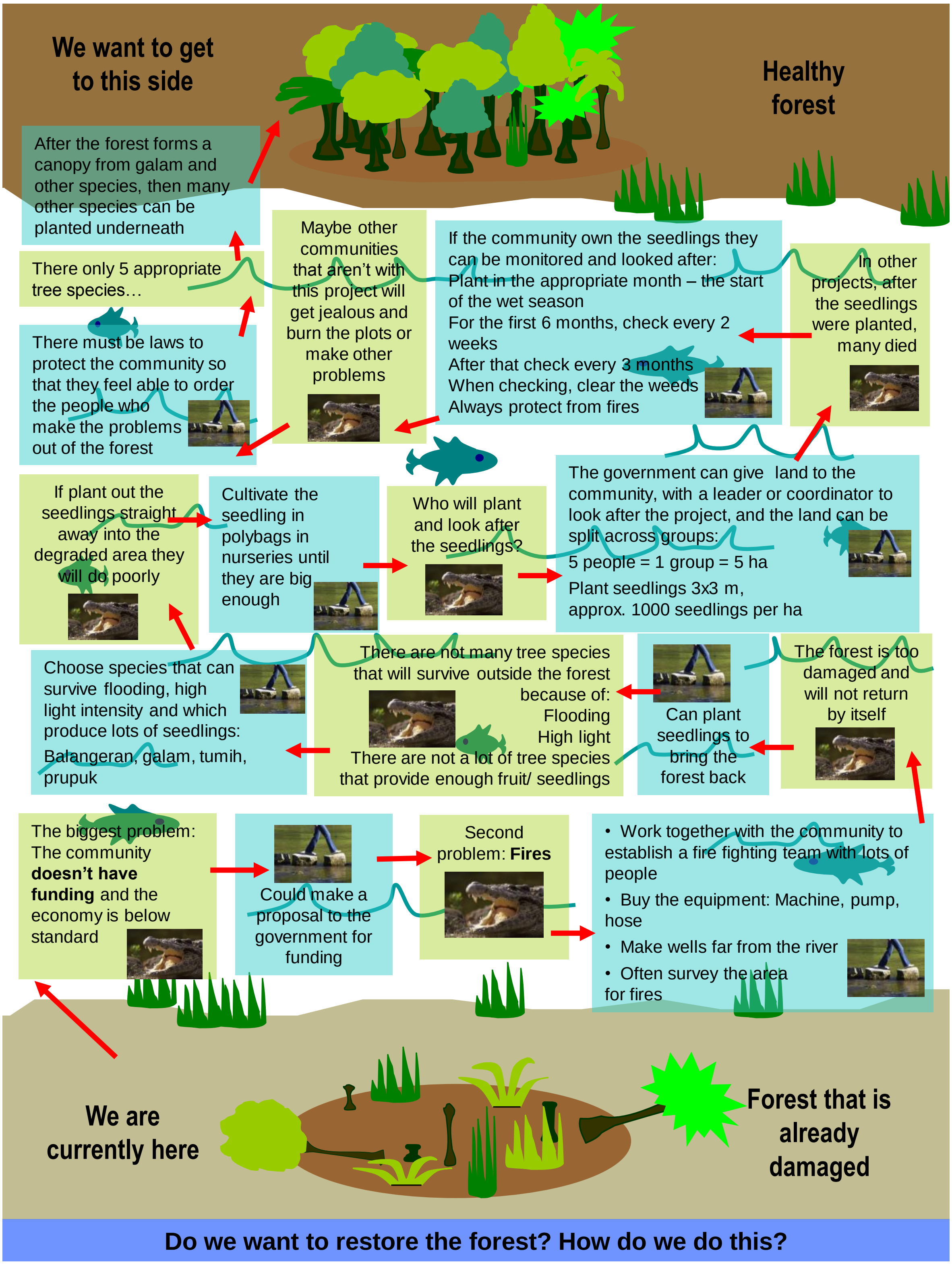


Figure 4.16: The synthesised findings of the focus groups of Topic 3: Stepping stones diagramming technique used as the discussional aid for the interviews (translated).

4.4.8 Credibility and dependency

Credibility and dependency of interpretations from the activities and discussion can be increased by triangulation; achieving the same conclusion through different routes (Baxter and Eyles 1997). In this study, by repeating focus groups of the same topics, but with different participants, I was able to see similar themes and interpretations emerging from the different groups, showing triangulation of sources. I only moved onto the next topic when I felt that no new (or very little new) information was being discussed. Furthermore, after the focus groups of each topic, the findings were visually represented, and taken out into the community, to two further demographic groups (women and elders), where the topics and findings were re-discussed. This showed if other members of the same community found agreement and recognition in the first set of findings, one of the criteria of Baxter and Eyles (1997) standards for credibility.

In addition to the participant activities, I kept a field diary and recorded personal experiences and observations. These added to my interpretation and discussion, and provided a further method of triangulation. Finally, an in-depth literature review of Indonesia's history and political influences and how this may have affected the study site and attitudes towards the landscape was used to draw comparisons to the interpretations of the primary data, generating theory triangulation (Baxter and Eyles 1997).

4.4.9 Analysis

Through the participation activities my aim was to develop an understanding of what the local community saw as potential barriers facing the restoration of this site, and also, to elucidate potential hidden barriers. In the interviews and focus groups I recorded, transcribed and translated the conversations, I took notes, and photographed the diagrams produced. After reaching saturation and completion of each topic within the focus groups, I compiled the findings into single findings sheets that were also used as visual stimuli in the interviews. Using the transcripts, I drew out, translated and sorted quotes and discussions into relevant themes/issues that developed. The translations were 'smoothed' in the sense that the meaning of each quote was as accurate as possible and the 'voice of the participants' still maintained. However, given the different grammatical structure of the Indonesian language compared to English, a degree of re-structuring sentences was required to allow sense to be conveyed properly. For each topic, I produced a 'first-draft summary', bringing together themes and interpretations. At the completion of each topic, all themes from the previous topics were also revisited, allowing evolution of the interpretations. These 'first-draft summaries' were then explored during peer debriefing sessions held with my supervisor, as a means to add credibility to my interpretations. From there, the overriding themes were bridged together to address the final goals of the research.

4.5 Integration of Knowledge: Addressing the 'barrier gaps'

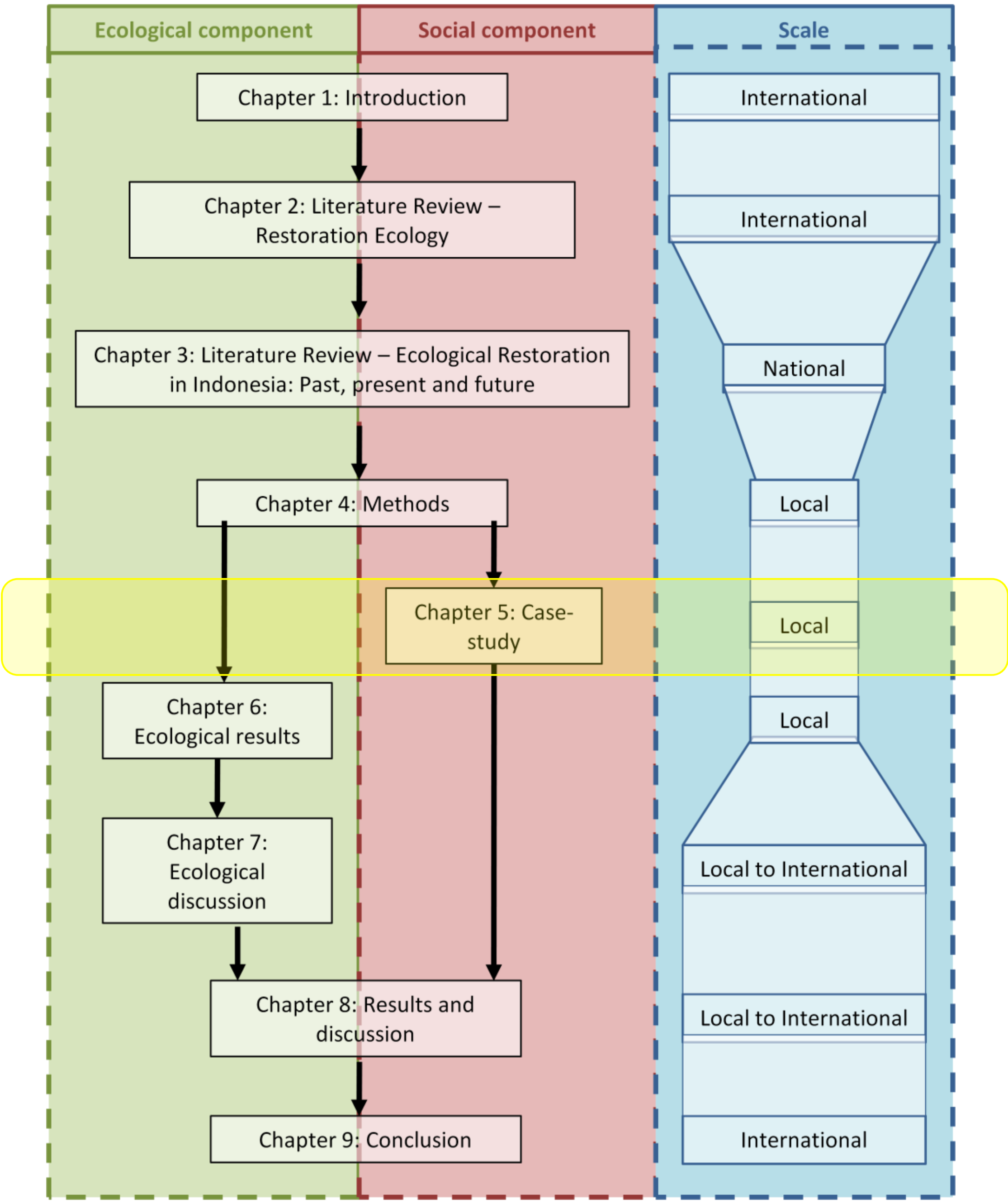
Higgs (2005) describes this necessity of addressing the 'two-culture problem': to no longer keep the ecological aspects separate from the social, political, historical aspects. He describes the gap between these sciences and calls for the need of some integrated learning programs in RE, closing the gap. Similarly, in restoration projects, it is essential that practical routes are established to address the 'gaps between the disciplines', and it is hoped this study has made some steps towards determining these methods.

At the outset of this research, it was difficult to anticipate how these routes might evolve. Instead, maximum opportunity for cross-transfer of knowledge from the ecological study site and the village, and emerging barriers was provided. Having one focal researcher at the heart of the study, dealing with the both the 'ecological' and 'social' aspects, allowed themes and concepts to flow across the so-called ‘gap’, so that the findings evolved as a whole rather then two halves. Results could be exchanged easily between the study site and the community, and the routes by which this occurred and the responses and reactions this incurred were recorded through data-keeping and a field diary. Thus, whilst the methods outlined above allowed an understanding of the restoration barriers facing this study site, these methods also facilitated the observation of potential new, future routes to addressing the ‘barrier gaps’, later discussed.

4.6 Conclusions

The aim of this study was to explore both the social and ecological barriers that are currently preventing regeneration of a degraded TPSF site, and how these might be overcome. The methods to achieving that have been described above. Equally, by containing both the social and the ecological aspects within one study, it was hoped that routes for integrating these two disciplines might be developed. As is discussed in greater depth in Chapters 8 and 9, it was found that the results rather than the methods can and should be integrated, but this can only be successfully done if all methods are undertaken and all data collected by a single body, rather than two factions. Thus, this methods chapter, whilst obviously distinct in is ecological then social components, should not be seen as two separate studies, but one single study that requires a variety of methods from a combination of disciplines in order to answer a single question.

5. Case-Study



Ecological component
Social component
Scale
Chapter 1: Introduction
Chapter 2: Literature Review – Restoration Ecology
Chapter 3: Literature Review – Ecological Restoration in Indonesia: Past, present and future
Chapter 4: Methods
Chapter 5: Case-study
Chapter 6: Ecological results
Chapter 7: Ecological discussion
Chapter 8: Results and discussion
Chapter 9: Conclusion
International
International
National
Local
Local
Local
Local to International
Local to International
International

5.1. <u>Introduction</u>

In any restoration project, location, site history and stakeholders are crucial to understanding both the barriers facing the restoration and the solutions to alleviating these barriers. Furthermore, the stakeholders involved in the process of engagement will undoubtedly influence the data collected. This chapter provides a link between the methods used to collect the data (Chapter 4), and the actual data collected (Chapters 6-8). The data presented in this chapter were specifically collected in order to represent the socio-demographics of participating stakeholders, along with a discussion of all stakeholders related to the site.

5.2 <u>Study site</u>

5.2.1 The forest

From 1966 to 1996 the upper catchment of the Sabangau River was classified as 'production forest', in which selective 'concession logging' was carried out legally under license. A logging railway was constructed from the river running 24 km into the forest. This created an access route and a means to transport felled trees to the river. After 1996, illegal logging continued until 2004, and during this time many small canals and skid trails were constructed for the purposes of transporting felled trees. As a result of the selective logging, clear fell logging, illegal logging and subsequent fires, this site has undergone many changes from its natural state, which are most extensive in the riverine and transitional forest zones (see fig. 4.2).

5.2.2 The governance

Without institutional, local and national governmental support, any kind of changes in land-management, land access and procedural processes are difficult, if not impossible to negotiate. The roles of the various institutions and government bodies involved in the management of the ecological study area are discussed below.

CIMTROP

The research location, the Natural Laboratory of Peat Swamp Forest (NLPSF), and its research camp, covers an area of 500 km^2 in the Upper Sabangau Catchment, and is overseen by the organization CIMTROP. CIMTROP (the Centre for International cooperation in the Management of Tropical Peatlands) was established within the Forestry Department of the local university, University of Palangka Raya (UNPAR) in 1998. CIMTROP-UNPAR is a semi-independent institute focusing on the management and restoration of tropical peatlands, through international collaboration and local research. All full-time research assistants at the Natural Laboratory are local men, employed by CIMTROP. There is also a Patrol Team, established by CIMTROP, with 5 men from Kereng Bangkirai who work within the local community, and patrol the forest edge and river, reminding local forest users of legal and non-legal forest activities, of fire management techniques, and reasons for using the forest sustainably.

CIMTROP aims to find win-win solutions through wise-use and sustainable management that will both protect the peatland and the forest, but also protect and support the interests of the local communities. They do this through facilitating and conducting ecological research at two research sites which they manage, educating the local communities, advising local government, and raising international awareness through collaborations with foreign universities and holding conferences and workshops (information from pers. comm. Limin, Director of CIMTROP).

To conduct research in Indonesia requires a letter of support from an Indonesian academic organization, who then acts as the researcher's 'sponsor' throughout their time in the country. There were numerous benefits to my sponsor being CIMTROP: CIMTROP is the key gate-keeper to gain access to the NLPSF. I had already collaborated with CIMTROP since 2004, and built up a positive relationship. Furthermore, CIMTROP had collaborated with my university and one of my research supervisors since the mid 1990s, allowing me to join a well-established partnership. CIMTROP also has built up a positive relationship with the local community of Kereng Bangkirai, and CIMTROP's experienced staff provided the assistance and guidance I needed throughout my studies. Finally, I felt comfortable with the work priorities and ethics CIMTROP displayed with regard to their research and development in the surrounding communities. This was important as in some respects my research activities were governed by CIMTROP.

There were, however, certain limitations of working through CIMTROP. Whilst their activities support local livelihood and community enhancement, they were the recognized managers of the land. Although local knowledge and perspective might be used to guide some of the decision-making, the agenda is predefined: the community interaction is 'consultation', in which 'outsiders' (CIMTROP, myself) pre-define the problem, the local community are asked their opinion, and the outsiders accept or reject local opinion, and decide on the action (Walsh and Mitchell 2002).

As such, this research is limited in the sense that 'empowerment' cannot be the target, as the power-relations, agenda and broad desired outcomes are determined and fixed. One could argue, however, within the aims of ER, 'true empowerment' rarely exists, as 'true ER' creates certain limitations and expectations of what must be achieved. CIMTROP, in essence, follows the expectations of ER, as it is looking to meet the social *and* ecological needs of the area.

Local government

The presence and activities of any foreign researcher must be declared to the local government. Provided approval is gained from the national government in Jakarta, the local government is not normally involved in the research conducted, although they must be aware of the researcher's presence. CIMTROP fosters a good relationship with the local government, often advising them on land-management and conservation issues. Further, in September 2005, the Governor of Central Kalimantan made a public pledge 'to sustainably manage the peat swamp forest of this region'.

RISTEK

RISTEK, the State Ministry for Research and Technology, approves the entry and activities of any foreign researcher into the country. CIMTROP and RISTEK generally have a smooth working relationship. At the local scale, CIMTROP was the only institution I needed to have any direct contact with to conduct my research, however, my permits and all my research activities had to be approved by RISTEK.

5.2.3 The local community

The Sabangau River rises in the TPSF of Central Kalilmantan, due north-west of Palangka Raya, and meanders south for about 150 km until meeting the Java Sea. Along its banks are numerous settlements and villages, which have been expanding in number and size during the last 50 years as a consequence of the Government transmigrations programme and population growth.

Demographic surveys were made in 2002 and 2003 in the settlements along the Sabangau and Katingan Rivers (the Katingan river runs south, approximately parallel to the Sabangau, due west), and their findings are summarised below (Lyons 2003, Smith 2002):

The largest village and fishing port along the Sabangau River is Kereng Bangkirai, which is also the nearest settlement to the NLPSF and to Palangka Raya. At the time of this study Kereng Bangkirai had a population size of approx. 5,500 individuals, from 1,500 families. Approximately 75% of this population was Muslim, and 25% Christian. It should be noted that in 1972 over 70 'tribal families' joined the existing 30 'tribal families', through the transmigration program, taking the population size from the low hundreds to over five thousand. Many of the migrants were relatively local, from other districts in Central Kalimantan, rather than, as was more common, Java, Sumatra or West Kalimantan.

The village contained two nursery schools, five elementary schools and three junior high schools. It had one health clinic, one doctor, two nurses, and two midwives. It had a concrete road running to Palangka Raya (approx. 15 km away), with a functioning taxi service between the village and the city (in this region, roads still remained scarce and of poor quality, with many villages only connected to other settlements by river or canal). T

The village heads described the harvesting of non-timber forest products (NTFPs) as a main livelihood activity of the villagers and essential for their subsistence needs. Few people had permanent jobs, but instead followed seasonal patterns to make an income from their land and the natural resources. Also, more regular jobs were often supplemented by collection and use or sale of forest resources. Harvested NTFPs included: rattan, a climbing spiny palm, for making mats; bark of the gemur (*Alseodaphne coriacea*) tree, for making insect repellent; tree sap from the jelutong (*Dyera polyphylla*) tree for making latex; fuel wood; bats, as an edible delicacy; forest pigs, for food; birds, to sell as pets; deer, for food; and fish, for food.

a) 

b) 

Figure 5.1: Kereng Bangkirai (a) main road, Jl. Mangkuraya (b) the harbour

5.2.4 Rights to the land

Land ownership and access rights in Indonesia are often complicated and confused, as discussed in 3.7.2. The degraded area of TPSF which was the focus site for this study is no different. An overview of some key features relating to ownership, management and access of this area is presented below. The data is collated from discussions with government and Adat village representatives from Kereng Bangkirai, the head and senior staff of CIMTROP and the local community. The data correlates strongly with other literature regarding land law, access and property rights in Indonesia during this time (3.7.2).

Before 1910 – The area was forested, with little, if any, human activity or claims to the land.

1910-1930 – The 'village' (less than ten houses) established along the river; families and households cleared and claimed small plots of land.

Around 1950 – President Soekarno made a law that the community could work land up to 5 km from the river into the forest; further inside was for the logging companies. Many people from the local community still remember and apply this law (some also say 3 km). However, President Suharto abolished this law.

1957 – The village was recognized by the government. More families moved there. Government law and land management gradually replaced that of Adat law.

1971 – Transmigrants from Kahayan and Kapuas regions moved to Kereng; land was cleared, 70 new houses built and 60% more people moved to the village. People originally from the area relied on the forest for income and personal needs. Transmigrants more commonly farmed plots of land.

1979 – President Suharto made a law that all forest was under the control of the state.

1971-1995 – Numerous logging permits were issued by the government to logging companies, who established along the Sabangau River (i.e. forest classified as Production Forest). Over the years the species which could be legally logged increased and the minimal trunk size decreased. The community was still able to access the forest, and generally the forest remained in good enough health to meet their needs. They felt excluded from participating in the logging.

1995 – President Suharto banned all logging companies

1995-2004 – Period of illegal logging. Logging companies continued to operate, with government turning a blind eye. The community was free to participate, but the regulating and provisioning ES the community depended on were notably in decline. CIMTROP worked to prevent illegal logging in the NLPSF (see below) with good success. The government finally became involved in 2004; then illegal logging in the area largely came to an end.

1998 – CIMTROP and the Natural Laboratory of Peat Swamp Forest (NLPSF, 500 km^2) was established. Most of the forest used by the local community fell under the control of CIMTROP. Whilst fires and logging were prohibited, collection of forest products was allowed.

2004 – Sabangau National Park (568,700 Ha) was established in 2004. This park included the area of the NLPSF, however, CIMTROP was largely left to control this area of the Park.

5.3 <u>Recruitment</u>

5.3.1 Gender

As far as I observed, gender equality with regard to participation was not an issue in this village. The area was a mix of Muslims and Christians, and both Muslim and Christian women could be found in all types of jobs, both before and after marriage and after having children. Whilst there was a tendency for women to be the primary ‘home-carer’, household chores were shared between married couples and older children, and men often played a large role in child-care. Whilst it was rare to have a woman going to work and a man stay at home, it was perfectly acceptable for both to be educated and work, in agriculture, teaching, government jobs, etc. However, colleagues working in the more remote areas had observed women being forced into young marriages with reduced chances of education.

The only time there were mixed-gender participatory activities was, to involve the older members of the community, those above 60 were interviewed in their homes (see 5.3.2). Given the home interviews were much more informal, sometimes when an older man was being interviewed, younger women of the household might participate, or an older married couple might be interviewed together, or family groups would naturally form during the interview. In these instances, I remained attentive to any inhibition of the women to speak, by the presence of men, but did not witness any instances. Given the informality and the family composition, it seemed these were quite natural and comfortable discussion groups. In fact on a couple of instances, I witnessed the women telling them ‘no, no that’s not how it was’, showing that all participants were able to express their views.

Of the 154 participants, 69 were male, and 85 were female. This ratio became slightly weighted towards the females towards the end of Topic 2 and Topic 3. In a couple of the family homes that were used to do the informal female interviews, they were houses that clearly supported friendly neighbour relationships. Thus, after the first one or two meetings, after which word spread of their nature, there was an influx of participants (mainly female) to these homes, ‘dropping by’. Given that the interviews were informal, I did not wish to create restrictions on numbers. Whilst normally the group size for women home interviews was between 2-9 women, on 4 occasions it increased to 10-15. When the group sizes were ten or above, several of the women took the role of observer rather than participant.

5.3.2 Age

Participant ages ranged from 17 (female) and 24 (male) to over 80 (male and female; exact ages often unknown) (fig. 5.2). Only participants over the age of 30 were invited to Topic 1, as this focused on the history of the area. Participants over 60, regardless of gender, were interviewed in their homes.

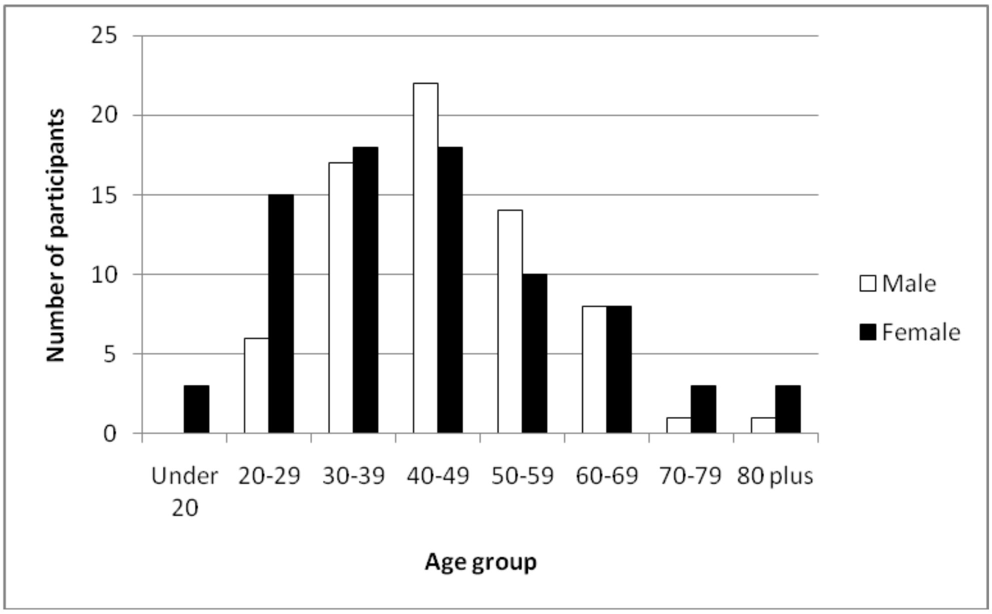


Figure 5.2: The ages of participants across genders.

Through personal observation, there were no obvious ages at which people were perceived to become adult, or at an age at which their opinions became especially valid. The age at which children left education varied, depending on family circumstance, and after this, they were expected to help support the family, either assisting in the home, finding a job or some form of income, or working on the family land. Girls as young as 15 occasionally wed, although normally they were in their late-teens or 20's. There was an attachment by men to the age 25; being referred to as the age 'their body changes, and they become grown up', though this did not especially correlate to the age they marry (also normally in their 20's).

Older members of the community were treated with respect, but there was not an obvious tendency towards elders having more authority. There were two heads of the village (one government, one *Adat* – traditional law), and both of these were middle-aged people.

Based on this there were no obvious ages to specify as a cut-off point for participants being too young or too old. Smith (2002) interviewed those above 16, and gave no cut off point for older participants. However, her surveys used mainly one-to-one interviews. I largely used focus groups or group interview discussions, and, as stated above, respect was often given to those with a higher education level or in positions of authority. Participants, therefore, as young as 16 might have felt uncomfortable taking an active role in discussions. Thus, I determined to set a non-strict minimal age of 20. Consequently, whilst 3 women participants were under 20 (17, 17 and 19 respectively), the youngest male participant was 24 (fig. 5.2). Given that no especially young men participated, I did not witness across the male focus groups any inhibition based on age: a young man was just as likely as an older to man to participate actively or to take the role of observer. For the women, however, there was a slight tendency that the youngest women did not participate so actively, however I felt this was more due to their not having yet formed strong opinions or knowledge, rather than an inability to speak out. For example, when the interviews side-tracked into more jovial topics, the younger women took a role in the discussions.

5.3.3 Religion

Approximately 80% of the participants were Muslim, 15% Christian and 5% Kaharingan (the local religion) (fig. 5.3). This reflected the proportions of the participants from the village.

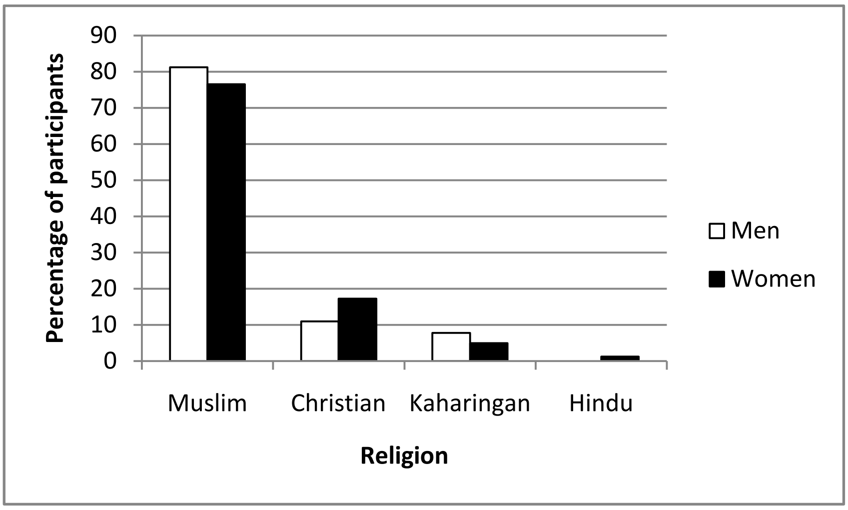


Figure 5.3: The percentage of participants from the different religions.

There were some Hindus and Catholics in Kereng, but they are very few in number and hardly any were recruited as participants. Religion was an important feature of life in Central Kalimantan, and acted as a defining, identifying characteristic. Despite this, given the accepting and non-confrontational nature of this culture, in reality I saw the religious component causing little tension. I have, numerous times, heard the expression 'I'm a Dayak first, Christian/Muslim second', and this unity of culture rather than religion shows strongly. The only affecting component in relation to this study was the associated 'taboo' of discussing non-halal animal products, for example, pig-hunting. Without Christian's in the group I found it awkward and difficult to establish pig-hunting frequency, etc.

5.3.4 Occupation

Occupations were associated with different perceptions of wealth, ease of living and life-style, and thus it was important to cover all the main occupation groups. The most common male partipant occupation was fishing, followed by 'unemployed' and farmer. The most common female occupation was housewife, followed by farmer, shop keeper and fisherwoman (fig. 5.4).

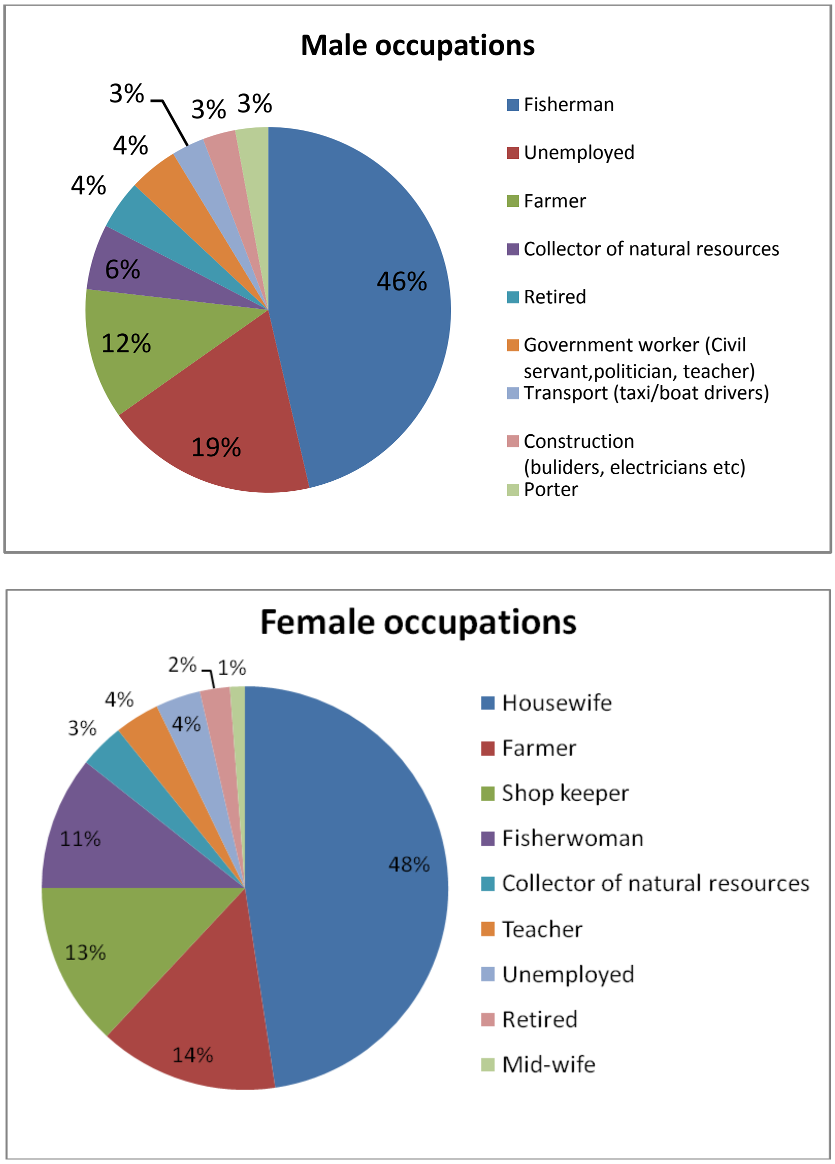


Figure 5.4: The percentage of occupations of the male and female participants

Occupations were often associated with different attitudes or respect. For example, shop owners were often seen as having a very 'comfortable' livelihood, those working for the government were considered to have prestigious jobs, whilst those working on the land, whilst not with negative connotations, did not receive as high a level of respect. As I had not previously witnessed obvious tensions or inhibitions amongst villagers, based on their occupations, I chose to have focus groups with participants of mixed occupations. However, I remained sensitive that some inhibitions may have occurred around those with more ‘prestigious’ jobs. I did not witness this, and, in fact, as the topics revolved around the community’s interactions and knowledge of the forest, the jelutong collectors and fishermen, who might ordinarily be inhibited speaking out in front of a civil servant, in this instance were better equipped to answer my questions. Furthermore, as the collectors of natural resources and farmers out numbered those in ‘higher up’ occupations in all the focus groups, again, this reduced any inclination not to speak out.

Whilst many of the men were fully active fishermen, others often described their job as ‘I used to do this, but now I just fish’, or mixed in with other occupations, such as farming. This highlights how this had become the fall-back and also supplementary occupation for nearly all participants. A lot of the men also described how they used to help with the logging companies, but now were forced in to fishing. A surprisingly low number listed their primary occupation as collector of natural resources, a reduction from the 2002 survey in which 10% gave this as their main occupation (Smith 2002).

‘Unemployed’ has a different connotation to unemployment in the UK. People may have proper employment in which they receive a salary, such as a teacher or builder, or they have a livelihood, such as farmer or rubber collector, which earns them money, or else they would describe themselves ‘without work’. However, as there are no state benefits, ‘without work’ generally meant they have no *fixed* work or livelihood, but instead, for example, would ‘wait around the harbor and help carry baggage for tips’.

The women most frequently described themselves either as house wives, or as collectors/sellers of natural resources, such as edible ferns or fire wood. If the latter, I classified this of collector of natural resources. Often, the women would farm on a small scale, e.g. vegetables, chicken, pigs etc., and were therefore recorded as farmers, or were fisherwomen, although they did this on a smaller scale than the men. The men would go on long trips to fish, where as the women would keep the house, and fish in their spare time in nearby water ways.

All the participants were asked if they collected natural resources (including fish) from the surrounding area, and if they were no longer able to collect these products would it have a negative impact on their lives. Of the 154 participants, only 6% of the male participants said they did not collect natural produce, and 7% said it would not be a problem if they could not collect it any longer. Of the female participants, 13% said that they did not collect any forest produce, and 16% said it would not affect them if they could not collect them anymore.

5.3.5 Residential block

Kereng Bangkirai was split into 4 spatial, residential blocks (Block A, B, C, D) (fig. 5.5). Each block had certain associations in terms of wealth, occupations and conduct, thus it was important that people from all blocks were represented. Of the 69 male participants, 7% were from Block A, 24% were from Block B, 17% were from Block C and 52% were from Block D. Of the 85 female participants, 7% were from Block A, 18% were from Block B, 27% were from Block C and 48% were from Block D (fig. 5.6).

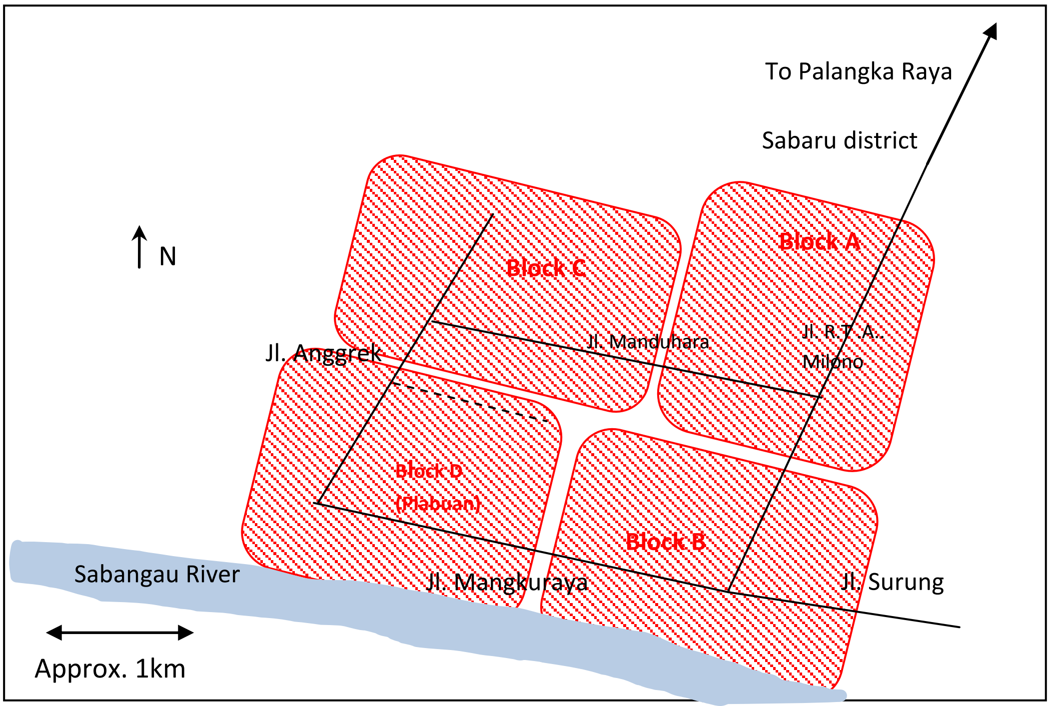


Figure 5.5: A stylised sketch of Kereng Bangkirai showing the village blocks (Jl. – Jalan – Road).

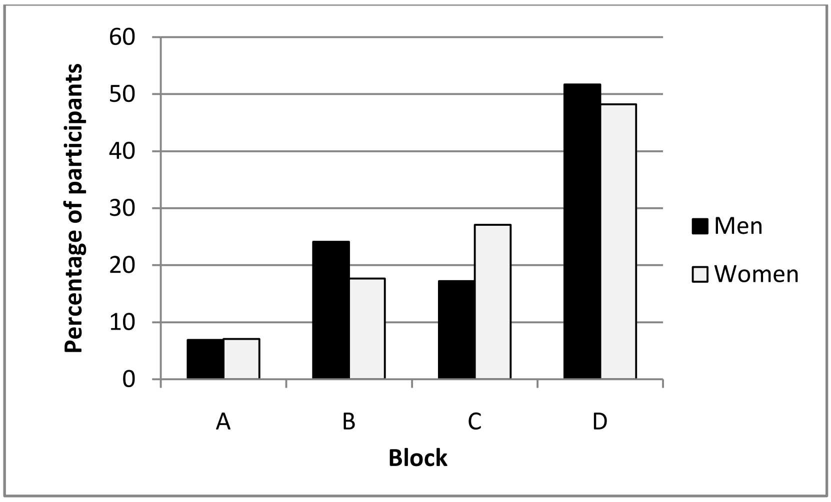


Figure 5.6: The percentage of male and female participants with respect to their residential block.

Block D (also called Plabuan meaning Harbour) was the region by the river and harbour (South-West), Block B also bordered to the river (South-East), Block C was away from the river, out towards the forest and agricultural area (North-East) and Block A followed the main road out of Kereng towards Palangka Raya (North-East). Block A was the newest block, as houses were initially built nearest the river. Block A continued to extend with new housing estates, until the most northern end of Block A was governmentally split into a separate district, Sabaru. Sabaru, which was mainly inhabited by newcomers, was not included as an area for recruitment in this study. People from Block A, and more so from Sabaru, were considered to be less involved with the forest and its resources, often owning shops or commuting to Palangka Raya for work.

There have been, at different times, different conflicts between the blocks. At one time there was a ‘gang-war’ between two blocks, and on another instance, rumours that one block was being giving preferential treatment in finding jobs. Therefore, both to minimise conflict, and to represent the different views and needs of the different blocks, individuals from all blocks participated in the activities. Whilst there may have been some underlying tension between the blocks, I did not witness any evidence of it throughout the sessions, although the different perception of the different blocks was sometimes apparent.

The majority of the participants were from Block D and least from Block A (fig. 5.6). Block A had fewer participants as it was more difficult to find interested and knowledgeable people from this block with regard to the topics discussed. For two reasons, Block D was the largest group represented. Firstly, Block D inhabitants probably were the most often involved in both land-management or natural resource collection issues. Being situated at the harbour, they were not only often keen fisherpeople and linked with the surrounding land and forest, but also, consequently, they are often recruited by organistations like CIMTROP, WWF, etc. It was therefore possible to find numerous willing participants. Secondly, there is a very small road, with lots of houses, that ran parallel and between Jl. Mangkuraya and Jl.Manduhara (fig. 5.5). I wished to represent the participants of this road in addition to those living on Jl. Mangkuraya (Blocks D and B) and Jl. Manduhara (Blocks C and A). At the time when I conducted these interviews I was not clear which block these participants represented: as can be seen from the map it had the potential to be in any of the four, and was a central location. In the end, it was defined as Block D, pushing up the numbers of this block further.

The major occupations for men and women, with respect to the four blocks, also represented different occupational groups (fig. 5.7). For the men, Blocks B and D represented the majority of fishermen, being the two blocks adjacent to the river. Whereas Blocks A and C had the majority of farmers, being located closer to agricultural land. For the women, being a housewife was common across all four blocks, but most so in Block D. In Block B fishing and shop keeping were also common occupations, as might be expected given their proximity to the river, and it was also common for women to sell collected NTFPs. I was surprised to see this was not also the case in Block D. Block C had a dominance of female farmers, even over shadowing the percentage of housewives.

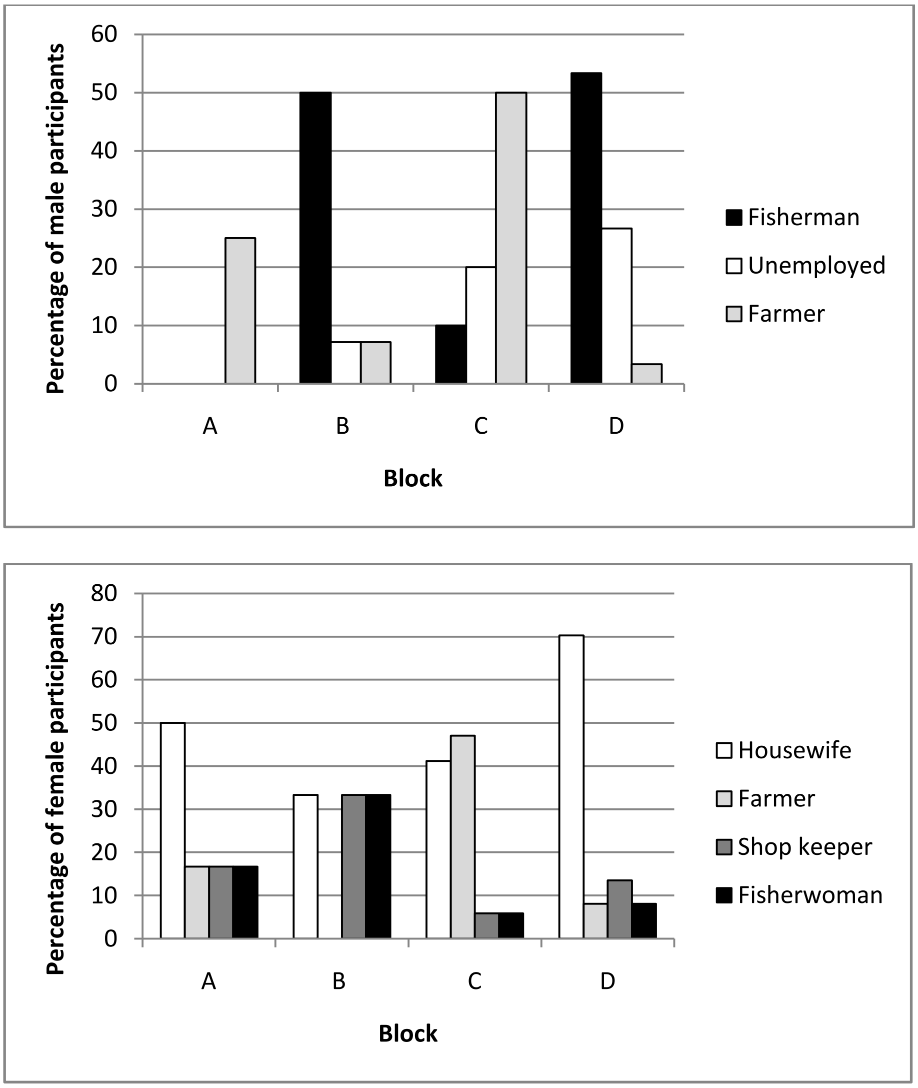


Figure 5.7: The percentage of male and female participants with respect to their block and the main occupations

5.3.6 Level of education

Final level of education was a useful indicator of wealth. The majority of the participants had reached up to primary school education only, suggesting general low wealth in the community (fig.5.8). There was little difference between the level of education for men and women, however slightly more women had received no education. All those who attained no education were over the age of 49 for both sexes.

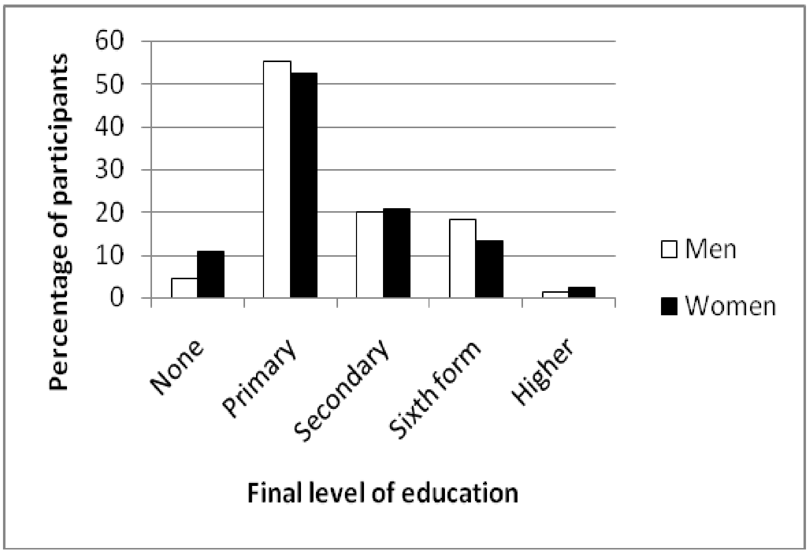
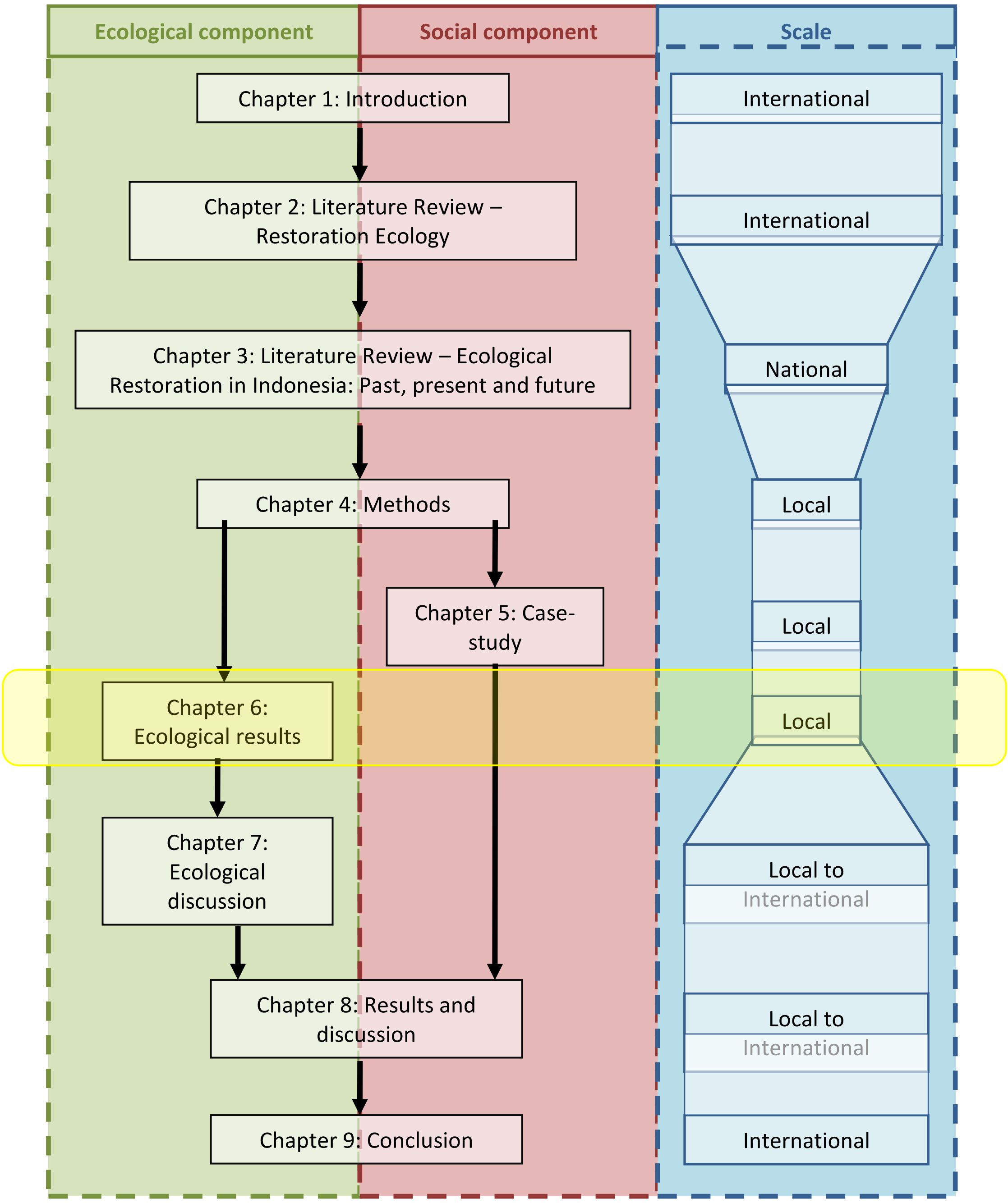


Figure 5.8: The final level of education attained by the participants.

5.4 <u>Conclusions</u>

Given the strong interplay between the land and the surrounding community it was necessary not just to see the participants as stake-holders of the land, but also to understand the nuances of their culture and village and how this might impact on the data collected. This overview provides some of the more relevant observations regarding the participants, representing the ethnographic componant of this research. This greater depth of understanding was necessary to explore and understand the data collected and the results presented in subsequent chapters.

6. Ecological Results



6.1 Introduction

In this chapter the data from the ecological aspects of this investigation are presented. As described in Chapter 4 (section 4.2.1) the ecological study site encompassed natural forest (that represented the control), a forest edge zone and a degraded forest area. Within this, five forest zones (FZs) were identified and their forest characteristics fully described (fig. 4.3, table 4.9): a natural forest zone (NF) located approximately 1 km within the forest, and four forest zones representing different degrees of forest degradation; closed-canopy disturbed forest (CCDisF), forest edge (FE), open-canopy disturbed forest (OCDisF) and degraded forest (DegF). Within each of these FZs, several ecological conditions, which may have become regeneration barriers, were studied. These were: seed rain, seed dispersal, seed bank, nutrient availability and pH of the peat, water table, light intensity, competition with herbaceous vegetation and mycorrhizal availability. These conditions were measured and analysed in comparison to the natural forest to determine if they significantly differed, which could suggest that they had become regeneration barriers. Seedlings of three TPSF tree species: *Dyera polyphylla*, *Shorea balangeran* and *Combretocarpus rotundatus* were cultivated and transplanted into mixed seedling plots in each forest zone (section 4.3.2). In eight plots in each FZ, the transplanted seedlings were grown under the natural environmental conditions of that respective FZ; these represented the control seedling treatment (Con). A furthereight plots had fertiliser added to each seedling in the form of slow-release nutrient tablets – nutrient addition (NA); eight plots were provided with shade cover (SC) and eight plots had the non-tree vegetation regularly cleared from the plots – competition removed (CR) (section 4.3.4). The survival and growth of these seedlings in all plots was recorded for seven months, and these data were analysed to investigate the impact of the seedling treatments in relation to the control seedlings and in relation to the FZ for each species. All the data analysis described above is presented in this chapter. Chapter 7 then discusses the ecological significance of these findings.

6.2 The process of seed dispersal

6.2.1 Levels of seed-dispersal and seed rain

Seed traps were established in each FZ. For one year the fruit and seeds found in these traps were collected and processed, and, based on identification of over-hanging tree species, the percentage of seeds arriving to the trap by seed rain or seed dispersal was calculated. The total weight of fruits and seeds collected over a one-year period (expressed as kg ha^{-1}), was calculated for each FZ (fig. 6.1). Similar fruit and seed weights (between 200-300 kg ha^{-1} yr^{-1}) were obtained in both the NF and the CCDisF, however, FE, OCDisF and DegF had significantly lower fruit and seed weights than the NF (FE = 98 kg ha^{-1} yr^{-1}, OCDisF = 13 kg ha^{-1} yr^{-1}, DegF = 7 kg ha^{-1} yr^{-1}, p-values = 0.066*, 0.002** and 0.001** respectively).

The average total number of species of seeds and fruits found over the year was calculated for each FZ (fig. 6.2). The NF, CCDisF and FE all had similar average total species numbers (7.1, 7.6 and 7.5, respectively), however, OCDisF and DegF had significantly lower species numbers than the NF (OCDisF = 3.1 species, DegF = 1.4 species, p-values = 0.012* and 0.001**).

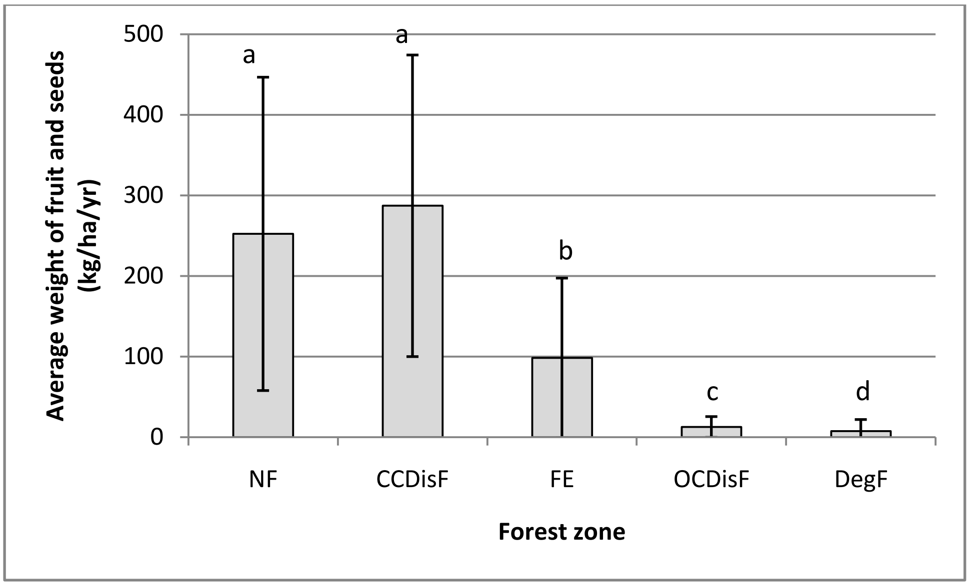


Figure 6.1: The total weight of seeds and fruit collected over one year in each FZ.

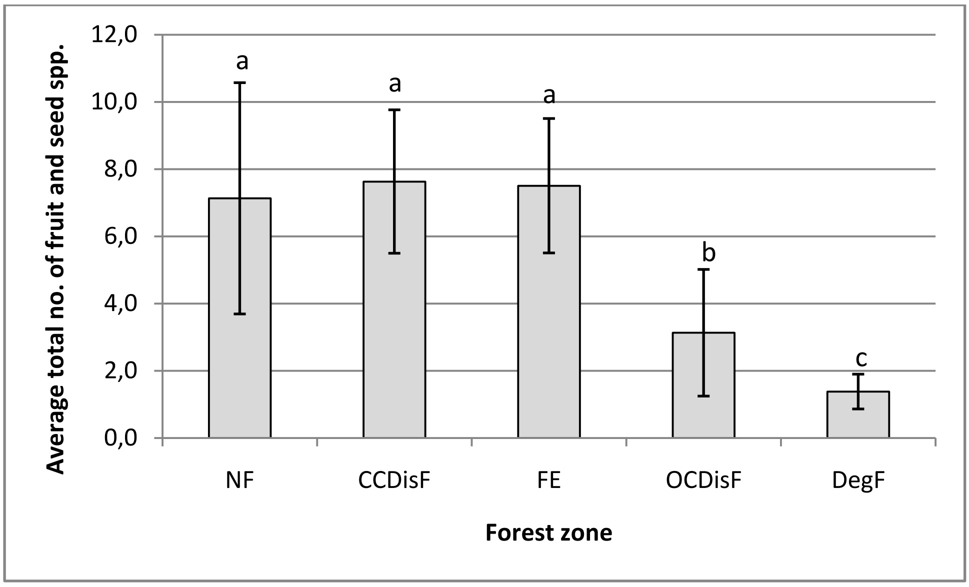


Figure 6.2: The average total number of species of seeds and fruits found over one year in each FZ.

The percentages of species arriving in the traps through seed rain or through dispersal were calculated (fig. 6.3). The NF had the highest percentage of species arriving by dispersal (82%);this was significantly higher than dispersal in CCDisF (53%, p-value = 0.006**) and FE (56%, p-value = 0.004**). For the OCDisF and the DegF, the percentages of seeds arriving by dispersal (62% and 69% respectively) were not significantly different from in the NF.

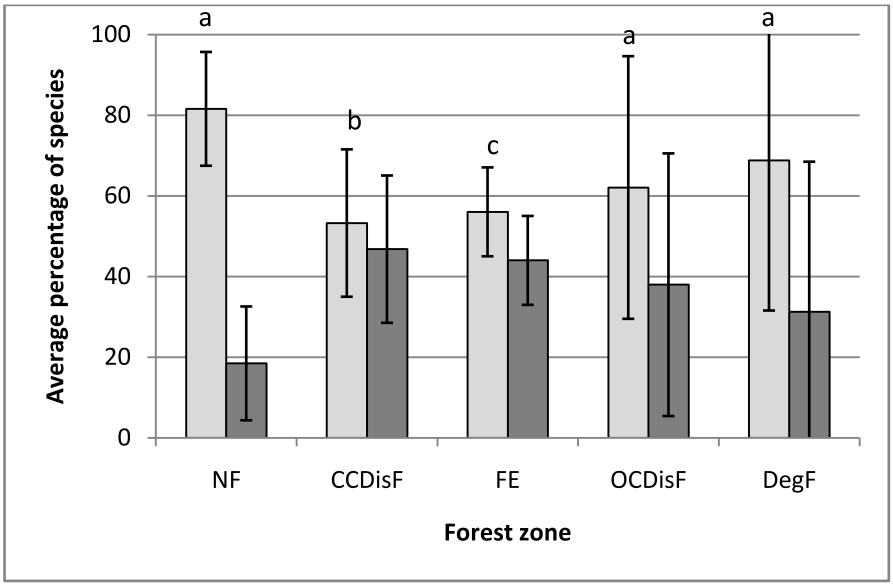


Figure 6.3: The average percentage of species of seeds found over one year that arrived through dispersal (pale grey) or seed rain (dark grey).

The dispersed species were classified as either animal- or wind-dispersed (fig 6.4). Animal-dispersal was most dominant in the three least disturbed FZ (NF = 83%, CCDisF = 70% and FE = 80%) and there was no significant difference between these zones regarding the percentage of animal-mediated seed dispersal. In the two most disturbed FZs animal-dispersal was significantly reduced and wind-dispersal dominated; OCDisF = 31% and DegF = 0%,p-values = 0.009** and <0.001**respectively.

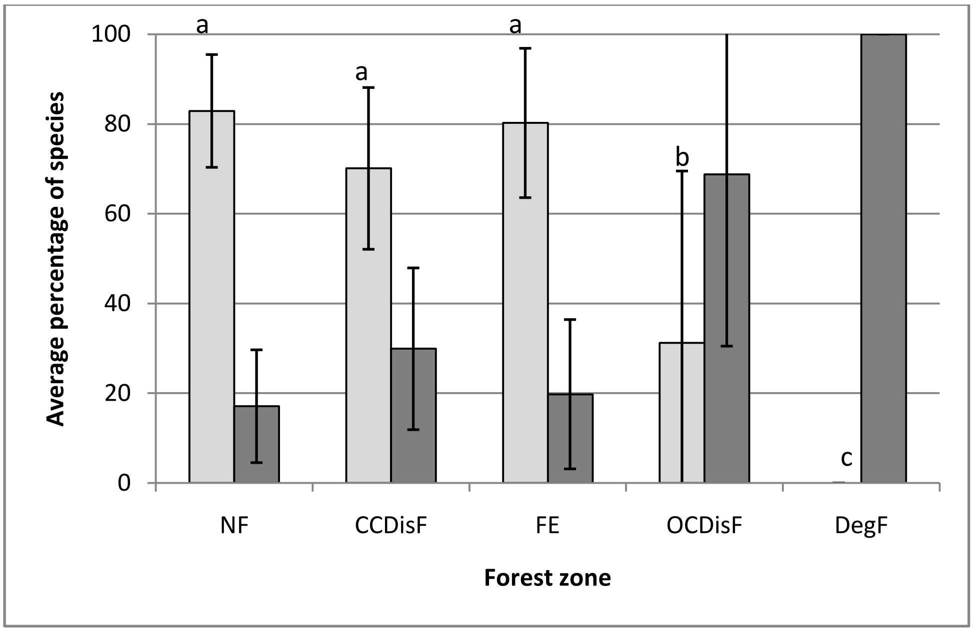


Figure 6.4: The average percentage of species of seeds that arrived through either animal-dispersal (pale grey) or wind-dispersal (dark grey).

6.2.2 Seed banks

Surface peat samples (5cm depth) were collected every three months from each FZ for a one year period and the samples were processed to establish the total number of seeds present. These samples were then laid-out on germination trays and monitored for six-months to establish germination and survival rates of seedlings. Over a one year period, the cumulative number of seeds collected across all FZs was 64 seeds, or 16 seeds in every 3 month collection, with an average of 3.2 seeds per transect or 0.64 seeds per peat sample, equal to a density of 40.96 seeds m^{-2}. 'Season' (Sept-07, Dec-07, Mar-08 and Jun-08) was assessed as a variable using the Friedman repeat measures test. Given the low sample sizes, with a large number of samples containing no seeds, repeat measures ANOVA was not used. No effect of season on seed abundance was observed. Therefore, the total seed number found in each FZ was averaged for each season and across the year (Table 6.1). Whilst the FE had the greatest number of seeds overall (80 seeds m^{-2}), this was not significantly different from NF

(38.4 seeds m^{-2}), and, indeed, none of the FZs had significantly more or less seeds than the NF.

Table 6.1: The average number of seeds found in each FZ, for each season and the average for the year, represented as m^2.

Forest Zone	Sep-07	Dec-07	Mar-07	Jun-07	Average	Average for $1m^2$
NF	2	0	0.4	0	0.6	38.4
CCDisF	1	0.8	0.2	0.2	0.55	35.2
FE	0.8	3	0	1.2	1.25	80
OCDisF	0	1.6	0	0.4	0.5	32
DegF	0	0	0.2	1	0.3	19.2

The number of species of seeds found in the peat samples was assessed within each FZ, in relation to 'season', using the Friedman repeat measures test, but no effect was observed. The number of species found was averaged across replicates with regard to FZ, for each season and for the year (Table 6.2).The number of species of seeds found throughout the year in each FZ were analysed using ANOVA; the results show no significant difference between the FZ compared to the NF. The highest number of species was found in the CCDisF, with 0.4 species per sample, or 5 species during the whole year. A total of 11 species were found across all samples from all FZ. Of these, five were classified by morphospecies, but the remaining six were identified to genus or species. All six were tree species, four relatively large seeded; 5 animal-dispersed, 1 wind-dispersed. Seeds of *Combretocarpus rotundatus* and *Tristaniopsis* spp. were found in all disturbed FZs, but were absent from the NF.

Table 6.2: The average number of species of seed found in each FZ for each season and the average for the year, and the total number of species found in each FZ during one year.

Forest Zone	Sep-07	Dec-07	Mar-07	Jun-07	Average	Total no. spp.
NF	0.6	0	0.4	0	0.25	5
CCDisF	0.6	0.6	0.2	0.2	0.4	5
FE	0.2	0.4	0	0.4	0.25	2
OCDisF	0	0.2	0	0.4	0.15	2
DegF	0	0	0.2	0.4	0.15	1

Apart from *Combretocarpus rotundatus* none of the seeds recorded during the peat sample processing went on to germinate. Instead, the germinated seedlings were from very small seeds (indistinguishable and inseparable from the wet peat) or from sprouting roots, presumably cut during the peat collection process. The total number of seedlings that germinated from seeds (during their six month period in the nursery) were analysed across season, within each FZ, using the Friedman repeat measures test. The analysis showed there was no seasonal variation for any FZ. The number of seedlings germinated from seed was averaged within each season, and for the year, for each FZ (Table 6.3). The numbers of seedlings germinating in the disturbed FZ were compared to the NF zone using ANOVA. Only FE was observed to have a significantly greater number of seedling germinations, (1.15 seedlings per sample, or 73.6 seedlings $m^{-2}year^{-1}$), than the NF (0.25 seedlings per sample, or 16 seedlings m^{-2} $year^{-1}$, p-value = 0.020*).

Table 6.3: Seasonal and annual average numbers of seedlings germinated from seed in each FZ, represented as m^2.

Forest Zone	Sep-07	Dec-07	Mar-08	Jun-08	Average	Average for 1m^2
NF	0.8	0.2	0	0	0.25	16
CCDisF	0.6	0.2	1	0.4	0.55	35.2
FE	2.2	0.8	1.2	0.4	1.15	73.6
OCDisF	0	0.2	0	0.8	0.25	16
DegF	0.2	0	0.6	0.4	0.3	19.2

Although the sample size was not large enough to run statistical analysis, the percentage survival of seedlings germinated from seed (defined as still alive at the final six month recording), the number of seedlings that sprouted from roots (here called sprouting roots), and the percentage survival of sprouting roots are summarized in tables 6.4, 6.5, 6.6 below. FE has the highest productivity in terms of seed bank regeneration (though the total number of seeds per FZ was not significantly different, table 6.1), with 25.6 sprouting roots m^{-2} compared to 3.2 seedlings m^{-2} in NF.

Table 6.4: Seasonal and annual average percentage survival of seedlings germinated from seed in each FZ. N denotes no seedlings germinated.

Forest Zone	Sep-07	Dec-07	Mar-07	Jun-07	Average for 1yr
NF	50	0	N	N	25
CCDisF	25	100	63	50	59
FE	56	50	42	100	62
OCDisF	N	100	N	0	50
DegF	100	N	0	0	33

Table 6.5: Seasonal and annual average numbers of sprouting roots in each FZ, also represented as m^2.

Forest Zone	Sep-07	Dec-07	Mar-07	Jun-07	Average for 1yr	Average for $1m^2$
NF	0.2	0	0	0	0.1	3.2
CCDisF	0	0	0	0.8	0,2	12.8
FE	0.4	0.4	0.6	0.2	0.4	25.6
OCDisF	0	0.6	0	0	0.2	9.6
DegF	0	0	0	0	0	0

Table 6.6: Seasonal and annual average percentage survival of sprouting roots in each FZ. N denotes no seedlings germinated.

Forest Zone	Sep-07	Dec-07	Mar-07	Jun-07	Average for 1yr
NF	0	N	N	N	0
CCDisF	N	N	N	34	34
FE	50	50	100	0	50
OCDisF	N	25	N	N	25
DegF	N	N	N	N	N

Nine morphospecies were identified as seedlings germinating either from seeds or roots. Of these, only one species, *Combretocarpus rotundatus* was identified with any certainty. The number of species which germinated was analysed with regard to season, within each FZ, using Friedman repeat measures test and showed no seasonal variation in species abundance. On this basis, the number of species found in each FZ was averaged for each season and for the whole year (Table 6.7), and compared to the NF using ANOVA. This analysis showed that only FE had a significantly greater number of seedling species in one year (average 0.95 species, total 8) than the NF (average 0.25 species, total 3), p-value 0.040*.

Table 6.7: Average number of species of seedlings germinated either from root or seed with regard to FZ, averaged within season, then for one year, and the total number of species found in each FZ.

Forest Zone	Sep-07	Dec-07	Mar-07	Jun-07	Average for 1yr	Total no. spp
NF	0.8	0.2	0	0	0.25	3
CCDisF	0.4	0.2	0.8	0.8	0.55	3
FE	1	1.2	1	0.6	0.95	8
OCDisF	0	0.6	0	0.8	0.35	6
DegF	0.2	0.55	0.95	0.35	0.2	3

6.3 <u>The process of recruitment and growth</u>

6.3.1 Nutrient availability and peat soil properties

Five surface peat samples (10 cm depth) were collected from each transect, during both the peak-wet (February 2008) and peak-dry season (September 2007), and these samples were analysed for pH, percentage organic carbon content (%org-C), percentage-nitrogen (%N), and phosphate-total (P-Total).

The data show that there is no significant difference for pH during either the wet season or the dry season in relation to level of forest degradation. pH is, however, highly significantly season-dependent (p-value < 0.001** for all FZs); the pH drops from an average of 3.9 in the wet season to an average of 3.2 in the dry season (fig 6.5.a, table 6.8).

Values for %org-C showed little variation within or across the three least disturbed FZs, averaging 57.3%, but values were much lower in the DegF zone, falling to 47% (table 6.8, fig. 6.5.b). There was no significant difference in the %org-C values between the wet and dry seasons. In the dry season all disturbed FZs had significantly lower %org-C in comparison to the NF zone (p-value = 0.06*, 0.02*, 0.003**, 0.06* for CCDisF, FE, OCDisF and DegF respectively), however this effect was less significant in the wet season.

In both the wet season and the dry season FE and DegF showed %N to be significantly lower than the NF (%N = 1.32% at FE wet season, 1.23% at DegF wet season, 0.72% at FE dry season, NF %N = 2.05% wet season and 1.13% dry season, wet season p-values = 0.0057** at FE and 0.0009** at DegF, dry season p-value = 0.03* at FE, table 6.8), however this was not a uniform effect across all disturbed FZ. A strong seasonal effect was observed with significantly more N available in the wet season than the dry season (p-value = 0.0023**, <0.001**, 0.003**, 0.003** for NF, CCDF, FE, OCDF respectively – not significant for DegF) (fig. 6.5.c).

Given that %org-C remains relatively constant for both seasons and across all FZs the C:N ratio reflects the patterns in the %-nitrogen values. That is, there are some across-FZ effects where the C:N is significantly higher (C:N = 45.49 at FE wet season, 39.45 at DegF wet season, 80.13 at FE dry season, table 6.8) compared to the NF zone (C:N = 28.48 wet season, 54.77 dry season) (wet season; p-value = 0.0148* at FE and 0.049* at DegF, dry season; p-value = 0.008** at FE). Again, there is a strong seasonal effect with a significantly higher C:N in the dry season compared to the wet season (p-value = 0.0055**, 0.0002**, 0.0003**, 0.009** for NF, CCDF, FE, OCDF respectively – not significant for DegF).

In the dry season, total phosphorus was significantly lower for all FZs when compared to the NF zone (ranging from 291.81ppm at NF to 157.99ppm at FE to 207.87ppm at DegF, table 6.8) (fig 6.5. e). In the most degraded zone, although P-Total was still significantly lower than inside the forest, it was the least significant of all the disturbed FZs (dry season; p-value= 0.0002**, 0.0009**, 0.0008** and 0.03* for CCDF, FE, OCDF and DegF respectively). In the wet season there was no significant difference in P-Total across the different FZs. There was also no significant difference across the seasons, for any of the FZs.

Table 6.8 Average values of pH, %org-C, %N, C/N and Total-P of peat samples in relation to FZ and season, n = 5.

Chemical component	Season	NF		CCDisF		FE		OCDisF		DegF	
		Ave.	**SD**	**Ave.**	**SD**	**Ave.**	**SD**	**Ave.**	**SD**	**Ave.**	**SD**
pH	Wet	3.97	0.09	3.82	0.11	3.82	0.15	3.92	0.08	3.92	0.10
pH	Dry	3.15	0.08	3.28	0.17	3.18	0.11	3.09	0.14	3.30	0.25
%org-C	Wet	57.39	0.25	57.10	0.26	57.15	0.14	54.33	6.04	47.80	10.63
%org-C	Dry	57.49	0.12	57.31	0.14	57.29	0.11	57.01	0.23	53.06	5.43
%N	Wet	2.05	0.29	1.89	0.10	1.32	0.32	1.77	0.50	1.23	0.21
%N	Dry	1.13	0.37	0.80	0.16	0.72	0.05	0.80	0.15	1.59	0.77
C/N	Wet	28.48	4.04	30.22	1.72	45.49	11.61	32.64	10.01	39.45	9.78
C/N	Dry	54.77	15.10	74.05	15.42	80.13	5.86	73.80	14.76	38.30	14.58
Total-P (ppm)	Wet	235.96	60.87	193.22	37.64	223.22	59.15	198.74	34.85	166.40	22.71
Total-P (ppm)	Dry	291.81	27.58	171.20	33.86	157.99	51.54	178.81	40.70	207.87	71.40

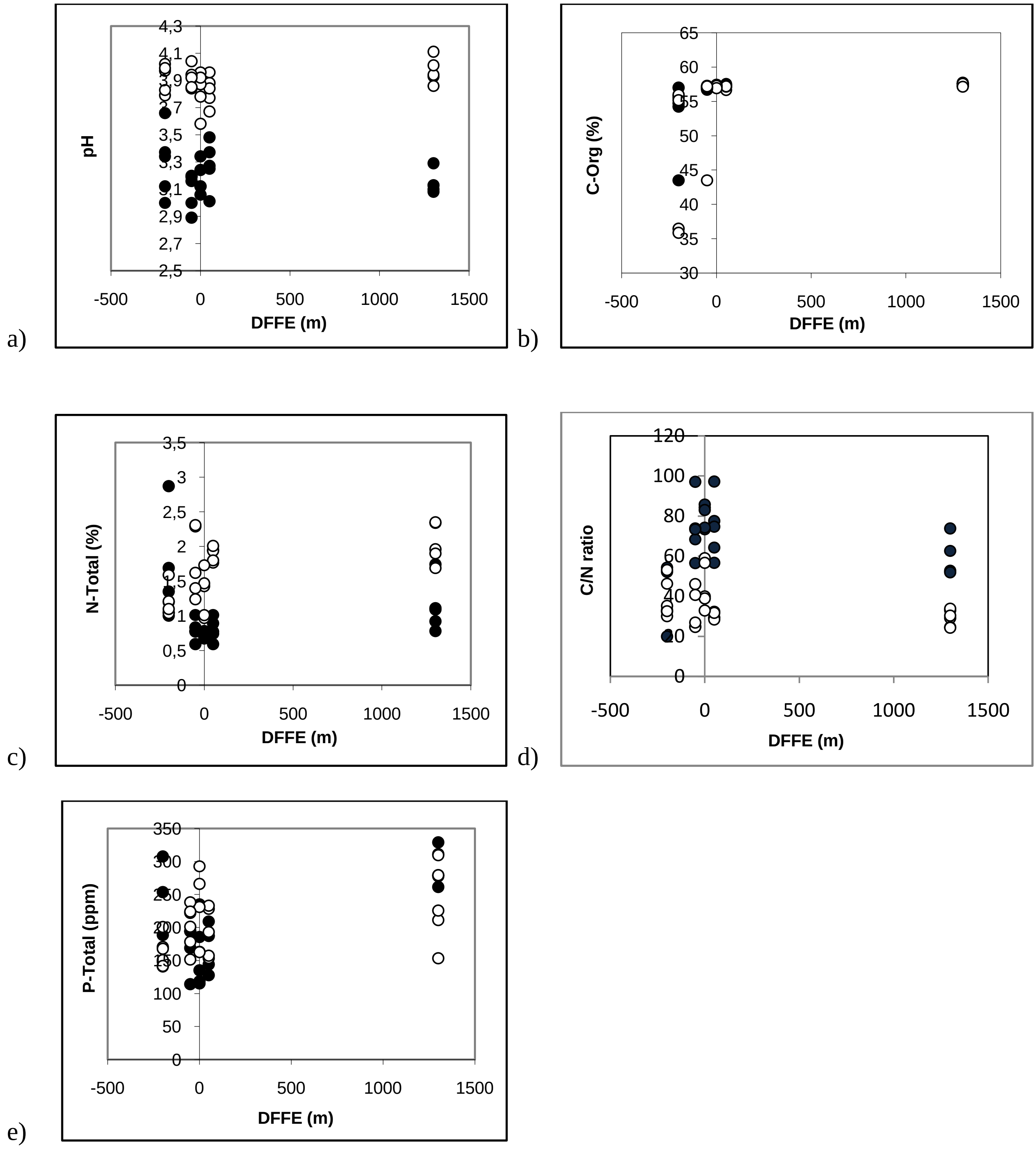


Figure 6.5: a) pH, b) %org-C, c) %N, d) C/N ratio and e) P-Total of peat samples taken at varying distances from the forest edge (DFFE), during the peak wet season, February 2008 (white circles) and during the peak dry season, September 2007 (black circles). N.B. in 1.b) the white circles frequently obscure black circles at several of the distances due to the high degree of overlap.

Regarding the effect of nutrient addition (NA) on seedlings' performance compared to the control seedlings (Con) two aspects were considered: How each seedling treatment responded to the different FZ in comparison to the NF zone, and, for each FZ, how the NA seedling performance compared to the Con seedlings. Comparisons were made for: species' survival, increase in basal diameter (BD), increase in height and change in leaf number (LN).

The survival rates of Con and NA *D. polyphylla* seedlings showed the same response in relation to FZ; there was no significant difference for the CCDisF, FE, or OCDisF in relation to the NF (survival: Con; 92%, 92%, 92% and 79%, NA; 83%, 100%, 96% and 83% for NF, CCDisF, FE and OCDisF respectively). However both treatments had significantly lower survival rates in the DegF zone compared to the NF zone (survival rates in DegF: Con; 29%, NA; 29%, p-values = 0.012* and 0.005** respectively). Across seedling treatment, within each FZ, the Con and NA seedlings showed no significant difference (fig. 6.6.a).

The Con and the NA *D. polyphylla* seedlings in the disturbed FZ had significantly greater increases in BD than those in the NF. This was significant for all four disturbed forest zones for Con seedlings, and significant for FE, OCDisF and DegF for NA seedlings (Inc. BD (cm): Con; 0.04, 0.07, 0.12, 0.16 and 0.15, NA; 0.04, 0.06, 0.14, 0.33, and 0.18 for NF, CCDisF, FE, OCDisF and DegF respectively, p-values of Con seedlings = 0.003**, <0.001**, <0.001** and <0.001** for CCDisF, FE, OCDisF and DegF, p-values of NA seedlings = 0.003**, 0.001** and <0.001** for FE, OCDisF and DegF). Regarding differences across the seedling treatments within each FZ, only the NA seedlings in the OCDisF had a greater increase in BD as compared to the Con seedlings (p-value = 0.005**) (fig. 6.6.b).

For the increase in height, the Con seedlings showed no effect of FZ (Inc. height (cm): 1.84, 2.45, 2.49, 2.48 and 2.65 for NF, CCDisF, FE, OCDisF and DegF respectively). The NA seedlings had significantly greater increases in height in the FE and OCDisF zones compared to the NF zone (Inc. height (cm): 2.40, 3.02, 3.83, 4.86 and 2.60 for NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.050* and 0.018* for FE and OCDisF). Only in the OCDisF was an effect of seedling treatment observed, with the NA seedlings attaining significantly greater height increases compared to the Con seedlings (p-value = 0.021*) (fig. 6.6.c).

There was no significant difference in the change in LN in relation to the FZ for the *D. polyphylla* Con and NA seedlings apart from the Con seedlings in the DegF zone had a greater decrease in LN as compared to the NF seedlings (Change. LN: Con; 1.29, 0.73, 1.23, -0.52 and -1.93, NA; 0.60, 1.19, 1.73, 1.10 and -0.25 for NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.042* for DegF Con seedlings). There was no significant difference between any FZ when the change in LN of the NA seedlings was compared to the Con seedlings (fig. 6.6.d).

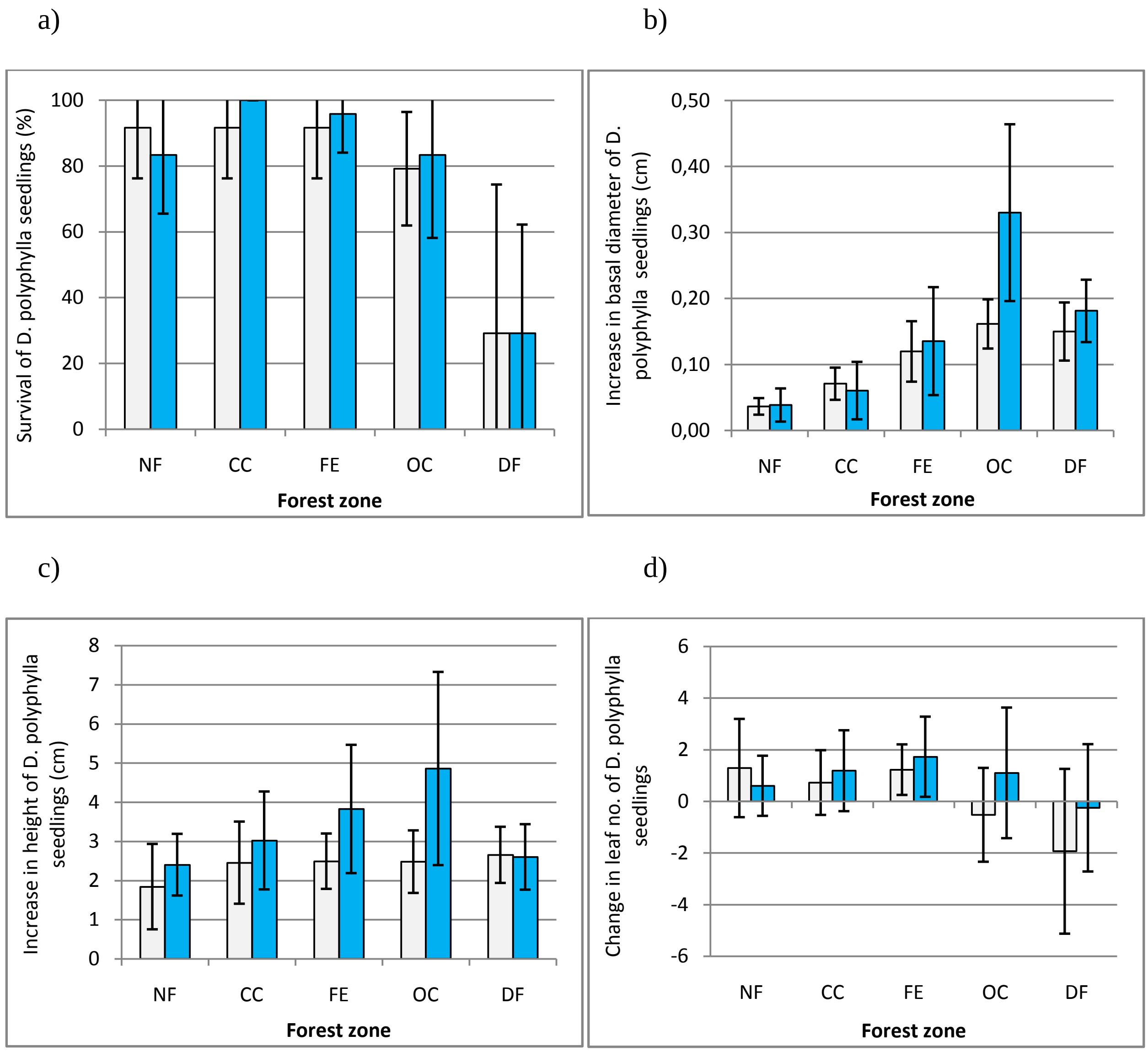


Figure 6.6: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and NA (blue)*D. polyphylla* seedlings respective to each FZ.

The survival rate of the *S. balangeran* Con seedlings only differed significantly (were lower than) the NF in the DegF (Survival: 88%, 88%, 96%, 96% and 58% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value of DegF = 0.057*). Survival rates of the *S. balangeran* NA seedlings showed no significant difference across FZ (Survival rates; 83%, 88%, 100%, 67% and 63% for the NF, CCDisF, FE, OCDisF and DegF respectively). Regarding the difference across the two seedling treatments, within each FZ, only in the

OCDisF did NA seedling have a significantly lower survival rate compared to the Con seedlings (p-value = 0.028*) (fig. 6.7.a).

The increase in BD of *S. balangeran* seedlings was significantly affected by FZ for both Con and NA seedlings. Con seedlings had significantly greater increases in BD in FE, OCDisF and DegF compared to NF (Inc. BD (cm); 0.02, 0.03, 0.05, 0.08 and 0.08 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.020*, <0.001**, 0.003** for FE, OCDisF and DegF). The same effect was observed for NA seedlings, though BD increases were only significantly greater in the OCDisF and DegF (Inc. BD (cm); 0.02, 0.03, 0.05, 0.11 and 0.10 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.002**, <0.001** for OCDisF and DegF). There was no significant difference observed for BD increases across the two seeding treatments within any FZ (fig. 6.7.b).

The increase in height of the *S. balangeran* seedlings was also significantly affected by FZ for both Con and NA seedlings. Con seedlings had significantly greater height increases in the OCDisF compared to the NF (Inc. height (cm): 2.39, 1.68, 3.04, 5.58 and 3.36, p-value = 0.001** for OCDisF). NA seedlings had significantly greater increases in height in the OCDisF and DegF (Inc. height (cm): 1.67, 2.14, 3.69, 7.33 and 4.55, p-values = 0.001** and 0.011* for OCDisF and DegF respectively). There was no significant difference in the height increases across these two seeding treatments within any FZ (fig. 6.7.c).

The change in LN for Con and NA *S.balangeran* seedlings was significantly affected by FZ. Con seedlings had significantly greaterincreases in LN in the FE and OCDisF compared to the NF (Change in LN: -0.23, -0.33, 0.94, 0.79 and -0.79, p-values = 0.010* and 0.058* for FE and OCDisF respectively). NA seedlings only had significantly greater increases in LN in the FE compared to the NF (Changes in LN: -0.24, -0.13, 1.13, 0.98 and

0.19, p-value = 0.049* for FE). There was no significant difference across these two seedling treatments within each FZ regarding change in LN (fig. 6.7.d).

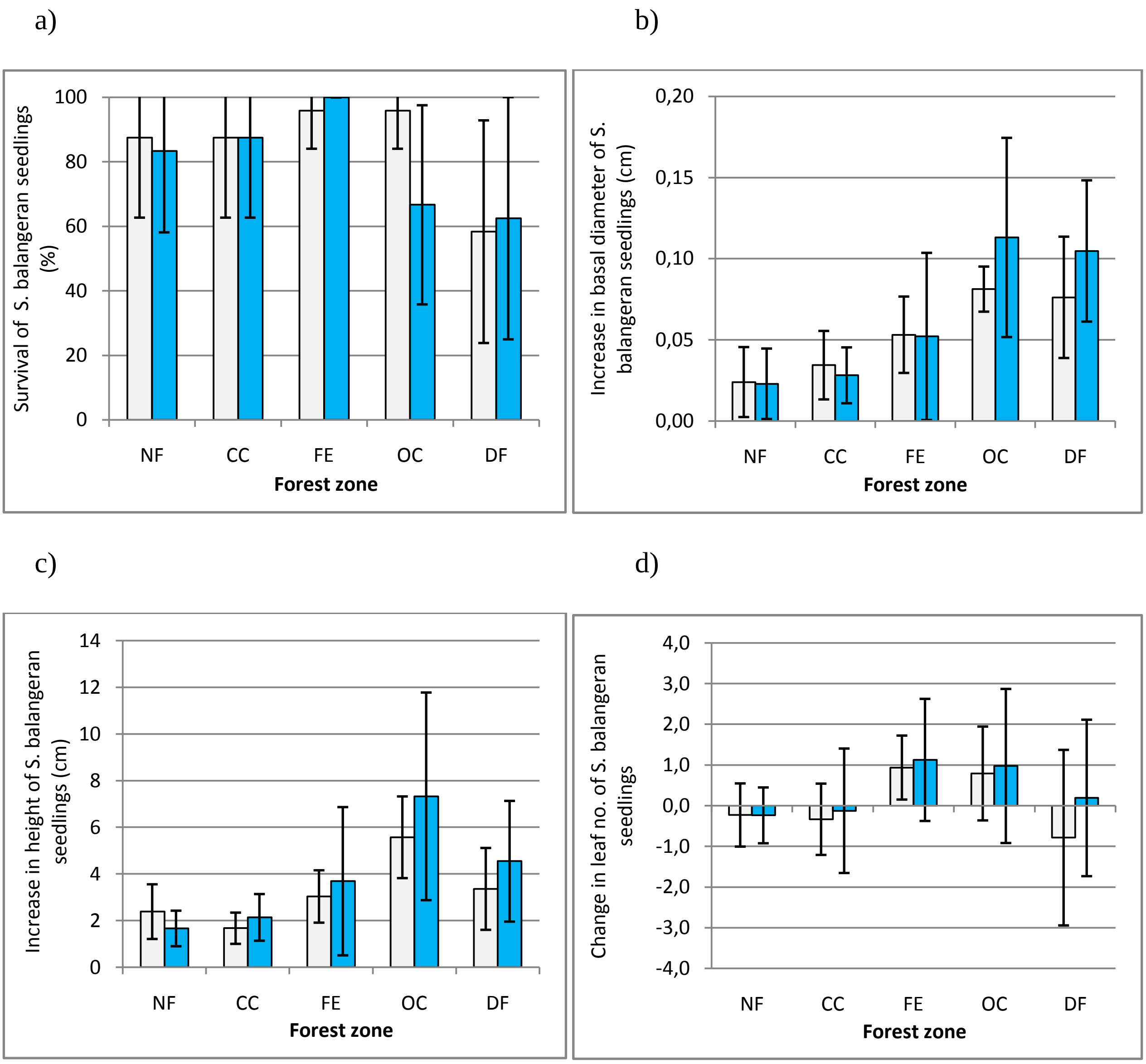


Figure 6.7: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and NA (blue) *S. balangeran* seedlings respective to each FZ.

Con *C. rotundatus* seedlings survival rates were significantly higher only in FE compared to the NF (Survival; 58%, 63%, 92%, 77% and 67% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value of FE = 0.050*). The NA seedlings' survival rates showed a greater effect, with FE, OCDisF, and DegF attaining higher survival rates than the NF

(Survival; 25%, 52%, 83%, 100% and 75% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.002**, 0.002**, 0.009** for FE, OCDisF and DegF). There was no significant difference in the survival rates between the Con and NA seedlings within any FZ (fig. 6.8.a).

BD increases for *C. rotundatus* Con seedlings were significantly greater for OCDisF and DegF compared to the NF (Inc. BD (cm); 0.03, 0.01, 0.03, 0.14 and 0.25 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = <0.001** and 0.001** for OCDisF and DegF). The same effect was observed for the NA seedlings; BD increases were significantly greater for OCDisF and DegF (Inc. BD (cm); 0.03, 0.02, 0.08, 0.42 and 0.37 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = <0.001** and 0.001** for OCDisF and DegF). Regarding the difference between seedling treatments within each FZ, NA seedlings had greater BD increases than Con seedlings in the FE and OCDisF (p-values = 0.029* and <0.001** respectively) (fig. 6.8.b).

Height increases for the Con and NA *C. rotundatus* seedlings were also greater in the OCDisF and DegF compared to the NF (Inc. height (cm): Con; 3.19, 3.40, 4.55, 11.43 and 18.29, NA; 3.90, 6.07, 6.97, 23.74, 22.37 for the NF, CCDisF, FE, OCDisF and DegF respectively. p-values = <0.001** and 0.001**, and 0.004** and 0.004** for Con OCDisF and DegF and NA OCDisF and DegF). NA seedlings had greater increases in height than the Con seedlings in the CCDisF, FE and OCDisF (p-values = 0.008**, 0.047* and 0.015* respectively) (fig. 6.8.c).

Changes in LN for both Con and NA *C. rotundatus* seedlings were significantly affected by FZ. Con seedlings had significantly greater increases in LN in the FE, OCDisF and DegF as compared to NF (Change. LN: -3.60, -2.71, -1.88, 2.71 and 6.57 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.027*, <0.001** and 0.001** for FE, OCDisF and DegF). NA seedlings had significantly greater increases in LN in the

OCDisF and DegF (Change in LN: -0.25, -2.83, 0.75, 18.73 and 9.48 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.027* and 0.012* for OCDisF and DegF). NA seedlings had greater increases in LN than the Con seedlings in the NF, FE and OCDisF (p-values = 0.019*, 0.042* and 0.001** respectively) (fig. 6.8.d).

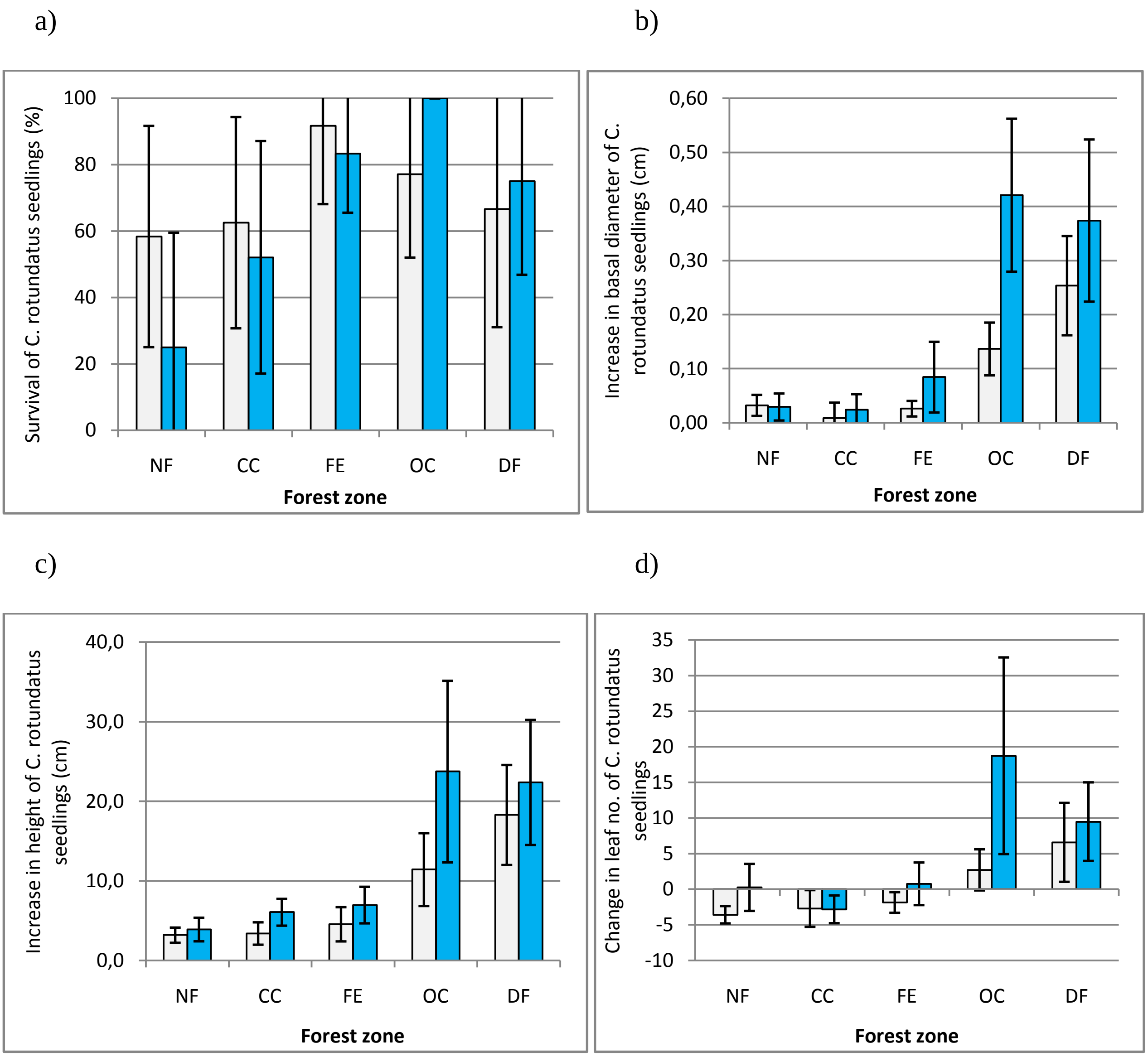


Figure 6.8: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and NA (blue) *C. rotundatus* seedlings respective to each FZ.

6.3.2 Water levels

Water level in relation to peat surface was recorded monthly across all FZs, with eight replicate points per FZ. The lowest water table levels occurred in October 2007 and August 2008. During the dry season, the water table fell below the peat surface across all FZs, to depths ranging from -54 cm (NF) to -22 cm (DegF). In November 2007 and September 2008 the rains started again; the water level began to rise, reaching maximum levels of -2 cm (CCDisF) and +12 cm (DegF), in January 2008, and +2cm (CCDisF) and +78 cm (DegF) in March 2009. Throughout the two years (across wet and dry seasons), the DegF maintained the highest water levels, with less disturbed FZs having lower water levels (fig. 6.9).

The average water level for each FZ was compared to the NF at the peak of the wet seasons and the peak of the dry seasons for both years (2007 and 2008). In the dry seasons, water table levels were significantly higher for the FE, OCDisF and DegF (2007; OCDisF p-value = 0.024* and DegF p-value = 0.009**, 2008; FE p-value = 0.005**, OCDisF p-value = 0.002**, DegF p-value = 0.001**). In the wet season, the water table was significantly higher for OCDisF and DegF only in 2009 (p-values = 0.003**, < 0.001** respectively).

Figure 6.9: Water table over two years with respect to FZ. NF – dark green, CCDisF – pale green, FE – yellow, OCDisF – orange, DegF – red.

6.3.3 Light levels

Within each FZ, light intensity was assessed by the proxy measure of canopy cover. This was recorded by taking canopy pictures at 1m above the ground surface and at the ground surface, during the dry season (June 2007). The percentage of open canopy assessed at ground level in the NF was, on average, 4.6%, and there was no significant difference between this percentage and that recorded in the CCDisF or FE. For the OCDisF and DegF, however, there was a significant increase in the percentage of open canopy compared to NF (% at 0m = 60% and 79% for OCDisF and DegF respectively, p-values = 0.001** and 0.001**). At 1 mheight a similar effect was observed withthe FE, OCDisF and DegF having greater percentage open canopy than the NF (% at 1m = 5.1%, 20.2%, 70.7%, 93.3% for NF, FE, OCDisF and DegF respectively, p-values = 0.016*, 0.002**, 0.001**) (fig. 6.10). In comparing the difference between canopy cover across the two heights (0m and 1m) within each FZ, only FE and DegF had significantly higher light levels at 1m than at ground level (p-values = 0.027* and 0.029* respectively).

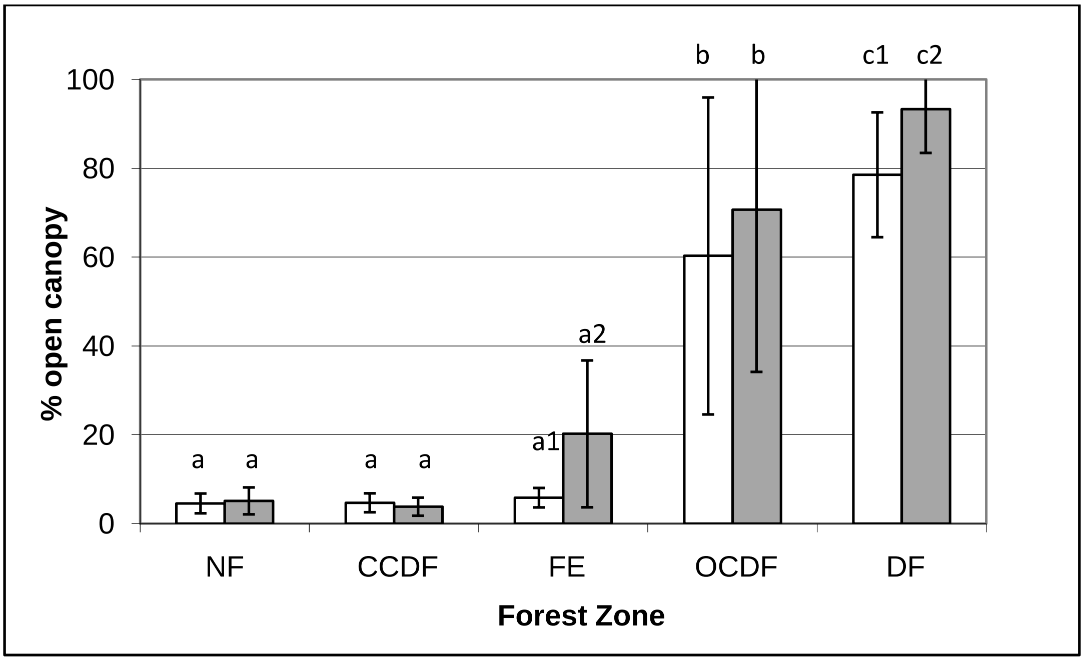


Figure 6.10: Light intensity, shown as percentage of open canopy, shown for each FZ, both at ground level (white bars) and 1m above the ground (grey bars). Data is averaged across each transect, and standard deviation is displayed as crossbars.

Two aspects were considered regarding the effect that shade cover (SC) had on seedlings compared to the control seedlings (Con): How each seedling treatment responded in the different FZs in comparison to the NF, and, for each FZ, how the performance of SC seedlings compared to that of the Con seedlings in terms of survival, increase in basal diameter (BD), increase in height and change in leaf number (LN).

D. polyphylla seedling survival for the Con and SC seedling treatments showed some effect of FZ. The Con seedlings in the DegF had lower survival compared to the NF (Survival: 92%, 92%, 92%, 79% and 29% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.012*). SC seedlings attained significantly greater survival rates in the OCDisF compared to the NF SC seedlings (Survival: 58%, 67%, 75% , 88% and 42% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.047*). SC seedling survival was significantly lower to the Con seedling survival in the NF (p-value = 0.018*) (fig. 6.11.a).

There was a strong effect of FZ for BD increases of both Con and SC *D. polyphylla* seedlings. The Con seedlings grown in the four disturbed FZs attained significantly greater BD increases than the NF seedlings (Inc. BD (cm): 0.04, 0.07, 0.12, 0.16 and 0.15 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.003**, <0.001**, <0.001** and <0.001** for CCDisF, FE, OCDisF and DegF). Similarly, the SC seedlings in the FE, OCDisF and DegF had significantly greater BD increases (Inc. BD (cm): 0.03, 0.03, 0.16, 0.20 and 0.24 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.040*, <0.001 and <0.001** for FE, OCDisF and DegF). Only in the CCDisF did SC seedlingshave lower BD increases than the Con seedlings (p-value = 0.006**) (fig. 6.11.b).

None of the *D. polyphylla* Con seedlings grown in the four disturbed FZs attained significantly different height increases than in the NF (Inc. height (cm): 1.84, 2.45, 2.49, 2.48 and 2.65 for the NF, CCDisF, FE, OCDisF and DegF respectively). For the SC seedlings only those in the OCDisF had significantly greater height increases than those grown in the NF (Inc. in height: 1.57, 1.08, 3.68, 3.74 and 2.48 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.002**). There was some effect across the two seedling treatments within each FZ; in the CCDisF, Con seedlings had greater height increases than the SC seedlings, but in the OCDisF the SC seedlings had greater height increases than the Con seedlings (p-values =0.006**for CCDisF, 0.033*for OCDisF) (fig. 6.11.c).

Con seedlings in the DegF had significantly greater decreases in LN compared to the NF (Change. LN: 1.29, 0.73, 1.23, -0.52 and -1.93 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.042*). SC seedlings in the FE had significantly greater increases in LN (Change in LN: -0.56, -1.21, 2.45, 1.00 and -2.50 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.003**). Regarding differences in LN change across seedling treatments, within FZ, the SC seedlings in the CCDisF had a significantly greater decrease in LN than the Con seedlings (p-value = 0.007**) (fig. 6.11.d).

a) b)

c) d)

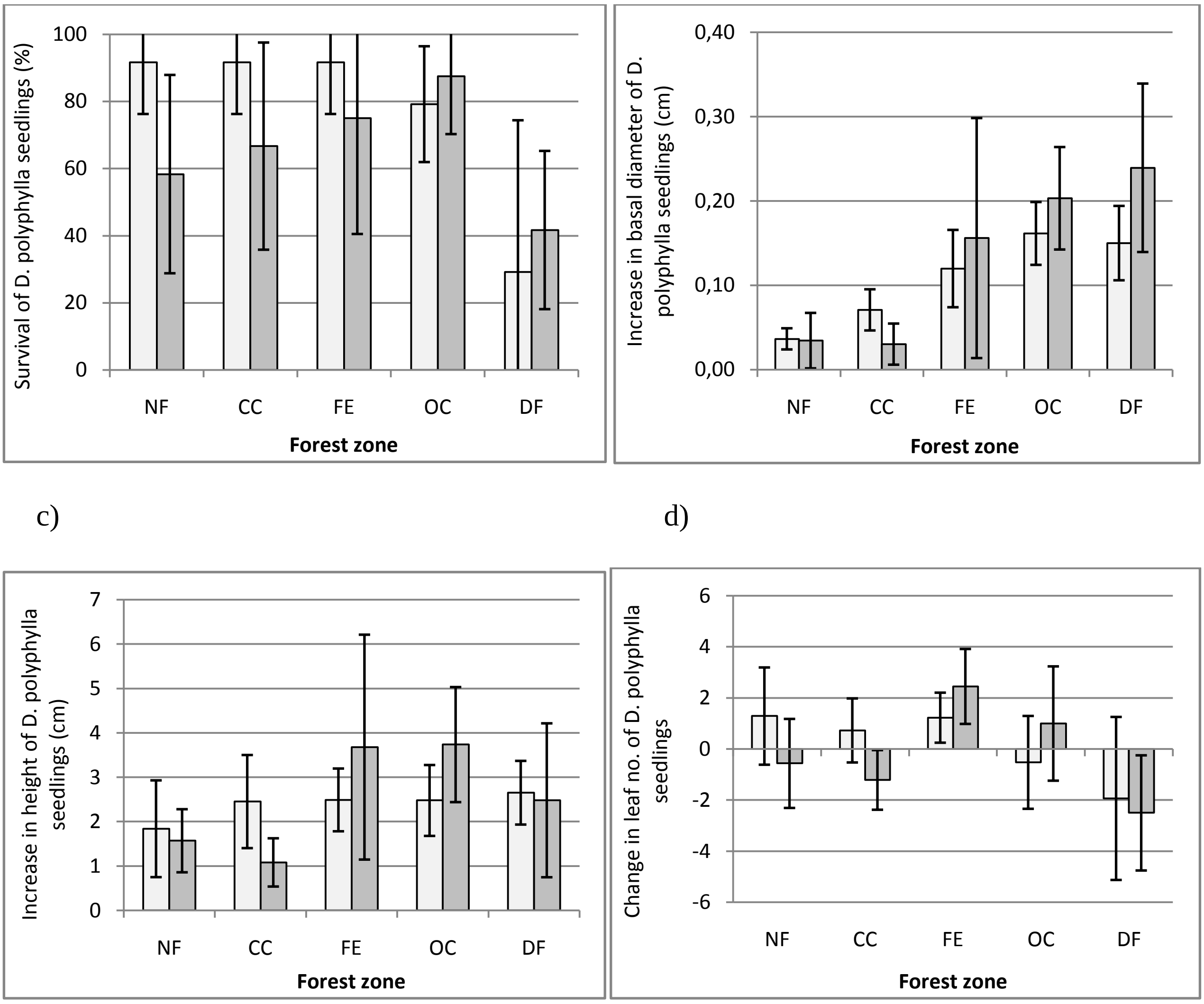


Figure 6.11: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and SC (grey) *D. polyphylla* seedlings respective to each FZ.

The *S. balangeran* Con seedling survival rate in the DegF was significantly lower than the NF (Survival: 88%, 88%, 96%, 96% and 58% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.057*). The SC seedling survival rates in the FE were significantly greater than in the NF (Survival: 63%, 58%, 88%, 83% and 71% for the NF, CCDisF, FE, OCDisF andDegF respectively, p-value = 0.025*). Con seedlings had significantly greater survival rates than the SC seedlings in the NF and CCDisF (p-values = 0.025* and 0.046* respectively) (fig. 6.12.a).

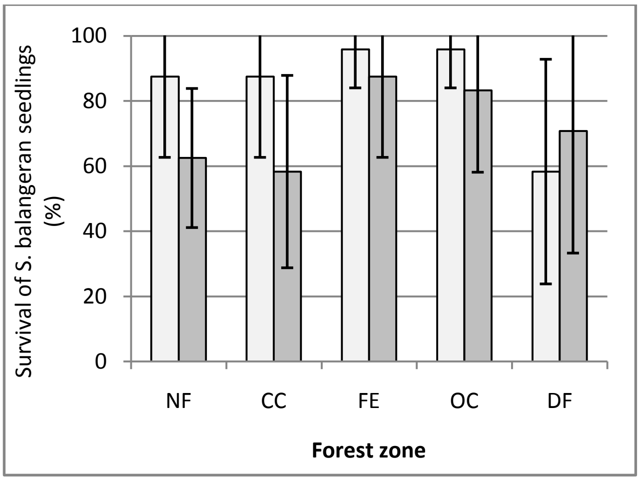
S. balangeran Con seedlings had significantly greater BD increases in the FE, OCDisF and DegF zones compared to the NF (Inc. BD (cm): 0.02, 0.03, 0.05, 0.08 and 0.08 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.020*, <0.001** and 0.003** for FE, OCDisF and DegF), whilst SC seedlings had significantly greater BD increases in the OCDisF and DegF (Inc. BD (cm): 0.03, 0.02, 0.05, 0.12 and 0.12 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = <0.001** and 0.001** OCDisF and DegF). There was little effect of seedling treatment within each FZ, although SC seedlings had significantly greater BD increases than Con seedlings in the OCDisF (p-value = 0.009**) (fig. 6.12.b).

Increase in height was not strongly affected by FZ for the *S. Balangeran* Con seedlings, with only OCDisF seedlings attaining greater height increases compared to the NF (Inc. height (cm): 2.39, 1.68, 3.04, 5.58 and 3.36 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.001**). For the SC seedlings, however, there was a stronger effect of FZ; FE, OCDisF and DegF seedlings attained greater height increases compared to the NF (Inc. height (cm): 0.91, 1.37, 5.52, 7.80 and 5.24 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.002**, <0.001** and 0.007** for FE, OCDisF and DegF). Only in the NF zone did Con seedlings have greater height increases than the SC seedlings (p-value = 0.008**) (fig. 6.12.c).

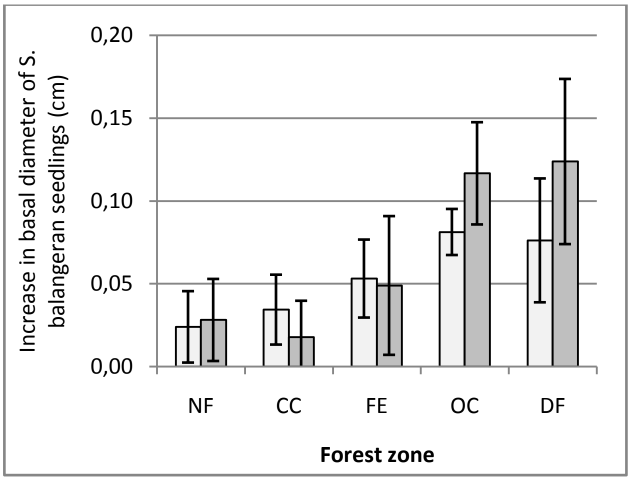
FZ did affect the change in LN of the Con and SC *S. balangeran* seedlings, with both having significantly greater increases in LN in the FE and OCDisF compared to the NF (Change in LN: Con: -0.23, -0.33, 0.94, 0.79 and -0.79, SC: -0.60, -1.54, 1.10, 1.33 and 0.33

for the NF, CCDisF, FE, OCDisF and DegF respectively. Con p-values = 0.010* and 0.058*, SC p-values = 0.011* and 0.047* for the FE and OCDisF respectively). There was, however, no significant difference in the change in LN between the seedling treatments in any FZ (fig. 6.12.d).

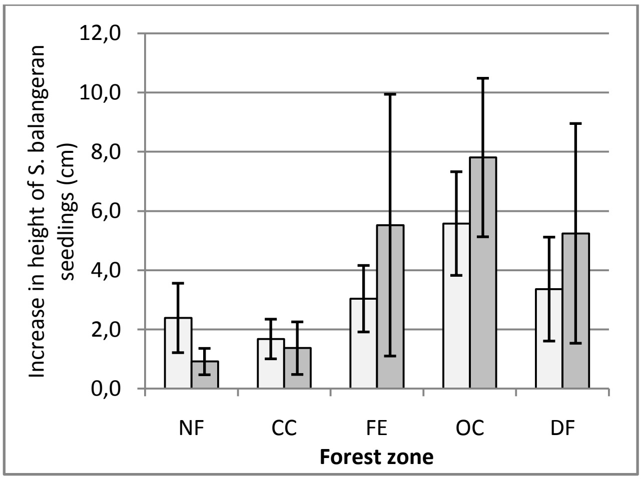
a)



b)



c)



d)

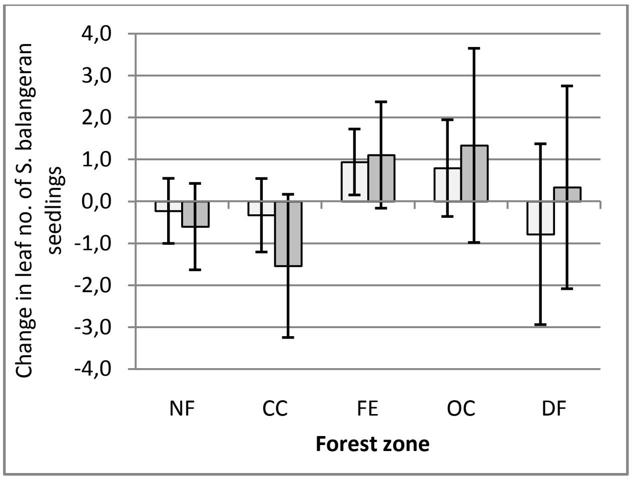


Figure 6.12: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and SC (grey) *S. balangeran* seedlings respective to each FZ.

Survival rates of the *C. rotundatus* seedlings showed a slight effect of FZ for the Con seedlings; seedlings in the FE showed greater survival rates than those in the NF (Survival: 58%, 63%, 92%, 77% and 67% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.050*). SC seedlings showed a greater effect of FZ, with seedlings in the FE, OCDisF and DegF all attaining higher survival rates than in the NF (Survival: 4%, 13%, 73%, 100% and 79% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.002**, <0.001** and <0.001** for FE, OCDisF and DegF). Con seedlings attained higher survival rates than the SC seedlings in the NF and the CCDisF (p-values = 0.001** and 0.004** respectively) (fig. 6.13.a).

The number of replicate SC seedlings surviving in the NF was too low to carry out analysis between their increases in BD, height and LN and those SC seedlings in the other FZs. Analysis was done, therefore, through one-way ANOVA across all four of the disturbed FZs, with post-hoc testing of the least significant difference (LSD) test to describe the relationship across these four zones.

The increases in BD for *C. rotundatus* Con seedlings were significantly greater for OCDisF and DegF compared to the NF (Inc. BD (cm); 0.03, 0.01, 0.03, 0.14 and 0.25 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = <0.001** and 0.001** for OCDisF and DegF). There was an overall significant difference across the four disturbed FZs for the SC BD increases (p-value = 0.015*), and CCDisF seedlings had significantly lower increases in BD than the OCDisF and the DegF zones (p-values = 0.006** and 0.012* respectively), while FE had significantly lower BD increases than the OCDisF (p-value = 0.030*) (Inc. BD (cm): 0.10, 0.01, 0.14, 0.27 and 0.24 for the NF, CCDisF, FE, OCDisF and DegF respectively). Regarding the difference across the Con and SC seedling treatments within each FZ, SC seedlings attained greater BD increases than the Con seedlings in the FE and OCDisF (p-values = 0.021* and 0.004** respectively) (fig. 6.13.b).

The increases in height for *C. rotundatus* Con seedlings were significantly greater for OCDisF and DegF as compared to the NF (Inc. height (cm); 3.19, 3.40, 4.55, 11.43 and 18.25 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = <0.001** and

0.001** for OCDisF and DegF). There was some significant difference across the four disturbed FZs for the SC height increases (p-value = 0.075), and CCDisF had significantly lower increases in height than the DegF (p-value = 0.013*) (Inc. height (cm): 3.40, 4.80, 13.45, 14.40 and 18.80 for the NF, CCDisF, FE, OCDisF and DegF respectively). For the difference across the Con and SC seedling treatments within each FZ, SC seedlings attained greater height increases than Con seedlings in the FE (p-value = 0.007**) (fig. 6.13.c).

C. rotundatus Con seedling LN change was affected by FZ, with significantly greater LN increases for the FE, OCDisF and DegF as compared to the NF (Change in LN: -3.60, -2.71, -1.88, 2.71 and 6.57 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.027*, <0.001** and 0.001** for FE, OCDisF and DegF). There was some significant difference across the four disturbed FZs for the SC seedlingLN change (p-value = 0.075), and CCDisF was shown to have significantly greater decrease in LN than the OCDisF and DegF (p-value = 0.044* and 0.027* respectively) (Change in LN: 0.00, -3.25, 1.67, 5.71 and 6.69 for the NF, CCDisF, FE, OCDisF and DegF respectively). There was no significant difference between Con and SC seedling treatments within any FZ (fig. 6.13.d).

a) b)

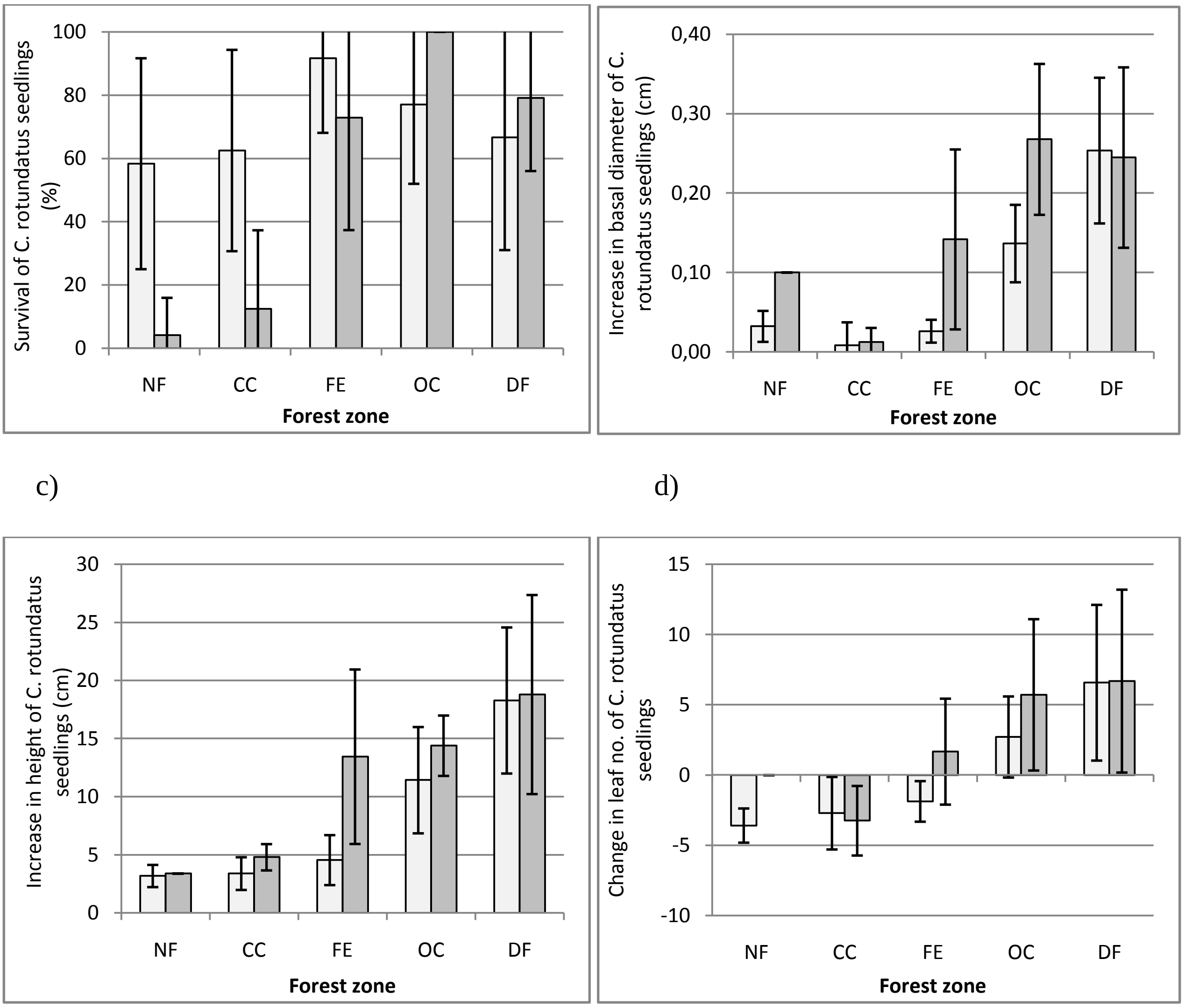


Figure 6.13: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and SC (grey) *C. rotundatus* seedlings respective to each FZ.

6.3.4 Competition with herbaceous vegetation

The percentage ground cover of pandans, sedges and lianas, and of seedlings, saplings and trees was recorded at three monthly intervals for one-year across the eight replicate plots located in each forest zone. Any vegetation that was not covered by one of these categories was classified as ‘other’ and included vegetation such as moss, algae and orchids. This ‘other’ group was excluded from the analysis as it represented a very small proportion of the ground cover. The average percentage ground cover of each of these respective groups was analysed across the year. There was no significant effect of season apart from for seedlings in three FZs (CCDisF, OCDisF and DegF), and only across some, not all, of the three-monthly recordings. Given, therefore, that season was seen not to be an important controlling factor in vegetation ground cover, the first recording only (June 2007) was used for subsequent analysis.

Average percentage ground cover for non-tree vegetation types (pandans, sedges and lianas) (fig. 6.14) and tree-vegetation types (seedlings, saplings and trees) (fig. 6.15) was calculated for each FZ, and compared to the NF. Pandan had high ground cover for the zones inside the forest (average = 10%, 1%, 8% for NF, CCDisF and FE respectively) with no significant difference across these zones, but significantly lower ground cover for the two most disturbed FZ where no pandan was recorded (p-value = 0.038* for both OCDisF and DegF, compared to NF). No sedge cover was recorded in either NF or CCDisF, however, sedge ground cover was 22%, 31% and 28% for FE, OCDisF and DegF respectively, thus significantly different from the NF (p-value = <0.001**, <0.001** and 0.038* respectively). Lianas were found across all FZs apart from DegF. The CCDisF and DegF had significantly lower ground cover of lianas than the NF (p-values = 0.038* and <0.001** respectively). Overall, non-tree vegetation was significantly lower in the CCDisF (average = 3%, p-value = 0.007**) compared to the NF, (average = 14%) and significantly higher for FE and OCDisF (average = 41% and 34%, p-values = <0.001** and 0.030* respectively).

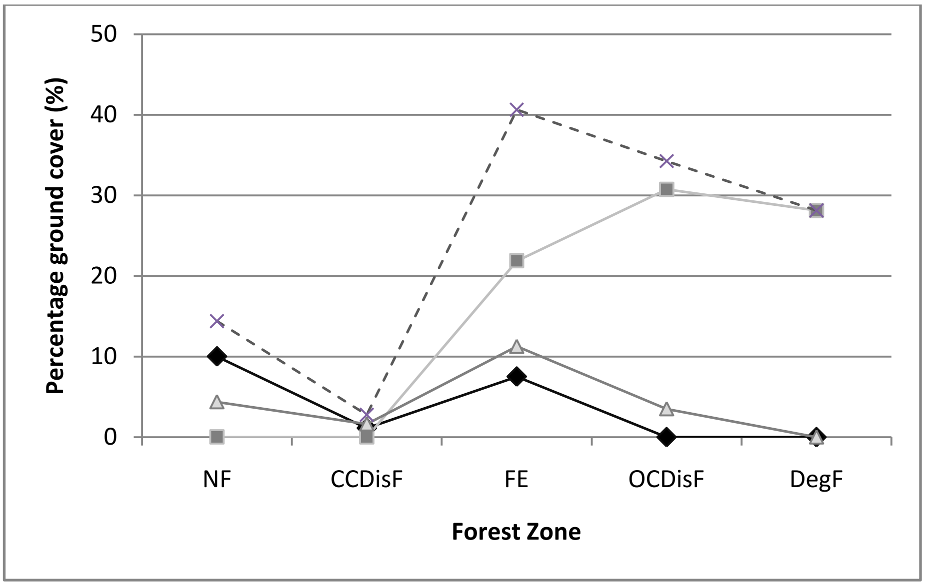


Figure 6.14: The percentage of ground cover for pandans (black diamonds), sedges (grey squares), lianas (grey triangles) and the sum of these percentages as non-tree vegetation (crosses) with respect to each FZ.

The average percentage ground cover for tree-vegetation types at each FZ was compared to the NF. Seedling percentage ground cover did not significantly differ from the NF (average = 13%) in the CCDisF, FE or OCDisF, however, seedlings in the DegF had significantly lower ground cover (average = 5%, p-value = 0.013*). Sapling percentage ground cover did not significantly differ for any of the FZs in comparison to the NF (average = 3%). Tree ground cover, similar to seedling cover, showed no significant difference from the NF (average = 3%) in the CCDisF, FE or OCDisF, but there was no percentage ground cover for trees in the DegF (average = 0%, p-value = <0.001**). Overall, all tree vegetation ground cover showed no significant difference from the NF (average = 20%) in the CCDisF, FE or OCDisF, but the percentage ground cover for all tree vegetation in the DegF was significantly lower (average = 6%, p-value = <0.001**).

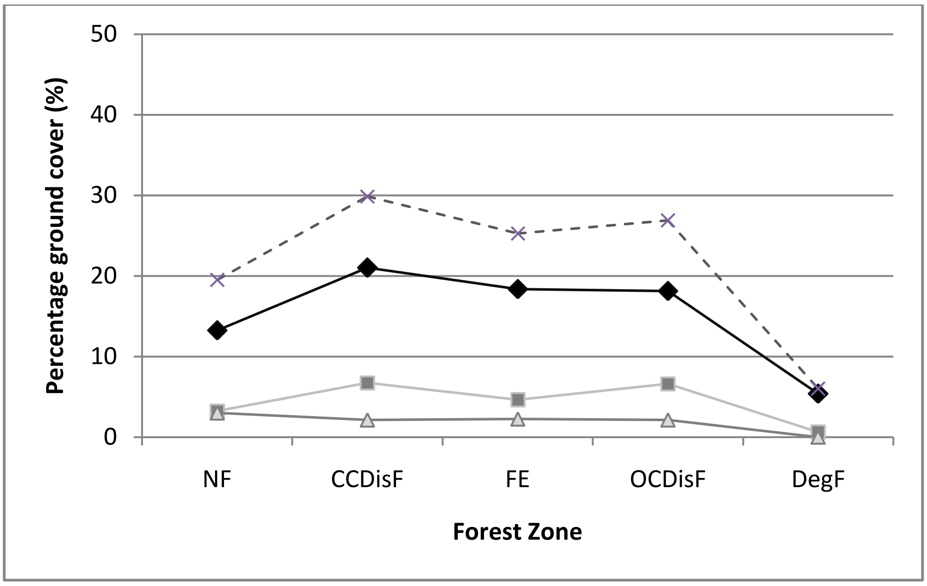


Figure 6.15: The percentage of ground cover for seedlings (black diamonds), saplings (grey squares), trees (grey triangles) and the sum of these percentages as tree-vegetation (crosses) with respect to each FZ.

Regarding the effect that competition removal (CR) had on transplanted seedlings compared to the control seedlings (Con) two aspects were considered: How each seedling treatment responded to the different FZs in comparison to the NF zone, and, in each FZ, how the CR seedlings compared to the Con seedlings. This was compared for: species' survival, increase in basal diameter (BD), increase in height and change in leaf number (LN).

Whilst *D. polyphylla* seedlings showed some effect of FZ with DegF seedling survival rates being significantly lower than in the NF (Survival: 92%, 92%, 92%, 79% and 29% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value for DegF = 0.012*), the CR seedlings showed no effect of FZ (Survival: 75%, 96%, 88%, 71% and 48% for the NF, CCDisF, FE, OCDisF and DegF respectively). There was also no significant difference between the survival rates of the Con and CR seedlings in any FZ (fig. 6.16.a).

The increase in BD for both the Con and the CR seedlings was significantly affected by FZ, with seedlings in all disturbed FZs for both seedling treatments attaining greater BD increases compared to the NF (Inc.BD Con (cm); 0.04, 0.07, 0.12, 0.16 and 0.15 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values for Con = 0.003**, <0.001**,

<0.001** and <0.001** for CCDisF, FE, OCDisF and DegF. Inc. BD CR (cm); 0.02, 0.06, 0.09, 0.13 and 0.13 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values for CR = 0.002**, 0.001**, 0.002** and 0.001** for CCDisF, FE, OCDisF and DegF.) There was no significant difference between the Con and CR seedlings regarding their BD increases in all FZs (fig. 6.16.b).

The height increases of *D. polyphylla* Con seedlings showed no effect of FZ (Inc. height (cm): 1.84, 2.45, 2.49, 2.48 and 2.65). The CR seedlings, however, showed some effect of FZ with the OCDisF seedlings attaining greater height increases than the NF seedlings (Inc. height (cm): 1.90, 1.25, 1.54, 3.13 and 2.05, p-value for OCDisF = 0.022*). Con seedlings had greater height increases compared to CR seedlings in the CCDisF and the FE (p-values = 0.001** and 0.009** respectively) (fig. 6.16.c).

There was a slight effect of FZregarding change in LN for the *D. polyphylla* Con seedlings, with NF seedlings attaining a greater increase in LN than the DegF seedlings (Change. LN: 1.29, 0.73, 1.23, -0.52, -1.93 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.042* for DegF). For the CR seedlings there was no effect of FZ (Change. LN: 0.00, 0.71, 1.04, 0.73, 0.88 for the NF, CCDisF, FE, OCDisF and DegF respectively). There was no significant difference between the Con and CR seedlings' change in LN in any FZ (fig. 6.16.d).

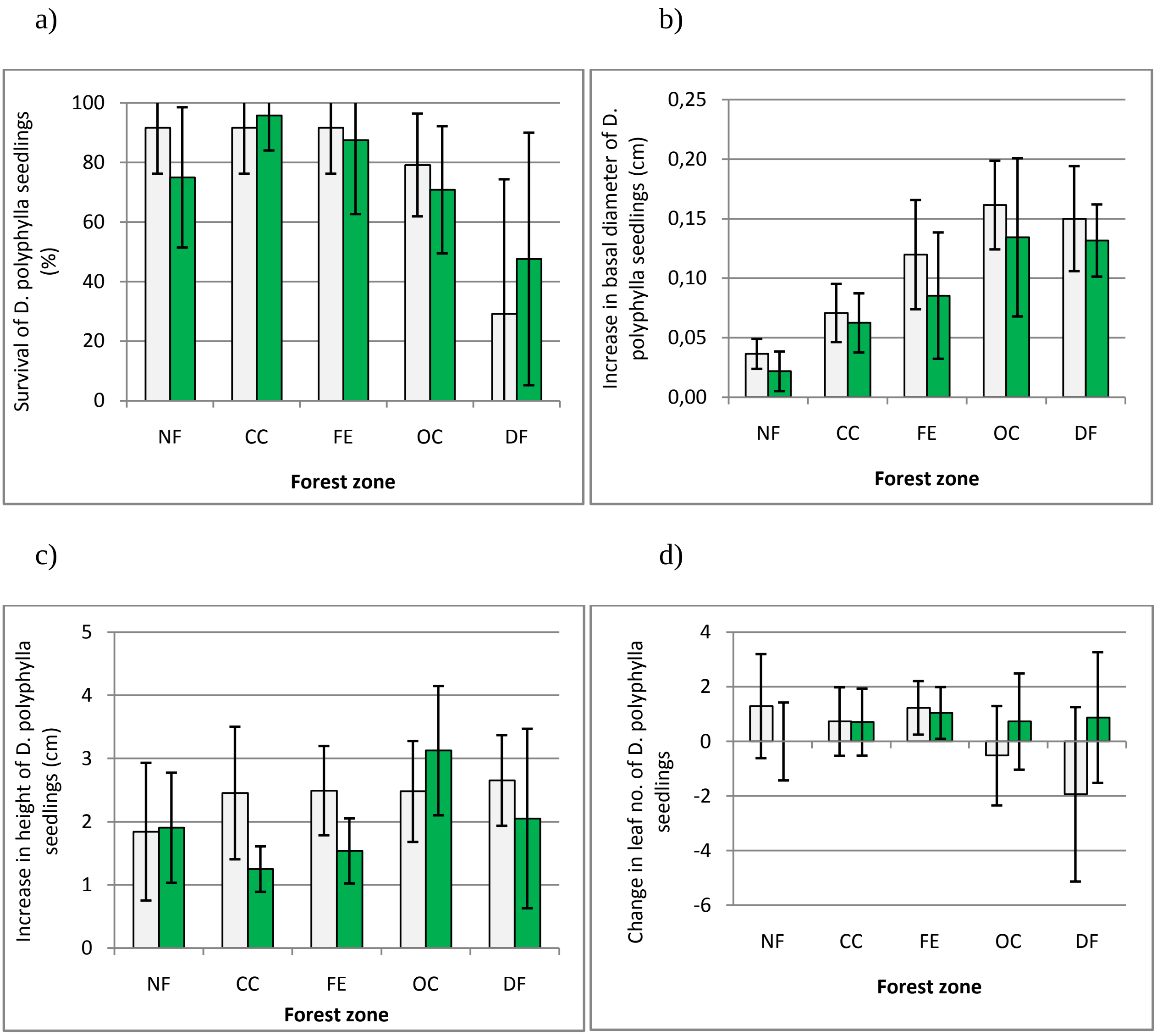


Figure 6.16: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and CR (green) *D. polyphylla* seedlings respective to each FZ.

Survival rates of *S. balangeran* Con seedlings showed a slight effect of FZ, with the DegF seedlings having a lower survival rate than the NF seedlings (Survival: 88%, 88%, 96%, 96% and 58% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value = 0.057*). The survival rates of *S. balangeran* CR seedlings showed no effect of forest zone (Survival: 83%, 96%, 100%, 96% and 67% for the NF, CCDisF, FE, OCDisF and DegF respectively). There was no significant difference between the two seedling treatments' survival rates in any FZ (fig. 6.17.a).

BD increases showed a significant effect of FZ for both the Con and CR *S. balangeran* seedlings: Con seedlings had significantly greater BD increases in the FE, OCDisF and DegF compared to the NF (Inc. BD (cm): 0.02, 0.03, 0.05, 0.08 and 0.08 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.020*, <0.001** and 0.003** for FE, OCDisF and DegF). CR seedlings had significantly greater BD increases in the OCDisF and DegF (Inc. BD (cm): 0.02, 0.04, 0.04, 0.07 and 0.08 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = <0.001** and <0.001** for OCDisF and DegF). There was no significant difference between the BD increases for the two seedlings treatments for any FZ (fig. 6.17.b).

Con seedlings only had significantly greater height increases in the OCDisF compared to the NF (Inc. height (cm): 2.39, 1.68, 3.04, 5.58 and 3.36 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value for OCDisF = 0.001**). CR seedlings had significantly lower increases in height in the CCDisF and significantly greater increases in height in the OCDisF compared to the NF (Inc. height (cm): 3.30, 1.24, 2.49, 7.24 and 4.33 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.004** and 0.006** for CCDisF and OCDisF). There was no significant difference between the height increases for the two seedling treatments for any FZ (fig. 6.17.c).

Both Con and CR *S. balangeran* seedlings showed an effect of FZ regarding change in LN, with both seedling treatments having greater increases in LN in the FE and OCDisF compared to the NF (Change. LN: Con: -0.23, -0.33, 0.94, 0.79 and -0.79 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values for Con = 0.010* and 0.058* for FE and OCDisF. Change. LN: CR: -0.23, -0.52, 1.17, 1.81 and 0.83 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values for CR = 0.003** and 0.002** for FE and OCDisF). There was no significant difference between the two seedlings treatments' changes in LN in any FZ (fig. 6.17.d).

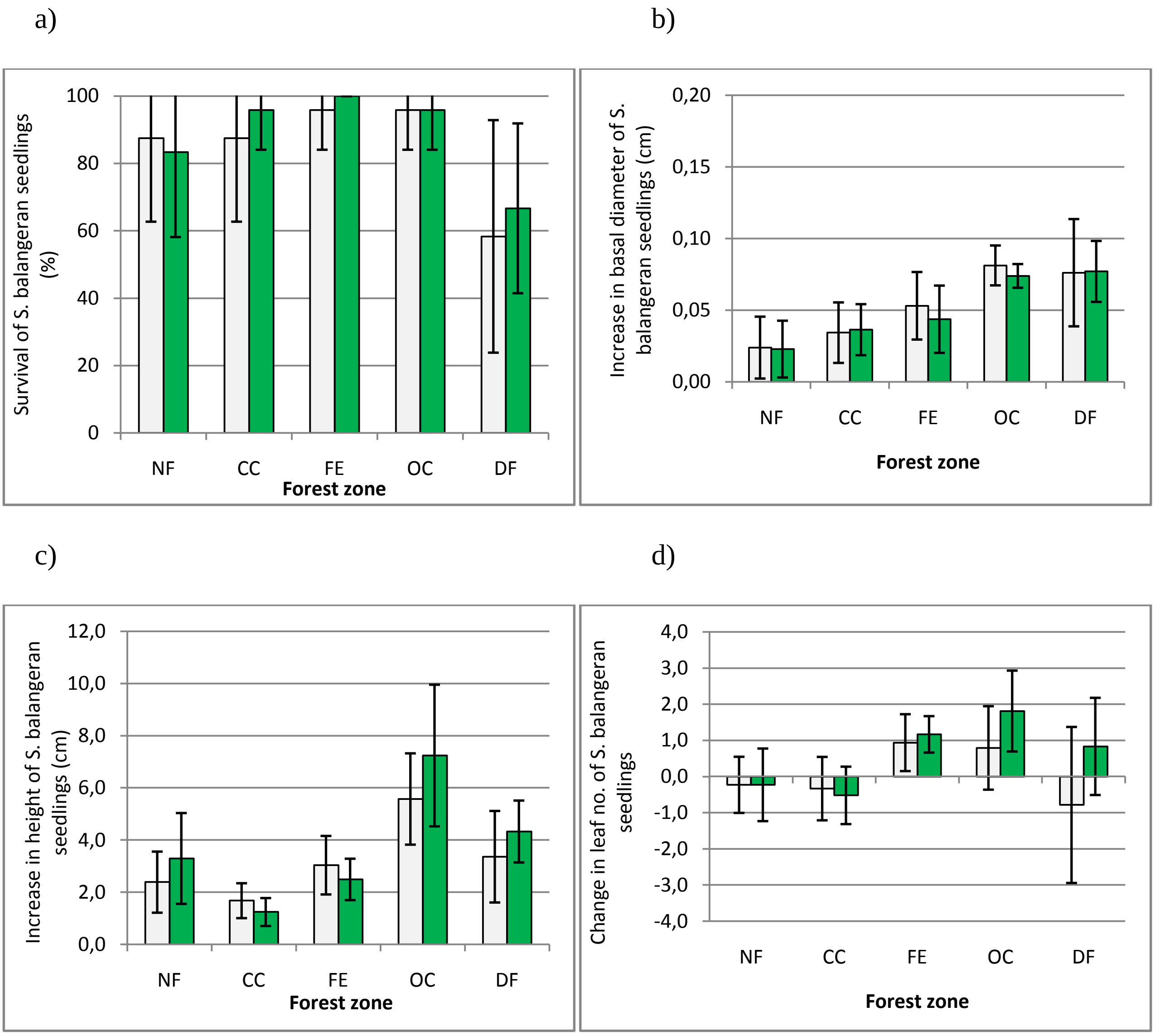


Figure 6.17: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and CR (green) *S. balangeran* seedlings respective to each FZ.

Con seedlings of *C. rotundatus* only had higher survival rates in the FE compared with the NF (Survival: 58%, 63%, 92%, 77% and 67% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-value for FE = 0.050*). Survival rates for CR seedlings showed a much greater effect of FZ, with FE, OCDisF and DegF seedlings all attaining significantly greater survival rates than in the NF (Survival: 0%, 23%, 56%, 92% and 88% for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.002**, <0.001** and <0.001** for FE, OCDisF and DegF). Furthermore, Con seedlings attained higher survival rates than CR in the NF, CCDisF and FE (p-values = 0.002**, 0.024*, 0.021*for NF, CCDisF and FE respectively) (fig. 6.18.a).

None of the *C. rotundatus* CR seedlings in the NF survived and, therefore, analysis between their increases in BD, height and LN and those CR seedlings in the other FZs could not be performed. Analysis was done, therefore, through one-way ANOVA across all four of the disturbed FZs, with post-hoc testing of the least significant difference (LSD) to describe the relationship across these four zones.

BD increases for *C. rotundatus* Con seedlings were significantly greater for OCDisF and DegF as compared to the NF (Inc. BD (cm); 0.03, 0.01, 0.03, 0.14 and 0.25 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = <0.001** and 0.001** for OCDisF and DegF). There were significant differences across the four disturbed FZs for the CR seedling BD increases (p-value = <0.001**), and CCDisF had significantly lower BD increases than the OCDisF and DegF (p-values = 0.004** and <0.001** respectively), FE had significantly lower BD increases than the OCDisF and DegF (p-values = 0.006** and <0.001** respectively) and OCDisF had significantly lower BD increases than the DegF (p-value = 0.021*) (Inc. BD (cm): 0.02, 0.04, 0.10 and 0.15 for the CCDisF, FE, OCDisF and DegF respectively). Regarding the difference within each FZ,Con seedlings attained greater BD increases than CR seedlings in the DegF only (p-value = 0.017*) (N.B. No analysis was done in NF as all CR seedlings died) (fig. 6.18.b).

Height increases for *C. rotundatus* Con seedlings were significantly greater for OCDisF and DegF compared to the NF (Inc. height (cm); 3.19, 3.40, 4.55, 11.43 and 18.25 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = <0.001** and 0.001** for OCDisF and DegF). There was a significant difference across the four disturbed FZs for the CR seedling height increases (p-value = <0.001**): CCDisF had significantly lower height increases than the OCDisF and DegF (p-values = 0.001** and <0.001** respectively) and FE had significantly lower height increases than the OCDisF and DegF (p-values = 0.001** and <0.001** respectively) (Inc. height (cm): 3.10, 4.59, 12.57 and 16.23 for the CCDisF, FE, OCDisF and DegF respectively). There was no significant difference between the height increases of Con and CR seedlings within any FZ (fig. 6.18.c).

Change in LN for *C. rotundatus* Con seedlings was affected by FZ, with significantly greater increases in LN for the FE, OCDisF and DegF seedlings compared to the NF (Change. LN; -3.60, -2.71, -1.88, 2.71 and 6.57 for the NF, CCDisF, FE, OCDisF and DegF respectively, p-values = 0.027*, <0.001** and 0.001** for FE, OCDisF and DegF). There was significant difference across the four disturbed FZs for the CR seedlings' change in LN (p-value = <0.001**). CCDisF had greater decreases in LN than the OCDisF and DegF (p-value = 0.023* and 0.005** respectively) and FE had greater decreases in LN than the OCDisF and DegF (p-value = 0.004** and 0.001** respectively) (Change. LN: -1.00, -1.36, 2.75 and 3.83 for the CCDisF, FE, OCDisF and DegF respectively). There was no significant difference between Con and CR seedlings' change in LN in any FZ(fig. 6.18.d).

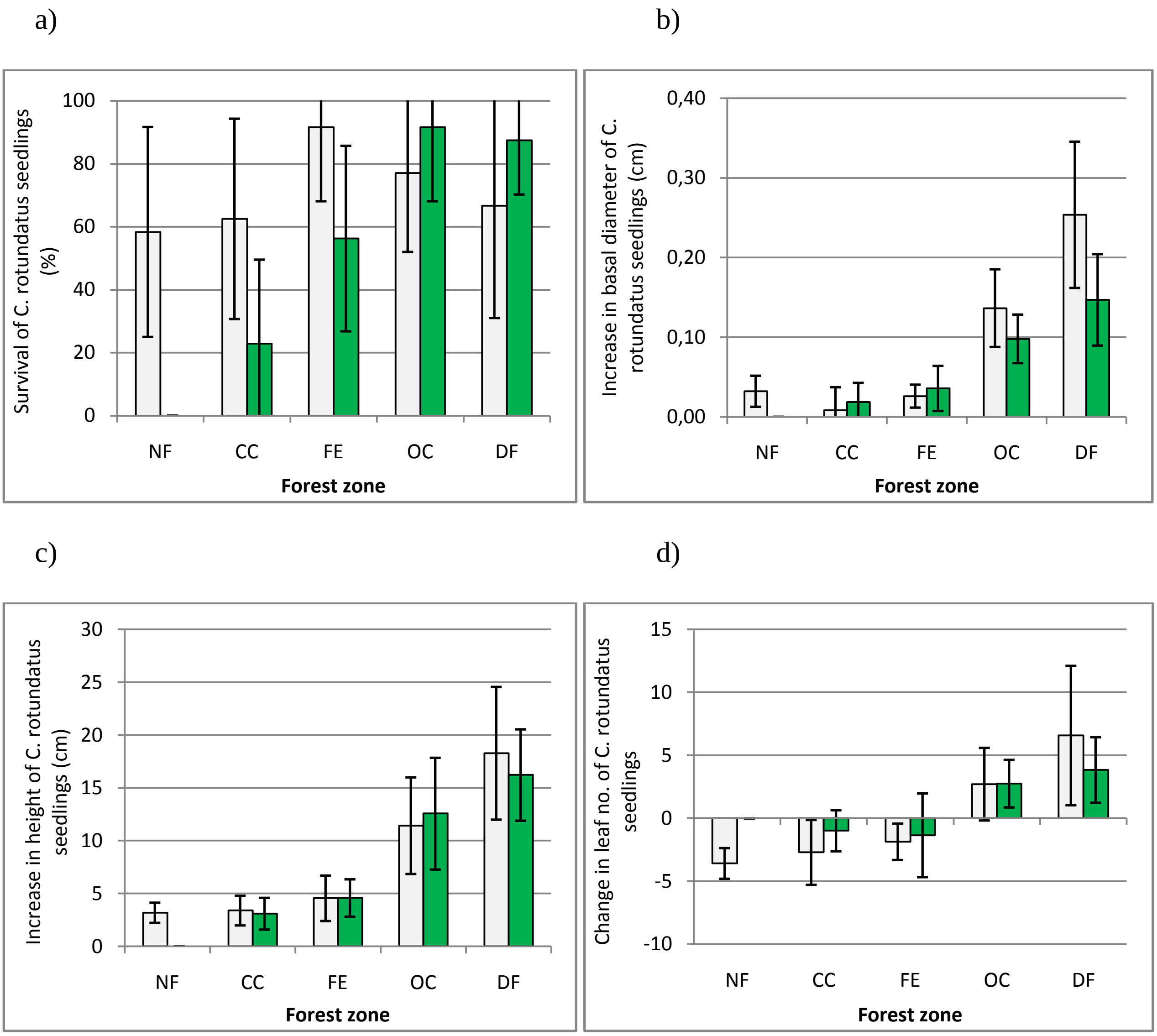


Figure 6.18: The survival (a), increase in BD (b), increase in height (c) and change in LN (d) for Con (white) and CR (green) *C. rotundatus* seedlings respective to each FZ.

6.3.5 Mycorrhizal colonisation levels

Mycorrhizal availability was considered across the FZs through an investigation of the performance of transplanted seedlings of *S. balangeran* and *D. polyphylla*, some of which were inoculated with their corresponding mycorrhizal species. The percentage colonization of mycorrhizae in the roots of both the inoculated and control seedlings was examined 6-months and 12-months after transplantation (wet season and dry season). The BD, height, LN, root and shoot biomass and N and P content of the shoots was then measured in the seedlings. These data have been presented in a separate published, paper (Graham *et al.* 2013, see attached CD). An overview of the results is provided below.

The percentage mycorrhizal colonization of roots in the inoculated and control seedlings was measured during the peak wet and peak dry seasons and the effect of mycorrhizal treatment was considered in relation to both seedling traits and FZ. In the degraded area, mycorrhizal colonization of non-inoculated roots was low, with both tree species supporting significantly higher colonization levels in inoculated seedlings. Both tree species showed high survival rates in all FZs, and survival, growth and biomass production were not affected by mycorrhizal treatment. Both species grew faster, and accumulated greater biomass in the more degraded FZs, although LN was negatively affected. N and P levels reduced for both tree species' seedlings in the more degraded FZs, however, the inoculated seedlings of *D. polyphylla* had higher nutrient levels across all FZs, and in some instances, so had the *S. balangeran* seedlings.

Table 6.9: Summarizing the effects observed on seedling traits for *S. balangeran* and *D. polyphylla* seedlings in relation to forest zone, mycorrhizal treatment (deg. = degraded).

Seedling trait	**Across forest zones**		**Across mycorrhizal treatments**	
	S. bal.	***D. pol.***	***S. bal.***	***D. pol.***
Survival	No effect	No effect	No effect	No effect
BD	More deg. > less deg.	More deg. > less deg.	No effect	No effect
Height	No effect	No effect	No effect	No effect
LN	Less deg. > more deg.	Less deg. > more deg.	No effect	No effect
Shoot biomass	More deg. > less deg.	No effect	No effect	No effect
Root biomass	More deg. > less deg.	Less deg. > more deg.	No effect	No effect
N content	Less deg. > more deg.	Cont. no effect, *G. dec.* and *G. cla.* Less deg. > more deg.	*S. col.* > cont. (slight)	*G. dec.* and *G. cla.* >cont.
P content	FE low	Less deg. > more deg.	*S. col.* > cont. (slight)	*G. dec.* and *G. cla.* > cont.

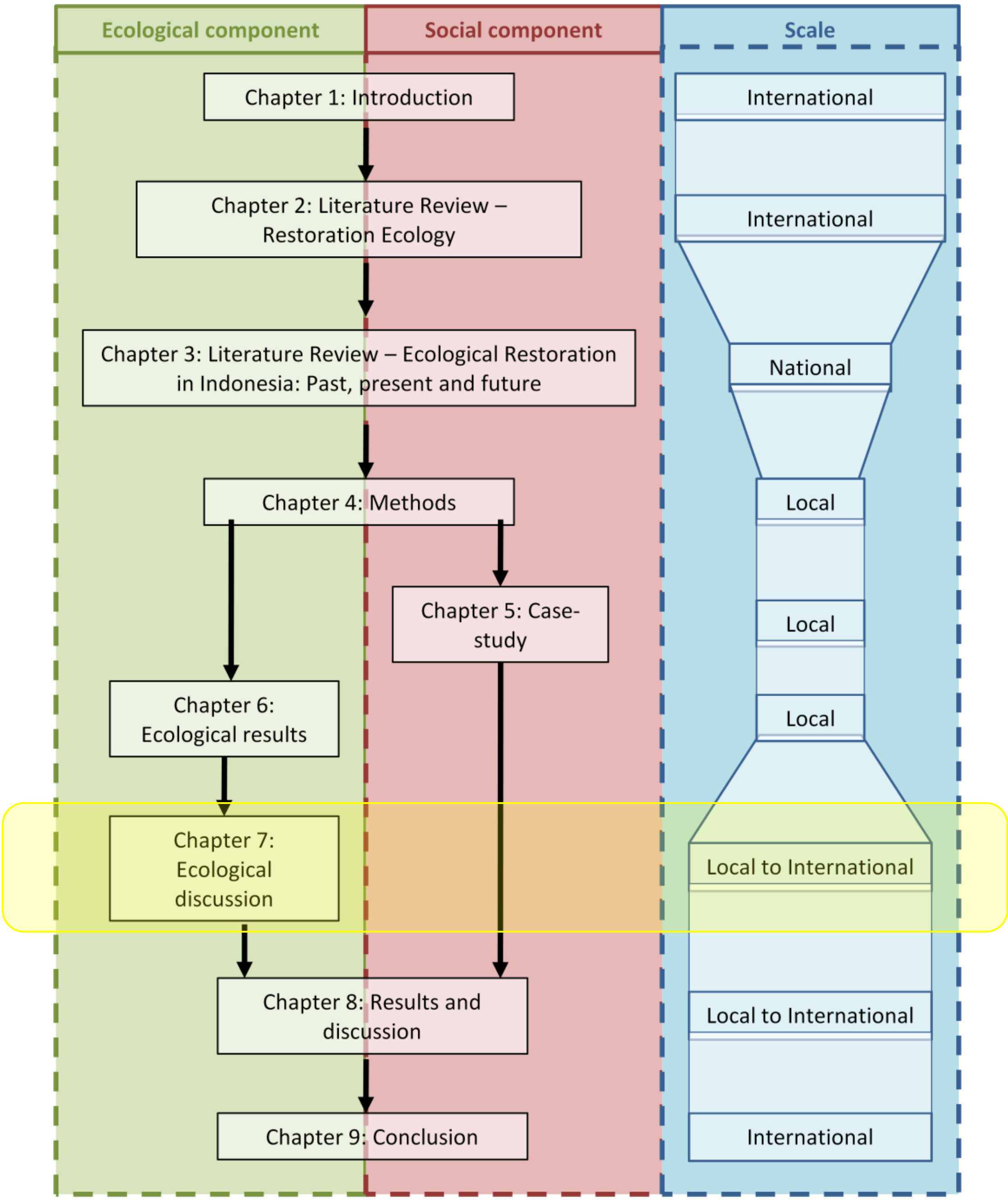
6.4 Conclusions

Overall the analyzed data reveal some distinct differences in the observed environmental conditions between the NF and the disturbed FZs; seed rain and the number of tree species in the seed rain was reduced in the more disturbed forest zones, and a lower percentage of the seeds that did reach the FZs arrived through animal dispersal. %-orgC, %N and Total-P values for the surface peat were reduced in some of the disturbed FZs, however pH was unaffected by level of degradation. In both the wet and dry seasons, the water table in the disturbed FZs was higher than in the NF, resulting in issues of flooding but not drought. Light levels significantly increased in the FE, OCDisF and DegF, and although this effect was somewhat ameliorated by the ground-cover vegetation; even beneath this cover, however, the light levels were still greater than under the canopy cover created by the forest. The ground cover of pandan and lianas reduced in outside the forest whilst cover of sedges increased, and overall non-tree vegetation ground cover was greater outside the forest. Finally, levels of mycorrhizae in the degraded FZs appeared to be below optimal levels for the two species investigated.

The impact of forest degradation on seedling survival and growth further indicated alterations to the environmental conditions. Providing nutrient additions to the seedlings improved the growth of two of the three tree species planted in some of the disturbed zones; shade cover was advantageous to only one species outside the forest; removal of invasive ground cover vegetation either had no effect or actually reduced survival of one species and the growth of another; finally, mycorrhizal inoculation improved nutrient uptake in two species of seedlings, and, given the higher colonisation levels of the inoculated seedlings, the results suggest some further unrecorded advantage.

These findings are discussed in the next chapter, with particular reference to their relevance as potential regeneration barriers to forest regeneration.

7. Ecological Discussion



7.1. Introduction

The changes in seed dispersal, seed rain, seed bank, nutrient availability and pH of the peat, water table, light intensity, competition and mycorrhizae availability were studied in relation to degree of degradation (ranging across five forest zones (FZs); the natural FZ (NF), the closed-canopy disturbed FZ (CCDisF), the forest edge (FE), the open-canopy disturbed FZ (OCDisF) and the degraded forest (DegF)). Also seedlings of tree species *Dyera polyphylla*, *Shorea balangeran* and *Combretocarpus rotundatus*, selected due to being pioneer or early succession, and representing different components of the framework species method, 4.3.2, were transplanted into each FZ. Their tolerance to the different levels of degradation and their responses to three treatments, namely, nutrient addition (NA), shade covered (SC) and competition removed (CR), were monitored. In Chapter 6 these results were presented. In this chapter, these results are discussed in depth, with a focus on how the results compare to other studies in this region and in this forest type, and the implications of these findings for the identification of active regeneration barriers. There are currently very few studies in TPSF on these topics, however, and it was not always possible to compare the results with other studies from comparable ecosystems or within the same geographic region. The following chapter, Chapter 8, then links the ecological and social data and draws conclusions as to overall regeneration barriers affecting this site and what action might be taken to alleviate them.

7.2. <u>The process of seed dispersal</u>

7.2.1. Level of seed-dispersal and seed rain

The biomass and species-diversity of seeds dispersed into the more degraded FZs were significantly reduced compared to the NF. Several other similar studies in tropical forest ecosystems investigating the level of seed rain across the forest edge-degraded transition zone have found similar results i.e. that within a few meters beyond the forest edge both seed rain abundance and diversity significantly and immediately drop (Zimmerman *et al.* 2000, Aide and Cavalier 1994, Holl 1999, Martinez-Garza *et al.* 2009).

The proportion of seeds arriving in the traps through dispersal as opposed to seed rain, was high, and not significantly different between traps in NF, OCDisF and DegF. The predominant mode of seed dispersal, however, was animal-dispersal in the NF, CCDisF and FE where as in the OCDisF and DegF it was wind-dispersal. Holl (1999) also found a predominance of wind-dispersed seeds beyond the forest edge in a study of abandoned pasture and adjacent primary rain forest in southern Costa Rica, as did Martinez-Garza *et al.* (2009) in degraded tropical rainforest in Mexico. At the Kalimantan study site, Graham and Page (2012) have previously reported low frugivorous bird presence in the degraded zone and very low levels of bird seed dispersal.

Overall, the findings suggest that in the three least disturbed FZs, NF, CCDisF and FE, there was a high abundance and diversity of fruit and seed production which is presumably explained by the high tree cover and tree species diversity (see 4.2.1). By contrast, in the two most disturbed FZs, OCDisF and DegF, where both forest cover and tree species diversity were significantly lower, seed and fruit biomass and species diversity also declined. Of the fruits and seeds that were recorded, there was a high percentage of animal-dispersed seeds in the NF suggesting the presence of large numbers of dispersal agents, whilst, in the most disturbed areas animal-dispersal was replaced by wind-dispersal, a reflection of both the much smaller animal populations and the open forest canopy. In the CCDisF and FE, animal-dispersal was less important than in NF, but wind-dispersal was restricted owing to the closed canopy, hence most of the seeds produced in these locations settled beneath the parent trees. These findings have several implications for forest restoration initiatives. Firstly, the results of this and other studies indicate that animal-dispersal is the most important seed dispersal mechanism operating in TPSF, similar to Webb and Peart's (2001) findings in mixed-dipterocarp forest in West Kalimantan. Secondly, animal-dispersal of seeds is no longer occurring in the most disturbed zones, indicating that seed-rain and seed-dispersal, especially by animals, have become significant forest regeneration barriers at this site, as observed in TPSF in both Thailand (Tomita *et al.* 2000) and Sumatra (Giesen 2004). Thirdly, in the CCDisF and the FE, although tree biomass and species diversity remain high, neither of the two main modes of seed dispersal are operating, which may lead to future problems in terms of forest regeneration (Nathan and Casagrandi 2004, Wilson and Traveset 2000, Webb and Peart 2001). Many other studies in the tropics have also found seed-dispersal to be a major regeneration barrier (Aide *et al.* 2000, Hooper *et al.* 2005, Holl 1999) and have consequently stressed the potential importance of the use of direct seeding or transplanted seedlings to overcome this barrier (Florentine and Westbrooke 2004, Holl 2012).

7.2.2. Seed banks

Although tropical forests are generally thought to have smaller seed banks compared to temperate forests (in which 500 seeds m^{-2} is average, and up to 5000 seeds m^{-2} common (Bakker *et al.* 1996)), seed bank studies in tropical rainforests of South-East Asia also commonly reach into the hundreds of seeds per m^2 (Table 7.1). In this study, the average seed bank density based on seeds found in the surface peat samples across all five FZs was 40.96 seeds m^{-2}, much lower than other seed bank densities in tropical rainforest ecosystem in this region (Table 7.1).

Equally, the number of species of seed found in the seed bank was low in comparison with these other studies (Table 7.1); a total of just 11 species were found overall. Of these 11, the six which were identified were all tree species, four being relatively large seeded. Large-seeded tropical tree species are commonly recalcitrant (i.e. have little or no dormancy before germinating), and thus form only a transient quotient of any seed bank (Corlett 2009, Thompson 1992, Bakker *et al.* 1996). Of the two species found in the three most disturbed FZs (FE, OCDisF and DegF), *Combretocarpus rotundatus* is wind-dispersed, and *Tristaniopsis* spp. has a small dehiscent fruit with very small seeds. Both species are commonly found along the forest edge and in the degraded area. These species are adapted to disturbance and high light levels, i.e. they are pioneer secondary succession species (Giesen *et al.* 2009, Wibisono *et al.* 2005). These, therefore, would be the more typical species one would expect to find in a seed bank, given this group often support a longer seed dormancy to 'sit-out' unfavourable conditions (Corlett 2009, Janzen and Vázquez-Yanes 1991). These two species may, therefore, represent an important element for natural regeneration and restoration in this area.

Of these two species, only one, *Combretocarpus rotundatus* went on to germinate in the seedling study. Seedlings of other species emerged from very small seeds that could not be separated from the peat (see below). This supports the results of other studies which found seed banks of tropical rain forests in SE Asia were largely composed of small-seeded pioneer and secondary succession species (Metcalfe and Turner 1998, Metcalfe *et al.* 1998, Brearley *et al*, 2004). However, the seedling density was still very low compared to other studies (Table 7.1). FE was the only FZ to have significantly greater numbers of morphospecies of seedlings when compared to NF. However, the overall numbers of morphospecies (8 in total for FE, and 3 for NF) are much lower than those observed in other studies in this region. The FZ, FE, was shown further to have high activity overall regarding its seed bank, in that it continued to have the greatest number of rootlets, and the greatest percentage of survival of both seedlings and sprouting roots.

Table 7.1: Seed densities and number of species found in the seed banks of South-East Asian study sites; disturbed sites (D), primary forest (P). Adapted from Brealey *et al.* (2004) and Tang *et al.* (2006)

Site	**Forest type**	**Forest quality**	**Seeds (m^{-2})**	**No. spp.**	**Reference**
Sabangau, Central Kalimantan, Indonesia	TPSF	Combined	41 (From seed density)	11	This study
Sabangau, Central Kalimantan, Indonesia	TPSF	D	74 (From seedling density)	8	This study
Sabangau, Central Kalimantan, Indonesia	TPSF	P	16 (From seedling density)	3	This study
Barito Ulu, Central Kalimantan, Indonesia	Tropical lowland evergreen rainforest	P	175	25	Brealey *et al.* 2004
Barito Ulu, Central Kalimantan, Indonesia	Tropical lowland evergreen rainforest	D	573	24	Brealey *et al.* 2004
Chiang Mai, Thailand (site no.2)	Tropical rainforest	P	128	24	Cheke *et al.* 1979
Gogol Valley, Papua New Guinea	Tropical rainforest	P	398	-	Saulei and Swaine 1988
Gogol Valley, Papua New Guinea	Tropical rainforest	D	757	-	Saulei and Swaine 1988
Lungmanis, Sabah, Malaysia	Tropical rainforest	P	58	29	Liew 1973
Pasoh, Malaysia	Tropical lowland rainforest	P	131	30	Putz and Appanah 1987
Bukit Timah, Malaysia	Tropical lowland rainforest	-	1000	-	Metcalfe and Turner 1998

There was no seasonal effect observed for seed or seedling densities or species composition. Other studies note a seasonal effect in seed banks linked to the phenology of the surrounding forest (Tang *et al.* 2006, Grombone-Guaratini and Rodrigues 2002, Bakker *et al.* 1996). As TPSF is known to support continuous, year-round fruiting (Canon *et al.* 2007 a, b, Graham and Page 2012), this perhaps is the reason behind the absence of seed bank seasonality. This highlights a means to faster assessment of this potential barrier in restoration studies of TPSF, as the lack of seasonality means samples can be taken over a shorter period, at any time of year.

The following conclusions can be made: given that small seeds were problematic to separate from the peat, the initial seed density indicates the number of large seeds, classically recalcitrant, found within the forest, whilst the seed density ascertained indirectly from seedling germination indicates the number of small seeds, normally with longer dormancy, of the pioneer, secondary successor group (Corlett 2009, Thompson 1992). Regarding the first group, those of large seeds, a small seed bank was observed, as might be expected given that these were mainly tree species adapted to the wet environment of TPSF (large seeded species, and trees from moist conditions tend to have shorter, if any dormancy; Corlett 2009, Blakesley *et al.* 2002). However, the seed density ascertained from the seedling germination study was similarly low, highlighting that TPSF lacks a large seed bank. This may be due to the extremely moist environment which results in TPSF tree species having evolved rapid germination rates to avoid decomposition, even for those species adapted as pioneers or secondary successors (Corlett 2009, Blakesley *et al.* 2002). Some studies have noted that seed banks actually increase in degraded, disturbed or secondary forest compared to natural forest (Brearley *et al.* 2004, Saulei and Swaine 1988), due to the increased numbers of pioneer and secondary succession species associated with these environments that tend to display greater seed dormancy. Other studies have described a reduction in the seed bank in degraded forest areas, linking this to reduced seed input or damage to the seed bank (e.g. Aide and Cavelier 1994, Zimmerman *et al.* 2000). As the site used in this study had been degraded for a long time, assessment of the seed-bank soon after disturbance might have yielded different findings, although, given the short-lived nature of most tropical seed banks, it can be assumed that the seed bank only contains newly arrived seeds rather than those remaining from a time prior to forest disturbance (Aide and Cavelier 1994). However, if this small seed bank, which is relatively unchanged from the NF through to the DegF, is representative of TPSF generally, then it highlights that seed banks are not necessarily lost during degradation as previously thought (Page and Rieley 2005, Giessen 2004), but instead, that a large seed bank was never in operation. This shifts the importance to seed dispersal in order to promote new seedling recruitment (Bakker *et al.* 1996, Holl *et al.* 2000).

The second important finding in this study is that of the significantly higher seed bank regeneration activity observed for the FE, compared to all other FZs, in relation to seedling density and species composition. It might be hypothesised that in intact TPSF, which is continually wet and has year-round fruiting, that seed banks are unnecessary. Equally, outside the forest, the degraded environment bears so little resemblance to that of a natural forest gap that any seed bank would fail. The only location where a seed bank is both necessary and sufficiently protected to support one is, therefore, the forest edge. Although the seed bank here is still very small, it provides an important indication that regeneration at the forest edge is occurring.

Finally, it was observed that seedlings emerged not only from the small seeds in the seed bank, but also from fine root hairs that were cut during the collection of the soil sample; this has not been noted in other studies. Whilst this study was not able to identify the species of sprouting roots, it suggests an interesting avenue in TPSF restoration, in that there was a high propensity for root matter to sprout, even without the addition of hormone rooting powder. This could highlight a potential route for seedling cultivation.

The number of seeds, and consequently the number of species, identified from the soil samples did not include seeds smaller than were easily visible to the human eye. In other studies it is suggested that for analysis of seed density peat samples should be sieved or submerged to separate seeds from the soil (Bakker *et al.* 1996). This method was not possible because when peat samples were wetted organic matter fragments floated alongside small seeds and it was not possible to sieve the samples as one might with mineral soils. As a result, the values for total species numbers and seed density per m^2 may be underestimates. Not all previous studies have considered seed density directly, but have based seed density values on the number of seedlings emerging from soil samples in germination trials (e.g. Tang *et al.* 2006, Tekle and Bekele 2000). Given that seedling emergence data in this study were comparable to those of seed density (16 – 73.6 seedlings m^{-2} depending on FZ), it suggests that this ecosystem does indeed have an overall low seed bank despite restrictions on the use of more accurate seed-retrieval methods such as sieving.

7.3. <u>The process of recruitment and growth</u>

7.3.1. Nutrient availability and peat soil properties

The following section discusses whether pH, org-C, N and P content of the surface peat altered with distance into the disturbed FZs in comparison to the NF; if there were seasonal effects; how the results compare to other studies; and their role as potential regeneration barriers. The underlying ecological reasons behind the observed nutrient availability and peat soil properties are interesting, and, on a larger scale, important for the advancement of RE as a science. The data collected here are sufficient to highlight potential barriers, but would require a more extensive soil chemistry study linked to longer-term tree planting trials in order to fully understand the causes and effects of these findings on forest regeneration in TPSF.

The data showed that there was no significant difference in pH values in relation to level of forest degradation, during both the wet and dry seasons. Values were, however, significantly season-dependent, with pH dropping from an average value of 3.89±0.07 in the wet season to 3.20±0.09 in the dry season, across all FZs. These values are comparable to other studies of peatlands in Central Kalimantan, (3.5-4.0 found by Kurnain *et al.* 2001 and Sarjawan *et al.* 2002, 2.8-3.1 found by Shepherd *et al.* 1997). The seasonal effect may be due to the extensive flooding of the peat surface during the wet season which restricts aerobic microbial decomposition processes in the peat, while a lower pH, as observed in the dry season, may be a consequence of higher aerobic microbial activity which produces carbonic, humic, and fulvic acids that lower pH (Sulistiyanto 2004).

Values for %org-C showed very little variation across the four least degraded FZs, averaging 56.88±1.04%, but were lower in the DegF, with an average value of 50.43±3.72%. The least degraded FZ values are similar to those found in other studies on peatland in Central Kaliamantan (49-57% found by Kurnain *et al.* 2001 and by Sarjawan *et al.* 2002), and given the lack of variation across the forested zones in this study, this suggests that the level of org-C is carefully controlled within the peatland ecosystem, with org-C input (from litter fall, root death etc.) and org-C output (through decomposition and respiration) held in a careful balance (Chimner and Ewel 2005, Brady 1997). The lowest %-orgC found in Central Kalimantan in other studies was 49% (Kurnain *et al.* 2001). This study observed even lower %-orgC in the DegF: there are peat sample location sites in which above-ground vegetation is entirely lost, thus the org-C input is greatly reduced. If decomposition rates then continue as normal, or indeed increase (Notohadiprawiro 1997), this could account for the loss of %org-C. As the peat decomposes the mineral component will come to form a larger fraction of the soil. A study in Sumatra observed %org-C in the mixed peat swamp forest was 54.9-56%, but found far lower %org-C of 41% in the low pole forest, a forest type associated with lower productivity and nutrient availability. There were no observed significant differences between the wet season and the dry season for %org-C. However, in the dry season the DegF had significantly lower %org-C compared to the NF, perhaps as a consequence of having potentially higher surface decomposition rates through the dry season due to surface drying from direct sun light.

In both the wet season and the dry season in some of the more degraded FZs, %N was found to be significantly lower compared to the NF. In other studies on tropical peatlands in this region and within Indonesia, values for %N range between 1-2.2% (Kurnain *et al.* 2001, Brady 1997, Shepherd 1997), while dry season values for some of the disturbed FZs in this study were lower at only 0.72-0.80%. Unfortunately, season was not accounted for in the other studies making direct comparison difficult. Some tropical peatland studies have shown that post-disturbance, %N will rise due to increased aerobic decomposition of the drier peat (Anshari *et al.* 2010), however this effect is likely short lived, with secondary TPSF having lower %N than primary forest (Yanbuaban *et al.* 2007) due to the draw down from the growing forest and leaching. These results indicate that N was more abundant during the wet rather than the dry season. In the dry season microbial activity is at its peak, thus organic N may be mineralised, e.g. to ammonium, and become available for plant uptake (Anshari *et al.* 2010), whereas during the wet seasons mineralisation is reduced under anaerobic conditions and there could be reduced plant uptake.

The C:N ratio follows the same pattern as %-N pattern: there are some effects observed across FZs, with a significantly higher C:N ratio in the degraded FZs compared to the NF. There is also a strong seasonal effect with a significantly higher C:N in the dry season (ranging from 28.48 in the NF to 45.49 in the FE) compared to the wet season (ranging from 54.77 in the NF to 80.13 in the FE). These C:N ratios for the wet season are comparable to those from other studies on tropical peatlands in Central Kalimantan (29-52 - Kurnain *et al.* 2001, and 30-40 - Brady 1997). Yet in the dry season at this site, due to the lower N values, the C:N ratio is exceptionally high reaching up to 80; no other studies found such high results. At such high levels, decomposition rates may reduce and N levels may be limiting to plant growth (Sulistiyanto 2004).

In the dry season the levels of total-P in the surface peat reduced significantly across all FZs compared to the NF. The total-P values for the NF are comparable, or slightly lower, than those obtained by other studies in this region (264±40 ppm in this study, 270-280 ppm (Shepherd *et al.* 1997), 300-900 ppm (0.3-0.9 g kg^{-1}; Sarjawan *et al.* 2002), 400-700 ppm (0.4-0.7 g kg^{-1}; Kurnain *et al.* 2001), 400-800 ppm (0.04-0.08 %P; Brady 1997)). The lowest P-total value of 158 ppm, was observed in the FE. This is below the values measured in other studies and suggests that P availability may be limiting to plant growth in this zone. In the DegF, although P-Total was still significantly lower than in the NF, it was the least significant of all the disturbed FZs. Yanbuaban *et al.* (2007) noted no change in P levels between primary and secondary TPSF soils in Thailand.

It can be seen that for all factors studied there were seasonal and/or FZ effects: pH is strongly seasonal, whilst this phenomona is uniform across all the FZs, suggesting that similar factors influence pH in both the natural forest and degraded areas. Org-C values were stable within the forest, but outside the forest there was large variations in %org-C suggesting some disruption to carbon cycling. Lowered org-C could, in the long-term, indicate lower overall organic matter and nutrient availability (Gomez-Pompa *et al.* 1991). Although N does not show a strong trend with regard to FZ, seasonally there is more N available in the wet season, and N is lower in the FE than in the NF. Perhaps the most notable finding was that in the dry season P is significantly less available in the more degraded FZs. Given that P availability has been observed to influence species composition (Paoli *et al.* 2006) and tree growth (Paoli *et al.* 2007) in TPSFs, this reduction in P availabilty likely indicates a potentially important barrier to forest regeneration and should be investigated more fully.

The second stage of the nutrient availability study considered the impact that nutrient addition had on the performance of seedling growth of the three TPSF tree species: *D. polyphylla, S. balangeran* and *C. rotundatus.* Their responses to nutrient additions provided further evidence of the potential forest regeneration barriers and potential restoration methods; they also highlighted different performance based on species traits.

All the *D. polyphylla* seedlings survived well under the environmental conditions from the NF through to the OCDisF (over 80% survival rate), and, probably due to the additional light availability (Wibisono *et al.* 2005, Rachmanadi and Luzuardi 2007 both found this species to be high light tolerant), the seedlings responded by growing faster in the more disturbed FZs (fig. 6.6). This applied to both the Con and NA seedlings with regard to BD increases, but only to NA seedlings with regard to increases in height. With the nutrient additions, the *D. polyphylla* seedlings were able to take better advantage of the extra light. In the OCDisF this effect was significant between the two seedling treatments. However, this effect did not continue in the DegF where survival rates were significantly lower for both seedling treatments. This suggests that the environmental conditions in the DegF became too extreme, and even with the extra support of nutrient additions, the NA seedlings were unable to maintain high survival or growth. This may account for the mixed success found in other replanting studies for this species (Wibisono and Gandrung, 2008, Giesen 2009): that there is a point when the degraded environmental conditions become to extreme for this species to do well, but until this point it displays its capabilities as an early-successional species, useful in restoration activities.

Interestingly, for the *S. balangeran* seedlings, whilst a similar effect was observed to that of the *D. polyphylla* seedlings regarding increased growth rates in the more degraded FZs, there was little benefit of the nutrient additions to the NA *S. balangeran* seedlings, and in fact, there was one detrimental effect. Survival rates did decline in the DegF for the Con seedlings, but not for the NA seedlings, however, in the OCDisF the NA seedlings showed significantly lower survival rates than the NF seedlings. Both the Con and the NA seedlings had significantly greater increases in BD and height in the disturbed FZs as compared to the NF, with no extra benefit from the nutrient addition treatment. Likewise, leaf number increased more at the forest edge compared to the NF, with no effect of nutrient addition. The high survival rates of the Con *S. balangeran* seedlings up to the OCDisF and the greater increases in BD, height and leaf number, in some cases even into the DegF, suggest this species is a stress-tolerant early-succession species, well adapted to degraded TPSF conditions and suitable for restoration activities, as also found by Wibisono and Gandrung (2008) and Lazuardi (2004). Furthermore, it received no extra benefit from nutrient additions, suggesting it is either well equipped to obtain nutrients without support, or it is a slow-resource user. Other studies have also shown that species adapted to degraded conditions can show remarkable abilities in sourcing nutrients in nutrient-depleted degraded environments. For example, Feldpausch *et al.* (2004) observed tree species of secondary forest vegetation in logged pasture-land of the Central Amazon Basin were still able to source N and P despite low levels in the soil. The presence of N-fixing plants, pools of deep N and mycorrhizae were suggested as possible reasons. Equally, in secondary forest on degraded peatland in Thailand, no relationship was found between the availability of nutrients in the peat and what plant uptake, again suggesting specialised mechanisms for acquiring nutrients in nutrient-limited environments (Yanbuaban *et al.* 2007). In a similar study in Costa Rica (Holl 1999), soil cores were analysed from a forested and an adjacent degraded area. The nutrient availability of the soil was greater inside compared to outside the forest, however, seedlings of three native species cultivated in the two different soil types showed no difference in growth; site-specificity was suggested as the explanation.

The seedlings of *C. rotundatus* appeared to be better adapted to the degraded TPSF conditions compared to the *S. balangeran* seedlings. Survival rates were low for the *C. rotundatus* seedlings in the NF and CCDisF (less than 60%), however, upon reaching the degraded FZs, survival rates did not drop below 60% and were often greater than 80%. This effect was significant in the FE for the Con seedlings, and in the FE, OCDisF and DegF for the NA *C. rotundatus* seedlings, yet in terms of the survival rates there was no significant difference between the two seedling treatment types. The increase in BD and height and LN change was also greater as compared to the NF. It was also the *C. rotundatus* seedlings that showed the most pronounced effects of nutrient additions, which is surprising as other work has shown it to tolerate low nutrients (Matsubara *et al.* 2003). NA seedlings attained significantly greater BD, height and LN increases compared to the Con seedlings across all FZs except the DegF. These findings suggest that, of these three species, *C. rotundatus* is the most specifically adapted to degraded TPSF conditions as a pioneer species, as also found by van Eijk and Leenman (2004) Giesen (2004) and Whitmore (1984), and it was also the species that obtained the most benefit from a nutrient addition treatment.

The nutrient availability studies described above indicated that %N decreased at the forest edge and Total-P decreased significantly across all FZs in comparison to the NF; %C also decreased in the most degraded FZ. Whilst *S. balangeran* seedlings gained no benefit from nutrient additions, suggesting that this is a very hardy species capable of sourcing nutrients in low availability, both *D. polyphylla* and *C. rotundatus* seedlings benefitted from nutrient additions; *D. polyphylla* seedlings in the OCDisF and *C. rotundatus* seedlings in the FE and OCDisF. Across FE and OCDisF both N and P levels were significantly lower compared to the NF, suggesting that it was low availability of one or both of these nutrients that was slowing potential seedling growth. Paoli *et al.* (2006, 2007) showed in West Kalimantan forests, including TPSF, that net primary productivity, biomass and tree growth were all closely linked with nutrient availability, especially P availability. Whilst in Brazilian secondary forest it was shown that nitrogen limitation post-degradation can exist decades after the disturbance event (Amazonas *et al.* 2011).

Interestingly, in this study, the nutrient additions did not provide an advantage to any species in the DegF. This may have been because the environmental conditions were so stressful in this DegF (e.g. in terms of high light intensity and flooding) that even with nutrient additions the seedlings were not able to improve their growth rates. However, %N was not uniformly significantly lower in this FZ, and whilst Total-P was significantly lower than in the NF the surface peat had higher Total-P levels than all the other degraded zones, so it is possible the nutrient limitation was a barrier primarily in the FE and OCDisF. Other studies have also found similar– that nutrient additions in degraded tropical forest areas in the Amazon can lead to an increase in tree biomass (Davidson *et al.* 2004) or transplanted seedlings biomass in Costa Rica (Holl *et al.* 2000) and Mexico (Tobon *et al.* 2011), however that this effect can be species-specific. Holl *et al.* (2000) in Costa Rica, showed that when seedlings of three tree species were transplanted into a degraded area of forest, where half the seedlings were treated with NPK, all three species showed increased growth rates with the fertilizer addition.

7.3.2 Water levels

Water level was observed to fluctuate annually between approximately -50 cm below the peat surface to +5 cm above the peat surface in the forested zones, and from -20 cm to +15-80 cm in the degraded open zones. Peak wet season values occurred during January 2008 and March 2009 and the peak dry seasons were November 2007 and September 2008. These finding are comparable to other studies in TPSF in Central Kalimantan that have recorded peatland water table and annual water level fluctuations (Takashi *et al.* 2002, Takashi and Yonetani 1997, Wösten *et al.* 2008).

Water table was observed to be higher throughout the two years of study in the more degraded FZs (fig. 6.a). This effect was found to be significant for FZs FE (one dry season) and OCDF and DF (one wet season and both dry seasons). After TPSF degradation (which often comprises drainage that may be coupled with fires) peatlands are prone to flooding in the wet season (Page *et al.* 2009, Wösten *et al.* 2008) owing to subsidence of the peat surface (Hooijer *et al.* 2012). This study site had been logged and burned but had undergone relatively little impact from drainage. Nevertheless, deforestation and burning would both have led to a lowering of the peat surface through an increased rate of peat subsidence driven by higher peat surface temperatures (Jauhiainen *et al.* 2012) and peat combustion (Page *et al.* 2002), presumably resulting in the higher flood levels during the wet season.

Wösten *et al. (*2008) suggest that a water table depth of between -40 to +100cm is an optimal range for TPSF systems, and beyond this range, hydrological rehabilitation should be addressed before other restoration initiatives are initiated. The implication of these results, at least from the point of view of regeneration and seedling transplants, is that whilst other environmental conditions might become more severe during the dry season, such as ground surface temperature and surface drying, drought should not prove problematic. However, flooding in the wet season at this site (reaching +80 cm) must be taken into account given that Giesen (2004) and van Eijk *et al.* (2009) both observed that tree seedlings could withstand flood levels of +50 cm, but that high mortality occurred at flood depths of +150 cm during which even well-grown seedlings were submerged.

7.3.3 Light levels

Although it was obvious that light intensity would increase beyond the forest edge, in the more degraded FZs, it was unclear if this high light intensity would be ameliorated to some degree by the growth of invasive vegetation i.e. sedges and shrubs. In several restoration studies it has been found that some transplant species have greater success if planted beneath invasive vegetation for this reason (Rotinsulu *et al.* 2007, Zimmerman *et al.* 2000, Callaway and Walker 1997), whilst in other studies high light intensity has been found to have a negative impact on forest regeneration (Loik and Holl 1999).

The data analysis showed that light intensity did significantly increase in the two most disturbed FZs, OCDF and DF, with FE occurring as the point of transition (fig.6.10). Furthermore, whilst it was shown that at least for FE and DegF the invasive vegetation did reduce light intensity significantly at ground level when compared to light levels at a height of 1 m above the ground, the overall increase in light intensity was still significantly higher than in the NF. Whilst there may have been some degree of amelioration of this environmental condition from the point of view of a seedling on the ground, overall there was a significant, and thus potentially problematic, increase in light intensity across both the OCDisF and the DegF. This effect disappeared at 50 m inside the forest edge (CCDisF), which is a useful characteristic to be aware of when considering planting sites for shade-tolerant species.

The next step was to ascertain if this effect impacted negatively on seedling growth and survival. Overall it appeared that inside the forest, where 70% natural shade cover was already available from the forest canopy, that the shade covers became redundant and in fact were often detrimental, indicated by the high seedling mortality. Out in the open, disturbed FZs, however, where light intensity was significantly higher, protection from the mid-day sun did, in some cases, prove to be beneficial.

For the *D. polyphylla* Con seedlings, the survival rates only significantly reduced once in the most degraded FZ. The NF SC seedlings had significantly lower survival rates than the NF Con seedlings, however, in all other FZs the survival rates for the two seedling treatments did not significantly differ. Both for SC and Con seedlings, the increase in BD during the seven-month growth period was greater in the more degraded FZs. There was no difference in these degraded FZs between the increases in BD across the two seedling treatments, but in the CCDisF the Con seedlings had greater increases in BD than the SC seedlings, showing the detrimental effect of the shading in the forested zones. Height increases of *D. polyphylla* Con seedlings showed no effect of FZ, however, the OCDisF SC seedlings benefitted from the shade cover, with significantly greater height increases than both the NF SC seedlings and the OCDisF Con seedlings. In the CCDisF the Con seedlings also showed a greater increase in height than the SC seedlings. The leaf number change showed some effect of FZ, with NF Con seedlings having a greater increase in leaf number than in the DegF, and the CCDisF Con seedlings attaining a greater increase in leaf number as compared to their respective SC seedlings. The SC seedlings in the FE had a greater increase in leaf number than the SC NF seedlings. Overall, these data show that the *D. polyphylla* seedlings were more sun-loving, and whilst they also grew well inside the forest, reducing their light availability further in the closed-canopy areas through the additional use of shade covers was detrimental. Outside the forest there was a slight benefit of increased height for the shade covered seedlings, but this effect was not uniform, and does not particularly point to this ameliorative method being necessary for this species. Wibisono *et* *al. (*2005) and Rachmanadi and Luzuardi (2007) also describe *D. polyphylla* as high-light tolerant, highlighting it again as an early succession species.

The results for the *S. balangeran* seedlings were very similar to those for the *D. polyphylla* seedlings. Survival of the *S. balangeran* Con seedlings remained high until the DegF. However, in the NF and CCDisF the survival rates of the SC seedlings were lower than the respective Con seedlings. In the FE the survival rates between the two treatments no longer differed. The increase in growth of the Con and SC seedlings was affected by FZ with the seedlings attaining greater BD and height increases in the more degraded FZs. The SC seedlings attained greater BD than the Con seedlings in the OCDisF, but had lower increases in height than the Con seedlings in the NF. There was also a greater increase in leaf number in the more degraded FZs, although with no difference between the treatments. Thus, again, we see an early succesion species that was more sun-loving, as also shown by Giesen (2009), that grew well inside and outside the forest but could not tolerate high shade, and only attained a slight benefit in the open, degraded area when shaded.

C. rotundatus seedlings showed the most negative response to growth in deep shade but appeared to obtain the most benefit from the shade cover in the degraded area. Under deep shade *C. rotundatus* SC seedlings suffered high mortality (in the NF and CCDisF) but showed high survival rates under shade cover in the FE, OCDisF and DegF. The inability to tolerate deep shade again highlights this species as a pioneer. Only in the two closed-canopy FZs did the SC seedlings have lower survival rates than the Con seedlings. Regarding their growth rates, in the NF and CCDisF, the SC seedlings did not grow any slower than the Con seedlings, and both Con and SC seedlings had greater BD and height increases in the FE, OCDisF and DegF than the NF seedlings. Furthermore, in the FE and OCDisF for BD increases, and in the FE for height increases, SC seedlings had greater growth increases than the Con seedlings. The change in leaf number also became greater in the more degraded FZs, although there was no difference between seedling treatments.

Overall therefore, it would appear that while light intensity is significantly greater in the degraded FZs, this does not necessarily become a regeneration barrier. This conclusion is, to some extent, dependent on species, and some benefit can be obtained for all three species through the use of shade cover in the most degraded areas. A study in deciduous forest in Thailand found a similar result with six different species responding differently to gap/canopy environments (Marod *et al.* 2004). In another study in Puerto Rico, transplanted tree seedlings responded negatively to grass removal due to the increased drying and light intensity (Zimmerman *et al.* 2000). Khurana and Singh (2001) describe that most tropical closed-forest species do grow best in the high light of gaps, and tend towards sun-loving, as supported by the findings of this study.

7.3.4 Competition with herbaceous vegetation

The competition from non-tree and tree vegetation that seedlings faced across the five FZs was not seasonally dependent. Competition did, however significantly alter in relation to FZ. Inside the forest the non-tree vegetation ground cover was dominated by pandans whilst outside dominance switched to sedges (fig 6.14). The sum of non-tree vegetation ground cover was also significantly higher for the FE and OCDisF, showing that sedges provided a significantly higher degree of ground cover than pandans. In contrast, seedling, sapling and tree ground cover did not follow this trend, with cover showing no significant difference from NF through to the OCDisF, and only becoming significantly lower in the DegF, where non-tree vegetation was also not at its highest percentage ground cover. These results suggest that whilst percentage ground cover of tree vegetation was significantly lower in the most degraded FZ, this effect was largely uncoupled from competition with the non-tree vegetation. This is further reinforced by the fact that no seasonal effect was observed for non-tree vegetation, yet a seasonal effect was sometimes observed for the seedling ground cover, suggesting other more important factors were acting upon them. This result was further demonstrated in the results from the seedling transplantation trials with the competition removed treatment.

Other studies which considered ground cover of herbaceous and tree vegetation also observed that herbaceous vegetation cover rose significantly outside the forest (Holl 1999, Aide and Cavalier 1994), as was shown in this study. These studies also observed that tree and seedling cover significantly reduced outside the forest, which was also observed to some extent in this study, but to a lesser degree.

The effect of competition removal (CR) on the transplanted *D. polyphylla* seedlings was slight, and, if anything, harmful. The survival of the *D. polyphylla* Con and CR seedlings was greater than 70% across all FZs apart from in the DegF, in which survival significantly lowered for Con seedlings, although there was no difference between seedling treatments in any FZ. In the DegF, the Con seedlings had significantly lower survival rates compared to their respective NF seedlings, whilst the DegF CR showed no significant difference. Both the Con and the CR seedlings had significantly higher BD increases in all the disturbed FZs, as compared to the NF, but there was no effect of seedling treatment in any FZ. The Con seedlings showed no effect of FZ regarding height increases. For the CR seedlings, however, the seedlings in the OCDisF had significantly greater increases in height as compared to the NF CR seedlings, but the CCDisF and FE CR seedlings had lower height increases than the respective Con seedlings, suggesting that competition removal impacts negatively on seedling height increases for these FZs. There was little effect on LN; the Con seedlings on the DegF had a lower change in LN than the NF Con seedlings. CR seedlings leaf number change showed no effect of FZ, and there was no effect of seedling treatment on any FZ.

The *S. balangeran* seedlings showed no effect of competition removal on seedling survival, or change in BD, height or LN. The survival of *S. balangeran* Con and CR seedlings was high (over 80%) for all FZs apart from the DegF, in which survival dropped to approximately 60%, significantly lower than the NF for the Con seedlings. Increases in BD were greater on the more degraded FZs for both Con and CR seedlings, likewise for height (in the OCDisF), and for LN (in the FE and OCDisF) compared to the NF. But in all the above cases there was no significant difference across the two seedling treatments, suggesting *S. balangeran* seedlings are not affected by their surrounding vegetative competition, in any forest environment.

The *C. rotundatus* seedlings showed quite a distinct, but negative response to removal of competition. All the CR seedlings died in the NF, whilst nearly 60% of the Con seedlings survived. Likewise, in the CCDisF and FE, CR seedling survival was lower compared to the respective Con seedling survival. Survival improved in the most degraded zones, and showed no further difference between the seedling treatments. For the growth of *C. rotundatus* seedlings, BD, height and LN changes were all greater in the more degraded FZs. The effect of competition removal on the CR seedlings' growth rates was less than that of survival; there was no effect on height or LN, but BD increases were lower for CR seedlings on the DegF compared to the NF. Overall then, this suggests that *C. rotundatus* seedlings received some benefit from having the surrounding vegetation intact, and removing the 'competition' actually negatively affected survival in the forest and, to a lesser extent, growth rates outside the forest, again highlighting this species as a pioneer with rapid drawdown of resources, and as such a strong competitor. But as there are no negative impacts of not removing the competition there is every reason to leave the surrounding vegetation intact when transplanting this species.

The effect of herbaceous vegetation on seedling regeneration in degraded areas is perhaps the most varied of all the potential regeneration barriers in the literature. Wilson (1999) describes that whilst both facilitation and competition can feature in regeneration succession routes, that facilitation is more common in primary succession whilst competition is more common in secondary succession. In a mega-analysis Gomez-Aparicio (2009) further describes how invasive species in restoration activities can prove to have a facilitator role, especially in the tropics. Some studies, such as Holl *et al.* (2000) in Costa Rica, have shown that increased competition with grasses has negative impacts both on natural seedling regeneration (biodiversity and ground cover) and survival rates of transplanted seedlings. Similarly, Nepstad *et al.* (1996) found that exotic grasses in the degraded tropical forest of East Amazonia limited tree regeneration by competing with tree seedlings for water and nutrients, as did Hooper *et al.* (2005) in degraded tropical forest in Panama. In a seedling transplant study in degraded tropical forest in Sri Lanka, now dominated by grasses, the four transplanted tree species increased in growth and survival upon removal of root competition with the grasses, but removal of above-ground competition did not lead to the same benefit (Gunaratne *et al.* 2011). Conversely, other studies, such as Aide and Cavalier (1994) showed that the increased percentage of grass ground cover in degraded moist lowland forest in Colombia facilitated seed germination and transplanted seedlings showed greater survival and growth, although these authors did recognize that the thickness of the grass and the stage of degradation could influence whether this factor became a regeneration barrier. Likewise, a complex relationship was demonstrated by Holl (1999) in Costa Rica, where seedlings transplanted into degraded tropical forest grew better under grasses which ameliorated the harsh environmental conditions of increased air, soil temperatures and light intensity. Similarly, Zimmerman *et al.* (2000) showed in study plots from which vegetation had been removed in degraded tropical forest areas in Puerto Rico that the surface temperature increased and that tree seedling germination was lower, although seed survival was not impacted. This study, in common with those cited previously (e.g. Holl *et al.* 2000, Hooper *et al.* 2005), has demonstrated the importance of both site- and species-specificity when it comes to understanding the likely impact of herbaceous/invasive/pioneer vegetation on seedling regeneration. Overall, for this specific site it would appear that although herbaceous vegetation cover does increase significantly in the degraded FZs, that competition with tree seedlings does not play a large role in limiting seedling survival and growth. In fact, in some instances, the removal of the vegetation had a negative impact on seedling survival suggesting a facilitatory role by the invasive vegetation which reduced light intensity at ground level in two of the degraded FZs. Other potential ameliorative effects such as lowered air and soil temperatures and reduced drying of the surface peat would need to be further explored.

7.3.5 Mycorrhizal colonization levels

In the disturbed FZs the inoculated seedlings of *S. balangeran* and *D. polyphylla* had higher levels of mycorrhizal colonization compared to control seedlings which represented the naturally available levels of mycorrhizae in the peat. This result suggests limited availability of suitable mycorrhizal species in the disturbed zones, which was a disadvantage to the seedlings.

There was little or no effect of FZ or mycorrhizal treatment on seedling survival rates, BD and height increases, change in LN, or change in root and shoot biomass for either *S. balangeran* or *D. polyphylla*. Other studies have shown that seedling physiological aspects (biomass, height, leaf production) can be improved by mycorrhizal inoculation when seedlings are grown under nursery conditions (Turjaman *et al.* 2006) and to some extent also in the field (Turjaman *et al.* 2011). The data from this study suggest, however, that these growth advantages may not always continue into the field.

For *S. balangeran*, the seedling N content decreased with increasing level of forest degradation, for both the control and the *S. columnare*-inoculated seedlings. Only in one FZ, OCDisF, did the *S. columnare*-inoculated seedlings have a higher N content than the control seedlings. For *D. polyphylla* seedlings a more marked effect was observed; in all degraded FZs the nitrogen content of the control seedlings was low, suggesting that *D. polyphylla* seedlings had difficulty accessing N to their optimum levels. This observation was supported by the fact that in nearly all FZs the *G. decipiens*- and *G. clarum*-inoculated seedlings had much higher N contents. This was most significant inside the forest, suggesting that the benefit of increased N levels obtained by the mycorrhizae was active across all FZs, but that in the more disturbed FZs N was limited, even for inoculated seedlings. The little N that was available, however, could be accessed by the seedlings with the higher mycorrhizal colonization levels, unlike the control seedlings. Low N availability has been noted in other areas of degraded rainforest (e.g. Columbia - Aide and Cavalier 1994, Costa Rica - Holl 1999) including TPSF (Yanbuaban *et al.* 2007). In this study the chemical analysis of the surface peat showed that N levels were significantly lower in the FE throughout the year (and in the DegF in the wet season) as compared to the NF.

The P content of *S. balangeran* seedlings was little affected by FZ for either mycorrhizal treatment, and there was little difference between treatments. However, in the FE, the control seedlings contained significantly lower amounts of P compared to the FE and compared to the *S. columnare*-inoculated seedlings. This suggests that where P does become limited the *S. columnare*-inoculated seedlings are better able to counteract this effect, but that generally P was not limiting for the *S. balangeran* seedlings. The P content of the *D. polyphylla* control seedlings decreased in three of the disturbed FZs compared to the NF, suggesting that P did become limiting with increasing forest degradation. This effect was less marked, however, for inoculated seedlings; *G. clarum*-inoculated seedlings contained lower P levels compared to those in the NF except in the DegF, and *G. decipiens*-inoculated seedlings contained lower P levels in only two FZs. Equally, *G. clarum*-inoculated seedlings had higher P levels than the control seedlings in the CCDisF, and *G. decipiens*-inoculated seedlings in the NF, CCDisF and FE. As with nitrogen availability, reduced P levels are known to reduce in degraded rainforest areas as observed in TPSF (Yanbuaban *et al.* 2007) and elsewhere (e.g. Colombia - Aide and Cavalier 1994, Costa Rica - Holl 1999). Furthermore, this study demonstrated lower phosphorus levels in the disturbed FZs as compared to the NF, which supports the suggestion that P availability was lower for seedlings in the disturbed zones than in the forest, but that the mycorrhizal colonization can somewhat counter this effect.

These results suggest that both N and P became limiting for *S. balangeran* seedlings and especially so for *D. polyphylla* seedlings in the more disturbed FZs, however, the inoculated seedlings supporting higher levels of mycorrhizal colonization were better equipped to cope with these nutrient limitations. Studies on *D. polyphylla* seedlings in nurseries provided with *G. decipiens* and *G. clarum* showed increased nitrogen and phosphorus contents relative to control seedlings (Turjaman *et al.* 2006) and the results of this study suggest that this benefit is extended into the field. It is also interesting to note that the *S. balangeran* seedlings, which seemed to receive a less notable benefit from the mycorrhizae inoculation, also received no benefit from the nutrition addition study. This confirms the earlier suggestion that *S. balangeran* is well adapted to obtaining nutrients in low-availability environments, and may also not be highly dependent on mycorrhizae for this purpose.

Finally, other literature suggests that mycorrhizal symbiosis may confer further benefits to seedlings , such as increased resistance to drought and diseases (Dell 2002, Rillig 2004). These aspects were not addressed in this study, but given that the seedlings which were inoculated did permit higher mycorrhizal colonization levels than the control seedlings, which could only obtain their mycorrhizae naturally from the peat soil, there is a suggestion that the seedlings obtain other benefits from this symbiosis. Increased nutrient uptake has already been illustrated here, but others benefits may also be present, especially in the stressful, degraded TPSF environment.

7.4 Conclusions

Based on the results presented in Chapter 6 and the above discussions, it is possible to begin to interpret how the altered environmental conditions in degraded TPSF may be operating as potential and subsequently active regeneration barriers, based firstly on the change in the environmental state (table 7.2), and secondly, on the impact this changed environmental state has on tree seedling growth and survival (table 7.3).

Table 7.2: The changes in the environmental conditions in relation to the NF, and an assessment of whether each environmental condition has become a potential regeneration barrier.

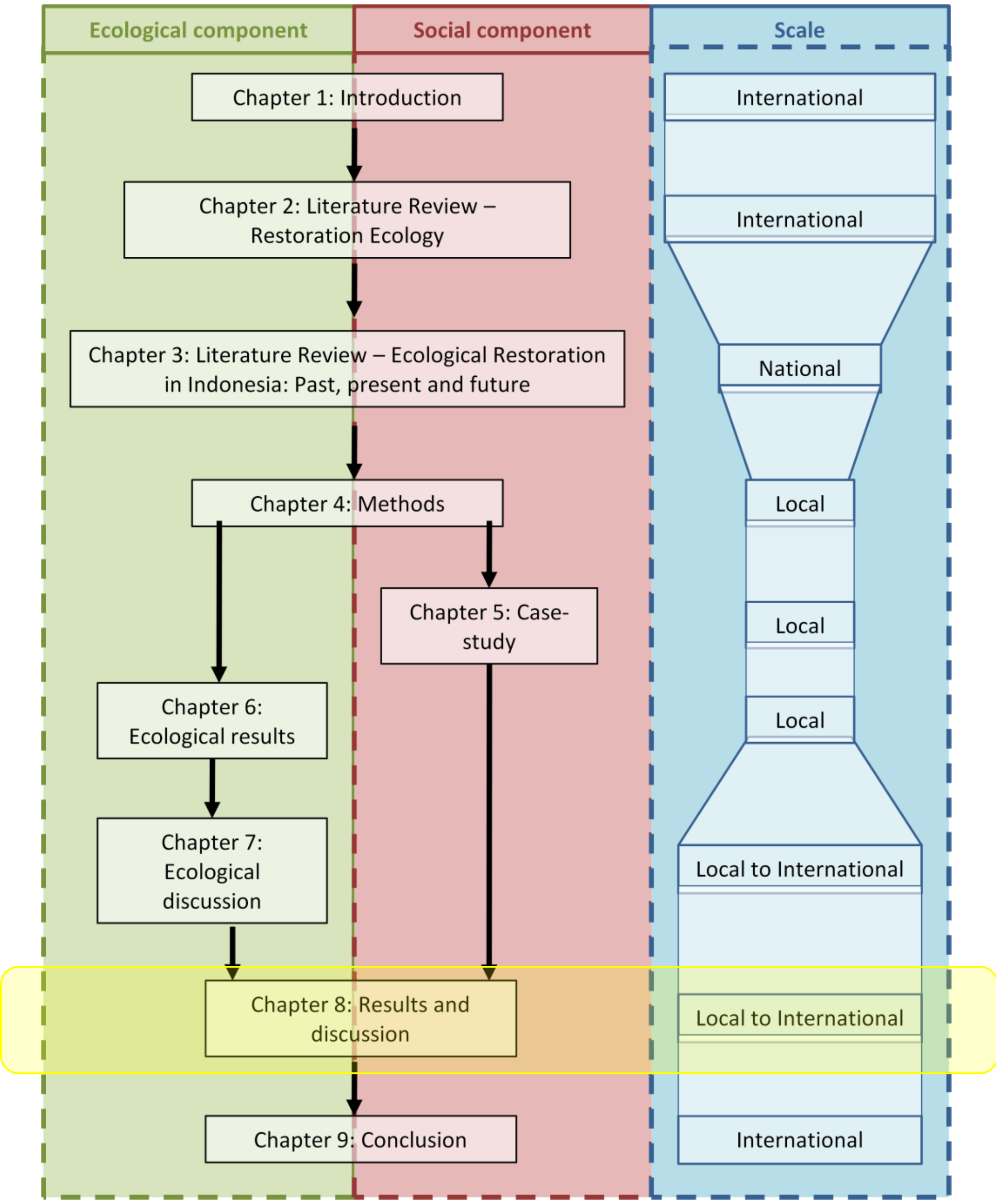
Environmental condition	**In what way altered from NF?**	**Potential regeneration barrier?**
Seed rain (volume and species)	Lower in FE, OCDisF and DegF	Yes
Animal-dispersal	Lower in OCDisF and DegF	Yes
Seed bank	None (no operational seed bank anywhere)	No
pH	None	No
%-orgC	Lower in the DegF	Yes
%N	Lower in the FE (and DegF)	Yes
Total-P	Lower in all deg. for. zones	Yes
Water – peak-wet season	Higher in OCDisF and DegF	Yes
Water – peak-dry season	Higher in FE, OCDisF and DegF	No
Light intensity	Higher in OCDisF and DegF	Yes
Competition with non-tree vegetation	Sedges and overall non-tree vegetation ground cover greater in FE and OCDisF	Yes
Mycorrhizae availability	Lower in the degraded FZs	Yes

Table 7.3: The seedlings responses to the ameliorative measures to overcome the changed environmental conditions, and an assessment of whether these indicate active regeneration barriers.

Seedling treatment	**Species**	**In what way different from NF?**	**Active regeneration barrier?**
Nutrient addition	*D. polyphylla*	Greater growth rates in the OCDisF	Yes; species-specific
	S. balangeran	No effect	
	C. rotundatus	Greater growth rates in the FE and OCDisF	
Shade cover	*D. polyphylla*	Greater growth rates in the OCDisF	Yes
	S. balangeran	Greater growth rates in the OCDisF	
	C. rotundatus	Greater growth rates in the FE and OCDisF	
Ground-vegetation removed	*D. polyphylla*	Decreased growth rates in the CCDisF and FE	No, in fact the ground cover had a positive effect on the seedlings and removal led to a negative effect
	S. balangeran	No effect	
	C. rotundatus	Decreased survival in the CCDisF and FE	
Mycorrhizae provided	*D. polyphylla*	Nutrient uptake improved (not growth or survival)	Yes
	S. balangeran	Nutrient uptake somewhat improved (not growth or survival)	

The results presented in Tables 7.2 and 7.3 could form the basis of the ecological component of a restoration action plan (RAP) for this specific site. However, these findings do not stand-alone. How the local community sees and understands these barriers will also be pivotal to both education programs regarding the RAP and to its implementation. Furthermore, when developing a RAP, ecological barriers are just one component. The social barriers must also be explored and addressed. In the next chapter, both the ecological and social findings are presented, with a discussion of how they combine into factors influencing the regeneration of the degraded landscape. The form that these factors take is also considered; negative (regeneration barriers), potential negative, inactive or positive and compound are identified, followed by a reflection on how this information might be used to develop a RAP.

8. Results and Discussion



8.1. Introduction

Chapters 6 and 7 provided a technical presentation and discussion of the ecological results of this study; how the study-site's environmental conditions have altered in the degraded forest zones compared to the natural forest, and how these changes (or lack of) have (or have not) become regeneration barriers. As discussed in Chapter 2, 'regeneration barrier' is a common term used to describe the environmental conditions altered through disturbance and degradation, which consequently impede or stop regeneration of a degraded site. Many studies have focused on assessing and determining these barriers in order to target restoration methods and design efficient and appropriate restoration action plans (RAP). The importance of working together with the local communities linked to the degraded area has also been highlighted. Numerous studies have shown that without appropriate participation of the communities, addressing issues under contention and incorporation of their aspirations, the restoration activities are likely to be limited in their success. Consequently, in the same way that there are ecological regeneration barriers, it could be argued there are also social regeneration barriers which need to be equally explored and addressed. This study aimed to explore both the ecological and the social factors that were potential regeneration barriers at this study-site. Furthermore, this study aimed to explore how these factors interlinked and might be represented in a unified understanding for a RAP, not as two separate blocks of results from two distinct disciplines.

As this study progressed, it became apparent that the 'potential' and 'active' regeneration barriers only told half of the story, especially in relation to social factors. During exploration of the factors influencing the landscape, some results showed that factors which might have been regeneration barriers, were in fact inactive. Equally there were factors that could have a positive impact on regeneration and restoration. These factors, it is argued in this study, are just as important to explore and include in a RAP.

To this end, this chapter presents the data, the factors influencing the landscape, from both the social and ecological studies, in the format of ‘negative factors’ (or ‘regeneration barriers’), ‘potential negative factors’, ‘inactive’, ‘positive’ and ‘compound’ factors.

Given the technical nature of the ecological data, these have first been presented in chapters 6 and 7 in a conventional physical science style, so that they might be used to guide subsequent ecological studies. At the outset of this chapter, then, a brief overview is provided of the social data collected from the local community, based on the three themed topics (past, present and future uses of and attitudes towards the forest) (see 4.4.7).

This thesis, however, aimed to address the socio-ecological gap currently facing ecological restoration, and did not want to present all the findings in two distinct blocks. Subsequently, in this chapter, all the factor-types, outlined above, which are influencing this landscape, are explored jointly from both their ecological and social perspectives. Having dealt with the technical aspects of the ecological results in previous chapters, the ecological findings are presented in this chapter in more common terms. To support the social findings, quotes from the participants are used to illustrate their view. At the end of this chapter the factors in their various forms are summarized and the development of a RAP is discussed based on this unified view.

Please note, the objective of this chapter is to detail the bridging of the social and ecological data with regard to each factor, and to present the social findings for the first time. The previous chapter, Chapter 7, provided in-depth discussion of the ecological results, with comparisons to appropriate literature. Relevant literature will also be cited in this chapter where it pertains to the social data, and to the bridging of the social and ecological findings or the methodology presented; purely ecological literature will not be re-cited.

8.2. Themes and attitudes of the local community towards forest restoration

In focus groups and interviews with the local community, three topics were discussed; history, present uses and future of the land. The outputs from the focus groups were annotated diagrams which were synthesised into single large posters, used in the interviews (translated versions shown in figures 4.9, 4.11, 4.13, 4.14b and 4.16). Upon transcription of the meetings, themes from within each topic were drawn out, and relevant quotes selected. An overview of these key themes is presented in Table 8.1. These were then further refined and combined with the ecological data to produce a detailed discussion of the environmental factors influencing the landscape (8.3).

As described in Chapter 5, a total of 154 members of the local community participated in the activities and shared their views on the landscape. These participants came from a diversity of gender, age, education, occupation and location within the village. It was anticipated that this would need to be taken into account in presenting the data from the community. It was quite remarkable, therefore, the singularity of their opinions and perspectives. As described in 5.3.1 the men and women often had different experiences of the same situation, but the end-point of their perspectives were often similar (and this study was not gender-based; not looking to explore this disparity unless necessary). Occasionally, views did diverge. Where this happened, this difference is described below, but the overall homogeneity of the participants' views is intentional and accurate.

Table 8.1: The themes and attitudes of the local community towards forest restoration; past, present and future, as developed from the focus groups and interviews.

Theme	**As explained by the community**	**Community attitudes**
History		
Desire to move forward / link to the past	In the last 50 years, the village has developed (more residents, school, road, logging companies – legal and illegal) but the forest has also become degraded.	The community were happy for the developments, but not at cost of forest lost. They had pride in their forest vocations and were saddened at the loss of their old way of life.
Feelings of being observers	Most of the degradation (logging, lack of government control, fires due to disturbance) was perceived as coming from external forces.	The community felt they were not to blame for what happened to their land. There were feelings of being overwhelmed, overtaken and pushed out. They acknowledged the short-term benefits but felt they had been mistreated and amends should be made.
Feelings of lack of options	The time of prosperity with the logging companies had gone, and they couldn't return to their previous vocations due to the degradation of the forest. They tried to maintain livelihoods with the few resources that were left.	They felt they had reached a point of real difficulty. They were aware their activities were not currently sustainable, that the money they made was only just sufficient and with general prices rising, they struggled to make ends meet.
Personal attitudes	They appeared as a forgiving and welcoming community, despite the difficulties they have faced and the perceived injustices.	Their acceptance of transmigrants and other settlers highlighted the important difference they saw between outsiders and those that became part of the community.
Outsiders	Perceived as those people or groups that came to the area, exploited a resource, then left again, e.g. the legal and illegal logging companies and fishermen from Banjarmasin.	Strong resentment was felt towards 'outsiders'. Whilst they acknowledged they themselves had partaken in some of the activities that led to the current state of the forest's degradation, they felt it was only due to an increased sense of competition and need that resulted from outsiders and the damage to the forest leaving resources scarce.

Present		
High awareness of ecology	Their knowledge, particularly of the men, of the forest and ecology was very high and perceptive. They were able to describe the water, atmosphere and soil and how this was controlled and affected by different forest qualities. They had knowledge on tree and animal species, their habits and seasons, which allowed them to work year-round in the seasons of the forest.	They were proud of the forest and their heritage, and this linked to a deep understanding of species and environment.
Importance of the forest	The forest provided the community with most of their livelihoods: logging, fishing, jelutong, gemur etc. It was the source of many of their personal needs, from mats, chicken cages and fish traps, and for food – primarily fish, but also, pig, deer, and bats, for the timber to build their houses, and natural medicines.	The most recurrent theme was the importance of the forest to the community; personal uses and livelihoods, but also how it linked to their culture, identity, tradition and heritage, sense of place and sense of well-being. How the community related and interacted with the forest defined much of how they described and identified themselves.
Sense of loss of forest	Through the fires and logging, and the overuse, the forest was no longer meeting their needs. The community was aware their current activities and use of the forest by themselves and by others was unsustainable.	The degradation of the forest left them worried about their future. They talked sadly about the current state of the forest, having lost both a means of income and a part of their history and identity.
Future		
Concern for the forest	The unsustainable use of the forest plus other factors such as fire left the community worried about the future of the forest and their future use of it.	The community strongly wanted to protect, restore and maintain the forest. They looked for ways to reduce their impact on the forest.
Attitude towards restoration	They saw the forest's restoration and subsequent management as a long-term solution to their current situation. They had numerous ideas and suggestions for how to bring about this regeneration, but did not feel financially or authoritively empowered to do it.	They were extremely motivated towards restoring the forest. They had seen the fleeting benefits of natural resource exploitation and wished to get back into balance with nature by re-creating their original livelihoods, for themselves, their children and their grandchildren.

Relationship with government	They were honest about the ways they felt the government had not managed the area well, regarding the logging, illegal logging and fire prevention. Indeed, when they felt the policies of the government were really inappropriate they even expressed the option of stepping outside the law. Despite this, they looked to the government as the main potential source of funding. They also saw the need of the government to provide the laws and authority necessary to bring about restoration.	They felt let down and abandoned by the government, and resented restrictions emplaced. Despite this, they were still keen to work together with the government. They felt that without the government, however keen the community, any forest protection and restoration would fail. Based on past experiences the community had little appreciation for government methods in restoration, and little trust in their intentions. Consequently they wanted to lead any activities, being merely facilitated by the government, and they wanted to ensure rights to the benefits of the restored forest.
Barriers to restoration	There were numerous issues the community saw as preventing the forest's restoration; funding, fire, logging, outsiders, lack of species knowledge, management.	The community said they needed to feel truly involved in the activities and invested in the final outcomes. That would mean that final ownership and the recipients of future benefits would need to be established from the start and the commitment and period of commitment made clear. For a long time the community had been left to do whatever was necessary to make ends meet, and they felt it would take patience and commitment to allow all the community to truly believe in a RAP.
Practicalities – implementing restoration	The community described the actual implementation of restoration largely as fighting fire and planting seedlings, both of which required long-term inputs. The methods they proposed for both of these were detailed: they outlined a comprehensive fire-fighting regime, and similar for replanting – from seed sourcing, through to creating a closed-canopy and introducing mid-succession species.	The community did not wish to just carry out orders, but already had their own ideas and methods for restoration.
Alternative livelihoods	There was a large emphasis on the generation of alternative livelihoods, such a forest restoration and fish-farming. These would be routes by which they could improve their living standard and reduce their impact on the natural forest.	They felt previous livelihoods had been taken from them and not replaced. They had ideas for alternatives, but not the means to implement them.

8.3. Exploring the factors influencing the regeneration of this degraded landscape

Typically, restoration ecology studies investigate the environmental conditions that have become active regeneration barriers at a degraded site. As described in 8.1 this study felt that in order to successfully combine social and ecological data, and to show the array of factors influencing the degraded landscape, from the negative factors (regeneration barriers) to the positive, new and more extensive terminology was needed. This terminology is defined below and used to present the factors found to be influencing this landscape, with combined social and ecological data.

Table 8.2: A summary of the terminology developed in this study to describe the factors influencing the regeneration of the degraded landscape.

Factor	**Definition**
Negative	Also called regeneration barriers, these are factors acting upon the degraded area such that they would need to be directly removed or overcome in order for regeneration to take place.
Potential negative	Factors causing some degree of negative impact on regeneration, or may become active negative factors based on an external trigger. These factors should be considered in developing a RAP, but are not as problematic as negative factors.
In-active	Factors that have neither a negative nor a positive effect on regeneration, and as such, would not need to be addressed in restoration activities.
Positive	Factors shown to support regeneration activities, and awareness of these factors and their incorporation into a RAP would be advantageous.
Compound	Factors that are not necessarily negative or positive, but which are complex factors affected by numerous events and as yet unresolved.

8.3.1. Negative factors (regeneration barriers)

Seed dispersal

> 'Galam is brought by wind, so first there is just balangeran and galam, but now it's all mixed, there's lots of species of tree. That's because the seeds are brought by birds, so the birds have to bring them, animals, and also seeds that are brought by the wind'. (Male participant, Meeting 1, 'Future' Discussion)

The number of seeds 'raining' from the forest (seed rain) was found to reduce significantly at the forest edge and out into the most degraded forest zone. This was true for both the volume of seeds and the number of species. Also, the seeds that did 'rain' in the degraded area were found to reach there through wind-dispersal rather than animal-dispersal, which was the reverse of that in the natural forest. The community was aware that in order to get a mixed array of species in the degraded area, they were dependent on animal-, primarily, bird-dispersal, but that currently it was mainly wind-dispersal that was in operation. The community named two of the common wind-dispersed species in their discussion, namely '*galam'* (*Melaleuca leucadendron*) and '*balangeran'* (*Shorea balangeran*). An understanding by the local community of the importance of seed dispersal was shown in another study in secondary succession forest after fallow swidden in Thailand, where the community's TEK was discussed and applied in restoration planning and participatory forest management (Wangpukapattanawong *et al.* 2010).

Flooding

> '…it destroys the forest when it floods, the people cutting down lots of the forest give the flood a chance, so in the wet season it can all flood. It'll be like this later, in the end the destruction of the forest, it'll be destroyed by water, so really I would say it's the same [risk] as fire'. (Male participant, Meeting 1, 'Future' Discussion)

> '…if it's the wet season, if the seedlings are still small and go under water, the seedlings can't grow. Really for balangeran and jelutong, they mainly can live in water, but if the water is too deep, they can't live.' (Female participant, Interview 1, 'Future' Discussion)

The ecological data showed that throughout the year, the degraded forest zones had significantly higher water levels than inside the forest. Furthermore, in the wet season the water depth in the degraded area could reach up to 80 cm thus transplanted seedlings, which are commonly recommended to be transplanted at 30 cm in height, would be submerged. This could prove to be an active regeneration barrier, although not all of the community were aware of this problem. Some of the participants did see that flooding posed just as great a risk as fire in terms of forest degradation and that it could cause a significant barrier to seedling regeneration or transplanting. The peat swamp forest ecosystem naturally floods in the wet season, however, with rivers spilling over to the surrounding land – to the extent that the community living along the side of the river Sabangau build their houses on 3 m stilts. Some people therefore did express views that flooding was a 'natural' state of this ecosystem, and not something to be worried about. Given that at least some of the community were already recognizing what the ecological data showed, that the flooding is more extreme in the degraded area, bodes well for convincing the whole community that this factor should be addressed.

Nutrient availability

> ‘Because the soil is not very fertile and the fertilizer is expensive so [farming is] difficult in the long-term’ (Male participant, Meeting 2, ‘Present’ Discussion)

A common story from the community: Immediately after an area of forest was cleared for settlement, the land was fertile and the community was successful in growing many kinds of crops, including rice. However, after 2-3 harvesting cycles, the yields quickly dropped, and the community complained that they could no longer grow crops without applying large amounts of fertilizer. This pattern, well understood in tropical forest ecology, is that in intact forest, despite soil infertility, primary productivity can be high thanks to efficient recycling of nutrients. Post-logging, this recycling process is lost. As a consequence of this poor long-term farming success, the community generally rejected farming, putting extra emphasis on the importance of their dependence on the forest.

This traditional knowledge is supported by the ecological findings: the total-phosphorus levels were lower in all the degraded forest zones, as was the percentage of nitrogen though less uniformly so, compared to the natural forest. This is further supported by the fact that if fertilizer was used by the community, the most common was chicken waste (naturally high in phosphorus) despite NPK fertilizer also being sold. Also, in the nutrient-addition transplant-seedling trials, two of the three species responded favourably to the nutrient additions, suggesting that natural levels are below optimum for forest regeneration. The only type of 'farming' the community expressed any interest in was forest gardens, which would protect the peat.

The ecological data showed that nutrients become further limited in an already low nutrient environment. This is further supported by numerous forms of traditional knowledge, thus the community demonstrated awareness of the issue of nutrient availability and that this is an active regeneration barrier that would need to be addressed.

Lack of options and money

The time of prosperity with the logging companies had gone (see below), and the community described that they could not go back to their previous vocations, such as *jelutong* and *gemur* collection, due to the degree of forest degradation. They were dependent on the forest for personal needs; they could harvest produce, such as fish, without having to pay anything, as opposed to all other forms of meat, for which they would have to pay. Similarly, they felt the weight of the ban on logging as they needed wood for building and for cooking. They linked their personal funds closely to what they could do in the forest. They felt that they had not only lost their forest, but also their traditions, ways of life and professions. Many members of the community had turned to fishing, although they saw that too was already becoming unsustainable. They had to work multiple 'side jobs' to bring in enough money. The money they were making was only just sufficient and with general prices rising, they struggled to make ends meet.

> 'So now … there are no professional fishermen, there aren't any professionals any more, also there aren't any professional jelutong collectors any more, we have to find secondary jobs. At the side, there are the needs of the economy

> that are increasing, prices of things are increasingly expensive, and we don't have enough.' (Male participant, Meeting 4, 'History' Discussion)

> 'Lots of forest that the community feels, especially the wood, the community really needs the forest here, and now to cut down trees is forbidden, wood is expensive, so it's hard for the community. So that's the difficulty… you need wood for things for your house, now you have to buy it, it's difficult'. (Female participant, Interview 6, 'Present' Discussion)

There was a large emphasis throughout the discussions on the need for alternative livelihoods. They felt previous livelihoods had been taken from them and not replaced, they had ideas for alternatives, but not the means to implement them. They cited alternative livelihoods, such a forest restoration and fish-farming as routes by which they could improve their living standard and reduce their impact on the natural forest. They felt they had few choices or options available to them, and they longed to break this cycle of forest degradation, but could not see a way to do it themselves.

> 'I feel it's hard, because it's only in the forest that there's work for people, there isn't any other. Maybe if there was other work, the forest could come back… But I feel there's no other work… First there has to be work for the community here, so that the forest isn't disturbed anymore.' (Female participant, Interview 2, 'Future' Discussion)

The community showed an awareness that the activities they engaged in were becoming less sustainable and more damaging to the forest, however, they could see no way to break this cycle and consequently would continue to do this unless alternatives were provided. Other research in Indonesia has highlighted similar problems; the loss of access to good quality natural resources through various external forces resulting in difficulty for the communities to support themselves on the remaining livelihoods available (O'Connor 2004, Armitage 2002, Tsing 2005, Timmer 2010). Some studies have documented work which has focused on facilitating the communities in alternative livelihoods post-degradation, to provide them with routes to sustainable land-use and recovered economies (Mertz 2005, Tynela *et al.* 2002).

No funding for restoration

The community uniformly felt the biggest barrier facing forest restoration was the lack of funding. They were aware that forest restoration is a long-term and an expensive activity; without funding this community could not give up their daily salaries and invest time and money into it, despite what they might wish. Furthermore, they had no solutions to this barrier. They did not know how to source funding for themselves and instead expressed hope that some external sponsor, including the government, and the researcher, could provide/source funding for them.

> 'Funding [is the biggest problem facing restoration]. Actually we really wish to be recruited from the community to restore the forest, replant the forest, look after the forest… But for us to cultivate the forest and plant the forest we have to be given a salary'. (Male participant, Meeting 4, 'Future' Discussion)

> 'Automatically if it's us ourselves that has to find the funding, then we can't, we have no ideas or how the funding can appear. Yeah, so if you ask us how to

find the funding I feel that we sitting here are confused… because we only had primary school education on average, so we don't really understand where we would have to look…'. (Male participant, Meeting 4, 'Future' Discussion)

'…however many hectares for however much salary, because it needs a salary, definitely there needs to be payment. It always comes back to funding and payments' (Female participant, Interview 3, 'Future' Discussion)

The implementation of ER is often constrained by monetary aspects (Hobbs and Miller 2007, Clewell and Aronson 2006) especially in tropical, developing countries, such as Indonesia (Aide *et al.* 2000, Holl 2012). Although meta-analysis shows that restoration activities most often have a positive benefit-cost ratio (Neβhöver *et al.* 2011), communities often need immediate incomes and so must resort to short-term economic payoffs (see above, Schuyt *et al.* 2007, Williams and Mawdsley 2006). Recent developments, such as REDD+ and payment for ecosystem services, provide potentials for new routes to funding, (Alexander *et al.* 2011, van Andel and Aronson 2012b, Sasaki *et al.* 2011, Aronson *et al.* 2007), especially in Indoensia and on tropical peatlands (Spracken *et al.* 2008, van Noordwijk *et al.* 2008). However, for these projects to achieve long-term success it will be essential to ensure that the local communities have fair access to these opportunities and funding, otherwise, issues such as those described above in 'Lack of options and money' will continue (Wright 2011, Moeliono *et al.* 2012).

'Outsiders' (but not Transmigrants)

> [1956] 'There were only, maybe, 3 huts, and all spread out. If you walked from one hut to another, it would take about half an hour to walk, and all in the forest' (Female participant, Interview 11, 'History' Discussion)

> 'In the year 1971 the local resettlement started. Erected in Block A, Block B and Block C, so a total of 70 houses at that time.' (Male participant, Meeting 3, 'History' Discussion)

Despite previous expectations that there would be tensions between original inhabitants and transmigrants based on other research (O'Connor 2004, Fearnside 1997), and given that the transmigrants arrived with special government subsidies and received land and houses, this was not found to be the case. The village was very small previously, and the community wanted to develop, especially regarding better infrastructure including roads, schools and health clinics. The villagers saw the arrival of the transmigrants as the point where the government started to pay attention to the village; the government school was built, the road was given tarmac, shops opened and life became easier. They did see not see the increase of population (from the hundreds to the thousands) as becoming too busy, but pleasantly busy. The community was very proud of their village, and those that came to stay appeared to be quickly accepted. These oral histories of the village were often presented by the women, detailing how different village events transpired and how it affected their day-to-day lives. The end point, however, that of pleasure in the development and acceptance of the settlers, was expressed by both the men and women.

> ‘No, it wasn’t really busy, but there started to be enough people here… education started… and after the transmigrancy started the road started to be built’ (Female participant, Interview 11, ‘History’ Discussion)

Despite this general positive attitude towards transmigrants and others that have moved to Kereng to make it their home, keeping resource use within the community, those that had come, taken resources and left received much anger from the local community. ‘Outsiders’ were blamed for numerous activities related to the destruction of the forest: the fires, the over-fishing and the illegal and legal logging. People were generally very bitter when talking about ‘outsiders’, feeling that things were stolen from them, and that through outsiders’ lack of care or negligence, the place they live and work had been damaged.

> ‘They arrived just for the work, and they arrived just to take the riches of nature and I consider they stole the riches of the forest here’ (Male participant, Meeting 1, ‘History’ Discussion)

> ‘That made them extinct it was the outsiders from South Kalimantan that collected baby fish and carried them back to South Kalimantan. So baby fish here all ran out, were taken, sometimes with the parent fish’. (Male participant, Meeting 4, ‘History’ Discussion)

It could be argued that much of degradation have largely been due to external forces. The concession-based logging and illegal logging was facilitated and established by the government (or through a lack of enforcement of government law), and the fires, even if the majority were not started by ‘outsiders’ as claimed, were only able to really take effect and cause damage after the initial disturbance caused by the logging. Consequently the community did not feel they were to blame for what had happened to their land. There was a feeling of being overwhelmed, overtaken and pushed out by these activities, even when they, in the short-term, benefitted the community.

> ‘So, that which made the Sabangau damaged, not this local Sabangau community, and if you counted, from 100% its maybe 0.5% only that the community did, that means only half a percent of the community damaged the forest’. (Male participant, Meeting 4, ‘History’ Discussion)

Outsiders, it was claimed, unlike the local community, did not have a vested interest in the long-term sustainability of the forest resources, and so were careless and over-exploited. This resulted in the community no longer wishing themselves to care for the long-term – if others were going to destroy the forest, why shouldn’t they partake? And it also left them feeling frustrated that they would often get the blame for doing this damage. These attitudes are commonly cited in other studies in Indonesia where the abuse of land-rights/-access/-use by the previous governments have left the community feeling as on-lookers, being marginalized and left without a voice, unable to contend with these external forces (Armitage 2002, Tsing 2005).

> ‘If people from outside arrive, invade, like that and take the potential, then although only observers, just watching, then the time will come, in the middle, they start to join in, in the end they’re doing it’ (Male participant, Interview 12, ‘History’ Discussion)

> ‘…now because the arrangement has changed, life like that, for example I myself cut some trees down, leaving some with hope that they can grow again, returning to non-damaged forest, but then somebody else arrives later to where I was working, and later takes what I left. Why, rather than somebody else, why don’t I myself take it? So because the arrangements changed, life is competitive, this means that better than other people take something, why don’t I myself take it?’ (Male participant, Meeting 4, ‘Present’ Discussion)

In order to exclude these people the community felt they neither had the laws nor the rights. They wanted to be empowered and facilitated to remove these people, but needed the government to support them. One way they felt they would gain the rights to forbid outsiders was if the forest were restored by their hand, then they felt they would have claim and could ask outsiders to leave. As described in Sections 3. 6 and 3.7 both during and after the governance of New Order, local communities have lost much ownership and access to land and natual resources (O’Connor 2004, Mertz *et al.* 2005, Sikor and Lund 2009, Peluso 2012). Only recently, through the development of the democratic government, have local communities been able to feel the have a voice regarding land rights issues (Engel and Palmer 2006, Moeliono *et al.* 2012). Whether the views of the community regarding outsiders are considered justified or not, the emotion of the community associated with this issue was very strong, and changed political climate is now empowering these communities to realize and expect certain rights to their land. Trust and real investment into the area would need to be proven by external restoration groups and relationships re-built to ensure equity and agreement on lond management activities.

High light intensity

> 'Yeah, that's really another factor – the heat. It's because we see the soil, other species [than balangeran and jelutong] they grow in the forest underneath [the canopy], not directly under the direct sun, and that means that in shaded places only can they grow well.' (Male participant, Meeting 4, 'Future' Discussion)

The increased light intensity moving from under the forest canopy out into the degraded area is a factor which both the traditional ecological knowledge and the ecological data recognized. Light intensity was significantly higher in the degraded area compared to in the forest, and the small amount of shade provided by the invasive vegetation did not provide the same level of shade as the trees. Furthermore, the three species of seedlings all grew better in the degraded areas when provided with some shade-cover. Consequently, this was a barrier understood by the community, and one which would need to be addressed in order for natural forest regeneration in this area to proceed successfully.

Fire

Due to the conditions created by the logging, the community has become accustomed to fires. They blamed fires on humans and especially on 'outsider fishermen' who are careless with cigarettes and cooking fires. They were also honest to admit they too sometimes started fires to clear the pandan grass, necessary to yield good fish stocks. In earlier times, when the forest was healthy, the grass would burn, but not the forest. Now they could no longer be sure of this and they worried about starting big fires themselves.

> ‘Burning the forest before, for the community of Kereng Bangkirai, was a tradition. Every year *rasau* [pandan grass] was burnt by the fishermen, because if *rasau* is too dense, fishing is difficult. So that was the reason for burning, and every 3 years it would return again. So it became a tradition, burning the rasau, by the community, but not until burning the forest. And why was this? Because the forest was still luxurious and the ground was wet. But now just try to burn the grass, and the forest will all be lost, burning with it’. (Male participant, Meeting 4, ‘History’ Discussion)

They saw fire as a huge barrier, and linked it closely with both the current safety and health of the forest and any restoration activities. They were aware fire could lead to rapid and large-scale forest degradation.

> ‘First of all this is [the forest] should be protected from fire because if it’s illegal logging it can destroy, but slowly, not too fast, but if it’s fire maybe it can [destroy] 10 hectares in one day. That’s what’s important, it destroys and later there no trees will grow, only fire’. (Male participant, Meeting 2, ‘Future’ Discussion)

> ‘We have to replant [the land], but if we replant it, it must be looked after so fires don’t happen’ (Male participant, Meeting 1, ‘History’ Discussion)

In order to combat this barrier, they felt the need for large-scale organisation, effective equipment and effective government policy and support – the latter two they felt had been lacking. Even with all these in place, they still saw fire as a huge obstacle and one that could overwhelm even skilled fire-fighters. They felt much man-power would be required, which meant incentives would be needed, either by paying fire-fighting salaries and/or the community having something of their own to protect i.e. replanted forest.

> 'Sometimes the local community sees that the policies about forest fire prevention, that come down from [the government], aren't quite appropriate… They rent a plane to send water – how much does it cost to rent that? Extremely expensive. Try giving all that money to the local community to give an incentive then buy simple equipment that get results… When we see what the Department of Forestry is doing, it's very wrong, they buy lots of cars; fire engines, then they buy big machines for putting out fires, that are carried by 6-10 people, only then can they be lifted, and that work is wrong. Where are the people that can carry a machine as heavy as that into the forest? Because the fires are in the forest.' (Male participant, Interview 12, 'History' Discussion)

The problem of fire in Indonesia, and particularly in TPSF, has been well documented (Byron and Shepherd 1998, Hoscilo *et al.* 2011), as has its relevance as a regeneration barrier (Page *et al.* 2009). Solutions to overcoming this huge barrier include hydrological restoration and political and education activities linked to fire management and prevention activities (Page *et al.* 2009, Spracken *et al.* 2008). There has, to date, been little progress in overcoming this barrier, and perhaps incorporation of the views and ideas of the local community could enhance success.

8.3.2. Potential negative factors

These are factors causing some degree of negative impact on regeneration, or may become active negative factors based on an external trigger. These factors should be considered in developing a RAP, but are not as problematic as negative factors.

Mycorrhizal colonization level

Mycorrhizal colonization level was an ecological/physical science factor that was not yet appreciated through traditional knowledge: mycorrhizae are not visible to the eye and their role is not apparent to a lay-person. Similarly, they are not normally taught in the school science curriculum until, at the earliest, sixth-form. Mycorrhizae were not mentioned by members of the community, thus, these results can only be presented from an ecological view-point.

This study showed that seedlings that were inoculated with mycorrhizae maintained a higher mycorrhizal colonization level than the control seedlings in nearly all the degraded forest zones. Given it is the plants that control the percentage of mycorrhizal colonization in their roots, the fact that infection levels were higher in the inoculated seedlings illustrates that there was a benefit to supporting these mycorrhizal associations and that the natural colonization levels were below optimal. It was, however, surprising that for none of the tree species was seedling survival, growth or biomass production affected by mycorrhizal treatment. Higher mycorrhizal levels instead seemed to serve the function, especially in *D. polyphylla,* of increasing the nutrient availability to the seedlings. This then raises the question is this the only benefit that the seedlings attain, especially given that the effect on nutrient uptake was not pronounced for *S. balangeran* seedlings? Or were the seedlings benefiting in some other way, such as resistance to low moisture availability during the dry season?

Whilst the benefit of mycorrhizal association to the seedlings still requires further exploration, the results indicate that a definite benefit was present. There is a cost to the plant of supporting higher inoculation levels, yet those higher mycorrhiae levels were maintained. It would seem advantageous, therefore, that any reforestation activities to consider the use of mycorrhizal inoculation. The social data highlight the need for education relating to this factor. Inoculating seedlings with mycorrhizae, whilst not expensive, would involve cost, and in any truly participatory RAP development, this activity would first need to be explained to the community.

Selecting species

The tropical peat swamp forests of Central Kalimantan contain over 150 tree species. Whilst some of these may have suitable morphological and physiological characteristics to cope with the extreme environmental conditions present in degraded peatland and thereby have the essential traits to become successful transplant seedlings, many other species will not survive outside the forest (Graham 2009). There is extremely limited species-specific information for this ecosystem, making appropriate species selection for transplant seedlings difficult (Graham 2009, Page *et al.* 2009). For the ecological component of this study, three species were selected based on their known commercial value and tolerance to degraded conditions, which made them useful transplant species, although their exact tolerances and optimum growth conditions were further explored in this study. Knowledge of these three species, however, only makes up a small percentage of the information needed across a much wider array of TPSF tree species. Parataxonomy and parabiology have been shown to be important resources in supporting reforestation and conservation programs across the tropics (Wangpakapattana *et al.* 2010, Shiel and Lawrence 2004), and both were shown to be relevant in this study also. The community was able to mention five potential transplant species. Furthermore, they understood the principles behind selecting species, showing knowledge of selecting appropriate conditions for each species, selecting those with flood, drought and fire tolerance, and using nurse species to create a canopy under which other species could grow. This knowledge would be advantageous in restoration activities; much of the research necessary to select transplant species for reforestation could be quickly understood and implemented by the local community. However, this does not remove the barrier of the great amount of work still to be done; that species-selection and optimum species transplant locations must still be explored, which will take time and effort:

> 'We would plant *galam* then the second maybe *krupuk* or *balangeran*. That's three types, there are others that could grow too… Like *jelutong*… We see in the area, the area at the front, *galam*, then behind it *krupuk*, then the area behind that *balangeran*. Our meaning is like this; you have to match the land, match the place there… If after the *galam* has grown and underneath is a bit dark, maybe we can plant other trees that can't tolerate the heat. Because once it's dark there, maybe they'll want to grow'. (Male participant, Meeting 2, 'Future' Discussion)

> 'So, make 1Ha of land and plant lots of different species because the land is still natural so those which we plant there we can see if they develop, for example, after a period of time we can see how many centimeters they're grown, and if they're weak, so maybe, from the number of species maybe there'll be some that are good, or some that are less good. So that is truly

research that can become apparent' (Male participant, Meeting 4, 'History' Discussion)

Drought

'… so if it's in April or May, there's still rain to water our plants, so that in the dry season, once it's truly the dry season the roots are already growing. [But if you plant] in the dry season the plants can't [tolerate] it, the soil is dry, there's no watering, the ground is hot, so the roots are hard to grow into the dry [earth].' (Female participant, Interview 1, 'Future' Discussion)

In common with the community's TEK on high light intensity and flooding, the community also observed that in the dry season the ground is much hotter and drier in the degraded area, which would theoretically, therefore, be an active barrier, or negative factor. Likewise, from the scientific knowledge on tropical peatland degradation, drought, as well as flooding, is cited as a barrier to natural regeneration (Page *et al.* 2009). Unlike numerous other areas of degraded tropical peatland, this location has been logged but not severely drained, thus although the peat has to some extent subsided and compacted (resulting in increased flood risk), through the dry season, the ecological data show that the water level does not drop below normal levels, and in fact, is higher than inside the forest. Nevertheless, as the quote from the participant above describes, drought does not only deal with water level, but also surface drying and ground surface temperature, which have been shown to impact negatively on seedling restoration activities (Holl *et al.* 2000, Holl 2012). These aspects were not considered in this study, but given personal observations and the TEK on this factor, they do require further investigation before they can be dismissed as ‘inactive factors’.

The community’s physical dependence on the forest

The local community, from when the village originated (1920s), right up to present day, was very dependent and reliant on the forest. This was something they were aware of and consequently they were already worried about what will happen as the forest becomes more degraded.

> ‘I feel that for the community here the forest is extremely important, because it can continue our lives, because we not on state employment’ (Female participant, Interview 3, ‘Present’ Discussion)

> ‘Yeah, we’re happy only if [the forest] is healthy and we can find lots of produce but if we can’t find produce it can’t make us happy’ (Female participant, Interview 4, ‘Present’ Discussion).

The community have lots of specific uses for forest products, ranging for their own personal needs (firewood, fish – their main source of protein, medicinal plants), produce they can sell (*jelutong* tree sap – converted to rubber, *gemur* tree bark – converted to mosquito repellent, bats, birds, fish, grass mats), and happenstance findings that they can either sell or use themselves (pigs, deer, orchids).

> ‘Lots of people collect firewood. They collect the branches and twigs of the dead wood that’s already available… And that means the wood is free to

> collect, so we don't need to buy cooking gas.' (Male participant, Meeting 3, 'Present' Discussion)

> 'The principle of collecting from the forest is that whatever can become money… for example, a pig is caught, it's sold becoming money, for example if fishing is difficult then you can collect jelutong, or you can collect gemur. You can work on anything around about concurrently.' (Male participant, Meeting 2, 'Present' Discussion).

They are now aware that much of what they collect is in severe decline; *jelutong, gemur*, fish, through a combination of over-harvesting and habitat loss. But due to their high dependency on these livelihoods or personal needs they continue to exploit these resources. This high dependency on forest products by small communities in Indonesia, and the difficulties they face as the forest becomes less productive is also described by Tsing (2005), stressing the importance of the provisioning ES to this community (TEEB 2010). Dependency and exploitation must be addressed as restoration takes place, with alternative livelihoods and incomes provided, otherwise the problem will re-occur (McManus 2006, Moeliono *et al.* 2012).

> 'Pleasant, not pleasant, whichever, if we've got work in the forest. If cutting down trees, maybe it's just for our needs, and we don't know if it's good or not good for the forest, what's important is our needs are met' (Female participant, Interview 3, 'Present' Discussion).

> 'The government with their rules has to make an alternative, for example, make [fish] ponds, that means make a livelihood from fish. A livelihood like that could change the paradigm of the community. The community take from the forest, takes the animals from the forest, he needs to change his work so a livelihood in fishing, it can give an alternative.' (Male participant, Meeting 4, 'Future' Discussion)

The community's idea of how the forest should be restored

> 'This is the problem of restoring the forest, for the future of the community, except if the community can restore a forest, change the forest that's already damaged. So the area that's already burnt, they should plant it with a forest that can benefit the community itself. For example, rubber trees, jelutong, fruit, and others that can benefit the community. Whatever will help the community. For planting others like balangeran, I feel not. Galam, other wood don't have a benefit for the community except for getting a salary. Except if there's compensation'. (Male participant, Meeting 3, 'Future' Discussion)

The community had lots of ideas for how the future forest should be used. Primarily they saw it to be designed to benefit them; rubber trees, fruit trees, rattan, dahanen, even the original trees used to close the canopy (galam and balangeran) could be harvested for timber. However, they also saw that the restored forest should not only serve their immediate needs, but also the animals of the forest and nature – which in the long-term will protect the community too. They said that if the restored forest more immediately served their needs, they would use less, and damage less, of the remaining natural forest. Whilst the community is highly supportive of restoration, it is based on their own ideas and it would be to serve them, and they already have very exact ideas of how they would like to see the restoration take place. This factor could be used positively; their enthusiasm and interest, but also this factor would need to be handled carefully. The final goals of restoration activities are value-laden, and are often associated with pre-determined qualifications, funding requirements, etc. (Tongway and Ludwig 2012, Clewell and Aronson 2006). The ideas of the community may not exactly match the actual targets or end-points of a RAP. It would, therefore, be necessary to involve the community not just in the implementation but also the planning stages of the restoration; their hopes and ideas could be aired and where not met, full explanation and even alternatives provided. Other restoration studies have shown that where the local community's aspirations are neither met nor explained leads to misunderstandings and conflict (McManus 2006, Collier 2011).

The community's desire to be empowered to protect and be in charge of restoration activities

Linked closely to the previous potential negative factor 'The community's idea of how the forest should be restored' is the fact the community also hopes to be empowered to protect the restored forest, and, to some greater or lesser degree, to be in charge of the forest. They feel that the forest was theirs at the start, and if they restore it, they would want to determine themselves who has access rights and who does what in it. Based on the past history of inequitable misuse of the forest resources from external forces (largely the government and the logging companies), this desire to be in control and ensure the community has rights and access to the benefits is understandable, and highlighted in other studies too (O'Connor 2004, Armitage 2002). Recently, land-management endeavors in Indonesia have focused on trying to restore the *adat* rights to the local communities, though often with mixed success

(Engel and Palmer 2006, Mertz 2005). This desire by the community to be ‘in charge’ whilst understandable, may not be entirely feasible depending on the restoration scenario. If not addressed, explained and resolved openly, however, could result in bitterness and conflict on the part of the community:

> ‘The forest has laws, so the problem was, before the government was the coordinator, and also for an area like this you have to involve the community too, because the community knows better who likes to damage the forest, so then they can work together. For example, if there’s an organization from outside, and also can work with the government, and the government also must work with the community, so that there’s a balance, so that it’s stronger for protecting the forest’ (Female participant, Interview 1, ‘Future’ Discussion)

> ‘After the [restoration] group leaves, then the community will just destroy the forest again, and that can happen. My thinking is, I see the community, it’s not this community that damages the forest, it’s outsiders, so I want to ask do you really want the forest in this area to be restored until our children and grandchildren later? Yeah, really it’s like this, it has to depend together with this community. We can restore the forest and look after it, but only if the restoration there affects the community, or else I agree in its disturbance’. (Male participant, Meeting 1, ‘Future’ Discussion)

8.3.3. In-active factors

These are factors defined as neither having a negative nor a positive effect on regeneration, and as such, would not need to be addressed in restoration activities.

Seed banks

This study was the first to explore the ecological factor of a potentially reduced seed bank in the degraded area of TPSF acting as a regeneration barrier. Seed banks are the seeds that are present in the soil due to the natural build up of seed rain from the forest. In temperate forests these seed banks can last for decades, but in the tropics they tend to have a much shorter viability due to high decomposition rates. These seed banks can be important in forest regeneration following disturbance and degradation as they are a mechanism, along with seed dispersal, for seedlings to return. However, this study showed that, perhaps due to the extremely moist conditions of TPSF and rapid seed predation and seed germination, the natural forest area did not support a viable seed bank, and thus whilst there was also no seed bank observed in the degraded area, this was not an altered environmental condition due to degradation. Instead, this is the natural state of the ecosystem, and not a factor that would hinder regeneration. This factor was, therefore, classified as a inactive factor, which had no effect upon forest regeneration. Whether due to a lack of knowledge, or instead an awareness of its unimportance, none of the participants mentioned anything in relation to a seed bank, despite illustrating their thorough understanding of nearly all other ecological factors.

8.3.4. Positive factors

Factors which support regeneration activities, and awareness of these factors and their incorporation into a RAP would be advantageous.

Competition with non-tree vegetation / Clearing

> 'Don't, don't cut it. Because it cools the ground. We can cut [the grass] to make a path, but for the places we plant it's not necessary to cut. It's for protection in the dry season or when it's hot, [the seedlings] can be closed in by grass so it doesn't catch all the heat'. (Male participant, Meeting 3, 'Future' Discussion)

When it came to the issue of the increased amount of non-tree vegetation (primarily sedges) in the degraded area, no assumption was formed before the study started based on the scientific literature. This was because, although non-tree vegetation invariably increases in a degraded site, it does not always have the same effect on forest regeneration. Whilst in some cases, increased ground vegetation acts as a competitor and hinders the growth of tree seedlings, in other cases the vegetation ameliorates some of the harsh environmental conditions in degraded areas, acting as a facilitator to forest regeneration. The ecological data in this study complimented the TEK on this topic; the non-tree vegetation had a beneficial effect on the transplanted seedlings, and those growing in plots where the vegetation was removed had lower growth or survival rates. It would appear that the non-tree vegetation actually facilitates rather than hinders regeneration in this instance, and clearing before planting may not be needed, at least in the early stages of seedling growth.

All the participants who mentioned the invasive sedges present in the degraded site felt they should be left there to protect any transplanted seedlings.

The community's attitude towards the forest

The forest was very strongly part of the community's culture, identity and tradition:

> 'The wisdom of the traditional culture is to look after the nature for the long-term, truly to look after, with special warning because nearly all life is dependent on nature, that is, the forest' (Male participant, Interview 12, 'History' Discussion)

> 'Because Dayak people can't be far from the forest. Because the source of life is from the forest… Especially people from Kalimantan, if they moved to Java, or wherever, it would be quite hard because normally it's different. Normally people are close to the forest, if they move to another place that doesn't have forest it's hard for them to adapt' (Male participant, Meeting 2, 'Present' Discussion)

The participants were able to describe the forest in depth, and all aspects of its ecology. The forest made them happy and content; it was a place for children to play and old people to relax in the shade. They liked to hear the animals call, and see the forest as providing the animals with a home.

> ‘If we’re in the forest and we see a monkey climb it can make us laugh. If a person is stressed, normally if you take him round [the forest] he loses his stress’ (Female participant, Interview 4, ‘Present’ Discussion)

They appreciated the fresh air the forest provides, that it protected them from pollution and global warming, and that it kept their climate cool.

> ‘Really, the effect is like this, if the forest is gone and it’s the hot season, really we feel hot, but if there’s lots of trees the heat is less, and in the house now we have to use fans all the time. Before it was nice under the trees’ (Male participant, Interview 13, ‘History’ Discussion)

They also mentioned how it kept their water clean, controled the water levels and controled erosion. They were proud of all the tree species which could be used as timber and would list tree species as the symbols of the forest, mentioning birds, monkeys and orangutans as an afterthought.

> ‘All the wood [are symbols of the forest]… Maybe if we mention the names of all the trees one-by-one maybe [your poster] will be full!’ (Male participant, Meeting 3, ‘Present’ Discussion)

This closeness of Dayak people to the forest has been recorded elsewhere (Tsing 2005), highlighting the importance of the cultural ES (TEEB 2010) or the ecosystem benefits (Barbier *et al.* 2011) rather than just considering those of monetary value. A community that has this much respect and love for its forest is an advantage to any restoration project. They know intimately its states of health and have strong reasons to support its recovery.

The community's awareness of the state of the forest

Once the forest became degraded, the participants talked of it being bald, only having very few tree species, and that it was dry and barren. They described how all the animals had gone because they had lost their homes. They felt the degraded forest was hot, with no shade, that it was hard to walk there and hard to breathe, with the smoke and dust and pollution. The water became dirty and the area regularly flooded as it was no longer controlled by the forest. They felt it was lonely and quiet and it made them sad to see it.

> 'All that's left is rasau [grass] and balangeran at the river edge, that's all. Forest that's cut down, in ten years it can only just [grow] again… [Degraded forest] is not nice, it's hot and it makes my heart feel sad seeing all the trees that aren't there' (Female participant, Interview 2, 'Present' Discussion)

They were aware that the fish populations were getter smaller in number and size, and that they had to go further to catch a good yield.

> 'Where are the products? There are none! If the forest is already damaged you can't do anything' (Female participant, Interview 2, 'Present' Discussion).

> 'Yeah, because now when [the fish] are small we already catch them, so they don't have chance to get big, because 70% of the residents here fish so for the growth of fish they don't have chance to get big, because they're caught before

> that. So the point is, now the fish are nearly extinct, because there are so many fishing, same like logging [before]' (Male participant, Meeting 3, 'Present' Discussion)

All the uses of the forest were already seen to be less than than they used to be, so when faced with their outlook for the future, the participants thought they will either be greatly diminished or run out all together.

> 'I think there won't be [any forest] anymore because it's already ran out now, it's all already taken, so what again for the future, if it's all already taken' (Male participant, Meeting 1, 'Future' Discussion)

The community strongly wished to protect, restore and maintain the forest, thus protecting the provisioning and regulating services they relied upon (TEEB 2010). They needed it for their own uses, they felt a strong link to it, it provided them with their history. They were acutely aware of its degraded and progressively more degraded condition, and their role in this. They wished to break free of this cycle and be able to help the forest recover.

The community's forestry and restoration knowledge

The community understood many of the principles associated with good forestry, silviculture practice and reforestation. They mentioned concepts of harvesting wildlings, of seedling cultivation in nurseries, of transplant location, and after-planting care. Generally their understanding was good, and where not, education could improve this. Overall, the men seemed to know more specific details of a wider range of forest products and uses. The women knew these things to be important, providing the incomes for their families, and had good understanding of those products or activities that they could do locally (as opposed to the men who would go an excursions looking for produce whilst the women would stay at home with the children), e.g. fishing, gathering firewood, cultivating seedlings. Thus, whilst their depths of knowledges did sometimes differ, the attitudes in relation to the knowledge were similar. Other studies have shown the potential importance of a local community's TEK knowledge in restoration planning (Wangpakapattanawong *et al.* 2010), and this community's good understanding of the forest and forestry could only serve to benefit and make easier any restoration activities.

> 'What's good is, in my opinion, is the seedlings we take, we put them in grow pots. We cultivate them for however many months, not until one year, then we move them to the location. This way you're more certain, in my opinion, that [the seedlings] won't get stressed, won't have a stroke. Yeah, it's a good solution using grow pots'. (Male participant, Meeting 3, 'Future' Discussion)

> 'So all the seedlings can live if they start from around 50cm-1m, that's good' (Female participant, Interview 1, 'Future' Discussion)

> 'And don't just plant seedlings like that, plant and then straight away leave them. After they're planted they have to be looked after and cultivated, like that… That's what is good. If like the work of WWF they planted and then they left them and ran away… They weren't looked after, weren't supervised. Alive or dead, the seedlings that we planted, we don't know.' (Male participant, Meeting 1, 'Future' Discussion)

The community's attitude towards restoration

The community was very much in support of restoration of the forest. They had lots of their own ideas, from species to use, to methods to implement, and they saw it as an ideal route for the community to move forward: it would provide jobs in the short-term and livelihoods in the long-term.

> 'We wish for [forest restoration]. It can be like before, so that it can still be enjoyed by our children and grandchildren'. (Female participant, Interview 1, 'Future' Discussion)

> 'Automatically if the community here is involved in [a restoration project] I feel that we could manage, could work, could shape it together, to protect it eternally.' (Male participant, Meeting 3, 'History' Discussion)

However, they were not naïve regarding the process; they understood it would be a difficult and long undertaking.

> 'Yeah, maybe if in the long-term, like 10 or 15 years ahead, it will truly be successful, just the thinking of the community right now is, during the 10 or 15 years the community will be hungry, that will become a problem.' (Male participant, Meeting 4, 'Present' Discussion)

Especially important was an idea of '*holistic restoration'*. They didn't just talk about 'planting trees' but they talked about livelihoods, future generations, funding and economy, fires and so on. Clewell and Aronson (2006) discuss the importance of appreciating the motivations behind restoration, such as a recovery of natural capital and re-establishing the links between culture and nature, and how these motivations can shape the restoration goals and outcomes. This study's data indicate a very aware community that appreciates all the components of restoration, its benefits and difficulties, but still with a strong motivation towards it.

8.3.5. Compound factors

Factors that are not necessarily negative or positive, but which are complex factors affected by numerous events and as yet unresolved.

The community's relationship with the government

The relationship the community had with the government was complicated. On the one hand they didn't always trust or agree with the government. They mentioned issues of corruption with the restoration activities, how the government used the community as a scapegoat regarding the fires, and how they took away their livelihoods from logging without considering or providing them with an alternative.

> 'It was the fault of the government; why at that time did they give permits to accommodate [the illegal loggers] then at the end blame it on the community although it was the negligence of the government?' (Male participant, Meeting 4, 'History' Discussion)

Despite these bad feelings, they remained hopeful and keen that the government would empower them to bring about forest restoration. They saw it as the government's responsibility, as they took away the community's livelihoods that should provide another, and they indicated they would be willing to work in this way. They showed respect for government, seeing any law imposed as absolute and not one they could question, whether they agreed with the law or not.

> 'The point is, the community themselves can look after [the forest], and be supported by the government. So let the community themselves that want to look after the forest, but if the government doesn't support [them] then it probably won't happen too'. (Male participant, Meeting 2, 'Future' Discussion)

> 'For example, the community can protect the forest, and the government can support them with rules on collecting [forest produce]. For example, taking wood; that this is not allowed or that this is not allowed, hunting if forbidden, offhand use of fire or whatever as a foundation, on top of basic laws. Because the community is definitely scared of laws' (Male participant, Meeting 2, 'Future' Discussion)

They did however question whether it was likely the government would decide to take this responsibility upon themselves. They could see their own intentions and the actual final outputs as beneficial to all so they couldn't see why the government wouldn't support them, however, they had been hurt and ignored by the government before, leaving them doubtful.

> 'We don't yet know [if the government wants to help support the forest], because there hasn't been discussion of hopes with the government. Like for a long time we've heard it, but there's been nothing, just words. He [a politician] should try to tell us when! Everything has been forbidden, burning the forest,

> logging the forest... But there's nothing so I feel maybe it's still a contradiction with the rules of the government – there is no place to work but [they say] they give a place of work so that the forest won't be disturbed'. (Male participant, Meeting 1, 'Future' Discussion)

Furthermore, they worried about this relationship. They very much wished to be in control of their activities and did not wish to lose these to the government; they had disagreed with government methods in the past regarding the forest and worried they will lose access and land rights.

> 'The government has been traitorous. It's like this, if [the presidential candidate] wants to become the president, he makes lots of promises with the community, but after he's elected he doesn't care anymore with the people that elected him. [These candidates] promise but it's not written down, it's a shame, so the community can't prosecute.' (Male participant, Meeting 2, 'Future' Discussion)

The community wished to be empowered but not controlled by the government, they felt they had the know-how and expertise and plans to bring about restoration, but they saw that without the physical and lawful support of the government, their activities would be difficult. Whilst the community had high expectations and hopes for the government, in order for this relationship to work successfully, many of these issues of ownership, trust and duration of support would need to be addressed. This complex relationship with the government stems from the long history of the New Order government's attitude to and treatment of land-management and local communities' land rights (see section 3.4.3 and

Timmer 2010). Despite recent advances by the new government to change this perception (see section 3.7.2), it may take years, if not decades for trust to recover.

Logging (concession and illegal)

Logging has come in several forms for the community over the last thirty years; first there was the legal logging.

> ‘So from the mouth of the river there, to the territory of Kereng, until the source of the Sabangau, all was finished, divided by the [logging] companies’ (Male participant, Interview 12, ‘History’ Discussion)

The community had mixed emotions towards the logging companies. The male participants felt that the majority of workers were brought in from other regions, and any work the local people did get was menial, thus leaving them feeling made to be ‘observers’, separated and removed from what was happening to their forest. The counter-side to this, more commonly expressed by the women, was that it was a time of prosperity: although the work was not good they could make money in numerous ways from the presence of the logging companies. Their own activities in the forest were generally unaffected, and the forest was not yet so damaged that they could still collect gemur, jelutong, rattan, etc. However, they often said that they wouldn’t have been so happy if they had known what was coming i.e. the destruction of their forest:

> ‘Clearly we were happy before because we didn’t know the forest would become damaged. That was before. We didn’t know. If, now that we know,

> maybe we wouldn't be happy again' (Male participant, Meeting 2, 'History' Discussion)

> 'Before, our motto was like this: plant wood for our children and grandchildren. Now that I'm the grandchild, why can't I [receive this benefit]? … When I become the grandchild I should receive my granddad's trees. [The trees] don't run out, and the grandchildren thrive. But now the [logging] companies have become the grandchildren' (Male participant, Meeting 4, 'History' Discussion)

The next stage of logging was the 'illegal logging'. The time of the illegal logging was a time of mixed emotions for the local community. On the one hand it was a time of high prosperity, easy money and they were finally able to get a slice of the action (again a view more commonly expressed by the women). On the other hand they could now plainly see how destroyed the forest was becoming; they could no longer collect natural produce due to this damage, and they still felt that it was being done by 'outsiders' and they were 'observers' getting a bad deal (a hurt more commonly expressed by the male participants). Some people felt the reason the local community participated in the logging so heavily was this feeling of finally being able to 'get a piece of the action' whilst others felt it was because they had no alternative, their other livelihood options were gone.

They also did not hold themselves responsible for the damage even though they conducted much of it, as they felt the government could have, and did previously, control the logging companies, and when the government did finally undertake a proper ban, the illegal logging came to an end too – so it was the government's negligence that allowed the illegal logging to continue; what else was the community to do other than make the most of the opportunity?

> 'At the time of the illegal logging, it was extraordinary, and people did things without a care, all that was important was that they could take lots and lots of wood, with whatever method available…' (Male participant, Interview 12, 'History' Discussion)

Then the government finally did intervene on the illegal logging and it came to an end, which the community as a whole resented as it took away their income. However, given the impact it had on the forest they could understand the ban, but felt the government should have provided them with an alternative livelihood.

Finally, the most recent logging activities in the forest was the logging poles (small trees) used in construction and then quickly thrown away. The community saw this as particularly destructive as the trees were harvested before they reach (fruiting) maturity.

> '… and maybe for ten years the [community of Kereng Bangkirai] will work, then in ten years [the forest] will be gone. It's more than illegal logging. The illegal logging only took the big [trees], those measuring the size of a water thermos were not taken. But for the construction poles, those measuring like this [indicates arm] are taken' (Male participant, Meeting 2, 'Future' Discussion)

They felt messed around by the issue of logging; it was banned, it was not banned, a certain type was banned. They were now in a position, where their own personal needs – large trees but low in number, for building houses etc., and not for re-sale, was not allowed, and yet the wide-scale harvesting of poles, which they saw as far more destructive was continuing. They have little idea how to contend with this factor as it was something out of their control, controlled by external forces. Casson and Obidzinski (2002) discuss the changing face of illegal logging in Kalimantan, and how it represents not simply criminality but a 'complex economic and political system involving multiple stakeholders' (pp. 2133). Logging continues in Indonesia, despite some attempts by the government to control it (McCarthy 2000, Moeliono *et al.* 2012), but this external factor influencing the forest landscape, and the attitudes of the community regarding restoration success and land-management rights must be addressed in a RAP.

Access rights and land rights

One big concern of the local community associated with forest restoration was who would 'own' or over-see and control the new forest. In the past the community had experienced several painful events regarding land-rights, in relation to both governmental and company promises, or their own assumed rights, which were not respected. They often felt they 'did the work' whilst others 'took the credit/benefits' and given their attitudes towards outsiders, they felt it was very important that land-rights and access rights should be determined before they undertook any restoration. Land and access rights are a complicated issue in Indonesia, with often confusing laws and paper-work (Tsing 2005, Engel and Palmer 2006, Peluso 2012, Sikor and Lund 2009). This probably heightened the issue for the community and also potentially made it a more difficult issue to resolve – what would/could be their land right status in a restored forest? Without addressing this issue properly, it was clear much resentment or misunderstanding could arise.

> 'Then, unexpectedly [being in the forest] was forbidden, and without agreement, and it was extremely inhumane, because the community has still not yet removed their lives from the rich natural resources of this forest.' (Male participant, Interview 12, 'History' Discussion)

> 'We already replanted before. Will the planters, the community, own that or later, like with [a logging company]… when it's already productive it'll be taken by company, so it was their project, they got the results, we just got the bones, we got the honour only, they got the good meat, we just got our names mentioned'. (Female participant, Interview 1, 'Future' Discussion)

8.4. <u>Developing a restoration action plan</u>

The above findings can be used to guide and develop a RAP for this specific location. These findings are summarized on the next page, table 8.1. Other studies which have explored regeneration barriers in other ecosystems, although normally undertaken from an ecological perspective, have described the importance of establishing the barriers before proceeding with rehabilitation activities, and that the composition and form of these barriers are unique to each site (Holl *et al.* 2000, van Diggelen *et al.* 2012). This study aimed to explore what regeneration barriers were active at this site, and which other ecological and social factors were influencing regeneration. Based on the above findings, it became clear that the barriers which need to be addressed and targeted for further research were those which would allow the most efficient methods to be used to overcome the barriers (van Diggelen *et al.* 2012), or harness the more positive factors. Suggested methods for the next stage of the restoration of the site are outlined in table 8.2.

This study might have been a discreet exploration into the specific regeneration barriers facing this particular site. However, as outlined in Chapters 2 and 3, there is a much bigger question that needs to be addressed in RE; bridging the social and ecological factors, creating routes to explore both simultaneously and to create a holistic RAP as an output. It is hoped that the presentation of this work, both its methodologies and its results and discussion, has gone some way to meeting that need. In particular, it can be seen that the division of ecological and social factors is somewhat arbitrary as they overlap on numerous occasions, providing links between Western science and TEK (Wangpakapattanawong *et al.* 2010, Berkes *et al.* 2000, Shiel and Lawrence 2004). The separation of these combined ecological and social factors into negative, potential, inactive, positive and compound factors provides a more functional and holistic route to guiding the development of a RAP.

Table 8.3 The factor described by their factor type and their ecological and social dimensions.

Factor	**Factor type**	**Ecological dimension**	**Social dimension**
Seed dispersal	Negative	Present	Present
Flooding	Negative	Present	Present
Nutrient availability	Negative	Present	Present
Lack of options/money	Negative	Absent	Present
No funding for restoration	Negative	Absent	Present
Outsiders	Negative	Absent	Present
High light intensity	Negative	Present	Present
Fire	Negative	Not studied (present)	Present
Mycorrhizae availability	Potential	Present	Absent
Selecting transplant species	Potential	Present	Present
Drought	Potential	Present	Present
Community's physical dependence on the forest	Potential	Not studied (present)	Present
Community's ideas for forest restoration	Potential	Absent	Present
Community's desire to be in charge of restoration	Potential	Absent	Present
Seed banks	Inactive	Present	Absent?
Competition with non-tree vegetation	Positive	Present	Present
Community's attitude to the forest	Positive	Not studied (present)	Present
Community's awarenes of the state of the forest	Positive	Not studied (present)	Present
Community's forest and restoration knowledge	Positive	Absent	Present
Community's attitude to restoration	Positive	Absent	Present
Community's relationship with the government	Compound	Absent	Present
Logging	Compound	Not studied (present)	Present
Issues of access and ownership	Compound	Absent	Present

Table 8.4 The factors, their factor types, and what activities might be done to account for these factors..

Factor	**Factor type**	**Potential activities to account for this factor**
Seed dispersal	Negative	Seed sowing, seedling transplantation (Florentine and Westbrooke 2004, Holl 2012).
Flooding	Negative	Planting flood-tolerant species, creating artificial hummocks (Giesen 2009).
Nutrient availability	Negative	Transplanting seedlings with slow-release nutrient tablets or mycorrhizae inoculants (FORRU 2005, Turjaman *et al.* 2011).
Lack of options/money	Negative	Working with the community to develop viable alternative livelihood schemes such as fish-farming, and ensuring restoration-related work activities are paid well and fairly (fire management, reforestation, site-protection) (Salafsky and Wollenberg 2000).
No funding for restoration	Negative	Alternative livelihood schemes may find support from regional government, if the community is facilitated to learn routes of application. Carbon-market schemes provide a huge funding potential, especially on tropical peatlands. Restorationists and community could explore these possibilities (Alexander *et al.* 2011).
Outsiders	Negative	This issue links to two aspects; how external restorationists are accepted, and the trust and anger issues of the community to other outsiders. Addressing the first aspect, it is clear that those working in this area on the restoration that are not from the community must build relationships of trust and commitment, and be prepared to stay in the area for a length of time (Walsh and Mitchell 2002). The community was quick to accept those that stayed and invested in the community but not those transient visitors. The second aspect is more difficult to deal with. The community now has built up resentment and dislike of outsiders seen taking their resources in an unfair and exploitive manner. The main route to addressing these issues is to do with ownership and access rights, dealt with below. Clearly, not all 'outsiders' could be removed from activities in the area, and this is likely to be an aspect that will continue to require two-sided discussion and communication.
High light intensity	Negative	Shading was shown to improve growth and survival for some species, whilst for others it was not necessary. Shading could be created using fast-growing species to close a canopy and species which show high light tolerance (Holl 2012).
Fire	Negative	As this site is not drained, the risk of fire may be slightly lower than at other tropical peatland sites. However, due to the logging, fire still poses a risk in the area, as described by the community. Fire education is the first step to reducing fire-incidence, and would need to be a stage in the process. But, education would not prevent all fires, which can of course cause serious damage to any

		reforestation/regeneration activities. Fire prevention teams would be crucial (Page *et al.* 2009, Byron and Shepherd 1998). There was a vast array of ideas from the community as to how these might be organized, with practical suggestions of equipment and methods. This is an aspect that could encourage participation, involvement, alternative salaries and a sense of ownership that could be crucial to successful community involvement.
Mycorrhizae availability	Potential	The improvement to seedlings' growth and survival after mycorrhizal inoculation in the nursery, and, to a lesser extent in the field, is already established for several species (Turjaman *et al.* 2006, 2008, 2011). This work has shown some continued nutrient capture benefit for transplanted seedlings. As a restoration tool and a method to avoid a potential regeneration barrier, transplanted seedlings could be inoculated with their appropriate mycorrhizae.
Selecting transplant species	Potential	This is a factor that will require much future research and cannot be answered quickly. A current tropical peatland rehabilitation project, KFCP, is addressing this issue through a comprehensive literature review of grey literature that provides information on the silviculture and tolerances of TPSF tree species, in commissioning research on TPSF phenologies, optimum seedling nursery, transplant and after-care techniques, and investigations into species tolerances to environmental stresses such as flooding and nutrient limitation. This work will shortly become publicly available. It would not be advantageous for every TPSF restoration project to repeat similar studies as the findings are transferable. However, use of community knowledge and observation at the study site – of species that tolerate the degraded conditions well, or species that have other important traits, such as quick to close a canopy or attractive to animals, can be a good starting point in the meantime.
Drought	Potential	Planting drought-tolerant species as necessary. Planting at the start of the wet season, to give seedlings the best start (Poorter and Markesteijn 2007, Wösten *et al.* 2006)
Community's physical dependence on the forest	Potential	This aspect again links to alternative livelihoods and education. The community is aware that their dependence on the forest is damaging the forest, and this wish to break this cycle of overuse. Providing alternative means for the community, with education relating to this issue, would go a long way to breaking this cycle (Salafsky and Wollenberg 2000, Mertz 2005). However, whilst this may address aspects such as over-fishing, logging and hunting, there remain some deeper attachments to the forest-dependency in which open-discussion and compromises might need to occur. The community does not wish to over-harvest logs, but the associated house- and bridge-building and fire wood collection, for example, as their rights, and middle-ground on forest resource usage would go a long way to building acceptance with the community (Tsing 2005).

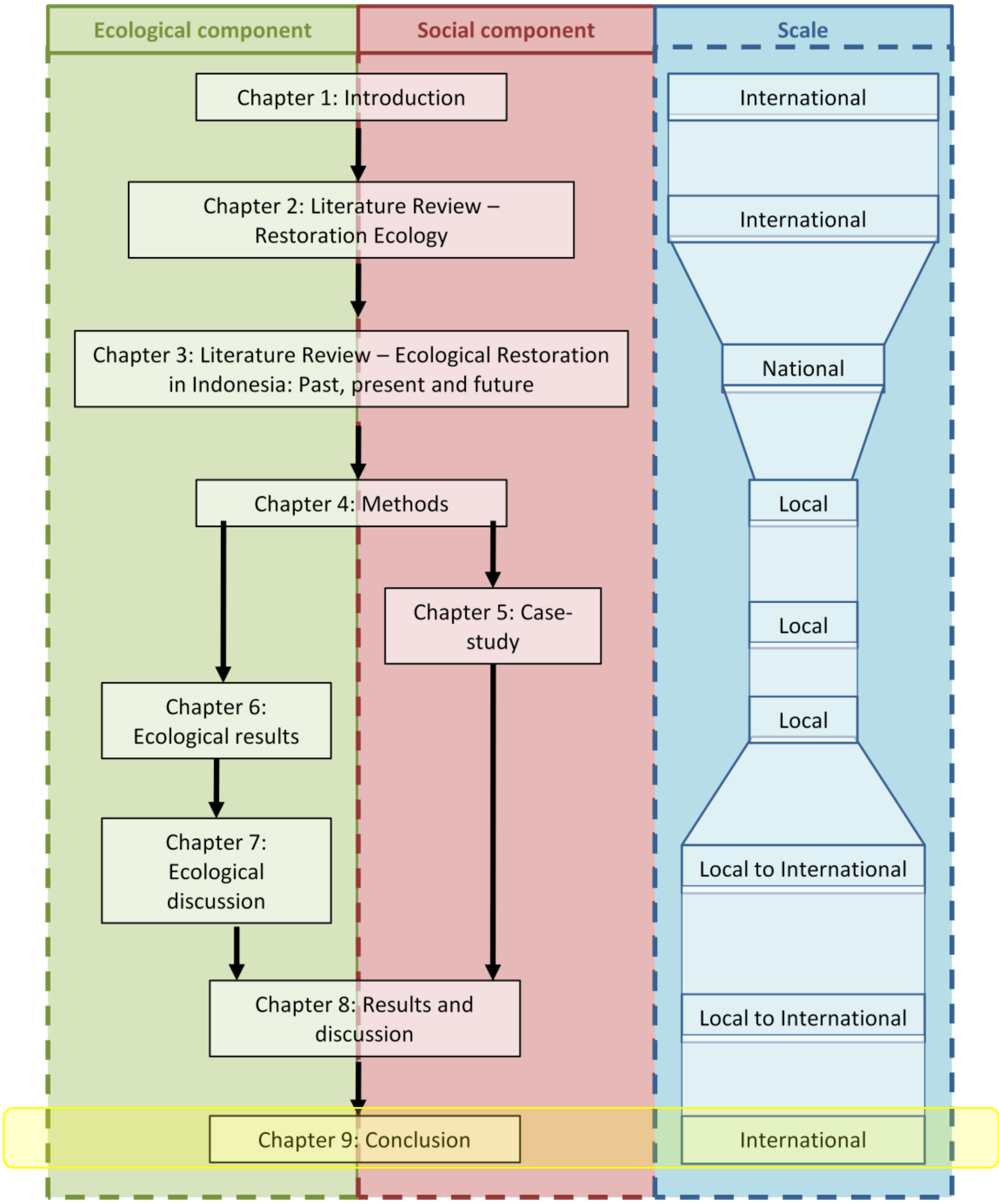
Community's ideas for forest restoration	Potential	A community so enthusiastic willing to invest in forest restoration is a positive aspect to the process (see below). However, this factor can become negative if restoration ideas already developed by the community are proposed and rejected. Transparency and community-involvement will be key to avoiding this issue, because through these methods the community should have an opportunity to contribute their ideas and, where it is not possible to implement these ideas, this can be discussed and explained in a direct manner (Collier 2011, McManus 2006).
Community's desire to be in charge of restoration	Potential	Similar to the above factor, but even more pronounced is the community's desire to govern the restoration activities. This stems from their issues of land rights and a lack of trust/confidence in those that have governed them before. As above, their aspirations in this regard might not always be achievable, but communication and transparency will reduce disappointment or conflict. Furthermore, careful development of documentation regarding land ownership and activities agreed by all stakeholders may reduce some of the issues that have led to this factor (Engel and Palmer 2006).
Seed banks	Inactive	No steps necessary
Competition with non-tree vegetation	Positive	Given that competition was found to positively affect growth of the transplanted seedlings, it should be actively left in place, at least until shown to affect otherwise (Gomez-Aparicio 2009).
Community's attitude to the forest	Positive	The community's desire to look-after and be a part of the forest should be recognized and encouraged at all stages of the RAP development and implementation. The more involvement and participation they have, the greater their sense of investment will be, thus improving the chances of long-term success (Higgs 2003).
Community's awareness of the state of the forest	Positive	Given the community's heightened awareness of the state of the forest, and their attitude towards the degradation, this increases their desire to support and be involved in the restoration.
Community's forest and restoration knowledge	Positive	In addition to strong connection with the forest, the community also displayed deep ecological knowledge regarding the forest and its restoration. This can be used to support and guide the development of the RAP and give a sense of propriety and pride to the community (Wangpakapattanawong *et al.* 2010, Berkes *et al.* 2000).
Community's attitude to restoration	Positive	Given the community's strong support of the restoration activities, their involvement should be encouraged at all stages. In fact not providing them with opportunity to be truly involved may lead to conflict or resentment. And through full-involvement, the overall and long-term success of any restoration activities is more assured (Collier 2011, McManus 2006, Higgs 2003).

Community's relationship with the government	Compound	As a compound factor this is not a factor that can easily be addressed or removed, but awareness of the issue and caution with it are required. Any land activity based in Indonesia, will, to an extent, require the involvement of the government. The community accepts a relationship with them in this work. But ensuring fairness, equity, transparency and communication between the government and the community may go a long way into addressing this issue.
Logging	Compound	The logging factor is both physical and emotional. The newly begun logging of small poles is a serious concern for forest regeneration and one that would need to be addressed, probably through appropriate law enforcement. The emotional aspect is more complex again linking to the community's relationship with the government, outsiders and with land-rights. They consider small-scale logging to be their right, and have strongly disliked the large-scale logging activities. Agreements of what is and is not allowed, who is allowed and why, or at least transparency on these fronts may help the community to address these issues, which would need to be resolved for both the security of the forest and the relationships between the stakeholders.
Issues of access and ownership	Compound	Many of the above aspects link to this issue; that the community wish for clearer, fairer, equitable land-rights. The feel through restoration this issue can and should be dealt with, and through their investment and participation in restoration, many of the needs resolved. Land-rights in Indonesia are often confused, and all the community's hopes may not be met in this regard. But, it is important to acknowledge that for successful restoration to proceed this is likely to be a crucial aspect that should be dealt with as best as possible.

8.4 Conclusions

This chapter has presented the findings from both the ecological and social data. The results although initially presented within their two scientific disciplines, have ultimately been presented as a single one, that of RE, with the end goal to use the data in developing a RAP. To this end all the results have been discussed as factors influencing the regeneration of a landscape, ranging from negative, potential negative, inactive, positive and compound. This chapter has shown that for any given factor, there are usually both ecological and social aspects, and that combining results from both data sources contributes to a deeper understanding of how the factors operate and how they might be addressed. Based on this work, the final section of this chapter outlined potential next steps for developing a RAP, detailing how the consideration of each factor might influence the RAP, and what activities might be necessary to remove or harness the factor.

9. Conclusions



9.1 Introduction

The aims of this study were to address both the methodological and physical barriers facing restoration ecology (RE), in the particular context of degraded TPSF in Indonesia. RE is a relatively new science, and its site-specificity and interdisciplinarity create barriers or challenges as to how this science is best approached. Indonesia is a rapidly evolving nation with a complex history. Its TPSF is the most expansive in the world, but rapid forest degradation needs urgent attention. The objectives of this study highlighted the research gaps, or barriers facing this particular science in this particular location. These were:

- At a given degraded tropical peat swamp forest study site in Indonesia, identify and explore the active regeneration barriers (covering both the social and ecological aspects of RE) that are affecting the site's recovery.
- Explore routes as to how these regeneration barriers might be addressed or alleviated to facilitate restoration, specifically for this site and more generally for the TPSF ecosystem and for other ecosystems.
- During this process, explore methods as to how the socio-ecological gap facing RE might be addressed.
- Make observations and address the larger debate of how appropriate ER is with regard to Indonesia's TPSF.

Chapter 4 outlined how these objectives were going to be explored, Chapter 5 set the scene regarding the stakeholders linked to the degraded landscape, Chapters 6 and 7 presented and discussed the ecological results, whilst Chapter 8 presented the social data then combined, presented and discussed the results from both the ecological and social research, with the discussion ending on the development of a RAP. This final chapter returns to the initial objectives. Based on the findings presented in Chapters 6, 7 and 8, this concluding chapter summarizes the work, and reflects on each of the initial objectives, to consider how well they have been addressed and what the final implications and applications might be both for TPSF restoration and the science of RE. As with all research, whilst some questions have been answered, others have been raised, and the final section in this chapter considers the limitations of this study and the direction that future research in these fields could take.

9.2 Determining the regeneration barriers (Objective One)

As described in Chapter 2, and specifically in '2.8.2 Site individuality versus landscape-management', one of the challenges facing ER is once the regeneration barriers facing a particular degraded site have been determined, can this knowledge be transferred to another site? This is further complicated by the fact that the barriers may be ecological, social, economic or political, and can have developed both pre- and post-disturbance. The result is that although the regeneration barriers for one site may be known, one cannot then simply extrapolate these barriers to other nearby sites (Curran *et al.* 2012, Holl *et al.* 2000). As proposed in 2.8.2, whilst it would therefore be inappropriate to try to develop a one-for-all RAP, one can instead stream-line the route by which the regeneration barriers are identified. This can be done by the method used in this study, that of 'anticipation and engagement'. 'Anticipation' refers to using the available literature and local knowledge to outline the most likely regeneration barriers at a specific site, whilst 'engagement' refers to exploring these potential barriers directly in the location and with the community, to determine which barriers are active. This route, used in this study, resulted in a comprehensive overview of the factors influencing the site, enabling the next step to be facilitated, that of developing a RAP.

The first stage was to ‘anticipate’ the likely barriers through an exploration of the literature (Chapters 2 and 3). Firstly, the ecological and social barriers commonly encountered in RE, specifically in tropical countries, were explored (Chapter 2), ranging from physical ecological barriers such as limitations of seed dispersal and competition with invasive species, to the more methodological social barriers of appropriate community participation and the combination of Western and TEK knowledge. These general barriers were then considered in relation to the specific site under study, a degraded TPSF in Central Kalimantan, Indonesia, in a second layer of anticipation. This highlighted the potential importance of these barriers in this particular ecosystem and this landscape, such as hydrology and fire, and the history of the local community’s and the wider community’s engagement with the land, such as logging, land-ownership and relations with the government. This stage also highlighted the relatively limited knowledge of the ecology of TPSF in relation to restoration, which is a barrier in itself.

From this increased knowledge base, it was possible to develop a list of potential regeneration barriers and design more targeted methods to explore them (Chapter 4). Aspects such as the logistics and difficulties of working in a swamp forest were taken into account, and best ecological practice based on the limited time and resources were developed. Methods for engaging with the community were developed, based on the context of who I was, and how the community was likely to want to, and be able to, participate. Topics to be discussed were decided that would address relevant issues whilst at the same time build relations and trust. This section can be seen as developing the methods for the engagement.

The results from the ecological and social components were initially presented separately (Chapters 5, 6, 7 and start of 8). Chapter 5 served as a bridge between the methods of engagement and the outputs, providing a greater context to the social dimension of landscape. Chapters 6 and 7 interpreted and discussed the ecological outputs, necessary to validate any physical science recommendations for the site. At the start of Chapter 8, the themes and data which emerged from the discussions with the local community were presened. Finally, the social and ecological data were combined in Chapter 8 (to be further discussed below, in 9.3 and 9.4) to achieve the first research objective, namely, a review of the active regeneration barriers operating at this specific study site. This work highlighted how crucial it is to develop this knowledge at the site-specific level, establishing what the regeneration barriers are, and how they would be most appropriately addressed unique to a given location.

Given the large area of degraded TPSF in SE Asia, possibly 9 m Ha (Hooijer *et al.* 2006), the desire to have a one-for-all RAP is tempting, especially with the increased application of landscape-scale restoration theory (Manning *et al.* 2006). However, this study argues that by over-looking the local-scale, by side-stepping true engagement with each study-site, the success of restoration can be compromised. Without site-specific engagement, the resultant activities can be less successful owing to the following reasons;

i) Un-economical; in this study it was observed that reduced water levels in the dry season were not a barrier for this site, unlike numerous other degraded TPSF locations. Investment in this theoretical regeneration barrier based on data from other study-sites would waste time and resources. Similarly, the community showed great depth of knowledge and understanding on many complex ecological and restoration aspects, such that general community education would be inefficient and patronising, as opposed to targeted education on specific topics, such as the use of mycorrhizae.

ii) Without full community-engagement, there is not only the possibility of over-looking important factors, but also of making the situation worse. This community showed a willingness and interest in restoration, but had many issues regarding ‘outsiders’ and the government overseeing the management of their landscape. Applying a RAP to this community without first establishing their involvement, understanding and agreement could result in further resentment and conflict. In Chapter 2 the difficulties of fair and open participation were discussed; the need to ensure all community members have an opportunity to be heard, empowering where possible, whilst at the same time not creating false promises of what role they might have. Through the methods undertaken in this study, male and female, young and old participants all had an opportunity to talk freely about their attitudes and desires for the land. Whilst not all their suggestions could be implemented, this open engagement built crucial relationships that would facilitate discussions and compromise on more complex issues, were restoration to be implemented at this site.

iii) Compromise the long-term success of the restoration activities. The community was strongly in support of the idea of forest restoration on their landscape, but felt locked into the continuing spiral of over-use and degradation. Routes to facilitate the community to invest long-term in forest restoration, such as through alternative livelihood schemes and jobs created through restoration such as fire-management, tree-planting and reforestation monitoring were all proposed by the community as viable solutions. Yet the community felt they could not bring about these activities by themselves, and instead would need to be facilitated through a RAP.

This study endeavoured to show a stream-lined method to determining the regeneration barriers that would need to be addressed in a RAP for a particular site. The method proposed uses anticipation and engagement to determine the factors influencing the landscape that, in the space of one year of study, would facilitate an economical, appropriate and long-lasting RAP. As the title of this thesis suggests, restoration should come 'from within'. This refers to the site-specific necessity of restoration, but also to the engagement and interaction with the stakeholders, the local community. Restoration that does not come through engagement, that does not come 'from within' risks missing crucial factors that influence the site, and ultimately risks the long-term success of the restoration activities.

9.3 Developing a restoration action plan (Objective Two)

After determining the active regeneration barriers at a site, it is then possible to develop an appropriate and targeted RAP, an approach supported by Holl *et al.* (2012) and van Diggelen *et al.* (2012). As described above, this study went through a detailed process of anticipation and engagement regarding the degraded landscape and the factors influencing it, both social and ecological, resulting in a comprehensive understanding of the main regeneration barriers. However, whilst other work has considered the fact that potential regeneration barriers may not all be active e.g. Holl *et al.* (2000), this study went a stage further. Given that numerous ecological and social factors were 'anticipated and engaged with', as expected, not all of these 'potential barriers' were shown to be 'active'. In fact, given the detailed engagement with the landscape and its stakeholders, some of the factors explored were found to be not only 'not active barriers', but actually to be beneficial for the regeneration of the site. It was realised that this method of categorising the factors, using 'negative', 'potential negative', 'inactive', 'positive', and 'compound' factors, provided a route to developing a more comprehensive RAP. This method has three main benefits compared to just focusing on developing a RAP based on only active regeneration barriers; 1) it allows full and complete use of the data collected, facilitating a more appropriate RAP, 2) it harnesses the positive as well as the negative aspects influencing a landscape, providing routes for further positive engagement with the stakeholders, 3) it is a method that brings together and combines social and ecological data, not just as two separate aspects in a final report, but cohesively, with single factors represented thoroughly by both the social and ecological data (see 9.4). This method could be applicable to other ecosystems in order to facilitate development of the most appropriate RAP.

9.4 The socio-ecological gap (Objective Three)

One of the greatest challenges facing ER, and numerous other land-management disciplines, is that of combining the ecological and social factors into a single study (Collier *et al.* 2011, Fry 2001, Higgs 2005). By not doing so, the project risks its long-term success, but methods for this integration are underdeveloped (McManus 2006, Donovan *et al.* 2011). This section aims to describe the experiences of one primary researcher in discovering and developing routes for discipline-combination, and the resulting outcomes.

This study encompassed ecological and social methods and aimed to develop routes to integrate both methods and results as the study progressed. Whilst the data collection had distinct, traditional social and ecological components (Chapter 4), it was hoped that these two studies would run concurrently, such that data would be amassed simultaneously, and opportunities for direct linkage of methods/early data would appear. However, as an individual PhD student/primary researcher, with a small team of research assistants, it proved logistically impossible to be 'in two places at once' (however, the method of anticipation and engagement to determine the factors influencing the landscape, as described in 9.2, can be applied for both social and ecological disciplines). The fieldwork began by exploring the ecological barriers (July 2007 – April 2009), and initially it was attempted to conduct some of the interviews and focus groups at the same time (October 2007 – March

2008). The schedule to participate in and supervise both the ecological and social work proved complicated, and it was therefore decided to initially just focus on the ecological activities. In April 2009, the ecological activities were nearly complete, and thus two months were spent focusing on the collection of social data. Whilst it was hoped that social and ecological methods might be linked, as achieved by Donovan *et al.* (2011), this study found there was little opportunity for this, both at the time in terms of logistics, and in hindsight, regarding methods for combination. Furthermore, it was important that the rigorous accuracy necessary in ecological data collection should be evident in the thesis, and the results presented in their ecological entirety, to facilitate future physical science research in these topics. There were also distinct advantages to leaving the social data collection to the end of the data-collection period. My fluency in Indonesian had greatly increased, reducing the language barrier between myself and the participants. I was better known and had built up more rapport with the community, and I had already married a member of their community. They often referred to me as 'a member of the village'. Their attitudes were open, honest and often in the style of wanting to educate me. It appeared they felt that as I had truly invested in their community, they could be honest, and also it was worth their effort to inform me clearly on their understandings. All this resulted in a very open and frank dialogue which would not have been possible at the start of the study.

The integration of the ecological and social results proved to be the most interesting and relevant to the aims of the study, that of establishing regeneration barriers that could be used to develop a RAP. The ecological data were analysed initially to identify the active physical regeneration barriers. Not all of the originally anticipated barriers were found to active, e.g. low water levels; some were found not to be relevant, such as the seed bank; and some were actually found to have a positive effect, such as competition with invasive species. The social data were also initially analysed separately, by transcribing the meetings with the participants, selecting and translating key quotes then categorising these quotes into themes, and outlining theme-summaries. This was done for each topic, then the themes from each topic were merged across topics to describe in-depth the themes/factors/barriers that were influencing the landscape, as seen by the community. At this point, two important points were noted; firstly that 'active barriers' only revealed a narrow slice of the results or the factors influencing the landscape (as described above), and secondly, that these factors appeared both in the social and the ecological results. Naturally, there were themes discussed by the participants that did not feature in the ecological data, such as economic and political factors. However, nearly all the ecological factors studied also came up in the meetings; seed dispersal, nutrient availability, species selection, seedling cultivation, etc. To present these ecological and social data sources as distinct would only tell half-the story, and limit full application of the data. A RAP should not only detail what physically needs to be done at a site, but also whether the community's TEK can contribute to a better understanding of the factors influencing that site, whether a factor requires education or discussion first with the local community, what the best route is to achieving a desired outcome with the community, etc. By combining the social and ecological data for each factor, the array of factors influencing the landscape at this site were successfully and accurately represented. This method would be transferable to other sites and ecosystems and could help close the socio-ecological gap in RE.

Whilst in theory this method could be conducted by an ecologist and a sociologist working separately who would then subsequently combine their data (as mentioned by Fry 2001), I would not recommend this path. From personal experience, the knowledge I gained from physically undertaking both the ecological and the social studies allowed a deep insight and an ability to negotiate and understand my data. Furthermore, relationships and engagement are key to restoration success (as described in 9.2). This includes relationships both with the local community and the landscape. This community was incredibly in-tune and perceptive regarding the forestry and ecology of the landscape, and our discussions were enhanced by the fact that we could discuss the ecological aspects as equals. I felt they respected me more, as I too was able to show some understanding of their forest; this may not have been possible for a sociologist based in the village. Furthermore, as a biologist by background, I felt myself also develop and change in my understanding and perception of the landscape during my work with the community, better understanding their constraints and difficulties and the driving forces regarding the forest degradation and restoration. As an ecologist working alone who then combined their data with a sociologist, this deeper perception would have been lost.

Papers that have discussed the problems facing the interdisciplinarity of landscape management often describe the following barriers; the language of the different disciplines (Collier *et al.* 2011, Norgaard *et al.* 2007, Donovan *et al.* 2011), the diverging theories (Collier *et al.* 2011, Donovan *et al.* 2011), methods (Collier *et al.* 2011, Fry 2001), and analysis (Fry 2001), the extra time required (Fry 2001, Donovan *et al.* 2011) and the lack of academic foundation to support the work (Fry 2001, Donovan *et al.* 2011). Taking each of these in turn: Language did prove an interesting barrier, as in writing this thesis my supervisors and I came up against several issues of style; writing in first-person, placing 'results' in the method chapter, switching between technical and common-use prose. To simply use one style would have left the other discipline poorly represented. To use both interchangeably with little explanation would have been confusing to the reader of either discipline. It was decided that through flagging and explaining style changes, and being as clear and fair to both disciplines as possible was the best route. Hopefully, as more written pieces of work appear in this field, a uniform writing style will emerge. For the methods and analysis, as described above, this study found no easy or beneficial routes to combining data collection or initial analysis, however, the method developed for combining data in the final analysis hopefully went some way to addressing this barrier. Regarding the extra time-requirements, as noted above, data collection required more time based on logistics, and equally, analysis was double the work. Despite this, based on the holistic and detailed nature of the outcomes from this study, the only sensible counter-argument to this barrier is the extra time is worth it. Finally, regarding the diverging theories of the two disciplines and the need for academic support, I agree strongly that without guidance and support this would have proved a grave obstacle. I had no sociology/human geography training at the outset of this PhD, and the potentially conflicting routes to undertaking a study of this nature could have been off-putting from the outset. I was extremely fortunate to have two highly engaged, interested and open PhD supervisors, one a biologist by background, but now head of a geography department, the other a human geographer, and both very interested in landscape-management and restoration. From this support base, the interdisciplinary obstacles were circumvented. I realise not all students would be as fortunate, and the need for more truly interdisciplinary academic foundations, where courses of this nature can be taught, will be key to countering this aspect of the socio-ecological gap (Higgs 2005, Fry 2001). For now, as Donovan *et al.* (2011) describes after her own interdisciplinary experience, one must be committed and accept the messiness of the interdisciplinarity.

9.5 Applying restoration to the degraded TPSF of Indonesia (Objective Four)

Restoration takes place within a specific site, and the larger social, political and economic aspects influencing this site are just as relevant as the ecological regeneration barriers (Clewell and Aronson 2013, Collier *et al.* 2011). This study was situated within Central Kalimantan, Indonesia. Chapter 3 described the past, present and future influences on this site, within the context of Indonesian TPSF, and in Chapter 8, the views of the community, where possible, were aligned to the bigger political and social factors. This section re-visits some of the attitudes of the community towards the restoration of this site and the barriers they face, as presented in Chapter 8, and frames them within the larger national and international debate.

The community is very close to the forest, they are physically dependent upon it and for many participants it formed a large part of their livelihood. More than this, they are linked culturally and emotionally to the forest; it creates for them their identity and their contentment. This kind of close link of Dayak communities to the forest has been noted elsewhere (Tsing 2005, Marjokorpi and Ruskolain 2003). As a result of various impacts, the health of the forest has, in the last several decades, under-gone massive negative decline. Logging, fires and over-use are the main factors, and rightly or wrongly, the community attribute these effects to external sources, ‘outsiders’ – at least as the instigators. Again, this is a common reaction by local communities to land-use of recent times, this feeling of being pushed out, to stand as ‘observers’ whilst ‘outsiders’ lay claim to what the community felt was theirs to use and manage (Armitage 2002, McCarthy 2005, Tsing 2005). Based on the New Order’s attitude regarding land-rights, land-use, the attaining of land and re-distributing it to logging and plantation companies and transmigrant settlements (see Chapter 3), this attitude is understandable. In recent years, with the change in government, there has been somewhat of a reversal in attitude to local land-rights with local communities being given a voice and an opportunity to reclaim their land, but this has had only limited success, and has been slow to filter down and be felt in all regions (Engel and Palmer 2006), and meanwhile, it seems, the local communities’ memories are long.

Consequently, this community, like many others in Indonesia, were left with land that is now functioning poorly to meet their needs, whilst livelihood options and education remained limited. As this community described, they felt ‘stuck’: they were in need of livelihoods, and in need of a functioning forest. The limited livelihood options available to them meant they continued to over-use the forest resources. They knew their activities are unsustainable, but see little alternative.

This position results in an interesting, complex situation, or what might be termed a ‘compound factor’. The community is very positive about restoration. Not only that, they already have detailed ideas and understandings that were relatively sound ecologically, and further addressed management, economics and social issues in design. In theory, designing and implementing a RAP with this community would be achievable and have long term success. Based on the history of mistrust, confusion and unfairness that has been felt by the community, they are, however, hesitant to work too closely with large organisations, authority figures, and particularly, the government. They also saw that their ideas will stay only as ideas without some source of external funding and facilitation, which would mean working with these big, external organisations. Some of the community were optimistic, given that they were convinced that wrongs were done to them and their ideas were good, that surely funding would come from somewhere. Others have been too hurt and let-down by the events in the recent past and think it is a lost cause.

Interestingly, as the study took place, the international world was also changing rapidly, in response to the challenge of climate change. The carbon-market, in the last five years, has gone from being a topic of discussion to a reality, with activities linked to REDD+ offering new potentials (Alexander *et al.* 2011, Sasaki *et al.* 2011), especially with regard to landscapes such as degraded TPSF in Indonesia, where there are opportunities to reduce carbon emissions as well as preserving biodiversity (Spracken *et al.* 2008, Alexander *et al.* 2011, van Noordwick *et al.* 2008). External funding opportunities, however, mean external policies and working alongside external aspirations and requirements (Collier *et al.*

2011). Many of these REDD+ pilot projects, as well as other forest restoration initiatives are large-scale (e.g. CKPP and KFCP in Central Kalimantan, both covering regions of over 100,000 Ha). As described in point 9.2 above, this study highlights and stresses the importance of site-specificity in ER, not only to ensure appropriate ecological activities, but also to build up the kind of trust and engagement with local stakeholders that is so essential for the long-term success of the work (McManus 2006, Collier *et al.* 2011). The challenges facing the world regarding climate change are huge, and with potentially already half of all SE Asia's TPSF degraded or converted to agriculture (over 120,000 km^2), the route whereby restoration can be carried out at a local-scale and yet also address the global issue of climate change is not clear. This study does not have a simple answer to the final barrier facing TPSF's restoration, that of scale. But this study has shown the possibility of developing an accurate and appropriate RAP when anticipation and engagement with a specific landscape is undertaken, and that the participation of the community in the RAP can begin from the design stage, with numerous benefits attached. Many of these benefits would be lost through landscape-scale management planning, and some compromise between the two must be sought.

9.6 Limitations of this study

Time and monetary restrictions, and the depth and breadth of social and ecological study mean that however well-intentioned and designed a research project, it will never answer all the potential questions involved in the debate. Whilst, as outlined above, this study did explore all its research objectives, there were also limitations to this work. This section provides a critique of this study, focusing on aspects of the relevant debates that were not addressed.

Regarding the ecological component of research, whilst as many of the likely regeneration barriers and their impacts on regeneration were explored, it was not possible to cover all possibilities. This study attempted to understand which environmental conditions had altered in the degraded area, compared to the natural forest, and the impact this had on natural regeneration. Whilst it was established that seed-rain and animal seed-dispersal were reduced in the degraded area, the next step would have been to also explore the ameliorative benefits of seed-sowing (Florentine and Westbrooke 2004, Holl 2012). Equally, whilst light intensity and benefits of shading were explored, as were low water levels, further ecological aspects that link to this would be a study of ground temperature and surface drying (Holl *et al.* 2000, Holl 2012). For the mycorrhizal study, whilst the percent of colonisation of mycorrhizae in the seedlings' roots was investigated, the mycorrhizal species composition found in these roots would further explain the change in mycorrhizal availability in degraded TPSF areas (Allen *et al.* 2003). Furthermore, the factors influencing ecosystems do not operate in isolation, which, to some extent, is how they were considered in this study, but will interact with one another. Some studies exploring regeneration barriers have developed multi-factoral experimental designs, such as Hooper *et al.* (2005) in the abandoned pastures of Panama. This kind of research enables better understanding of the barriers, and can facilitate more accurate restoration activities.

Only three native tree species were considered in the seedling transplant section of the study, yet even across these three species, very distinct ecological traits and tolerances were observed in relation to the degraded conditions. Very little is known about the ecological traits and tolerances of native TPSF tree species, and this study has highlighted importance of obtaining more species-by-species knowledge.

The other limitation linked to the ecological component of this study was the depth of understanding regarding each altered environmental condition. Entire theses can, and have, been written on single environmental conditions, e.g. nutrient cycling (Sulistiyanto 2004). This study aimed to explore as many potential regeneration barriers as possible; put simply, it enquired whether these environmental conditions had altered from their natural state, and if so, had they become an active regeneration barrier? This kind of broad understanding facilitates the development of an appropriate RAP. However, time constraints did not permit a more detailed scientific understanding of why they have become regeneration barriers. This knowledge would allow more exact restoration activities (Holl 2012). This limitation could equally apply to the social components of the study too, since more time would have allowed deeper exploration of, for example, limitations of imposed livelihoods and economics.

This study only focused on one study site and one group of stakeholders; the local community. It is proposed that the methodology developed in this thesis is transferable to other study locations, but as this research only investigated one location, this theory has not been tested. Stakeholders not only include the local community but also the local, regional and national government and other users of the landscapes. Their perspectives and aspirations also can strongly influence the likelihood or success of any restoration activities, and barriers can originate from their view-points and understandings too (Aide *et al.* 2000, van Andel and Aronson 2012b). Before any restoration activities could be implemented, similar investigations with the other stakeholders would also be necessary.

As described and discussed in other sections of this thesis, the primary researcher was married to a member of the local community during the research time. This was received positively by other members of the community, and possibly increased trust and disclosure between researcher and participants. Whilst this unusual factor may have resulted in benefits that might not always be achieved by other researchers at other locations, good, long-term social research can obviously build up strong relationships with participants without necessarily marrying into the community.

9.7 Recommendations for future research

New research invariably raises further questions and draws attention to new gaps in the discipline that should be addressed. Furthermore, as described above in the limitations of the study, certain aspects require further investigation.

This study only explored the social and ecological aspects influencing regeneration of this landscape, and, regarding the social aspects, only worked together with one group of stake-holders – the local community. As discussed in Aide *et al.* (2000), Rodrigues *et al.* (2011), and Aronson *et al.* (2007, 2010) economics and politics are also key aspects in ER and the development of a feasible RAP. Whilst these aspects did emerge in the participants' discussions they were only in the context of one group of stake-holders, and were not addressed in a rigorous, external manner. The next stage to implement restoration at this site would be to work with local government, respective land-holders and funding bodies, to determine what is physically possible, and their attitudes towards the activities, to ensure policy and infrastructure would be available to support these activities (Rodrigues *et al.* 2011, Clewell and Aronson 2013), and that goals were similar across all stakeholders (Tongway and Ludwig 2011).

This study aimed to address some of the issues of transferability of methods/results, and also to close the socio-ecological gap. In 9.2 and 9.3 the concept was presented that whilst the data and results regarding the regeneration barriers collected for a specific site are non-transferable, the methodology by which they are investigated, analysed and can be used to develop a RAP is transferable, and this methodology could be replicated across multiple locations. The next step would be to try these methods at other sites; in another location in Central Kalimantan, in degraded TPSF in Sumatra, or indeed in another ecosystem or country, to verify how transferable these methods really are. Some components of the method pioneered in this study might be used to guide site- and technique-selection for a range of locations, as outlined in the use of multi-criteria analysis methodology (Corsair *et al.* 2009), in which weightings can be applied to chosen criteria and indicators from a range of disciplines to facilitate decision making for site-selection (Lithgow *et al.* 2013, Orsi and Geneletti 2010). The methodology developed here, exploring the suite of factors influencing the landscape through both anticipation and engagement from both social and ecological data, might be too long a process for site selection. This might, however, serve as a site-selection method after the number of sites has first been reduced through more immediate, rapid assessment (such as satellite imagery, Lithgow *et al.* 2013). Many of the data investigated can be applied to Aronson *et al.* 's (1996) vital landscape attributes, that might be used to determine sites most in need or most responsive/appropriate for restoration. Thus, this novel methodology could be replicated and explored in its implication to restoration practice, both from the view of designing a RAP and helping in site-selection.

One barrier facing TPSF restoration is the limited knowledge of the ecological tolerances and silviculture of TPSF species, which is essential for successful reforestation activities (Graham 2009). This knowledge gap was also highlighted in discussions with the community. Studies are currently underway by one restoration project (KFCP), which is active on the degraded peatlands of the former MRP area, Central Kalimantan. This will be a long and slow process, but crucial to facilitating assisted forest regeneration,

An important next step to explore the validity of results from this study would be to design and implement a RAP at the study site, based on the regeneration barriers and linked activities suggested in Chapter 8. However, whilst this would be a ‘research’ endeavour, in reality it would also be an 'implementation project'. Government and other stakeholder support would first have to be attained, long-term funding would need to be secured, a large work-force would be needed, and all aspects of community education and involvement would need to be addressed (Tongway and Ludwig 2011). It could be argued that the implementation of any RAP should have an evaluation and monitoring component providing crucial feedback information to the project itself, and insight for other projects (Holl *et al.* 2012, Tongway and Ludwig 2011, 2012). Yet it should also be appreciated that at the onset of implementing a RAP it becomes more than a research endeavour, since it involves commitments and investment to and from the stakeholders. Given the feelings of mistrust and hurt felt by this community in relation to past land-management by external bodies, this 'research' should only begin once these other aspects have been guaranteed.

If a RAP were to be implemented at this site, one main focus of the research would be the success in overcoming the identified regeneration barriers and the possibility of further barriers overlooked or in need of combination. Further topics might include those discussed in the above section; seed sowing, mycorrhizal species composition, etc., and multi-factoral research design.

9.8 Closing Remarks

This study aimed to be as interdisciplinary as the field of RE itself. It aimed to consider from the local to the international scale, the social and ecological components influencing this study site. It made steps towards developing a targeted and accurate RAP for a specific location. It made progress in addressing the problem of site-specificity versus transferability of data by outlining potential methodologies that could facilitate engagement with the unique aspects of one site whilst stream-lining the determination of the regeneration barriers. It successfully combined social and ecological data into a single RAP, and detailed how this might be done for other studies. Finally, it considered the contextual issues facing the implementation of this RAP in degraded Indonesian TPSF, and in particular the challenges linked to the social, political and economic tensions and problems still present in this country.

As an individual study, it cannot answer every question or address every barrier, but hopefully the methodology developed in this thesis can be used to overcome some of the barriers not only facing degraded TPSF, but also other degraded tropical forest ecosystems and the barriers within RE. Much more work is needed to address and overcome the problems facing this landscape and its communities, and RE will continue to progress, to feature more studies and training resources of a truly interdisciplinary nature. Hopefully this study has been one step further in these journeys.

10. References

Adams, W. M. (2004) Against Extinction: The story of conservation (Earthscan, London)

Adams, W. M. and Infield, M. (2003) Who is on the gorilla's payroll? Claims on tourist revenue from a Ugandan national park. World development 31: 177-190

AFTree database (2013) The Agroforestree (AFT) Database. World Agroforestry Centre. http://www.worldagroforestrycentre.org/sea/node/108

Aide, T. M. and Cavalier, J. (1994) Barriers to lowland tropical forest restoration in the Sierra Nevada de Santa Marta, Colombia. Restoration Ecology 2: 219-229

Aide, T. M., Zimmerman, J. K., Pascarella, J. B., Rivera, L. and Marcano-Vega, H. (2000) Forest restoration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. Restoration Ecology 8: 328-338

Alcorn J. B. and Toledo V. M. (1998) Resilient resource management in Mexico's forest ecosystems: the contribution of property rights. *In:* Berkes, F. and Folke. C. (*Eds*.) Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge, UK. Pp. 216-249

Alexander, S., Nelson, C. R., Aronson, J., Lamb, D., Cliquet, A., Erwin, K. L., Finlayson, M., de Groot, R. S., Harris, J. A., Higgs, E. S., Hobbs, R. J., Robin Lewis III, R. R, Martinez, D. and Murcia, C. (2011) Opportunities and challenges for ecological restoration within REDD+. Restoration Ecology 19: 683–689

Allen, E. B., Allen, M. F., Egerton-Warburton, L., Corkidi, L. and Gómez-Pompa, A. (2003) Impacts of early- and late-seral mycorrhizae during restoration in seasonal tropical forest, Mexico. Ecological Applications 13: 1701-1717

Allen, E. B., Allen, M. F., Helm, D. J., Trappe, J. M., Molina, R. and Rincorn, E. (1995) Patterns and regulation of mycorrhizal plant and fungal diversity. Plant Soil 170:47-62

Allen, E. B., Rincon, E., Allen, M. F., Peres-Jimenez, A. and Hunt, P. (1998) Disturbance and seasonal dynamics of mycorrhizae in tropical deciduous forest in Mexico. Biotropica 30: 261-2744.

Amazonas, N. T., Martinelli, L. A., Piccolo, M. de C. and Rodrigues, R. R. (2011) Nitrogen dynamics during ecosystem development in tropical forest restoration. Forest Ecology and Management 262: 1551–1557

Amthor, J. S. and 21 others (1998) Terrestrial ecosystem responses to global change: a research strategy. Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-1998/27

Anshari, G. Z., Afifudin, M., Nuriman, M., Gusmayantil, E., Arianiel, L., Susana, R., Nusantara, R. W., Sugardjito, J. and Rafiastanto, A. (2010) Drainage and land use impacts on changes in selected peat properties and peat degradation inWest Kalimantan Province, Indonesia. Biogeosciences 7: 3403-3419

Armitage, D. (2002) Socio-institutional dynamics and political ecology of mangrove forest conservation in Sulawesi, Indonesia. Global Environmental Change 12:203-217

Aronson, J. (2011) Sustainability science demands that we define out terms across diverse disciplines. Editorial; Landscape Ecology 26: 457-60

Aronson, J. and Le Floc'h, E. (1996) Vital landscape attributes: Missing tools for restoration ecology. Restoration Ecology 4: 377-387

Aronson, J., Blignaut, J. N., Milton, S. J., Le Maitre, D., Esler, K. J., Limouzin, A., Fontaine, C, de Wit, M. P., Mugido, W., Prinsloo, P., van der Elst, L. and Lederer, N. (2010a) Are the socioeconomic benefits of restoration adequately quantified? A meta-analysis of recent papers (2000-2008) in Restoration Ecology and 12 other scientific journals. Restoration Ecology 18:143-154

Aronson, J., Blignaut, J., de Groot, R. S. *et al.* (2010b) The road to sustainability must bridge three great divides. Annals of the New York Academy of Sciences 1185 (special issue, Ecological Economics Reviews), 225-236

Aronson, J., Milton, S. J. and Blignaut, J. N. (2007) Restoring natural capital: Science, business and practice. Island Press, Washington, USA

Aspinall, E., Feith, H. and Van Klinken, G. (1999). The Last Days of President Suharto. Clayton, Victoria, Australia: Monash Asia Institute.

Bakker, J. P., Poschlod, P., Strykstra, R. J., Bakker, R. M. and Thompson, K. (1996) Seed banks and seed dispersal: important topics in restoration ecology. Acta Botanical Netherlands 45: 461-490

Ballhorn, U., Siegert, F., Mason, M. and Limin S. (2009) Derivation of burn scar depths and estimation of carbon emissions with LIDAR in Indonesian peatlands. PNAS 106: 21213-21218.

Balmford, A. and Whitten, T. (2003) Who should pay for tropical conservation, and how could the costs be met? Oryx 37: 238-250

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. and Turner, R. K. (2002) Economic reasons for conserving wild nature. Science 297: 950-953.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C. and Silliman, B. R. (2011) The value of esturine and coastal ecosystem services. Ecological Monographs 81: 169-193

Barton, G. (2002) Abdurrahman Wahid: Muslim, Democrat, Indonesian President – A view from the inside. UNSW Press

Baxter, J. and Eyles, J. (1997) Evaluating qualitative research in social geography: Establishing 'rigour' in interview analysis. Transactions of the Institute of British Geographers 22: 505-525

Bazzaz, F. A. (1991) Regeneration of tropical forests: physiological responses of pioneer and secondary species. *In:* Gómez-Pompa, A., Whitmore, T. C. and Hadley, M. (Eds.) Rainforest regeneration and management.

Berkes, F. (1999) Sacred ecology, traditional ecological knowledge and resource management. Taylor and Francis, Philadelphia.

Berkes, F., Colding, J. and Folke, C. (2000) Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications 10:1251-1262

Beukema, H. (2004) The role of jungle rubber in rainforest biodiversity conservation. *In.* Lammertink, M., Setiorini, U. and Prawiradilaga, D. (*Eds.*) As a phoenix from the flames? The recovery potential of biodiversity after logging, fire and abroforestry in Kalimantan and Sumatra. Netherlands Science Foundation, Lembaga Ilmu Pengatahuan Indonesia, PILI-NGO Movement Publications.

Blakesley, D., Elliott, S., Kuarak, C., Navakitbumrung, P., Zangkum, S. and Anusarnsunthorn, V. (2002) Propoagating framework tree species to restore seasonally dry tropical forest: implications of seasonal seed dispersal and dormancy. Forest Ecology and Management 164: 31-38

Brady, M. A. (1997) Effects of vegetation changes on organic matter dynamics in three coastal peat deposits in Sumatra, Indonesia. *In:* Rieley, J. O. and Page. S. E. (*Eds.*) Biodiversity and sustainability of tropical peatlands.

Bragazza, L., Siffi, C., Iacumin, P. and Gerdol, R. (2007) Mass loss and nutrient release during litter decay in peatland: The role of microbial adaptability to litter chemistry. Soil Biology and Biochemistry 39: 257-267

Brearley, F. Q., Prajadinata, S., Kidd, P. S., Proctor, J. and Suriantata (2004) Structure and floristics of an old secondary rain forest in Central Kalimantan, Indonesia, and a comparison with adjacent primary forest. Forest Ecology and Management 195: 385-397

Brown L. R (1997) State of the World 1997: A Worldwatch Institute Report on Progress Toward a Sustainable Society (14th edition). New York: W. W. Norton & Company.

Brundtland Commission (1987) Our common future. Commission on Environment and Development. Oxford University Press. Oxford.

Bunker, D. E. and Carson, W. P. (2005) Drought stress and tropical forest woody seedlings: Effect on community structure and composition. Journal of Ecology 93: 794-806

Butchart, S. H M. *et al.* (2010) Global biodiversity: Indicators of recent decline. Science 328: 1164-1168

Byron, N. and Shepherd, G. (1998) Indonesia and the 1997-98 El Niño: fire problems and long-term solutions. Natural Resource Perspectives 28

Cabin, R. J., Weller, S. G., Lorence, D. H., Cordell, S., Hadway, L. J., Montgomery, R., Goo, D. and Urakam, A. (2002) Effect of light, alien grasses and native species additions on Hawaiian dry forest restoration. Ecological Applications 12: 1595-1610

Calloway, R. M. and Walker, L. R. (1997) Competition and facilitation: a synthetic approach to interactions in plant communities. Ecology 78: 1958-1965

Cao, K. F. (2000) Water relations and gas exchange of tropical saplings during a prolonged drought in a Bornean heath forest, with reference to root architecture. Journal of Tropical Ecology 16: 101-116

Cardosa da Silva, J. M., Uhl, C. and Murray, G. (1996) Plant succession, landscape management, and the ecology of frugivorous birds in abandoned Amazonian pastures. Conservation Biology 10: 491-503

Casson, A. and Obidzinski, K. (2002) From new order to regional autonomy: shifting dynamics of 'illegal' logging in Kalimantan, Indonesia. Word Development 30: 2133-2151.

Caughley, G. (1994) Directions in Conservation Biology. Journal of Animal Ecology 63: 215-244

Chapman, C. A. and Chapman, L. J. (1995) Survival without dispersers: seedling recruitment under parents. Conservation Biology 9: 675-678

Chapman, C. A. and Chapman, L. J. (1999) Forest restoration in abandoned agricultural land: a case-study from East Africa. Conservation Biology 13: 1301-1311

Cheke, A. S., Nanakorn, W. and Yankoses, C. (1979) Dormancy and dispersal of seeds of secondary forest species under the canopy of a primary tropical rain forest in northern Thailand. Biotropica 11: 88-95

Chimner, R. A. and Ewel, K. C. (2005) A tropical freshwater peatland: II. Production, decomposition and peat formation. Wetlands Ecology and Management 13: 671-684

Clements, G. R., Sayer, J., Boedhihartono, A. K., Venter, O., Lovejoy, T., Koh, L. P. and Laurance, W. F. (2010) Cautious optimism over Norway-Indonesia REDD Pact. Conservation Biology 24: 1437-1438

Clewell, A. F. and Aronson, J. (2006) Motivations for the restoration of ecosystems. Conservation Biology 20: 420-428

Clewell, A. F. and Aronson, J. (2013) Ecological restoration: Principles, values and structure of an emerging profession. 2nd Edition. Island Press, Washington.

Clout, M. N. and Russell, J. C. (2006). The eradication of mammals from New Zealand islands. *In:* Assessment and Control of Biological Invasion Risks'. (*Eds.* Koike, F., Clout, M. N., Kawamichi, M., De Poorter, M. and Iwatsuki, K.) pp. 127–141

Collier, M. J. (2011) Incorporating socio-economic factors into restoration: Implications from industrially harvested peatlands. Restoration ecology 19: 559-563

Connell, J. H. (1971) On the role of natural enemies in preventing competitive exclusion in some marine animals and in rain forest trees. *In:* Den Boer, P. J. and Gradwell, G. R. (*Eds.*) Advanced study institute symposium on dynamics of numbers in populations. Oosterbeck, PUDOC, Wageningen.

Conservation International (2006) http://www.biodiversityhotspots.org/xp/Hotspots/sundaland/biodiversity.xml

Corlett, R. T. (1998) Frugivory and seed dispersal by vertebrates in the Oriental (Indomalaysian) Region. – Biological Reviews 73: 413-448

Corlett, R. T. (2009) The ecology of tropical east Asia. Oxford University Press.

Corsair, H. J., Ruch, J. B., Zherg, P. Q., Hobbs, B. F. and Koone, J. F. (2009) Multi-criteria decision analysis of stream restoration: potential and examples. Group decision and negotiation 18: 387-417

Costanza, R., d'Arge, R., de Groot, R., Farberk, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253-260

Costanza, R., Miltsch, W. J. and Day Jr., J. W. (2006) Creating a sustainable and desirable New Orleans. Ecological Engineering 26: 317-320

Cowling, R.M. and Pressey, R.L., (2003) Introduction to systematic conservation planning in the Cape Floristic Region. Biological Conservation 112: 1–3.

Craps, M., Dewulf, A., Mancero, M., Santos, E. and Bouwen, R. (2004) Constructing common ground and recreating differences between professional and indigenous communities in the Andes. Journal of Applied Social Psychology 14:578-593

Curran, L., Trigg, S., McDonald, A., Astiani, D., Hardiono, Y., Siregar, P., Caniago, I. and Kasischke, E. (2004) Lowland forest loss in protected areas of Indonesian Borneo. Science 303:1000

Curran, P., Smedley, D., Thompson, P. and Knight, A. T. (2012) Mapping restoration opportunity for collaborating with land-managers in a carbon credit-funded restoration program in the Makana municipality, Eastern Cape, South Africa. Restoration Ecology 20: 56-64

Cusack, D. And Montagnini, F. (2004) The role of native species plantations in recovery of understorey woody diversity in degraded pasturelands of Costa Rica. Forest Ecology and Management 188: 1-15

Daily, G. C. (1995) Restoring value to the world's degraded lands. Science 269:350-354

Daïnou, K., Bauduin, A., Bourland, N., Gillet, J., Fétéké, F. and Doucet, J. (2011) Soil seed bank characteristics in Cameroonian rainforests and implications for post-logging forest recovery. Ecological Engineering 37: 1499-1506

Davidson, E. A., de Carvalho, C. J. R., Vieira, I. C. G., Figueiredo, R. De O., Moutinho, P., Ishida, F. Y., Primos dos Santos, M. T., Guerrero, J., B., Kalif, K. and Saba, R. T. (2004) Nitrogen and phosphorus limitation of biomass growth in a tropical secondary forest. Ecological Applications 14: 8150-8163

de Jong, W. (1997) Developing swidden agriculture and the threat of biodiversity loss. Agriculture, ecosystems and the environment 62: 187-197

Dell, B. (2002) Role of mycorrhizal fungi in ecosystems. CMV Journal 1:47-60

DNPI (2010) Indonesia's Greenhouse Gas Abatement Cost Curve (DNPI, Jakarta, Indonesia).

Donovan, K., Sidaway, J. D. and Stewart, I. (2011) Bridging the geo-divide: reflections on an interdisciplinary (ESRC/NERC) studentship. Transactions of the Institute of British Geographers 36: 9-14

Duncan, R. S. (2006) Tree recruitment from on-site versus off-site propagule sources during tropical forest succession. New Forests 31: 131-150

Elliott, S., Blakesley, D., Maxwell, J. F., Doust, S. and Suwannarartana, S. (2006) How to plant a forest. The Forest Research Institute (CMU)

Engel, S. and Palmer, C. (2006) Who owns the rights? The determinants of community benefits from logging in Indonesia. Forest Policy and Economics 8: 434-446

Engelbrecht, B. M. J. and Kasar, T. A. (2003) Comparative drought-resistance of seedlings of 28 species of co-occurring tropical woody plants. Oecologia 136: 383-393

FAO (1993) Forest resource assessment 1990: Tropical countries. FAO Forestry Paper 112, Rome.

Fearnside, P.M. (1997) Transmigration in Indonesia: Lessons from its environmental and social impacts. Environmental Management 21: 553-570

Feldpausch, T. R., Rondon, M. A., Fernandes, E. C. M. Riha, S. J. and Wandelli, E. (2004) Carbon and Nutrient Accumulation in Secondary Forests Regenerating on Pastures in Central Amazonia. Ecological Applications 14: S164-S176

Fischer, C. R., Janos, D. P., Perry, D. A., Linderman, R. G. and Sohins, P. (1994) Mycorrhiza inoculum potentials in tropical secondary succession. Biotropica 26:369-377

Florentine, S. and Westbrooke, M. (2004) Restoration on abandoned tropical pasturelands – do we know enough? Journal for Nature Conservation 12: 85-94

Flowerdew, R. and Martin, D. (2005) Methods in Human Geography. A guide for students doing a research project. Second Edition. Reason Education Limited.

Forget, P. (1990) Seed-dispersal of *Vouacapoua americana* (Caesalpiniaceae) by caviomorph rodents in French Guiana. Journal of Tropical Ecology 6: 659-468

FORRU; Forest Restoration Research Unit (2005) How to plant a forest: The principles and practice of restoring tropical forests. Biology Department, Science Faculty, Chiang Mai University, Thailand.

FORRU; Forest Restoration Research Unit (2008) Research for restoring tropical forest ecosystems: a practical guide. Biology Department, Science Faculty, Chiang Mai University, Thailand.

Friday, L. E. (1997) Wicken fen, the making of a wetland nature reserve. Harley Books.

Fry, G. L. A. (2001) Multifunctional landscapes – towards trans-disciplinary research. Landscape and Urban Planning 57: 159-168

Fuller, D. (1999) Part of the action, or 'going native': Learning to cope with the 'politics of integration'. Area 31: 221-227

Furman, J. Stiglitz, E., Bosworth, B. P. and Radelet, S. (1998) Economic Crises: Evidence and Insights from East Asia. *Brookings Papers on Economic Activity* 2: 1-135

Furniss, C. (2006) Dossier: palm oil, seeds of destruction. Geographical 78: 45-59

Gadgil, M., Berkes, F. and Folke, C. (1993) Indigenous knowledge for biodiversity conservation. Ambio 22: 151-156

Ganade, G. and Brown, V. K. (2002) Succession in old pastures of central Amazonia: role of soil fertility and plant litter. Ecology 87: 743-754

García-Garrido, J. M. and Ocampo, J. A. (2002) Regulation of the plant defense response in arbuscular mycorrhizal symbiosis. Journal of Experimental Botany 53: 1377-1386.

Giesen, W. (2004) Causes of swamp forest degradation in Berbak National Park and recommendations for restoration. Water for Food and Ecosystems Programme Project on: Biodiversity & the EMRP Revised draft Euroconsult Mott MacDonald 45 "Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peat swamp forests". ARCADIS Euroconsult, Arnhem, the Netherlands

Glatzel, S., Lemke, S. and Gerold, G. (2006) Short-term effects of an exceptionally hot and dry summer on decomposition of surface peat in a restored temperate bog. European Journal of Soil Biology 42: 219-229

Gobster, P. (2001) Visions of nature: conflict and compatibility in urban park restoration. Landscape and Urban Planning 56: 35-51

Gomez-Aparicio, L. (2009) Special feature: Facilitation in plant communities - The role of plant interactions in the restoration of degraded ecosystems: a meta-analysis across life-forms and ecosystems. Journal of Ecology 97: 1202-1214

Gómez-Pompa, A., Whitmore, T. C. and Hadley, M. (1991) Rainforest regeneration and management.

Gorham, E. (1991) Northern Peatlands: Role in the Carbon Cycle and Probable Responses to Climatic Warming. Ecological Applications 1:182–195.

Graham, L. L. B and Page, S. E. (2012) Artificial bird perches for the regeneration of degraded tropical peat swamp forest: A restoration tool with limited potential. Restoration Ecology 20: 631-637

Graham, L. L. B, Turjaman, M. and Page, S. E. (2013) *Shorea balangeran* and *Dyera polyphylla* (syn. *Dyera lowii*) as tropical peat swamp forest restoration transplant species: effects of mycorrhizae and level of disturbance. Wetlands Ecology and Management (DOI) 10.1007/s11273-013-9302-x

Graham, L. L. B. (2009) A literature review of the ecology and silviculture of tropical peat swamp forest tree species found naturally occurring in Central Kalimantan. Report produced for Kalimantan Forest and Climate Partnership

Grombone-Guaratini, M. T. and Rodrigues, R. R. (2002) Seed bank and seed rain in a seasonal semi-deciduous forest in south-eastern Brazil. Journal of Tropical Ecology 18: 759-774

Gunaratne, A. M. T. A., Gunatilleke, C. V. S., Gunatilleke, I. A. U. N., Madawala Weerasinghe, H. M. S. P. and Burslem, D. F. R. P. (2011) Release from root competition promotes tree seedling survival and growth following transplantation into human-induced grasslands in Sri Lanka, Forest Ecology and Management, 262: 229-236

Gusfield, J. R. (1975) The community: A critical response. New York.

Hardjono, J. (1989) The Indonesian transmigration program in historical perspective. International migration 26:427-439

Harrison, M. E. (2009) Orang-utan feeding behaviour in Sabangau, Central Kalimantan. PhD thesis submitted to University of Cambridge

Harrison, M. E., Page, S. E. and Limin, S. H. (2009) The global impact of Indonesian forest fires. Biologist 56: 156-163

Hickey and Mohon (2004) Participation: From tyranny to transformation. Zed books

Higgs, E. (2003) Nature by Design. Cambridge, MIT Press.

Higgs, E. (2005) The two-culture problem: Ecological restoration and the integration of knowledge. Restoration Ecology 13:159-164

Hillman, M. (2006) Situated justice in environmental decision-making: lessons from river management in Southeastern Australia. Geoforum 37: 695-707

Hobbs, J. R. (2007) Setting effective and realistic restoration goals: key directions for research. Restoration Ecology 15: 354-357

Hobbs, J. R. and Miller, R. J. (2007) Habitat restoration – do we know what we're doing? Restoration Ecology 15:382:390

Holl, K. D. (1999) Factors limiting tropical rain forest regeneration in abandoned pasture: seed rain, seed germination, microclimate and soil. Biotropica 31: 229-242

Holl, K. D. (2012) Chapter 9: Restoration of tropical forests. *In:* van Andel, J. and Aronson, J. (2012) Restoration Ecology: The New Frontier. Second edition. Wiley-Blackwell Press.

Holl, K. D., Loik, M. E., Lin, E. H. V., and Samuels, I. A. (2000) Tropical montane forest restoration in Costa Rica: Overcoming barriers to dispersal and establishment. Restoration Ecology 8: 339-349

Holmes, K. R., Nelson, T. A., Coops, N. C. and Wulder, M. A.(2013) Biodiversity indicators show climate change will alter vegetation in parks and protected areas. Diversity 5: 352-373

Hooijer, A., Page, S. E. and Nussbaum, R. (2008) Statement on tropical peatland conservation and the possibilities for sustainable development. Kampar Science Based Management Support Project. Report submitted to APRIL (Asia Pacific Resources International Limited) August 2008.

Hooijer, A., Page, S., Canadell, J. G., Silvius, M., Kwadijk, J., Wösten, H. and Jauhiainen, J. (2010) Current and future CO_2 emissions from drained peatlands in Southeast Asia. Biogeosciences 7: 1505-1514

Hooijer, A., Page, S., Jauhiainen, J., Lee, W. A., Lu, X. X., Idris, A. and Anshari, G. (2012) Subsidence and carbon loss in drained tropical peatlands. Biogeosciences 9: 1053–1071,

Hooijer, A., Silvius, M., Wösten, H. and Page, S. (2006) PEAT-CO2, Assessment of CO2 emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943

Hooper, E., Legendre, P. and Condit, R. (2005) Barriers to forest regeneration and of deforested and abandoned land in Panama. Journal of Applied Ecological 42: 1165-1174

Hopfensperger, K. N., Engelheardt, K. A.M. and Seagle, S. W. (2006) The use of case studies in establishing feasibility for wetland restoration. Restoration Ecology 14: 578-586

Hoscilo, A. (2009) Fire regime, vegetation dynamics and land cover change in tropical peatland, Indonesia. PhD thesis, University of Leicester, UK.

Hoscilo, A., Page, S. E., Tansey, K. J. and J. O. Rieley (2011) Effect of repeated fires on land-cover change on peatland in southern Central Kalimantan, Indonesia, from 1973 to 2005. International Journal of Wildland Fire 20: 578–588

Howard, S. (1994) Methodological issues in overseas fieldwork: experiences from Nicaragua's Northern Atlantic Coast. *In*. Robson, E. J. and Willis, K. (*Eds*.) Postgraduate fieldwork in developing areas: a rough guide. Monograph No. 8, London: Developing Areas Research Group (DARG) of RGS/IBG. Pp. 19-35

Howe, H. F. and Smallwood, J. (1982) The ecology of seed dispersal. Annual review of ecology and systematics 13: 201-228

Howe, H. F., Schupp, E. W. and Westley, I. C. (1985) Early consequences of seed dispersal for a neotropical tree (*Virola surinamensis*). Ecology 66: 781-791

Huff, D. E. and Varley, J. D. (1999) Natural regulation in Yellowstone National Park's northern range. Ecological applications 9: 17-27

Ibrahim, S. (1997) Diversity of tree species in peat swamp forest in Peninsular Malaysia. *In*: Rieley J. O. and Page S. E. (*Eds.*), Biodiversity and Sustainability of Tropical Peatlands, Proceedings of the International Symposium on Biodiversity, Environmental Importance and Sustainability of Tropical Peat and Peatlands, Palangkaraya, Central Kalimantan, Indonesia, 4-8 September 1995. Samara Publishing Ltd. Cardigan, Pp. 211-220.

Immirizi, C. P. and Maltby, E. (1992) The global status of peatlands and their role in the carbon cycle. Wetlands Ecosystems Research Group, Report 11. Exeter, UK: University of Exeter.

Ismail, P. and Shamsudin, I. (2003) Raising planting materials of peat swamp forest species. Journal of Tropical Forest Science 15: 237-240

ITTO (2002) ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests. ITTO Policy Development Series No 13. ITTO, Yokohama, Japan.

Janos, D. P. (1980a) Mycorrhizae influence tropical succession. Biotropica 12:56-64

Janos, D. P. (1980b) Vesicular-arbuscular mycorrhizae affect lowland tropical rainforest plant growth. Ecology 61:151-162

Janzen, D. H. (1970) Herbivores and the number of tree species in tropical forests. American Naturalist 104: 501-528

Janzen, D. H. and Vázquez-Yanes, C. (1991) Aspects of tropical seed ecology of relevance to management of tropical forest wildlands. *In:* Gómez-Pompa, A., Whitmore, T. C. and Hadley, M. (Eds.) Rainforest regeneration and management. The Parthenon Publishing Group, Lancs, England, U.K.

Jauhiainen, J, Hooijer, A. and Page, S. E. (2012) Carbon dioxide emissions from an Acacia plantation on peatland in Sumatra, Indonesia. Biogeosciences 9: 617-630

Jepson, P., Jarvie, J. K., Mackinnon, K. and Monk, K. A. (2001) The end for Indonesia's lowland forest? Science 292:859-861

Johnson, N. C. and Wedin, D. A. (1997) Soil carbon, nutrients, and mycorrhizal fungal communities during grassification of a dry tropical forest. Ecological Applications 7: 171-182

Kessler, P. J. A. (2000) Secondary forest trees of Kalimantan, Indonesia. A Manual to 300 selected species. Tropenbos-Kalimantan Series 3. MOFEC-Tropenbos-Kalimantan Project, Wanariset, Samboja

Kettle, C. J. (2010) Ecological considerations for using dipterocarps for restoration of lowland rainforest in Southeast Asia. Biodiversity and Conservation 19: 1137-1151

Khan, M. L., Bhuyan, P. B. and Tripathi, R. S. (2005) Effects of forest disturbance on fruit set, seed dispersal and predation of Rudraksh (*Eleocarpus ganitrus* Roxb.) in NE India. Current Science 88: 133-142

Khurana, E. and Singh, J. S. (2001) Ecology of tree seed and seedlings: Implications for tropical forest conservation and restoration. Current Science 80: 748-757

Kiers, E. T., Lovelock, C. E., Krueger, E. L. and Herre, E. A. (2000) Differential effects of tropical arbuscular mycorrhizal fungal innocula on root colonization and tree seedling growth: implications for tropical forest diversity. Ecology Letters 3: 106-113

Kitchin, R. M. and Hubbard, P. J. (1999) Research, action and 'critical' geographies. Area 31: 195-198

KFCP (2009) Kalimantan Forests and Climate Partnership Design Document. http://www.iafcp.or.id/publication/detail/24/KFCP-Design-Document

Kurnain, A., Notohadikusumo, T., Radjagukguk, B. and Sri Hastuti (2001) Peat soil properties related to degree of decomposition under different land use systems. International Peat Journal 11: 67-77

Lamb, D., Erskine, P. D. and Parrotta, J. A. (2005) Restoration of degraded tropical forest landscapes. Science 310: 1628-1632

Lambers, H., Chapin, F. S. and Pons, T. L. (1998) Plant physiological ecology. Springer. Pp. 37-42

Langner, A. and Siegert, F. (2009) Spatiotemporal fire occurrence in Borneo over a period of 10 years. Global Change Biology 15: 48-62

Langner, A., Miettinen, J. and Siegert, F. (2007) Land cover change 2002-2005 in Borneo and the role of fire derived from MODIS imagery. Global Change Biology 13: 2329-2340

Lawrence, D. C. (1996) Trade-offs between rubber production and maintenance of diversity: the structure of rubber gardens in West Kalimantan, Indonesia. Agroforestry Systems 34: 84-100

Lawson, S. and MacFaul, L. (2010) Illegal Logging and Related Trade: Indicators of the Global Response. Royal Institute of International Affairs, London

Lazuardi, D. (2004) Teknik rehabilitasi hutan dan rawa gambut. Prosiding seminar ilmiah kesiapan teknologi untuk mendukung rehabilitasi hutan dan lahan rawa gambut di Kalimantan Tengah, Palangka Raya, 12 Mei 2004. Pp 29-37

Lee, H. S. (1979) Natural regeneration and reforestation in the peat swamp forests of Sarawak. Tropical Agricultural Research Center 12: 51-60

Lele, S., Wilshusen, P., Brockington, D., Seidler, R. and Bawa, K. (2010) Beyond exclusion: alternative approaches to biodiversity conservation in the developing countries. Current opinion in Environmental Sustainability 2: 94-100

Leverington, F., Hockings, M., Costa, K. L. and Courrau, J. (2008) Management effectiveness evaluation in protected areas: a global study (University of Queensland/IUCN WCPA/TNC/WWF, Gatton, Australia

Liew, T. C. (1973) Occurrence of seeds in virgin topsoil with particular reference to a secondary species in Sabah. Malaysian Forestry 36: 185-193

Lithgow, D., Martínez, M. L., Gallego-Fernández, J. B. (2013) Multi-criteria analysis to implement actions to coastal dune restoration. Restoration of coastal dunes. Springer series on Environmental management: 307-321

Loik, M. E. and Holl, K. D. (1999) Photosynthetic responses to light for rainforest seedlings planted to restore abandoned pasture, Costa Rica. Restoration Ecology 6: 253-261

Lovelock, C. E. and Ewel, J.J. (2005) Links between tree species, symbiotic fungal diversity and ecosystem functioning in simplified tropical ecosystems. New Phytologist 167: 219-228

Lyons, A. L. (2003) The importance of non-timber forest products to livelihoods and conservation in the Sebangau Catchment, Central Kalimantan, Indonesia. Report submitted to School of Development Studies, University of East Anglia.

MacLean, I. M. D. *et al.* (2008) Climate change causes rapid changes in the distribution and site abundance of birds in winter. Global Change Biology 14: 2489-2500

Manning, A. D., Lindenmayer, D. B. and Fischer, J. (2006) Stretch-goals and backcasting: approaches for overcoming barriers to large-scale ecological restoration. Restoration Ecology 14: 487–492.

Marjokorpi, A and Ruskolainen, K. (2003) The role of traditional forest gardens in conservation of tree species in West Kalimantan, Indonesia. Biodiversity and Conservation. 12:799-822

Marod, D., Kutintara, V., Tanaka, H. and Nakashizuka, T. (2004) Effects of drought and fire on seedling survival and growth under contrasting light conditions in a seasonal tropical forest. Journal of Vegetation Science 15: 691-700

Martinez-Garza, C., Flores-Palacios, A., De La Pena-Domene, M. and Howe, H. F. (2009) Seed rain in a tropical agricultural landscape. Journal of Tropical Ecology 25:541–550

Martinez-Garza, C., Tobon, W., Campo, J. and Howe, H. F. (2011) Drought mortality of tree seedlings in an eroded tropical pasture. Land degradation and development. Article published online: 18 May 2011. DOI: 10.1002/ldr.1127

Matsubara, T., Tuah, S. J., Limin, S. H. and Osaki, M. (2003) Nitrogen source for common tree species in peat swamp forests, Central Kalimantan inferred from ^{15}N analysis. Proceedings of the international symposium on land management and biodiversity in Southeast Asia, Bali, Indonesia, 17-20 September 2002

McCarthy, J. F. (2000) The changing regime: Forest property and Reformasi in Indonesia. Development and Change 31: 91-129

McCarthy, J. F. (2005) Between *Adat* and State: Institutional arrangements on Sumatra's Forest Frontier. Human Ecology 33:57-82

McManus, P. (2006) Mangrove Battlelines: culture/nature and ecological restoration. Australian Geographer 37: 57-71

McMillan, D. A. and Chavis, D. M. (1986) Sense of community: A definition and theory. Journal of Community Psychology 14:6-23

Mertz, O., Wadley, R. L. and Christensen, A. E. (2005) Local land use strategies in a globalising world: Subsistence farming, cash crops and income diversification. Agricultural systems 85: 209-215

Metcalfe, D. J. and Turner, L.M. (1998) Soil seed bank from lowland rain forest in Singapore: Canopy-gap and litter-gap demanders. Journal of Tropical Ecology 14: 103-108

Metcalfe, D. J. Grubb, P. J. and Turner, L.M. (1998) The ecology of very small-seeded shade-tolerant trees and shrubs in lowland rain forest in Singapore. Plant Ecology 134: 131-149

Miettinen, J. and Liew, S. C. (2010) Degradation and development of peatlands in Peninsular Malaysia and in the islands of Sumatra and Borneo since 1990. Land Degradation and Development 21: 285-296

Miettinen, J., Shi, C. and Liew, S. C. (2011) Deforestation rates in insular Southeast Asia between 2000 and 2010. Global Change Biology 17: 2261-2270

Millenium Ecosystem Assessment (MEA) (2005) Ecosystems and human well-being: General synthesis. Island Press, Washington, DC.

Moeliono, M., Wollenberg, E. and Limberg, G. (2012) The decentralization of forest governance: Politics, economics and the fight for control in Indonesian Borneo. Earthscan, London

Moller, H., Berkes, F., Lyver, P. O. and Kislalioglu, M. (2004) Combining science and traditional ecological knowledge: monitoring populations for co-management. Ecology and Society 9: online

Moser, S. (2008) Personality: a new positionality? Area 40:383-392

Muhamad, N and Rieley, J. (2001) Management of Tropical Peatlands in Indonesia: Mega-reclamation project in Central Kalimantan. *In:* Rieley, J and Page, S. (*Eds*.) Jakarta Symposium proceedings on: Peatlands for people, natural resources, 39 functions and sustainable management: Proceedings of International Symposium on Tropical Peatlands 22-23 August 2001

Murombedzi, J. (2003) Devolving the expropriation of nature: the 'devolution' of wildlife management in South Africa. *In*. Adams, W. and Mulligan, M. (Eds.) Decolonising Nature. Earthscan Pub., London.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. and Kent, J. (2000) Biodiversity hotspots for conservation priorities. Nature 403: 853 - 858

Nascimento, H. E. M. and Laurance, W.F. (2002) Total aboveground biomass in central Amazonian rainforests: a landscape-scale study. Forest Ecology and Management 168: 311-321

Nathan, R. and Casagrandi, R. (2004) A simple mechanistic model of seed dispersal, predation and plant establishment: Janzen-Connell and beyond. Journal of Ecology 92: 733-746

Nellemann, C., Corcoran, E., (Eds.) (2010) Dead planet, living planet - Biodiversity and ecosystem restoration for sustainable development: A rapid response assessment. United Nations Environment Programme, Nairobi

Nepstad, D. C., Uhl, C., Pereira, C. A., and da Silva, J. M.C. (1996) A comparative study of tree establishment in abandoned pasture and mature forest eastern Amazonia. Oikos 76: 25-39

Neβhöver, C., Aronson, J., Blignaut, J. N., Lehr, D., Vakrou A. and Wittmer H. (2011) Investing in ecological infrastructure. *In*. ten Brink P. (*Ed*.) The economics of ecosystems and biodiversity in national and international policy making. Earthscan, London/Washington. Pp 401-448.

Norgaard, R. B., Barnard, P. and Lavelle, P. (2007) Assessing and restoring natural capital across scales: lessons from the Millennium Ecosystem Assessment. *In:* Aronson, J., Milton, S. J. and Blignaut, J. N. (Eds.) Restoring Natural Capital: Science, Business and Practice. Island Press, Washington, USA

Notohadiprawiro, T. (1997) Twenty-five years experience in peatland development for agriculture in Indonesia. *In*. Rieley, J. O. and Page, S. E. (*Eds*.) Biodiversity and Sustainability of Tropical Peatlands. Samara, Cardigan

Nuyim, T. (2000) Whole aspect on nature and management of peat swamp forest in Thailand. Proceedings of the international symposium on tropical peatlands, Bogor, Indonesia, 22-23 November 1999. Hokkaido University and Indonesian Institute of Sciences. Pp. 109-117

O'Connor, C. M. (2004) Effects of central decisions on local livelihoods in Indonesia: Potential synergies between the programs of transmigration and industrial forest conversion. Population and Environment 25: 321-333

Orsi, F. and Geneletti, D. (2010) Identifying priority areas for forest landscape restoration in Chiapas (Mexico): An operational approach combining ecological and socioeconomic criteria. Landscape and urban planning 94: 20-30

Page, S. E. and Rieley, J. O. (2005) Wise use guidelines of tropical peatlands: Focus on Southeast Asia. Alterra Pub., Wageningen, The Netherlands

Page, S. E., Rieley, J. O. and Banks, C. J. (2011) Global and regional importance of the tropical peatland carbon pool. Global change biology 17: 798-818

Page, S. E., Rieley, J. O., Shotyk, Ø. W. and Weiss, D. (1999) Interdependence of peat and vegetation in a tropical peat swamp forest. Philosophical Transactions of the Royal Society B 354: 1885-1897

Page, S.E., Hoscilo, A., Wosten, H., Jauhiainen, J., Ritzema, H., Tansey, K., Silvius, M., Graham, L., Vasander, H., Rieley, J. and Limin, S. (2009) Ecological restoration of lowland tropical peatlands in Southeast Asia – Current knowledge and future research directions. *Ecosystems* 12: 888-905

Page, S.E., Siegert, F., Rieley, J.O., Boehm, H-D.V., Jaya, A. and Limin, S. (2002) The amount of carbon released from peat and forest fires in Indonesia in 1997. Nature 420: 61-65.

Palmer, L. (2006) 'Nature', Place and the recognition of Indigenous polities. Australian Geographer 37:33-43

Paoli, G. D. and Curran, L. M. (2007) Soil nutrients limit fine litter production and tree growth in mature lowland forest of Southwestern Borneo. Ecosystems 10: 503–518

Paoli, G. D., Curran, L. M. and Zak, D. R. (2006) Soil nutrients and beta diversity in the Bornean Dipterocarpaceae: evidence for niche partitioning by tropical rain forest trees. Journal of Ecology 94: 157-170

Parmesan, C. and Yohe, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37-42

Peluso, N. L. (2009) Rubber resources, rubber producing rights: Making racialised territories in West Kalimantan, Indonesia. Development and Change 40: 47-80

Peluso, N. L. (2012) What's nature got to do with it? A situated historical perspective on socio-natural commodities. Development and Change 43: 79-104

Picone, C. (2000) Diversity and abundance of arbuscular-mycorrhizal fungus spores in tropical forest and pasture. Biotropica 32: 734-750.

Pimental, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair, R. (1995) Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117-1123

Pimm, S. L., Russell, G. J., Gittleman, J. L. and Brooks, T. M. (1995) The future of biodiversity. Science 269: 347-350

Poorter, L. and Markesteijn, L. (2008) Seedling traits determine drought tolerance of tropical tree species. Biotropica 40: 321-331

Posa, M. C., Wijedasa, L. S. and Corlett, R. T. (2011) Biodiversity and conservation of tropical peat swamp forests. Bioscience 61: 49-57

Potter, L. and Lee, J. (1998) Tree planting in Indonesia: Trends, Impacts and Directions. Centre for International Forestry Research (CIFOR) Occasional paper No.18

Putz, F. E. and Appanah, S. (1987) Buried seeds, newly dispersed seeds and the dynamics of a lowland forest in Malaysia. Biotropica 19: 326-333

Rachmanadi, D. and Lazuardi, D. (2007) Strategi rehabilitasi hutan rawa gambut terdegradisi. Majalah Kehutanan Indonesia (MKI) Edisi IV Tahun 2007

Rands, M. R. W. and 11 others (2010) Biodiversity conservation: Challenges beyond 2010. Science 329: 1298-1303

Ricklefs, M. C. (2008) A modern history of Indonesia since c.1200. Fourth edition.

Rieley, J. O. and Page, S. E. (2005) Wise Use of Tropical Peatlands: Focus on Southeast Asia. Alterra Publishing.

Rillig M. C. (2004) Arbuscular mycorrhizae and terrestrial system processes. Ecology letters 7:740-754

Rodrigues, A. S. L., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Cowling, R. M., Fishpool, L. D. C., da Fonseca, G. A. B., Gaston, K. J., Hoffman, M., Long, J. S., Marquet, P. A., Pilgrim, J. D., Pressey, R. L., Schipper, J., Sechrest, W., Stuart, S. N., Underhill, L. G., Waller, R. W., Watts, M. E. J. and Yan, X. (2004) Effectiveness of the global protected area network in representing species diversity. Nature 428: 640-643

Rodrigues, R. R., Gandolfi, S., Nave, A. G., Aronson, J., Barreto, T. E., Vidal, C. Y. and Brancalion, P. H. S. (2011) Large-scale ecological restoration of high diversity forests in SE Brazil. Forest Ecology and Management 261: 1605-1613

Rodrigues, R. R., Lima, R.A.F., Gandolfi, S. and Nave, A. G. (2009) On the restoration of high diversity forests: 30 years of experiences in the Brazilian Atlantic Forest. Biological Conservation 142: 1242-1251

Rosenzweig, M. L. (2003) Win-win ecology: How Earth's species can survive in the midst of human enterprise. Oxford University Press

Rotinsulu, J. M., Sukaryanto, Yudha, Rahmawati, R. and Pidjath, C. (2007) Budidaya Ramin (*Gonystylus bancanus*) *In*: Usup, A. (*Ed*.) Central Kalimantan Peatlands Project Universitas Palangka Raya

Rowell, A. (1996) Green backlash. Routledge

Sack, L. and Grubb, P. J. (2002) The combined impacts of deep shade and drought on the growth and biomass allocation of shade-tolerant woody seedlings. Oecologia 131: 175-185

Saito, H., Shibuya, M., Tuah, S. J., Takahashi, K., Jamal, Y., Segah, H., Putir, P. E. and Limin, S. H. (2003) Preliminary selection of fast-growing tree species with tolerance to an open and dry tropical peat land in Central Kalimantan: To develop a preceding planting method. Proceedings of the international symposium on land management and biodiversity in Southeast Asia, Bali, Indonesia, 17-20 September 2002

Salafsky, N. and Wollenberg, E. (2000) Linking livelihoods and conservation: A conceptual framework and scale for assessing the integration of human needs and biodiversity. World Development 28:1421-1438

Santiago, L. S., Wright, S. J., Harms, K. E., Yavitt, J. B., Korine, C., Garcia, M. N. and Turner, B., L. (2012) Tropical tree seedling growth responses to nitrogen, phosphorus and potassium addition. Journal of Ecology 100: 309-316

Sarjawan, A., Notohadiprawiro, T., Radjagukguk, B. and Hastuti, S. (2002) Diversity of tropical peat characteristics in intact peatland forest, under the influence of forest type, peat thickness, and the position of the peat deposit. *In:* Rieley J. O., Page, S. E. and Setiadi, B. (*Eds.*) Peatlands for People – Natural Resource Function and Sustainable Development, Proceedings of the International Symposium on Tropical Peatlands, Jakarta, 22-23 August 2001.

Sasaki, N., Asner, G. P., Knorr, W., Durst, P.B., Priyadi, H. R. and Putz, F. E. (2011) Approaches to classifying and restoring degraded tropical forests for the anticipated REDD+ climate change mitigation mechanism. iForest - Biogeosciences and Forestry 4: 1-6

Saulei, S. M. and Swain, M. D. (1988) Rain forest seed dynamics during succession at Gogol, Papua New Guinea. Journal of Ecology 76: 1133-1152

Schoenberger, E. (1992) Self-criticism and self-awareness in research: a reply to Linda McDowell. Professional Geographer 44: 215-218

Schoot Ulterkamp, A. J. M. and Vlek, C. (2007) Practice and outcomes of multidisciplinary research for environmental sustainability. Journal of Social Issues 63: 175-197

Schütte, S. A. (2012) Against the odds: anti-corruption reform in Indonesia. Public administration and development 32: 38-48

Schuyt, K., Mansourian, S., Roscher, G. and Rambeloarisoa, G. (2007) Capturing economic benefits from restoring natural capital in transformed tropical forests. *In:* Aronson, J., Milton, S. J. and Blignaut, J. N. (Eds.) Restoring Natural Capital: Science, Business and Practice. Island Press, Washington, USA

SER: Society for Ecological Restoration International Science & Policy Working Group (2004) The SER International Primer on Ecological Restoration. www.ser.org & Tucson: Society for Ecological Restoration International.

Serje. M (2003) *Malocas* and *barrocones*. Tradition, biodiversity and participation in Colombian Amazon. UNESCO pp. 561-571

Shackelford, N., Hobbs, R. J., Burgar, J. M., Erickson, T. E., Fontaine, J. B., Laliberté, E., Ramalho, C. E., Perring, M. P. and Standish, R. J. (2013) Primed for Change: Developing Ecological Restoration for the 21st Century. Restoration Ecology 21: 297-304

Sharpe, B. (1998) 'First the forest': conservation, 'community' and 'participation' in SW Cameroon. Africa 68: 25-45

Sheil, D. and Lawrence, A. (2004) Tropical biologists, local people and conservation: New opportunities for collaboration. Trends in Ecology and Evolution 19:634-638

Shepherd, P. A., Rieley J. O. and Page S. E. (1997) The relationship between forest vegetation and peat characteristics in the upper catchment of Sungai Sebangau, Central Kalimantan. *In*: Rieley J. O. and Page S. E. (*Eds.*) Biodiversity and Sustainability of Tropical Peatlands. Samara Publishing Ltd. Pp. 191-207

Sikor, T. and Lund, C. (2009) Access and property: A question of power and authority. Development and Change 40: 1-22

Simbolon, H. and Mirmanto, E. (1999) Checklist of plant species in the peat swamp forests of Central Kalimantan, Indonesia. Proceedings of the International Symposium on Tropical Peatlands, Bogor, 22-23 November 1999

Simbolon, H., Kahono, S., Artiningsih, T., Girmansyah, D. and A. Sadeli (2003) Hutan Gambut Kelampangan, Kalimantan Tengah Pasca Kebakaran: Monitoring keadaan hutan, jamur dan seranga perombak dan penyerbuk. Laporan Perjalanan Lapangan, 27 Mei-8 Juni 2003, Bogor. Pp. 14

Sjarkowi, H. F. (2002) Socio-entropy system approach (SESA) towards sustainable management of a peatland forest ecosystem in Central Kalimantan. *In:* Rieley, J. O. and Page, S. E. (*Eds.*) Peatlands for people, natural resources, functions and sustainable management. Proceedings of the International Symposium on Tropical Peatlands. Jakarta, 22-23 August 2001, BPPT and Indonesian Peat Association. Pp. 224-35

Smith, V. (2002) Investigation into the human communities of the Sebangau Peat Swamp Forests, Central Kalimantan, Indonesia: Demography, attitudes and impacts. Report submitted to Oxford Brookes University.

Spracken, D., Yaron, G., Singh, T., Righelato, R. and Sweetman, T. (2008) The root of the matter: Carbon sequestration in forests and peatlands. *Ed.* Caldecott, Ben. Policy Exchange Pub., London

Stern, N. (2006) Review on the economics of climate change. H. M. Treasury, United Kingdom.

Stewart, W. P., Liebert, D. and Larkin, K. W. (2005) Community identities as visions for landscape change. Landscape and Urban Planning 69: 315-324

Stiles, E. W. (2000) Animals as seed dispersers. *In:* Fenner, M (Ed.) Seeds: The ecology of regeneration in plant communities. 2nd ed. CABI Publishing.

Sulistiyanto, Y. (2004) Nutrient dynamics in different sub-types of peat swamp forest in Central Kalimantan, Indonesia. PhD thesis, School of Geography, University of Nottingham, Nottingham.

Takashi, H. and Yonetani, Y. (1997) Studies on microclimate and hydrology of peat swamp forest in Central Kalimantan, Indonesia. *In*: J.O.Rieley and S.E. Page (*Eds.*) Biodiversity and Sustainability of Tropical Peatlands, Samara Publishing Ltd.

Takashi, H., Shimada, S., Ibie, B. F., Usup, A., Yudha, and Limin, S. H. (2002) Annual changes of water balance and a droughts index in tropical peat swamp forest of Central Kalimantan, Indonesia. *In:* Rieley, J and Page, S. (*Eds.*) Jakarta Symposium proceedings on: Peatlands for people, natural resources, 39 functions and sustainable management: Proceedings of International Symposium on Tropical Peatlands 22-23 August 2001

Tanaka, S., Wasli, M. E. B., Kotegawa, T., Seman, L., Sabang, J., Kendawang, J. J., Sakurai, K. and Morooka, Y. (2007) Soil properties of secondary forests under shifting cultivation by the Iban of Sarawak, Malaysia in relation to vegetation condition. Tropics 16: 385-398

Tang, Y.,Cao, M. and Fu, X. (2006) Soil seedbank in a dipterocarp rain forest in Xishuangbanna, Southwest China. Biotropica 38: 328-333

Tawaraya, K., Takaya, Y., Turjaman, M., Tuah, S. J., Limin, S. H., Tamai, Y., Cha, J. Y., Wagatsuma, T. and Osaki, M. (2003) Arbuscular mycorrhizal colonisation of tree species grown in peat swamp forests of Central Kalimantan, Indonesia. Forest Ecology and Management 182: 381-386

Taylor, J. G. (2003) Indonesia: peoples and histories. Yale University Press.

TEEB (2010) The economics of ecosystems and biodiversity (TEEB): Mainstreaming the economics of nature: A synthesis of the approach, conclusions and recommendation of TEEB

Tekle, K. and Bekele, T. (2000) The role of soil seed banks in the rehabilitation of degraded hillslopes in Southern Wello, Ethiopia. Biotropica 32:23-32

Thompson, K. (1992) The functional ecology of seed banks. *In:* Fenner, M. (*Ed*.) Seeds: The ecology of regeneration in plant communities. Pp. 231-258

Timmer, J. (2010) Being like the state: Emulations of legal culture in customary labor and land tenure arrangements in East Kalimantan, Indonesia. American Ethnologist 37: 703-712

Tobin, M. F., Lopez, O. R. and Kursar, T. A. (1999) Responses of tropical understorey plants to a severe drought: Tolerance and avoidance of water stress. Biotropica 31: 570-578

Tobon, W., Martinez-Garza, C. and Campo, J. (2011) Soil responses to restoration of a tropical pasture in Veracruz, South-eastern Mexico. Journal of Tropical Forest Science 23: 338-344

Toda, T., Takeda, H., Tokuchi, N., Ohta, S., Wacharinrat, C. and Kaitpraneet, S. (2007) Effects of forest fire on the nitrogen cycle in a dry dipterocarp forest, Thailand. Tropics 16:41-45

Tomita, M., Hirabuki, Y., Suzuki, K., Hara, K., Kaita N. and Araki U. (2000) Drastic recovery of *Melaleuca*-dominant scrub after a severe wild fire: a three-year period study in a degraded peat swamp, Thailand. ECO-HABITAT: JISE Research 7: 81-87

Tongway, D. J. and Ludwig, J. A. (2011) Restoring disturbed landscapes: Putting principles into practice. Island Press, Washington, USA.

Tongway, D. J. and Ludwig, J. A. (2012) Chapter 4: Planning and implementing successful landscape-scale restoration. *In:* van Andel, J. and Aronson, J. (eds.) Restoration Ecology: The New Frontier. Second edition. Wiley-Blackwell Press.

Townsend, A. R., Cleveland, C. C., Houlton, B. Z., Alden, C. B. and White J. W. C. (2011) Multi-element regulation of the tropical forest carbon cycle. Frontiers in Ecology and the Environment 9: 9-17

Tsing, A. L. (2005) Friction: An ethnography of global connection. Princeton University Press.

Turjaman, M., Santoso, E., Susanto, A., Gaman, S., Limin, S.H., Tamai, Y., Osaki, M. and Tawaraya, K. (2011) Ectomycorrhizal fungi promote growth of *Shorea balangeran* in degraded peat swamp forest. Wetlands Ecology and Management 19: 331-339.

Turjaman, M., Tamai, Sitepu, I.R., Santoso, E., Osaki, M. and Tawaraya, K. (2008) Improvement of early growth of two tropical peat swamp forest species *Ploiarium alternifolium* and *Calophyllum hosei* by two arbuscular mycorrhizal fungi under greenhouse conditions. New Forests 36: 1-12

Turjaman, M., Tamai, Y., Sagah, H., Limin, S. H., Cha, J. Y., Osaki, M. and Tawaraya, K. (2005) Inoculation with the ectomycorrhizal fungi *Pisolithus arhizus* and *Scleroderma* sp. Improves early growth of *Shorea pinanga* nursery seedlings. New Forests 30: 67-73

Turjaman, M., Tamai, Y., Sagah, H., Santoso, E., Osaki, M. and Tawaraya, K. (2006) Arbuscular mycorrhizal fungi increased early growth of two non-timber forest product species *Dyera polyphylla,* and *Aquilaria filarial* under greenhouse conditions. Mycorrhiza 16: 459-464

Turner, R. E. (2005) On the cusp of restoration: Science and society. Restoration Ecology 13: 165-175

Turner, R. K., van den Bergh, J. C. J. M., Söderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E., van Ireland, E. C. (2000) Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economic 35: 7-23

Twyman, C., Morrison, J. and Sporton, D. (1999) The final fifth: autobiography, reflexivity and interpretation in cross-cultural research. Area 31: 313-325

Tynela, T., Otsamo, R. and Otsamo, A. (2000) Indigenous livelihood systems in industrial tree-plantations in West Kalimantan, Indonesia: Economics and plant species richness. Agroforestry 57: 87-100

van Andel, J. and Aronson, J. (2012a) (eds.) Restoration Ecology: The New Frontier. Second edition. Wiley-Blackwell Press.

van Andel, J. and Aronson, J. (2012b) Chapter 22: Restoration ecology and the path to sustainability. *In:* van Andel, J. and Aronson, J. (Eds.) Restoration Ecology: The New Frontier. Second edition. Wiley-Blackwell Press.

van Andel, J., Grootjans, A. P. and Aronson, J. (2012) Chapter 2: Unifying concepts. *In:* van Andel, J. and Aronson, J. (Eds.) Restoration Ecology: The New Frontier. Second edition. Wiley-Blackwell Press.

van Diggelen, R., Hobbs, R. J. and Miko, L. (2012) Chapter 5: Landscape Ecology. *In:* van Andel, J. and Aronson, J. (Eds.) Restoration Ecology: The New Frontier. Second edition. Wiley-Blackwell Press.

van Eijk, P. and P. Leenman (2004) Regeneration of fire degraded peat swamp forest in Berbak National Park and implementation in replanting programmes. Water for Food & Ecosystems Programme project on: "Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peatswamp forest" Case study Air Hitam Laut river basin, Jambi Province, Indonesia. Alterra Green World Research, Wageningen, The Netherlands

van Eijk, P., Leenman, P., Wibisono, I. T. C. and Giesen, W. (2009) Regeneration and restoration of degraded peat swamp forest in Berbak National Park, Jambi, Sumatra, Indonesia. Malayan Nature Journal 61: 223-241

van Noordwijk, M., Purnomo, H., Peskett, L. and Setiono, B. (2008) Reducing emissions from deforestation and forest degradation (REDD) in Indonesia: options and challenges for fair and efficient payment distribution mechanisms. Working paper 81, World Agroforestry Centre (ICRAF), Bogor, Indonesia.

Vierra, I. C. G., Uhl, C. and Nepsted, D. (1994) The role of the shrub *Cordia multispicata* Cham. as a succession 'facilitator' in an abandoned pasture, Paragominas, Amazonia. Vegetatio 115: 91-99

Walker, B. H. (1993) Rangeland ecology: understanding and managing change. Ambio 22: 80-87

Wallace, A.R. (1869) *The Malay Archipelago*. Periplus Editions.

Walsh, F. and Mitchell, P. (2002) Planning for country: Cross-cultural approaches to decision-making on Aboriginal lands. Jukurrpa books.

Wang, B. C. and Smith, T. B. (2002) Closing the seed dispersal loop. Trends in Evolution and Ecology 17: 379-385

Wangpakapattanawonga, P., Kavinchana, N., Vaidhayakarna, C., Schmidt-Vogtb, D. and Elliott, S. (2010) Fallow to forest: Applying indigenous and scientific knowledge of swidden cultivation to tropical forest restoration. Forest Ecology and Management 260:1399-1406

Warren, D. M. and Pinkston, J. (1998) Indigenous African resource management of a tropical rainforest ecosystem: a case study of Yoruba of Ara, Nigeria. In. Berkes, F. and Folke, C. (*Eds*.) Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press.

Webb, C. O. and Peart, D. R. (2001) High seed dispersal rates in faunally intact tropical rainforest: theoretical and conservation implications. Ecological Letters 4: 491-499

White, S. C. (1996) Depoliticising development: the uses and abuses of participation. Development in practice 6: 6-15

Whitmore, T.C. (1984) Tropical rainforests of the Far East, 2nd Edition. Clarendon Press, Oxford

Wibisono, I. T. C. and Gandrung, A. Y. (2008) Ujicoba Penanaman Beberapa Jenis Tanaman Asli Hutan Rawa Gambut Pada Beberapa Lokasi Di Lahan Gambut Terdegradasi. Laporan Penelitian. Central Kalimantan Peatlands Project.

Wibisono, I. T. C., Siboro, L. and Suryadiputra, I. N. N. (2005) Panduan Rehabilitasi dan Teknik Silvikultur di Lahan Gambut. Wetlands International – Indonesia Program

Wicke, B., Sikkema, R., Dornburg, V. and Faaij, A. (2011) Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy 28:193-206

Williams, G. and Mawdsley, E. (2006) Postcolonial environmental justice: Government and governance in India. Geoforum 37: 660-670

Wilson, M. F. and Traveset, A. (2000) Ecology of seed dispersal. *In:* Fenner, M (*Ed*.) Seeds: The ecology of regeneration in plant communities. 2nd ed. CABI Publishing.

Wilson, S. D. (1999) Plant interactions during secondary succession. *In.* Walker, L. (Ed.) Ecosystems of disturbed ground. Elsevier, New York. Pp. 611–632

Worldbank (2013) http://www.worldbank.org/en/country/indonesia/overview

Wösten, J. H. M. and Ritzema, H. P. (2002) Challenges in land and water management for peatland development in Sarawak. *In:* Rieley, J and Page, S. (*Eds*.) Jakarta Symposium proceedings on: Peatlands for people, natural resources, 39 functions and sustainable management: Proceedings of International Symposium on Tropical Peatlands 22-23 August 2001

Wösten, J. H. M., Clymans, E., Page, S. E., Rieley, J. O. and Limin, S. H. (2008) Peat-water interrelations in tropical peatland ecosystems in Southeast Asia. Catena 73:212-224

Wösten, J. H. M., van der Berg, J., van Eijk, P., Gevers, G. J. M., Giesen, W. B. J. T., Hooijer, A., Idris, Leenman, P. H., Rais, D. S., Siderius, C., Silvius, M. J., Suryadiputra, N. and Wibisono, I. T. (2006) Interrelationships between hydrology and ecology in fire degraded tropical peat swamp forests. Water Resources Development 22:157-174

Wright, G. (2011) Indigenous people and customary land ownership under domestic REDD+ frameworks: A case study of Indonesia. Law, Environment and Development Journal 7: 117-133

Wright, S. J. (2002) Plant diversity in tropical forests: a review of mechanisms of species coexistence. Oecologia 130: 1-14

Yan, E. R., Wang, X. H. and Zhou, W. (2006) Estimates of soil respiration and net primary productivity of three forests at different succession stages in South China. Global Change Biology 12: 810-821

Yanbuaban, M., Nuyim, T., Matsubara, T., Watanabe, T. and Osaki, M. (2007) Nutritional ecology of plants grown in a tropical peat swamp. Tropics 16: 31-39

Zanini, L. and Ganade, G. (2005) Restoration of Araucaria Forest: The role of perches, pioneer species, and soil fertility. Restoration Ecology 13: 507-514

Zimmerman, J. K., Pascarella, J. B. and Aide, T. M. (2000) Barriers to forest regeneration in an abandoned pasture in Puerto Rico. Restoration Ecology 8: 350-360