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AN ASSESSMENT OF THE RESTORATION EFFORTS OF DEGRADED PEATLAND IN CENTRAL KALIMANTAN INDONESIA

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ABSTRACT

Indonesia’s tropical peatlands are an ecosystem of global significance. They contain immense stores of carbon and play a key role in regional and global climate systems. They provide habitat for iconic species such as the orangutan and Sumatran tiger, and they sustain the livelihoods of thousands of local people. Despite these values, Indonesia’s peatland ecosystems have been subject to extensive deforestation and degradation during the past two decades. Recurrent peatland fires related to these land use activities have caused smoke pollution across the region, resulting in substantial public health issues and political controversy. More than 50% of the nation’s 21 Mha of peatland can be considered as degraded. There is an urgent need to slow the rate of peatland degradation in Indonesia and to effectively restore the vast areas already damaged. A key consideration in this challenge is that tropical peatland restoration is an emerging field of scientific inquiry and little research has been published on the factors that constitute and influence successful restoration of tropical peatland ecosystems.

This thesis addresses this gap in the broader ecosystem restoration literature by focusing on a case study of the so-called “Ex-Mega Rice Project” area of Central Kalimantan (an area previously subject to extensive degradation) and examining how successful peatland restoration can be achieved in Indonesia by: (1) reviewing the drivers of peatland degradation in the country in order to better understand the competing interests and broader socioecological context in which restoration activities need to be carried out; (2) studying previous restoration initiatives in Indonesia to better understand the restoration techniques used and the factors influencing their relative effectiveness; (3) analysing the specific tropical peatland restoration technique of “re-wetting” to better understand which elements of the technique best support effective restoration outcomes; (4) analysing the specific issue of illegal oil palm development on Indonesian peatland, including a consideration of what sorts of interventions are required to halt illegal oil palm development and control the associated recurrent fires that have been shown to substantially constrain the effectiveness of restoration initiatives; and (5) presenting an overarching conceptual framework of the factors that influence effective peatland restoration, which can be used by policy makers to devise restoration interventions that should have a greater probability of success.

The drivers of peatland degradation in Indonesia can be categorised as direct and indirect. Direct drivers include logging, oil palm development and recurrent fires (mostly caused by large- and small-scale land use activities). Indirect drivers include climate change, the poverty and employment needs of local people, and the ineffective and sometimes perversely counter-productive land use governance systems.

Techniques previously used to restore peatlands in Indonesia include rewetting through canal blocking, re-forestation through seedling transplanting, the development of seed-based tree seedling nurseries, and measures that support natural regeneration such as the strategic planting of seed trees and additional seed dispersal. Previous restoration measures in the case study area were typically "small and pilot-based" and, as such, their impact were limited. That noted, of these techniques, rewetting appears to be the most common and the most likely to result in larger-scale successful peatland restoration.

A detailed analysis of rewetting activities in the case study area revealed that effective rewetting and peatland restoration can be achieved with or without spillways on "dam box" designs, and if special design consideration is given to dam crest elevation and dam spacing, and if the materials used to construct dams were sufficiently durable and appropriate. The case analysis also showed that rewetting dams built for restoration were frequently damaged, apparently by loggers and fishermen opposed to the restoration intervention in the area.

A detailed analysis of the extent of illegal oil palm development in the case study area is also included in this thesis. Spatial analysis and emissions modelling revealed that around 86,700 ha of palm oil plantations had been developed on "deep" peatland in the case study area (2004 to 2012) in direct contravention of a range of applicable laws, rules, decrees and ordinances aimed at conservation of deep peatland. Our modelling suggests that these oil palm plantations have directly resulted in between 3.73 M_tCO_{2e} (minimum) to 8.67 M_tCO_{2e} (maximum) of emissions annually between 2004 and 2012. Laws and government policies protecting peatlands must be properly enforced in Indonesia to not only halt the damage caused by this illegal development, but also to allow restoration activities to be enacted with a reasonable chance of success.

The final part of this thesis presents an assessment framework for evaluating the likelihood of success of different peatland restoration interventions in the tropics. The assessment framework includes a hierarchal structure that covers principal aspects, attributes, success indicators, standards for comparison, and decision criteria. The framework can be used by policy makers to improve the probability of success of future peatland restoration initiatives in Indonesia.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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Peer-reviewed papers

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Contributor	Statement of contribution
Dohong, A (Candidate)	Designed the study (90%) Wrote the paper (90%)
Dargusch, P	Advised on study contents (10%) Wrote and edited paper (10%)

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Dargusch, P	Advised on study contents (10%) Wrote and edited paper (10%)

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Peter Storer contributed to the proofreading of Chapters 2 and 6. Julie Sanderson contributed to the proofreading of Chapter 1, 3, 4 and 6. Paul Dargusch advised and commented on drafts of written materials for whole thesis.

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Keywords

assessment, climate change, deforestation, degradation, drainage, palm oil, peatland, re-vegetation, rewetting, restoration

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List of Abbreviations Used in the Thesis

AATHP	ASEAN Agreement on Transboundary Haze Pollution
AFOLU	Agriculture, Forestry and Land Use Change
APFP	ASEAN Peatland Forests Project
APMI	ASEAN Peatland Management Initiative
APMS	ASEAN Peatland Management Strategy
ASEAN	Association of South East Asian Nations
BAPPENAS	Badan Perencanaan Pembangunan Nasional
BAU	Business As Usual
BOSF	Borneo Orangutan Survival Foundation
BMPs	Best Management Practices
BPS	Badan Pusat Statistik
CBD	Convention on Biological Diversity
CCFPI	Climate Change, Forests and Peatland in Indonesia
CDM	Clean Development Mechanism
CIMTROP	Centre for International Management of Tropical Peatland
CKPP	Central Kalimantan Peatlands Project
C	Carbon
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
DOC	Dissolved Organic Carbon
EIA	Environmental Impact Assessment
EMRP	Ex-Mega Rice Project
FAO	Food and Agriculture Organization
GRDP	Gross Regional Domestic Product
GEC	Global Environment Centre
GIS	Geographical Information System
GOI	Government of Indonesia
G_tCO	Giga tons Carbon
IPCC	Intergovernmental Panel on Climate Change
ISPO	Indonesian Sustainable Palm Oil

KEYTROP	Keys for Securing Tropical Peat Carbon
KFCP	Kalimantan Forests and Climate Partnership
LULUCF	Land Use, Land Use Change and Forestry
$MgCO_2$	Mega grams Carbon Dioxide
Mha	Million hectare
MoARI	Ministry of Agriculture, Republic of Indonesia
MoDAEI	Minister of the Development and Acceleration of Eastern Indonesia
MODIS	Moderate Resolution Imaging Spectroradiometer
MoERI	Ministry of Environment, Republic of Indonesia
MoFRI	Ministry of Forestry, Republic of Indonesia
MoLHRRI	Ministry of Law and Human Rights, Republic of Indonesia
MPC	Main Primary Canal
MRPP	Merang REDD Petland Project
NGOs	Non-Governmental Organizations
NTFPs	Non-Timber Forest Products
OuTrop	Orangutan Tropical Peatland Project
UFCCC	United Nations Framework Convention on Climate Change
SE-Asian	Southeast Asian
tCO_{2e}	Ton Carbon Dioxide equivalent
TPSF	Tropical Peat Swamp Forest
REDD+	Reducing Emissions from Deforestation and Degradation Plus
RESTOPEAT	Restoration of Tropical Peatland for Sustainable of Renewable Natural Resources
RSPO	Roundtable on Sustainable Palm Oil
SER	Society for Ecological Restoration International
SNP	Sebangau National Park
POC	Particulate Organic Carbon
PORI	President Office, Republic of Indonesia
PPC	Parent Primary Canal
WHC	Wildlife Habitat Canada
WI	Wetlands International
WI-IP	Wetlands International Indonesia-Programme
WWF	World Wide Fund for Nature

CHAPTER 1 GENERAL INTRODUCTION

1.1 Background

Peat is formed through the long-term accumulation (over thousands of years) of organic matter (mostly decayed plants) and is mainly characterised by acidic, anaerobic, water logged and nutrient deficient conditions (Rieley et al., 2008; Yule, 2010). Peat layers accumulate when the rate of organic matter production exceeds its decomposition rate (Hooijer, 2013). Areas covered by peat layers are known as peatland (Rieley et al., 2008). Natural peat is primarily comprised of water (90%) and the remaining 10% is decayed plant remnants (Jaenicke et al., 2011).

Peatland is predominantly located in the temperate and boreal zones (88%) and the rest (12%) resides in the humid tropics. Tropical peatland is established under the climate settings of high temperature and high rainfalls, whereas the boreal and temperate peatlands are formed under low temperature and high precipitation. Tropical peatland can be differentiated from the boreal and temperate peatlands by its vegetation cover and formation characteristics. The former is mainly covered by peat swamp trees and the peat is formed from decayed woody materials, whereas the latter is mainly covered by Sphagnum, sedges, bryophytes, and herbaceous species (Rieley et al., 2008; Rieley & Page, 2008; Hooijer, 2013).

Tropical peatland occurs mainly in East Asia, South-East Asia, Southern Africa, the Caribbean and Central and South America (Rieley et al., 2008; Jaenicke et al., 2010; Page et al., 2011). More than 56% (equivalent to 24.78 Mha) of the global peatland area is located in South-East Asia, where Indonesia contributes around 87% (21 Mha) of the region's peatland extent (Page et al., 2011). In Indonesia, peatland is mainly located on three main islands, Sumatra (7.19 Mha), Kalimantan (5.76 Mha) and Papua (8.10 Mha), where it is found mainly on low-altitude coastal and sub-coastal areas (Wahyunto et al., 2004; Wahyunto et al., 2006; Dariah et al., 2010); but also found several hundred kilometres inland along river valleys and watersheds (Rieley & Page, 2008). Central Kalimantan province also has a total area of peatland around 3.01 Mha and this figure constitutes the third largest peatland area in the country (27%), as well as representing over 53% of the total peatlands area of the whole Kalimantan Islands (Wahyunto et al., 2004). In addition to this area, peatland in Central Kalimantan is estimated to hold > 56% of the total peat carbon in Kalimantan. Geographically, the peatlands of Central Kalimantan are primarily located on the southern part of the province scattered within eight districts.

Most of the peatland in Indonesia is classified as ombrotrophic (which has a rain-fed source of nutrients), besides a few basin peatlands, which are minerotrophic (with nutrients supplied from rainfall and surface run-off and/or ground water). The ombrogenous peatland supports dense peat swamp forest, which grows on a thick mass of organic materials accumulated over thousands of years (Rieley & Page, 2008).

Tropical peatland provides significant socioeconomic benefits and is an environmental resource that benefits both humans and plant and animal species (Safford, 1998; Joosten & Clarke, 2002; Rieley et al., 2008; Schumann & Joosten, 2008; Kimmel & Mander, 2010;). The advantages provided by peatland include provisioning/production services (e.g. timbers and non-timber products); regulation services (e.g. climate change, flood control, and prevention); cultural/informational services (e.g. ecotourism, educational and religious practices), and supporting services (e.g. biodiversity and nutrient cycling) (Joosten & Clarke, 2002; Kimmel & Mander, 2010).

The tropical peatland of Indonesia is of global importance for the sequestration of terrestrial carbon, which plays an important role in controlling and stabilising global climate change. A recent estimate shows that peatland in Indonesia contains around 57 G_tC, which represents 85% of the total carbon stock in the South-East Asian region (Page et al., 2011). Apart from its carbon sequestration potential, peatland also serves as a specific habitat for endemic and unique flora and fauna, many species of which are classified as endangered and protected, such as the Sumatran tiger and Orangutan (Morrogh-Bernard et al., 2003; Posa et al., 2011; Sunarto et al., 2012). Finally, peatland and peat swamp forest offer direct and indirect economic benefits to the local people, providing their livelihoods as well as other social-cultural functions (Silvius & Diemont, 2007; Rieley & Page, 2008).

Despite the substantial socioecological values and services of peatland in Indonesia, the ecosystem has undergone large-scale transformation to other land uses and as a result, vast areas of peatlands have been left degraded. Logging, conversion to industrial plantations, drainage, and fires have been cited as the major drivers of peatland degradation in Indonesia (Hooijer et al., 2006; Koh et al., 2011; Hooijer et al., 2012; Miettinen et al., 2012a; Miettinen et al., 2012b; Miettinen et al., 2012c; Margono et al., 2014).

Logging activities contributed to the disappearance of peat swamp forest in Indonesia during the 1970s and 1980s due to the Government of Indonesia placing heavy reliance on log exports as its main source of foreign exchange revenue (Brockhaus et al., 2012). The situation was made worse by rampant illegal logging activities, notably during the economic crisis of 1997–1998 and the commencement of full regional autonomy in 1999 (Casson & Obidzinski, 2002; Smith et al., 2003; Obidzinski, 2005). The degradation of peat swamp forest was amplified by the construction of logging access and artificial drainage canals associated with the logging activities (Böhm & Siegert, 2001; Jaenicke et al., 2010; Franke et al., 2012; Bryan et al., 2013).

Conversion of peat swamp forest for large-scale agriculture including industrial palm oil and timber plantations has removed peat swamp forest cover and exacerbated peatland degradation in Indonesia (Hooijer et al., 2006; Koh et al., 2011). An obvious example of peatland conversion to large-scale agriculture is the conversion of over 1.46 Mha of peat swamp forest for rice fields (the so-called Ex-Mega Rice Project, or EMRP) in Central Kalimantan between 1995 and 1998 (Mawardi, 2007; Page et al., 2009). The EMRP was eventually terminated as a failure in 1999 and lies abandoned. The trend of converting peatland to industrial palm oil and timber plantations has increased during the past two decades. For instance, the annual growth rates of palm oil located on peatland were 40.70% and 8.56% respectively during the epochs of 1990–2000 and 2000–2010 (Miettinen et al., 2012a). Total palm oil extent on peatland has significantly increased from between 0.17–0.26 Mha in 1990 to 0.53–0.72 Mha and 1.23–1.70 Mha respectively in 2000 and 2010 (Miettinen et al., 2012c; Gunarso et al., 2013). Similarly, total industrial acacia plantation has increased from 0.08 Mha in 2000 to 0.89 Mha in 2010 (Miettinen et al., 2012c).

In the meantime, massive construction of artificial drained canals in relation to the activities of logging, agriculture and industrial plantations have amplified the degree of peatland degradation in Indonesia. The existence of artificial canals increases surface water run-off and lowers the water table in the peat. This disrupts the integrity of the peatland's hydrological properties, which in turn will promote drying out and aerobic decomposition, leading to substantial losses of peat profile and peat carbon (Hooijer et al., 2006; Wosten et al., 2006; Page et al., 2009).

Fire is one of the principal drivers of destruction of peat swamp forest cover and the peat substrate layer. Repeated fires have devastating effects via removal of woody and non-woody vegetation (including parent trees, and established saplings and seedlings) and seed banks (Ballhorn et al., 2009; Palmer & Filoso, 2009; Hoscilo et al., 2011).

Peatland deforestation and degradation in Indonesia have brought negative consequences in terms of peat forest cover loss, carbon release, biodiversity extinction, and socioeconomic impact. Because of deforestation, conversion, drainage and repeated fires, peat swamp forest cover in Indonesia has significantly decreased from 81% (Hooijer et al., 2006) to around 37.70% in 2010 (Miettinen et al., 2012a). The annual rates of peat swamp forest cover loss in Indonesia were projected at 3.80% and 3.40% respectively during the periods of 1990–2000 and 2000–2010 (Miettinen et al., 2012c). More than 57% of peatland in Sumatera and Kalimantan is covered by marginal forest and unmanaged degraded areas (Miettinen & Liew, 2010). Indonesia (excluding Papua) has lost a total 4.57 Mha of peat swamp forest cover during 1990–2010 (Miettinen et al., 2011c).

The impact of peatland deforestation and degradation on carbon emissions is globally significant. Immense stores of carbon have been released into the atmosphere in connection with peat swamp forest removal, drainage and fires in Indonesia. As a result of this peatland destruction, Indonesia has become the one of the largest global emitting countries, just behind the United States and China (Hooijer et al., 2006). Finally, peatland deforestation and degradation have extensive impact on habitat fragmentation and biodiversity extinction. The population decline among endemic peat forest mammals such as Orangutan and Sumatran tigers, birds and other species has been linked with the disappearance of peat forest in Indonesia (Danielsen et al., 2009; Koh et al., 2011; Posa, 2011; Posa et al., 2011).

Restoration ecology is a field of scientific inquiry of growing interest (Aronson & van Andel, 2012). It can be briefly defined as the study of ecological restoration practices (Cairns & Heckman, 1996; van Andel & Aronson, 2012). Restoration ecology has to be differentiated from ecological restoration. The former is dedicating its endeavours to the construction and advancement of science and theoretical frameworks to direct restoration activities in accordance with sound scientific principles, whereas, the latter deals with the practical activities of restoring degraded ecosystems by employing a series of restorative management strategies and techniques, with the aim of returning degraded ecosystem structure and function to its pre-undisturbed characteristics (Hobbs & Cramer, 2008; Aronson et al., 2010).

The science and practice of peatland restoration have been advanced in the temperate and boreal regions. In the humid tropics, however, the activity has just been introduced in recent years (Page et al., 2009; Graham, 2013). In Indonesia, peatland restoration activities have been introduced and gained momentum since the early 1990s. Peatland restoration measures and techniques that have been introduced among others are: a) peatland rewetting through blocking drainage canals (Suryadiputra et al., 2005; Dohong & Lilia, 2008; Limin et al., 2008; Page et al., 2009; Jaenicke et al., 2011; Ritzema et al., 2014); and b) peat swamp forest restoration via seedling transplantation, seed production, and promotion of seed dispersal agents (Giesen, 2004; van Eijk & Leenman, 2004; Page et al., 2008; van Eijk et al., 2009; Graham & Page, 2012). It should be noted however, that those peatland restoration activities in Indonesia have been mostly ‘‘small-scale trials’’; as a result, restoration efforts will not have significant magnitude to address the current scale of degradation.

Importantly, peatland restoration in Indonesia is in its infancy and scientific knowledge and experiences developed from current peatland restoration practices have been limited (Page et al., 2009).

1.2 Rationale

Peatland restoration is believed to be one of the strategic answers to scaling-down peatland degradation in Indonesia. To make restoration successful in achieving its goals, restoration activities need to be guided and supported by ample scientific background and information.

An ecological restoration activity involves a series of key aspects and processes such as: understanding the sources of degradation; identifying the potential restoration barriers; defining and setting realistic goals; identifying restoration measures and techniques; and setting and implementing a monitoring system, and assessing restoration success (Hobbs & Norton, 1996; Greipsson, 2011).

Knowledge and scientific information about degradation drivers are key aspects in restoration so as to define the scale and magnitude the contribution and impacts that driver sources have to peatland degradation. Once the drivers and its impacts are known, the restoration goals, strategies and techniques can be defined to effectively manage the drivers. There is little scientific literature that presents a comprehensive study of the sources of peatland degradation drivers in Indonesia and this scientific gap needs to be addressed when planning peatland restoration.

Implementing peatland restoration is not an easy job; there are many potential barriers that may hamper the success of peatland restoration in Indonesia. These barriers may involve many aspects ranging from physical-ecological, hydrological, biological, socioeconomic, and regulatory policy (Zedler, 2000; Collier, 2011; Page et al., 2008; Graham, 2013). Physical, technical, socioeconomic and policy interventions have to be identified and employed to support the success of peatland restoration activities. There is a further lack of studies carried out to improve the comprehensive understanding of the potential barriers for restoring tropical peatland restoration.

Peatland restoration goals have to define the problems in realistic ways and consider resource availability and time constraints (Choi, 2007; Hobbs, 2007). A crucial step is defining the ecosystem services and biodiversity aspects that have to be targeted as the endpoint goals of the restoration activities. There are few studies offering insight into restoration measures and techniques that have been used in peatland restoration practices in Indonesia and this gap should be addressed to make sure the restoration measures and techniques used are effectively implemented.

Assessing the success of the employed restoration measures and techniques is another crucial step in peatland restoration. Measuring success brings understanding of whether or not the measures and techniques used have satisfied the desired peatland restoration goals. To assess the successful peatland restoration activities, a framework for assessment has to be developed. The skeleton of the assessment framework has to be equipped with principal elements including aspects, attributes, principal indicators, standards for comparison, and decision criteria. Until now, there has been little known about assessment frameworks applicable for measuring the success or otherwise of tropical peatland restoration. Hence, a study is needed to fill this gap.

1.3 Research problem and questions

1.3.1 Research problem

Given the rationale above and the notable scarcity of published research on tropical peatland restoration, particularly in Indonesia, the research problem addressed in this thesis is:

"What are the factors that influence successful peatland restoration in Central Kalimantan, Indonesia?"

1.3.2 Research questions

The specific questions of this thesis are as follows:

The specific questions addressed in this thesis are as follows:

Research Question 1: What factors drive degradation of peatland in Central Kalimantan, in Indonesia?

Research Question 2: What factors constrain successful peatland restoration in Central Kalimantan?

Research Question 3: What factors and techniques enable successful peatland restoration in Central Kalimantan?

Research Question 4: What interventions are needed to enable successful peatland restoration in Central Kalimantan, particularly in regards to illegal palm oil development?

1.4 Thesis structure outline

The thesis comprises eight chapters (see Figure 1.1).

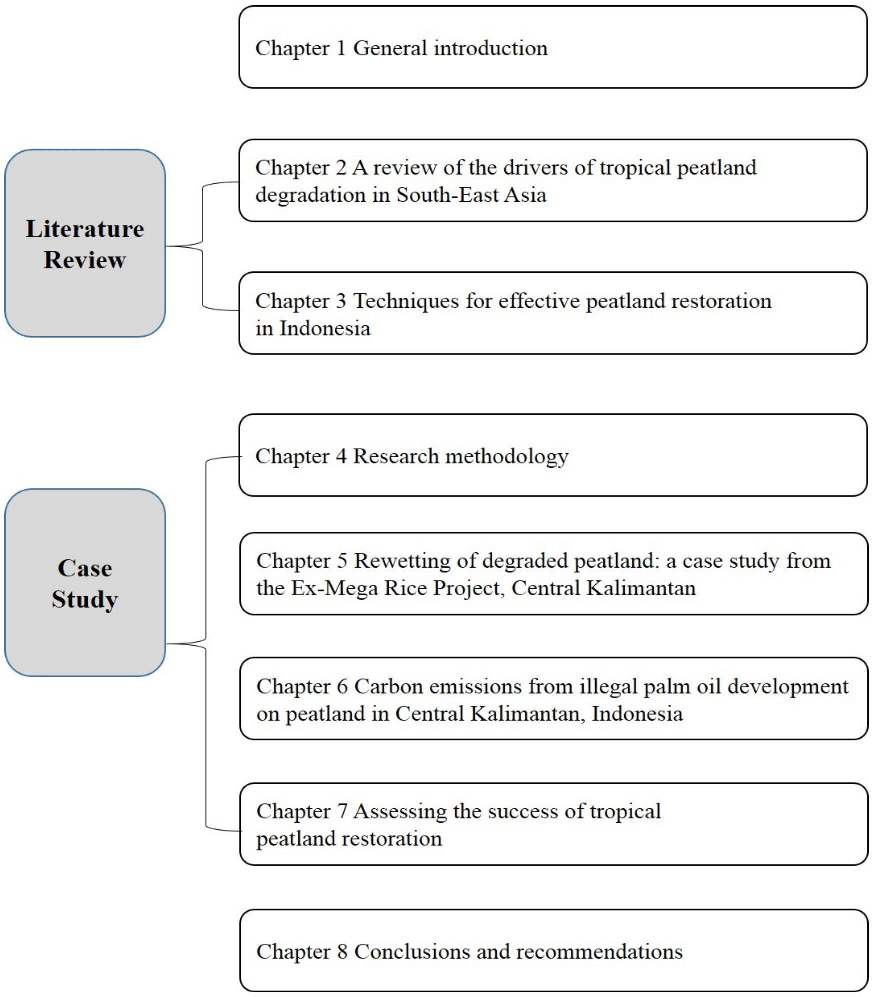


Figure 1.1 Schematic overview of the thesis structure

Chapter 1 (General Introduction): Presents the background of the research and its rationale, introduces the research problem and research questions, and presents a brief outline of the thesis structure.

Chapter 2 and Chapter 3 comprise a critical review of relevant published literature.

Chapter 2 (A Review of the Drivers of Tropical Peatland Degradation in South-East Asia): Provides information about the extent of peatland areas, the process and drivers of peatland degradation and the potential impacts of the degradation. Chapter 2 has been submitted to the *Journal of Environmental Management* for review for publication.

Chapter 3 (Techniques for Effective Peatland Restoration in Indonesia): Presents information about factors that may constrain the implementation of peatland restoration and provides evidence on the major measures and techniques that have been used for restoring peatland in Indonesia. This chapter ends with a discussion on the challenges of and recommendations for implementing peatland restoration in Indonesia. Chapter 3 was written and formatted in accordance with journal article requirements for the *Restoration Ecology* Journal but at the date of thesis submission the article was still to be submitted for publication.

Chapter 4 (Research Methodology): Provides a summary of the data collection and analysis methods used in the thesis. A detailed description of the case study area (the Ex-Mega Rice Project, Central Kalimantan (EMRP) is provided as is an overview of the case study-based approach.

Chapter 5 (Rewetting of Degraded Peatland: A Case Study from the Ex-Mega Rice Project, Central Kalimantan): Presents a specific case study about the implementation of peatland rewetting for restoring hydrological integrity in the EMRP. This chapter discusses the processes, techniques, performance and challenges of peatland rewetting in the EMRP. Chapter 5 was written and formatted in accordance with submission requirements for the *Ecological Application* Journal, however at the date of thesis submission the article had not been submitted.

Chapter 6 (Carbon Emissions from Illegal Palm Oil Development in Peatland, in Central Kalimantan, Indonesia): Provides information on the consequences of carbon emissions from inappropriate implementation of the peatland conservation regulatory measures, with regards to allocating and licensing palm oil plantations on deep peatland on the EMRP. Chapter 6 was written and formatted in accordance with requirements for submission to the *Environmental Research Letters* and at the date of thesis submission was under review for publication consideration.

Chapter 7 (Assessing the Success of Tropical Peatland Restoration): Provides a proposed assessment framework for evaluating the success of peatland restoration in Indonesia. The assessment framework for measuring peatland restoration success in the tropics was developed on the basis of a review of published literature and current practices of restoration in Indonesia. Chapter 5 was written and formatted in accordance with requirements for submission to *Nature Climate Change* journal, with submission to the journal planned for after the date of submission of this thesis.

Chapter 8 (Conclusion, Limitations, and Future Research): Presents a summary of the research and answers to the Research Problem and Research Questions. The limitations of the research and opportunities for future research are summarized. Recommendations for how to achieve better peatland restoration outcomes in Indonesia are also summarized.

CHAPTER 2 A REVIEW OF THE DRIVERS OF TROPICAL PEATLAND DEGRADATION IN SOUTHEAST ASIAN

Summary

The world's largest area of tropical peatland ecosystems is found in South-East Asian. These peatlands have globally significant carbon stocks and play an important role in regional and global climate systems. Despite the valuable social and economic services and ecosystem biodiversity these tropical peatlands provide, misguided land use policies have resulted in widespread peatland degradation in the region during the past 20 years. This paper reviews the drivers of peatland degradation in South-East Asian and confirms that logging, conversion to industrial plantations, drainage, and recurrent fires are the principal direct drivers of peatland degradation in South-East Asian, and that these drivers are compounded by a complex mix of indirect socioeconomic, policy and climate change-related factors. The review concludes by noting that in order to address the problem of peatland degradation, we first need to know more about how to design and assess "successful" peatland restoration initiatives, and what regulatory and policy interventions are likely to improve peatland conservation and restoration outcomes in the South-East Asian region.

2.1 The Southeast Asian's peatland: area extent, process and drivers of degradation

2.1.1 Introduction

Peat is commonly defined as the accumulation of the remains of plants and animals found under waterlogged, acidic and low nutrient conditions, which cause incomplete decomposition (Rydin & Jeglum, 2013; Yule, 2010). An area covered by a layer of peat is known as a peatland (Rieley & Page, 2008). The formation of peat depends on numerous determinants such as a positive climatic moisture balance, high relative humidity, and certain topographic and geological conditions (Rieley & Page, 2008).

Tropical peatland is different from boreal and temperate peatlands, particularly with respect to the climatic setting, peat matter formation, and vegetation cover. Tropical peatland forms at high temperature and under high precipitation. Tropical peat is comprised mainly of undecomposed remains of woody plants and the peat is typically covered by tropical rainforest. Meanwhile, boreal and temperate peatlands are located in cooler climates, where the peat matter is primarily generated by Sphagnum moss and covered in herbaceous vegetation (Rydin & Jeglum, 2013).

Although tropical peatlands represent only 12% of the global peatland area (381 Mha), they hold over 20% of the global peatland carbon stocks (Joosten, 2009). More than 54% (24 Mha) and 76% (67

G_tC) of the tropical peatland area and tropical peatland carbon stocks respectively occur in South-East Asian (Page et al., 2011).

Despite providing such valuable socio-ecological services, the peatlands of South-East Asian are subject to extensive transformation to other land uses such as large-scale industrial plantations (Koh et al., 2011; Miettinen et al., 2012a; Miettinen et al., 2012b; Miettinen et al., 2012c; Margono et al., 2014). Tropical peatlands have also been subject to extensive drainage activities (Hooijer et al., 2006; Page et al., 2009; Hooijer et al., 2012) and to recurrent fires (Langner et al., 2007; Hoscilo et al., 2011). Indonesia and Malaysia have together lost about 5.44 Mha of peat swamp forest cover between 1990 and 2010 (Miettinen et al., 2012c; Margono et al., 2014).

2.1.2 The area extent, spatial distribution, and peat carbon

The South-East Asian region contains the largest peatland area in the tropics (24 Mha)(Figure 2.1) The total global peatland area and peat carbon stock, compared with the tropical peatland in the South-East Asian region, Indonesia, Kalimantan and Central Kalimantan). Indonesia holds 87% this peatland area, and Malaysia holds 11% (Page et al., 2011). In the South-East Asian region, peatland is primarily found in the low altitude coastal and sub-coastal areas but is also found several hundred kilometres inland along the river valleys and watersheds (Figure 2.2; Table 2.1) (Rieley et al., 2008). In Indonesia, peatland is predominantly located on the low altitude coastal and sub-coastal areas of Sumatra, Kalimantan and Papua (Wahyunto et al., 2004; Wahyunto et al., 2006; Dariah et al., 2010). In Malaysia, peatland is primarily located in the western coastal areas of Sarawak and a small area of Sabah, on Borneo, as well as in larger areas located in the Malaysian Peninsula (Omar et al., 2010). Other small peatland areas in the South-East Asian region are found in the Mekong River Delta, Philippines, Southern Thailand and Brunei Darussalam (Chin & Parish, 2013).

As well as having the largest peatland area in the tropics, the South-East Asian region is also holds the largest peatland carbon stocks (Page et al., 2010; Page et al., 2011). A recent estimate reported that the region holds 60–67 G_tC, which is equivalent to 68–76% of the global tropical peat carbon stock (Joosten, 2009; Page et al., 2011). Indonesian peatland is estimated to contain about 57.40 G_tC or 85% of the South-East Asian peat carbon stock, while Malaysian peatlands hold approximately 9.13 G_tC or 14%.

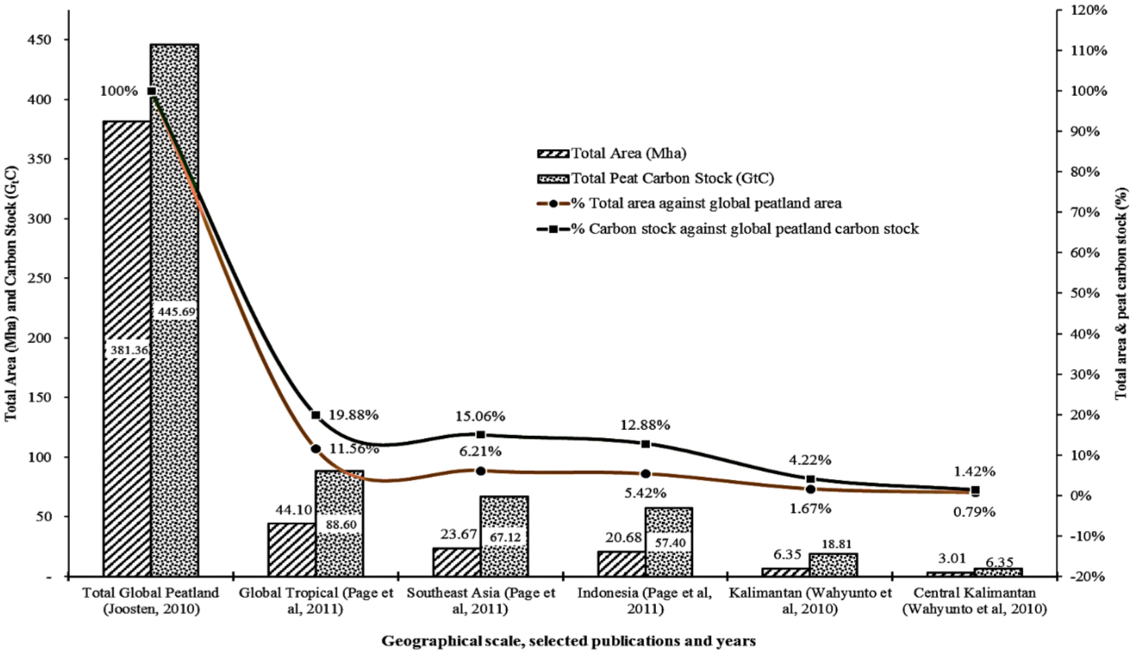


Figure 2.1 The total global peatland area and peat carbon stock, compared with the tropical peatland in the South East Asian region, Indonesia, Kalimantan and Central Kalimantan

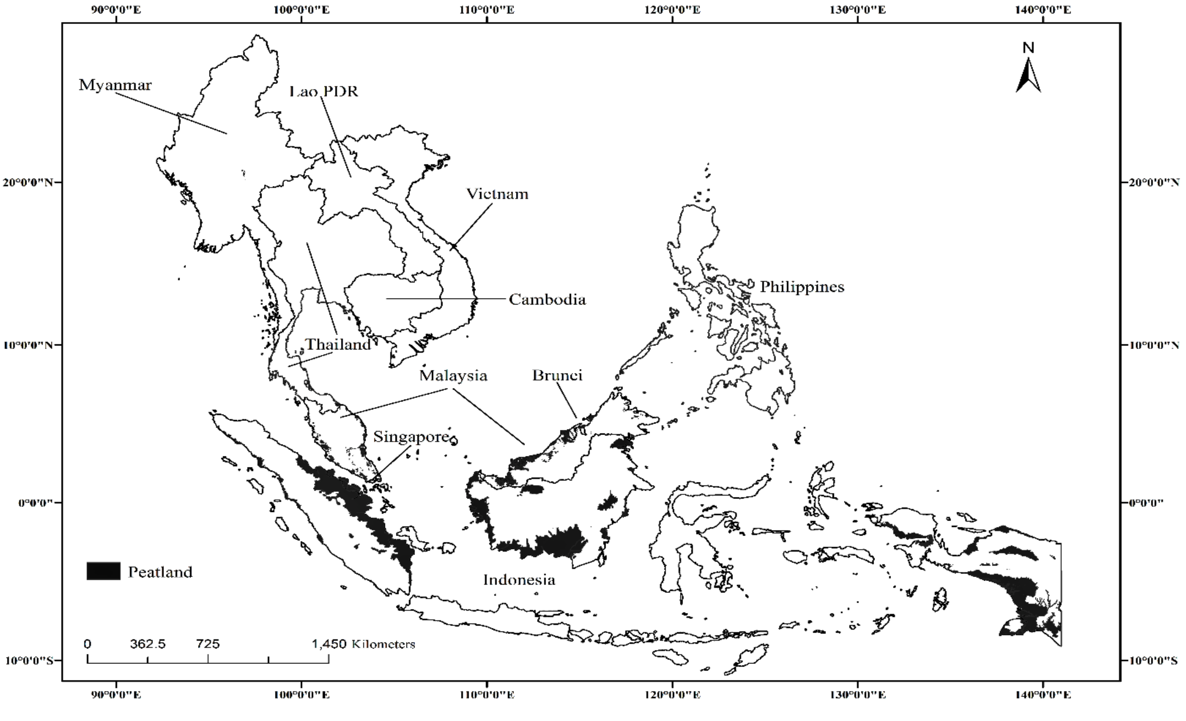


Figure 2.2 Spatial distribution of peatland area in the South East Asian region

Table 2.1 Total peatland area (Mha) and peat carbon stock (GtC) in the South-East Asian countries

Country		Joosten 2009	Page et al 2011	Major locations
Brunei	Total Area (Mha)	0.09 (0.30%)	0.09 (0.38%)	*Districts of Belait, Tutong & Temburong*[1]
	Total peat carbon stock (G_tC)	0.09 (0.15%)	0.32 (0.48%)	
Cambodia	Total Area (Mha)	-	-	*Region near Mekong River*[2]
	Total peat carbon stock (G_tC)	-	-	
Indonesia	Total Area (Mha)	26.50 (88.96%)	20.70 (87.45%)	*Sumatra, Kalimantan, Papua*[3]
	Total peat carbon stock (G_tC)	54.02 (89.90%)	57.37 (85.47%)	
Lao PDR	Total Area (Mha)	0.02 (0.07%)	-	*Phapho, Nong Phou & Nongphangden*[4]
	Total peat carbon stock (G_tC)	0.02 (0.03%)	-	
Malaysia	Total Area (Mha)	2.67 (8.96%)	2.59 (10.94%)	*Sarawak, Peninsular Malaysia and Sabah*[5]
	Total peat carbon stock (G_tC)	5.43 (9.04%)	9.13 (13.60%)	
Myanmar	Total Area (Mha)	0.19 (0.64%)	0.12 (0.51%)	Inle Lake[6]
	Total peat carbon stock (G_tC)	0.13 (0.22%)	0.09 (0.13%)	
Philippines	Total Area (Mha)	0.01 (0.03%)	0.06 (0.25%)	*Provinces of Agusan del Sur (the Agusan Marsh). Leyte Sab-a Basin, Laguna, Aurora*[7]
	Total peat carbon stock (G_tC)	0.09 (0.15%)	0.17 (0.25%)	
Singapore	Total Area (Mha)	0.01 (0.03%)	-	*The freshwater swamp forest at Nee Soon)*[8]
	Total peat carbon stock (G_tC)	0.03 (0.05%)	-	
Thailand	Total Area (Mha)	0.06 (0.20%)	0.06 (0.25%)	*Narathiwat, Nakhon Si Thammarat, Chomphon, Songkha, Phatthalung, Trat*[9]
	Total peat carbon stock (G_tC)	0.06 (0.10%)	0.03 (0.04%)	
Vietnam	Total Area (Mha)	0.24 (0.81%)	0.05 (0.21%)	*Provinces of Ca Mau, Kien Giang, Long An, Vo Doi National Park*[10]
	Total peat carbon stock (G_tC)	0.22 (0.37%)	0.01 (0.01%)	
Total Southeast Asian	Total Area (Mha)	**29.79 (100%)**	**23.67 (100%)**	
	Total peat carbon stock (G_tC)	**60.09 (100%)**	**67.12 (100%)**	
% of SE Asia Against Global Tropical Peatland	Total Area (Mha)*)	**63.02%**	**53.67%**	
	Total peat carbon stock (G_tC)*)	**67.86%**	**75.72%**	
Global Tropical Peatland (% against global peatland)	Total Area (Mha)	-	**44.10 (11.56%)**	
	Total peat carbon stock (G_tC)	-	**88.60 (19.88%)**	
Global Peatland (2008)	Total Area (Mha)	**381.36**	-	
	Total peat carbon stock (G_tC)	**445.69**	-	

Notes:

**) The total peatland area and peat carbon stock for the whole tropics adopted from Page et al, 2011*

Mha = million hectare

GtC = giga ton carbon

[1] http://www.aseanpeat.net/index.cfm?&menuid=136&parentid=71)

[2] *http://www.peat-portal.net/index.cfm?&menuid=63)*

[3] *Wahyunto et al., 2010*

[4] http://www.peat-portal.net/index.cfm?&menuid=64

[5] *Omar et al, 2010;* Wetlands International, 2010, http://www.wetlands.org/WatchRead/tabid/56/mod/1570/articleType/ArticleView/articleId/2675/A-Quick-Scan-of-Peatlands-in-Malaysia.aspx

[6] http://www.peat-portal.net/index.cfm?&menuid=65

[7] *http://www.aseanpeat.net/index.cfm?&menuid=85&parentid=69*

[8] *Ng & Lim, 1993; http://www.peat-portal.net/index.cfm?&menuid=166&parentid=72*

[9] *Tanit, N, 2003*

[10] *http://www.peat-portal.net/index.cfm?&menuid=123&parentid=70*

2.2 Factors influencing peatland degradation

2.2.1 Direct drivers

2.2.1.1 Logging

Both legal and illegal logging activities are major sources of peat swamp forest loss and degradation in the South-East Asian region. The removal of forest trees is the primary cause of peat swamp forest and peatland degradation in the tropics. Apart from tree removal, the construction of logging roads and wooden railways and drainage canal networks, in association with logging activities, further accelerate peat swamp forest cover loss and peatland degradation (Böhm & Siegert, 2001; Franke et al., 2012).

During the 1970s and 1980s, for instance, the Indonesian Government put heavy reliance on log exports as its primary source of foreign exchange revenue and as a result more than 60 Mha of forest was leased to about 579 forest concessionaires by the early 1990s (Brockhaus et al., 2012). As a result of their operations, the country's forest area and forest cover quality has decreased and fragmented. The situation was made worse by rampant illegal logging activities, especially during the economic crisis of 1997–1998 and the start of full regional autonomy in 1999 (Casson & Obidzinski, 2002; Smith et al., 2003; Obidzinski, 2005). By 2013, about 274 logging concessionaires were actively operating throughout Indonesia, covering a total area of 20.89 Mha (MoFRI, 2014).

A study of Borneo's forest from 1970–2010 mapped around 272,000 km of logging roads with a density of 0.48 km/km2 throughout the forests (Gaveau et al., 2014). The study also estimated that over 26.63 Mha (47.72%) of the 55.81 Mha of Borneo forests noted in 1973 had been logged by 2010. A similar study examined the extent of logging roads within forests in Sabah and Sarawak, Malaysian Borneo and Brunei over 1990–2009 and found that more than 364,000 km of logging roads had been constructed throughout the three regions, playing a crucial role in deforestation and forest degradation including peat swamp and mangrove forest habitats (Bryan et al., 2013).

It has been reported that the construction of logging roads and railways associated with logging activities increased significantly in Central Kalimantan, Indonesia between 1991 and 1997 (Böhm & Siegert, 2001). Böhm & Siegert (2001) studied 2.5 Mha of mainly peatland forest in the province and reported that the total length of logging roads and logging railways increased by 34% (4,419–6,621 km) and 25% (7,136–9,406 km), respectively, between 1991 and 1997 (Böhm & Siegert, 2001). The length of logging railways jumped to 11,000 km by 2000, following the start of the Ex-Mega Rice Project (EMRP) in the province during 1995–1999.

Scientific studies have shown that the construction of artificial drainage canals associated with logging activities on peat swamp forest is a trigger leading to long-term degradation of peatland and increased carbon emissions in the South-East Asian region. The existence of drainage canals within peat swamps increases surface run-off and reduces water storage capacity, which may disrupt the hydrological balance in peatland ecosystems (Wösten et al., 2008; Jaenicke et al., 2010; Ritzema et al., 2014). A study of 0.148 Mha in Sebangau National Park of Central Kalimantan, Indonesia noted about 65 drainage canals constructed by illegal loggers within the Bakung and Bangah catchment areas within the park. These canals have an average width of 2.4 m and a depth of 0.7 m and extend for 13 km (Jaenicke et al., 2010).

2.2.1.2 Conversion to large-scale agriculture and/or industrial plantations

The conversion of tropical peat swamp forest to large-scale agriculture including industrial plantations, is another principal driver of peat swamp forest loss and fragmentation in the South-East Asian region, particularly in Indonesia and Malaysia. A well-known example of large-scale peat swamp forest transformation into agriculture was the conversion of about 1.0 Mha of peatlands for rice fields in Central Kalimantan, Indonesia between 1995 and 1998. The project cleared and drained peat swamp forests in an attempt to develop rice fields and associated infrastructure such as irrigation canals, transportation infrastructure, and transmigration settlements. The project was eventually terminated in 1999 because it failed to deliver its initial goal of producing rice but the area has been subject to recurrent peat fires, over-drainage and other socioeconomic problems (Mawardi, 2007; Page et al., 2009; Ritzema et al., 2014).

The expansion of industrial plantations, particularly large-scale palm oil and wood (pulp) on peatlands in the South-East Asian region has grown exponentially during the past two decades. A study of 15.0 Mha of peatland in Peninsula Malaysia, Sumatra and Borneo reported that by 2010 over 3.11 Mha of peatland had been converted to industrial plantations, notably to large-scale palm oil and timber (pulp) production (Miettinen et al., 2012a). Large-scale palm oil plantations contributed 67% and industrial wood (pulp) plantations 27%, with the remaining area being converted to other types of plantations.

Another similar study for the same region reported a significant increase in the area of industrial plantations located on peatland; increasing from 0.27 Mha in 1990 to 1.03 Mha in 2000 and 3.20 Mha by 2010. The annualised growth rates of industrial plantations on peatland were 14.44% for 1990–2000 and 11.85% for 2000–2010 (Miettinen et al., 2012a).

The Sumatran provinces of Riau, South Sumatra, and Jambi experienced the greatest area of peatland conversion to industrial plantations. Sarawak, the Malaysian part of Borneo Island, was the second significant location for large-scale plantation (notably palm oil) development on peatland in the region.

A temporal analysis of the area of large-scale palm oil plantations on peatland shows an increased rate of growth during the past two decades. The annual growth rates of palm oil areas on peatland in the Malaysian Peninsula, Sumatra and Borneo from 1990 to 2000 ranged from 8.44 to 13.94%, giving a total growth over the decade of 24.94–268.65%. For the next decade (2000–2010), the rates of growth declined slightly, ranging from 8.78–9.96% p.a. or 134–159% overall (Gunarso et al., 2013; Miettinen et al., 2012b).

From these studies, it is evident that agriculture and industrial plantations (palm oil and timber pulp) constituted one of the principal drivers of peatland deforestation and degradation in the South-East Asian region. Large-scale agriculture and industrial plantations are predicted to continue to drive high rates of peat swamp forest loss and degradation, owing to the Indonesian Government's plan to double its annual palm oil production by 40 million tons by 2020 (Koh & Wilcove, 2009) and triple the total area of industrial timber plantations to 14.7 Mha by 2030 (MoFRI, 2014). One study has projected that palm oil plantations may occupy over 4.0 Mha of the peatland area in the South-East Asian region by 2020 (Miettinen et al., 2012b).

2.2.1.3 Artificial drainage canals

Peatland conversion to other land uses such as agriculture, plantation, forestry, and mining often involves the construction of drainage canals or ditches to lower the watertable and elevate the peatland surface so that these kinds of land use activities can take place (Charman, 2009; Hooijer et al., 2012; Rydin & Jeglum., 2013). However, the construction of drainage canals within peatland ecosystems disrupts the natural hydrological balance by increasing the surface water run-off and reducing water-storage capacity (Holden et al., 2004; Holden et al., 2006; Hooijer et al., 2012; Ritzema et al., 2014). The watertable drawdown enhances peat oxidation, consolidation and shrinkage, leading to peat subsidence and release of carbon emissions and increased fire risks, which will aggravate climate change (Holden et al., 2004; Parish et al., 2008; Hooijer et al., 2012; Schrier-Uijl et al., 2013).

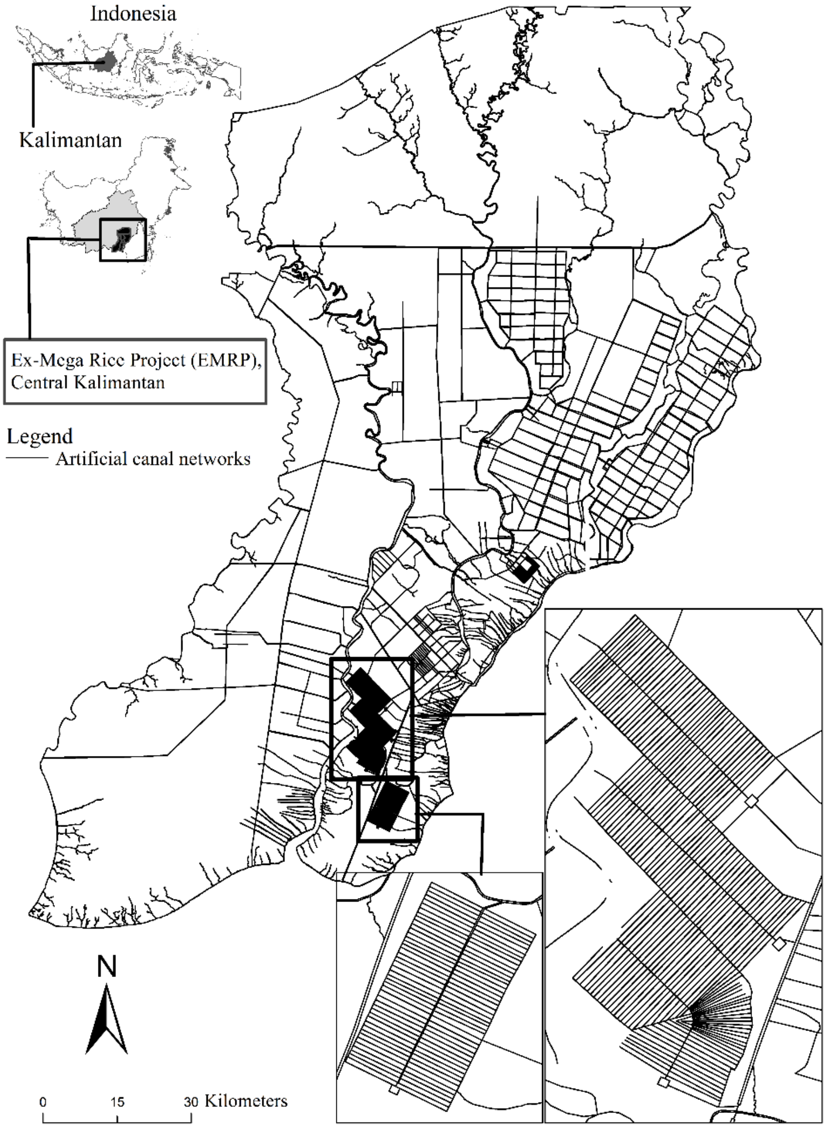


Figure 2.3 A massive network of artificial drainage canals in the Ex-Mega Rice Project, Central Kalimantan, Indonesia

Only a few scientific publications have presented reliable data on both the spatial and temporal extent of artificial drainage canals in the peatlands in the South-East Asian region. Some publications have surveyed the number and magnitude of artificial peatland drainage canals, particularly in the EMRP area, Sungai Puning, and Sebangau National Park in Central Kalimantan (Suryadiputra et al., 2005; Jaenicke et al., 2010; OuTrop, 2010; Ritzema et al., 2014;) and Merang area of South Sumatra, Indonesia (Suryadiputra et al., 2005). For example, it has been estimated that more than 4,700 km of artificial drainage canals have been constructed in association with the EMRP development in Central Kalimantan (Dohong & Lilia, 2008; Ritzema et al., 2014). At the South-East Asian region level, it is estimated that 12–13 Mha of peatland have been subjected to deforestation and drainage in the past three decades (Hooijer et al., 2006; Joosten & Couwenberg, 2009; Joosten, 2010).

2.2.1.4 Recurrent fires

Fire is one of the major drivers of peatland degradation in the South-East Asian region. The use of fire in the region is common as a cost-effective means of land clearing for crop management (Saharjo, 2007; Simorangkir, 2007; Lee et al., 2012). However, the socioecological and health impacts of this method of land clearance have received little attention from land managers and stakeholders in the region (Simorangkir, 2007).

Peat fires have devastating effects via the removal of both above- and below-ground carbon stocks, and the destruction of woody and non-woody vegetation (parent trees and saplings) and seed banks (Ballhorn et al., 2009; Page et al., 2009; Hoscilo et al., 2011). Studies in Central Kalimantan revealed that fires have devastating effects on peat organic matter and destroy on-site seed bank sources, established seedlings and saplings, and parent trees (Ballhorn et al., 2009; Page et al., 2009). During a single fire event in 2006, it was estimated that 385–1,310 million m3 of peat was lost over an area of 0.26 Mha in Central Kalimantan, Indonesia (Ballhorn et al., 2009).

Repeated mega-fire events in the past few decades have destroyed millions of hectares of peatland in the region. For instance, during the mega fire episodes of 1982–1983, 1997–1998 and 2006, about 0.55 Mha, 2.4 Mha and 2.0 Mha, respectively, of total peatland and peat swamp forest were destroyed by fires in Borneo, Indonesia and South-East Asian (Page et al., 2002; Langner et al., 2007; Page et al., 2009).

2.2.1.5 Poverty incidence and traditional farming practices

A study commissioned in the EMRP of Central Kalimantan reported 30–50% of the villagers in the area were living below the international poverty line of US$1 per day per capita and nearly 75–80% of the local villagers' income was spent on primary food supplies (Suyanto et al., 2009).

The high incidence of poverty in peatland is due to two main reasons: (a) the local communities are highly reliant on timber, non-timber products and fisheries provided by peat swamp forests as their main sources of livelihood; and (b) peatland is marginal and infertile land, so it is less productive as a medium for crop cultivation.

Local communities are also highly reliant on timber and non-timber products for most of their livelihoods (Anshari et al., 2005; Suyanto et al., 2009; Jewitt et al., 2014). This may cause overexploitation, leading to the depletion and degradation of resources, which may push people deeper into poverty (Anshari et al., 2005).

Traditional slash and burnt practices, using fire as a means of clearing land vegetation to make way for crop cultivation, is common practice in the South-East Asian region (Chokkalingam et al., 2005;

Saharjo, 2007; Simorangkir, 2007; Lee et al., 2012). The use of traditional slash and burn agriculture on peatland is not merely seen as “a cheap and cost-effective” means of clearing agriculture lands but it also is used by local farmers as a technique to produce ash fertiliser to promote soil nutrients, address peat acidity and improve crop productivity (Dohong & Lilia, 2003; Saharjo, 2007). The use of fire in agricultural land preparation may adversely affect the chemical and physical properties of peatland soils, leading to substantial losses of organic matter and nutrients after the fire events through erosion, leaching and volatilisation (Saharjo, 2007).

2.2.2 Indirect drivers

2.2.2.1 Climate change

Climate change has resulted in prolonged droughts (El Niño) and excessive precipitation rates (La Niña) in peatland areas of the South-East Asian region and has indirectly driven the frequency of peat fire, peat oxidisation and floods, exacerbating the rates of peatland degradation.

A recent report from the Intergovernmental Panel on Climate Change revealed that, on average, the global temperature had warmed by 0.8^{o}C from 1880 to 2012 and higher precipitation rates and sea level rise were predicted due to climate change caused by the continuously increasing atmospheric greenhouse gases concentrations from anthropogenic activities (Stocker et al., 2014).

The raised temperatures, lack of precipitation, decreased peat humidity and increased peat evaporation during drought periods lowers the watertable in peatland areas. The watertable drawdown then enhances peat oxidation and accelerates peat decomposition or mineralisation, leading to peat subsidence and higher carbon emissions release (Mäkiranta et al., 2009; Bu et al., 2011; Rydin & Jeglum, 2013).

The watertable could drop by up to 1.0-1.7 m below the peat surface within deforested and drained peatland areas during the extended drought periods (El Niño events) in Central Kalimantan and Jambi provinces of Indonesia (Wösten et al., 2007; Ballhorn et al., 2009; Page et al., 2009). A substantial drop in the watertable during extended drought periods makes the peat more susceptible to fires (Parish et al., 2008; Wosten et al., 2008). Meanwhile, excessive precipitation associated with La Niña episodes may increase the flooding risk, which may hinder the re-establishment of vegetation and affect the longevity of established vegetation, especially for those peat swamp tree species that have low tolerance to prolonged inundation (Page & Rieley, 2008). It has been recommended that watertables be maintained at a maximum of 100 cm above the peat surface during flood events and no more than 40 cm below the surface in drought periods to reduce the risk of subsidence and fires (Wösten et al., 2008).

One study predicts that future rainfall in the South-East Asian region will decrease substantially, particularly in Sumatra and Borneo, Indonesia (Li et al., 2007). The decreased rainfall could affect the water storage capacity and humidity of peatland, which may trigger the watertable to decline and dry out the peat surface, which could enhance peat oxidation and mineralisation leading to substantial peat subsidence and release of carbon emissions (Jauhiainen et al., 2008; Rydin & Jeglum, 2013).

2.2.2.2 Land use policy and governance

The lack of clear regulatory and policy measures on peatland conservation, protection and restoration, as well as inconsistent enforcement of the existing peatland conservation and protection ordinances, is considered the one of the major causes of peatland deforestation and degradation in the South-East Asian region.

Currently, at the ASEAN (Association of South-East Asian Nations) regional level, there are only three policy instruments that can be directly or indirectly linked to the management, conservation and restoration of peatland. These are: (a) the ASEAN Agreement on Transboundary Haze Pollution (AATHP); (b) the ASEAN Peatland Management Initiative (APMI), and (c) the ASEAN Peatland Management Strategy (APMS) 2006–2020 (Chin & Parish, 2013; Koh-KL, 2013; Ramirez, 2013). The AATHP sets out general cooperation frameworks and mechanism for tackling transboundary haze pollution among 10 ASEAN member states, including how to share resources to address forest and peatland fires. This agreement was ratified by all 10 ASEAN member states and came into force on the 25th of November, 2005 (Chin & Parish, 2013). The APMI aims to promote sustainable peatland management practices in the region through the implementation of multiple objectives such as capacity building and increasing knowledge on sustainable peatland management, peat fire prevention and control, facilitating national and local activities on peatland management (including fire prevention and control), and developing regional strategy and collaboration mechanisms to enhance sustainable peatland management (Ramirez, 2013; D'Cruz, 2014). Finally, the APMS sets out guidance for actions to support the implementation of sustainable management practices and peatland rehabilitation in the South-East Asian region for the period of 2006–2020. The APMS contains over 25 operational objectives and 100 collective actions within 13 focal areas, including peatland restoration and rehabilitation (Ramirez, 2013).

It should be noted, however, that the AATHP is the only one out of those three strategic policies that is legally binding on all ASEAN member states for its implementation; the other two are merely voluntary initiatives among ASEAN member states.

At a national level, apart from Indonesia and Malaysia, the other ASEAN member states have no clear national regulatory and policy measures that specifically regulate peatland conservation, protection, and restoration. Indonesia has a few national and sectoral regulations and policies governing peatland utilisation, conservation/protection, and restoration. The oldest and the most cited law for peatland conservation and management is the Presidential Decree No 32 of 1990 concerning Protected Area Management (in Indonesia) (PORI, 1990). The presidential decree is not specifically about peatland regulation but rather defines peatland for protection purposes. The decree defines a peatland as an area of peat with a minimum depth of 3 m, and hence this deep peat much be assigned as a protected area. This 3 m peat depth regulatory threshold has been widely used as the basis for other national and sectoral ordinances when it comes to peatland management and utilisation issues. For example, the enactment of Agriculture Minister Regulation No. 14 of 2009 allows oil palm cultivation on peatland of < 3 m depth, which may trigger peatland deforestation and degradation in those areas (Koh et al., 2009; Murdiyarso et al., 2010).

The Indonesian Government introduced a 2-year moratorium on primary forest and peatland conversion in 2011 (PORI, 2011a) and the moratorium was extended for another 2 years in 2013 (PORI, 2013). While recognising the political will of the Indonesian Government in addressing its primary forest and peatland deforestation and degradation, the efficacy of this moratorium policy is still questionable. For example, there are millions of hectares of primary forest and peatland targeted for the moratorium that have already been gazetted as conservation and protections sites and, secondly, substantial areas with non-forestland and peatland status, which hold high forest stands and peat carbon stocks, have been excluded from the moratorium target ((Murdiyarso et al., 2011; Sloan, 2014).

In Malaysia, to ensure the conservation and wise of wetlands (including peatland), as well as to fulfil national obligations under the Ramsar Convention, the Government enacted its National Wetlands Policy in 2004 (Talaat et al., 2012; APFP, 2014;). The management of forested peatland in Malaysia is also guided by the National Forest Policy, enacted in 1978 and then amended in 1993 (Talaat et al., 2012).

Apart from limited regulatory policies on peatland conservation, protection and restoration activities, the progress on developing national action plans for peatland management among South-East Asian member states is slow. By 2013, only three countries—Indonesia, Malaysia and the Philippines—out of 10 ASEAN member states had completed their National Action Plan for peatland management as outlined in the APMS 2006–2020 (D'Cruz, 2014). This lack of adequate regulatory measures and governance is another driver of peatland deforestation and degradation in the South-East Asian region.

Table 2.2 Summary of peatland deforestation and degradation drivers in South-East Asia

Drivers of peatland deforestation and degradation	Mechanisms that cause deforestation and degradation of peatland	References
Direct:		
Logging (legal and illegal activities)	• Removal of peat swamp trees, which creates larger canopy gaps, increases micro climate and decreases humidity • Construction of logging roads and railways to ease access and transportation into interior forests • Construction of artificial drainage for transporting felled logs. Artificial canals/ditches disturb the natural hydrological balance due to increases in surface run-off and reduce water storage capacity	Böhm & Siegert, 2002; Casson & Obidzinski, 2002; Smith et al., 2003; Obidzinski, 2005; Page et al., 2009; Franke et al., 2012; Brockhaus et al., 2012; Bryan et al., 2013; Gaveau et al., 2014
Conversion to large-scale agriculture including industrial plantations	• Land clearing to remove both woody and non-woody vegetation, replaced by monoculture plants such as palm oil, Acacia crassicarpa, rubber (Hevea braziliensis). • Construction of artificial drainage to lower the ground watertable so that crops cultivation may take place. Artificial canals increase surface run-off and reduce water storage capacity in the peatland	Hooijer et al., 2006; Mawardi, 2007; Page et al., 2009b; Koh et al., 2011; Jeanicke et al., 2011; Miettinen et al., 2012a; Miettinen et al., 2012e; Gunarso et al., 2013; Wilcove et al., 2013
Artificial drainage	• Draining the excess water up to a certain required ground watertable level so that the peatland surface is elevated, thereby allowing cultivation. A lower watertable enhances peat oxidation, consolidation and shrinkage, leading to peat subsidence and carbon emissions release.	Suryadiputra et al., 2005; Hooijer et al., 2006; Parish et al., 2007; Dohong & Lilia, 2008; Joosten, 2009; Joosten and Couwenberg, 2009; Murdiyarso et al., 2010; OuTrop., 2010; Jeanicke et al., 2011; Hooijer et al., 2013; Rydin & Jeglum, 2013; Ritzema et al., 2014
Recurrent fires	• Clearing land for crop management • Peat fires remove both above-and-below carbon stocks, thereby releasing immense stores of CO_2 to the atmosphere. In addition,	Page et al., 2002; Saharjo, 2007; Simorangkir, 2007; Ballhorn et al., 2009; Page et

	fires also destroy woody and non-woody vegetation and on-site seed banks	al., 2009; Hoscilo et al., 2012; Lee et al., 2012
Poverty and traditional farming practices	• Higher reliance of local people on timber and non-timber forest products for livelihood sources. The removal of timber and other products creates peat swamp forest degradation • The use of fire for clearing agriculture land is commonly practised by local farmers.	Dohong & Lilia, 2003; Anshari et al., 2005; Chokkalingam et al., 2005; Simorangkir, 2007; Silvius & Diemont, 2007; Suyanto et al., 2009; Lee et al., 2012; Jewitt et al., 2014
Indirect:		
Climate change	• Extended droughts (El Niño) and excessive precipitation rates (La Niña) induced by climate change affect the eco-hydrology properties (water storage, humidity, evaporation) and vegetation structure and richness in peatland areas • Prolong droughts during the El Niño events will drawdown the watertables leading to the enhancement of peat oxidation, increases microbial activities, peat subsidence and hence, increases the release of CO_2 emission	Makiranta et al., 2009; Bu et al., 2011; Redyn & Jeglum, 2013; Wosten et al., 2006a; Wosten et al., 2006b; Li et al., 2007; Page et al., 2008; Parish et al., 2008; Wosten et al., 2008; Jauhiainen et al., 2008; Balhorn et al., 2009; Page et al., 2009; Redyn & Jeglum, 2013; Stocker et al., 2014
Land use policy and governance	• There are not many regulatory and policy measures that are specifically regulated about peatland conservation and protection • Inconsistency and lack of enforcement of existing regulatory and policy measures	Murdiyarso et al., 2011; Sloan et al., 2012; Talaat et al., 2012; Chin & Parish, 2013; Koh-KL, 2013; Ramirez, 2013; D'Cruz, 2014; Sloan, 2014

2.3 The impacts of peatland deforestation and degradation

2.3.1 Peat swamp forest cover loss

Logging and peat swamp forest conversion to other uses has substantial impact on peat swamp forest structure and quality, as well as on biodiversity, leading to the loss of peat swamp forest cover in the region.

Many studies have noted the decline of peat swamp forest cover in the South-East Asian region, notably in Indonesia and Malaysia, in the past three decades (Hooijer et al., 2006; BAPPENAS, 2009;

Joosten, 2010; Miettinen et al., 2012c). In 1985, about 84% of peatland in the South-East Asian region and 81% in Indonesia was covered by primary and secondary peat swamp forests (Hooijer et al., 2006). These figures declined significantly to 79–80% in 1990, and 57–75% in 2000 (Joosten, 2010; Miettinen et al., 2012c). Forest cover continued to decline and by 2010, it was estimated that the remaining peat swamp forest cover was 36% in the South-East Asian region and 38% in Indonesia (Miettinen et al., 2012c) (Figure 2.4). It is estimated that the annual rate of peat swamp forest deforestation was 2.2% in South-East Asia over the period 2000–2010 (Miettinen et al., 2011). The Indonesian Sumatran provinces of Jambi and Riau, and Sarawak (Malaysian part of Borneo), were the epicentres of peatland deforestation activities in the region, with an average annual deforestation rate of over 5% for the same period.

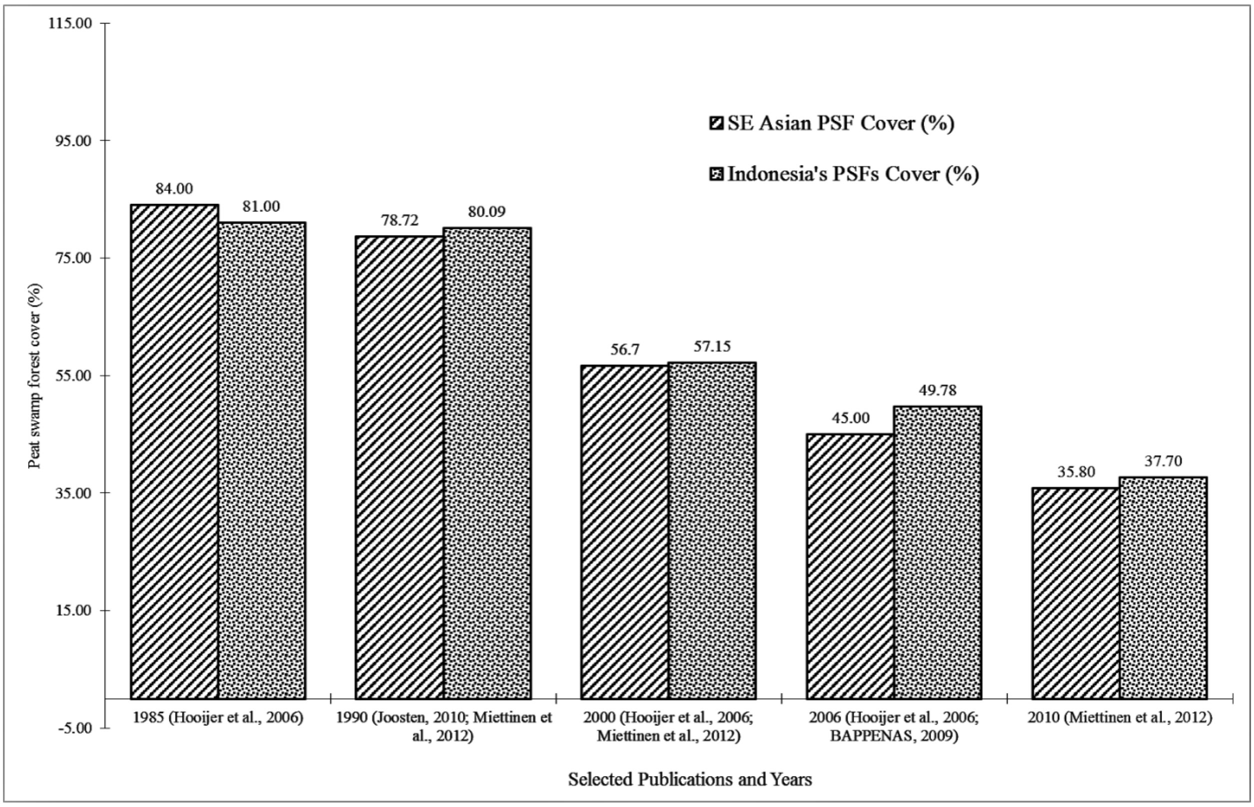


Figure 2.4 Estimates of the percentage of peat swamp forest cover of the Southeast Asian region and Indonesia in selected years from various sources

The peat swamp forest cover in Sumatra and Kalimantan reportedly declined from 78.70% in 1990 to 53.30% and 37.70% respectively in 2000 and 2010. The annual rates of peat swamp forest cover loss in Indonesia were estimated at 3.80% from 1990 to 2000 and 3.40% from 2000 to 2010 (Miettinen et al., 2012c). Sumatra’s provinces of Jambi, Riau and South Sumatra experienced the highest peat swamp forest cover loss during the past two decades.

The area of peat swamp forest in Indonesia and Malaysia is predicted to continue to decline in the next few decades owing to the expansion of palm oil plantations. It is projected that, by 2020, palm oil plantations would occupy 28% and 42% of the total peatland area in the two countries (Miettinen et al., 2012b).

2.3.2 The release of carbon emissions

Many studies have reported the release of large volumes of carbon emissions into the atmosphere from peatland deforestation and degradation, drainage and recurrent fires in the South-East Asian region. Major sources of carbon loss and CO_2 emissions come predominantly from the removal of above- and below-ground forest biomass, peat decomposition and oxidation caused by drainage, and peat combustion caused by fires (Page et al., 2002; Hooijer et al., 2006; Page et al., 2009; Hergoualc'h & Verchot, 2011; Hooijer et al., 2012; Jauhiainen et al., 2012).

One study estimated that 0.140 G_tC (equivalent to 0.513 G_tCO_{2e}) were lost via above-ground biomass removal resulting from the conversion of 0.880 Mha peat swamp forest into large-scale oil palm plantations in Peninsula Malaysia, Sumatra and Borneo in the 2000s (Koh et al., 2011).

Peatland draining for large-scale agriculture and industrial plantations has become a global concern in recent decades owing to substantial release of CO_2 emissions resulting from peat oxidation and decomposition, which is contributing to global climate change (Hooijer et al., 2012; Biancalani & Avagyan, 2014). A recent global estimate is that 1.0 G_tCO_2 is emitted annually due to peatland drainage, and the South-East Asian region is responsible for nearly 70% of these emissions (Biancalani et al., 2014). In addition, it is reported that, by 2008, over 12 Mha of peatland in the South-East Asian region had been deforested and drained and emitted about 0.600 G_tCO_2 annually, equivalent to 50 tons/ha/yr (Joosten & Couwenberg, 2009). Several studies have shown how various different forms of peatland land use have resulted in different levels of greenhouse gas emissions (Table 2.3).

Table 2.3 The impact of drainage depth and CO2e emissions in various land use types from selected publications

Average drainage depth (cm)	Land Use Type	Average CO_2 emission released ($tCO_2eha^{-1}yr^{-1}$)	Reference
10	Multiple land uses (review)	9	Couwenberg et al., 2010
60	Large-scale palm oil plantation	43	Agus et al., 2013
65	Palm oil and Acacia plantations	66	Couwenberg & Hooijer, 2013
70	Palm oil plantation (after 5 years of palm oil)	73	Hooijer et al., 2012
72	Palm oil plantation	34-66	Husnain et al., 2014
75	Palm oil plantation (the first 5 years of palm oil)	178	Hooijer et al., 2012
80	Acacia timber plantation	94	Jauhiainen et al., 2012
81	Acacia timber plantation	66	Husnain et al., 2014

The impacts of recurrent peatland fires on the release of carbon emissions are vast and substantial. For example, a single mega-fire disaster in 1997 released 0.81–2.576 G_tCO from peat and vegetation combustion in Indonesia (Page et al., 2002). Another study estimated 0.77–0.179 G_tCO was released annually to the atmosphere from fires in Indonesia, Malaysia, and Papua New Guinea during 2000–2006 (van der Werf et al., 2008). These vast carbon emissions can enhance regional and global climate change.

2.3.3 Biodiversity loss

A number of studies conducted in Indonesia and Malaysia have demonstrated a strong relationship between the peat swamp forest habitat quality and species richness and biodiversity (Danielsen et al., 2009; Azhar et al., 2011; Posa et al., 2011; Sunarto et al., 2012). Primary peat swamp forest supports a higher species richness than secondary and logged peat swamp forests or monoculture industrial plantations (Felton et al., 2003; Danielsen et al., 2009; Azhar et al., 2011).

Several studies indicated a strongly negative impact of peat swamp forest fragmentation, caused by logging and other degradation drivers, on the decline of endemic mammal populations and their distribution in Indonesia, particularly in Sumatra and Kalimantan (Felton et al., 2003; Quinten et al., 2010; Sunarto et al., 2012). For instance, a study in West Kalimantan found a lower density (21%

less) of orang-outang populations in the logged peat swamp forest compared with those in primary ones (Felton et al., 2003). This shows the significant impact of logging activities on peat swamp forest degradation leading to the destruction of the primary habitat of endemic primate species.

Conversion of peat swamp forest into large-scale monoculture and industrial plantations significant reduces biodiversity (Danielsen et al., 2009; Azhar et al., 2011; Koh et al., 2011). For example, a literature review reported that palm oil plantations contained only 23–31% of the vertebrates and 21–29% of the invertebrates that were found in the adjacent primary and secondary forests (Danielsen et al., 2009).

There is a positive correlation between primary and secondary peat swamp forests deforestation and degradation and declining biodiversity richness and composition. Even so, secondary peat swamp forest still offers higher biodiversity conservation values compared with those monoculture plantations (Posa, 2011; Posa et al., 2011).

Table 2.4 Ecological-biodiversity impacts of peatland deforestation and degradation drivers at various spatial scales in the tropical region from selected published literature

Type and source of impacts	***Degradation drivers***	***Geographical scale and study period***	***Magnitude and scale of impacts***	***Reference***
I. Peat swamp forest cover loss due to conversion to other land uses	*Logging (legal and illegal)*	*South-East Asian (Brunei, Malaysian part of Borneo and Indonesian part of Borneo)*	*16.4 Mha (1973–2010), Borneo's coastal lowlands including peat swamp forest (< 500 m asl)*	Gaveau et al., 2014
Forest cover loss (deforestation and forest degradation) rate	*Logging (legal and illegal)*	*Central Kalimantan, Indonesia (total study area 0.338 Mha)*	*0.009 Mha (for the year 2009 only)*	Franke et al., 2012
Forest cover loss (deforestation and forest degradation) rate	*Industrial plantations (large-scale palm oil)*	*Malaysia (Peninsular, Sabah and Sarawak)*	*0.666 Mha (2009)*	Omar et al., 2010
Forest cover loss (deforestation and forest degradation) rate	*Industrial plantations (large-scale palm oil)*	*South-East Asian (Peninsular Malaysia, Sumatra and Borneo), total study area 14.77 Mha*	*0.878 Mha (2000)*	Koh et al., 2011
Forest cover loss (deforestation and forest degradation) rate	*Industrial plantations (large-scale palm oil and pulp wood)*	*South-East Asian (Peninsular Malaysia, Sumatra and Borneo), total study area 15.49 Mha*	*0.266 Mha (1990) 1.027 Mha (2000) 2.295 Mha (2007) 3.146 Mha (2010)*	Miettinen et al., 2012

Forest cover loss (deforestation and forest degradation) rate	*Combined land use (logging, large-scale agriculture, industrial plantations, peat drainage, fires, and others)*	*Sarawak Malaysia*	*0.353 Mha (2005–2010)*	Schrier-Ujil et al., 2013
Forest cover loss (deforestation and forest degradation) rate	*Combined land use (logging, large-scale agriculture, industrial plantations, peat drainage, fires, and others)*	*South-East Asian (Brunei, Indonesia, Malaysia and Papua New Guinea), study covering a total peatland area of 27.20 Mha*	*10.6 Mha (1990–2000)* *12.1 Mha (2006, projected)*	Hooijer et al., 2006
Forest cover loss (deforestation and forest degradation) rate	*Combined land use (logging, large-scale agriculture, industrial plantations, peat drainage, fires, and others)*	*South-East Asian (Brunei, Indonesia, Malaysia and Papua New Guinea), study covering a total peatland area 27.20 Mha*	*12.9 Mha*	Hooijer et al., 2010
Forest cover loss (deforestation and forest degradation) rate	*Combined land use (logging, large-scale agriculture, industrial plantations, peat drainage, fires, and others)*	*South-East Asian (Indonesia, Peninsular and Bornean part of Malaysia) study areas covered 11–14 Mha peat swamp forest between 2000 and 2010.*	*2,76 Mha (2000–2010)*	Miettinen et al., 2011

Forest cover loss (deforestation and forest degradation) rate	*Combined land use (logging, large-scale agriculture, industrial plantations, peat drainage, fires, and others)*	*South-East Asian (Peninsular Malaysia, Sumatra, and Borneo)*	*3.23 Mha (1990–2000)* *2.21 Mha (2000–2010)*	Miettinen et al., 2012
Forest cover loss (deforestation and forest degradation) rate	*Combined land use drivers (logging, large-scale agriculture, industrial plantations, peat drainage, fires, and others)*	*Indonesia (covering a total wetlands area of 39.6 Mha)*	*2.60 Mha (2000-2012)*	Marggono et al., 2014
II. Carbon dioxide emissions:				
Carbon loss from the removal of above-ground (ABG) biomass	*Large-scale palm oil plantations*	*South-East Asian (Peninsular Malaysia, Sumatra and Borneo); 0.880 Mha palm oil plantation on peatlands*	*140 million M_gCO or 513.38 million M_gCO_{2e}*	Koh et al., 2011
Carbon loss from the removal of natural peat swamps forest	*Large-scale palm oil plantations*	*Southeast Asian region*	*153–359 M_gCO or 561.05–1,316.45 $M_gCO_{2e}ha^{-1}$*	Schrier-Ujil et al., 2013
Carbon loss due to loss of peat swamps forest carbon sequestration service for peat accumulation	*Large-scale palm oil plantations*	*South-East Asian (Peninsular Malaysia, Sumatra, and Borneo); 0.880 Mha palm oil plantations on peatlands*	*0.660 million MgCO or 2.42 million $M_gCO_{2e}yr^{-1}$*	Koh et al., 2011

Carbon emission from below-ground peat oxidation	*Large-scale palm oil plantations*	*South-East Asian (Peninsular Malaysia, Sumatra, and Borneo); 0.880 Mha palm oil plantation on peatlands*	*4.6 million* M_gCOyr^{-1} *or 16.87 million* $M_gCO_{2e}yr^{-1}$	Koh et al., 2011
Carbon loss due to loss of peat forest carbon accumulation, land clearance by fire, biomass carbon stocks change, and peat carbon loss in palm oil plantations	*Large-scale palm oil plantation*	*Tropical peatland region; Carbon loss over 25-year plantation cycle)*	*1,486.1* $MgCO_2ha^{-1}$ *over 25-year plantation cycle or* *59.4 ± 10.2* $MgCO_{2e}ha^{-1}yr^{-1}$	Murdiyarso et al., 2010
Carbon emission from decomposition induced by drained peatland	*Combined land use (logging, large-scale agriculture, industrial plantations, peat drainage, fires, and others)*	*South-East Asian (Brunei, Indonesia, Malaysia and Papua New Guinea), study covering a total peatland area of 27.20 Mha*	*632* $M_gCO_{2e}yr^{-1}$	Hooijer et al., 2006
Carbon emission from decomposition of drained peatlands	*Combined land use (logging, large-scale agriculture, industrial plantations, peat drainage, fires, and others)*	*South-East Asian (Brunei, Indonesia, Malaysia and Papua New Guinea), study covering a total peatland area of 27.20 Mha*	*355–855* $M_gCO_{2e}yr^{-1}$	Hooijer et al., 2010
Carbon emission from decomposition induced by drained peatland	*Industrial plantations (palm oil, pulp, and others)*	*South-East Asian (Indonesia, Peninsular and Bornean part of Malaysia) study covering a total of 15.53 Mha of peatland*	*20* $M_gCO_{2e}yr^{-1}$ *(1990);* *79* $M_gCO_{2e}yr^{-1}$ *(2000);* *233* $M_gCO_{2e}yr^{-1}$ *(2010)* *(0.75 m average watertable assumed)*	Miettinen et al., 2012

Carbon emissions from fires associated with peatland drainage and degradation	*Combined land use (logging, large-scale agriculture, industrial plantation, peat drainage, fires, and others)*	*South-East Asian (Brunei, Indonesia, Malaysia and Papua New Guinea), study covering a total peatland area of 27.20 Mha)*	*1,400* $M_gCO_{2e}yr^{-1}$ *(1997–2006)*	Hooijer et al., 2010
Carbon emission from peat oxidation of below-ground biomass	*Large-scale palm oil plantations*	*South-East Asian (Peninsular Malaysia, Sumatra, and Borneo); 0.880 Mha palm oil plantation on peatlands*	*16.87* $M_gCO_{2e}yr^{-1}$	Koh et al., 2011
Carbon emissions from recurrent fires	*Deforestation and drained peatland*	*Indonesia*	*810–2,570 million* $M_gCO_{2e}yr^{-1}$*(1997)*	Page et al., 2002
	Deforestation and drained peatland	*South-East Asian (Indonesia, Malaysia, and Papua New Guinea)*	*128 million* M_gCOyr^{-1}*(2000-2006)*	van der Werf et al., 2008
III. Biodiversity impacts				
Impact of peat swamp forest conversion to palm oil on biodiversity decline/elimination	*Large-scale palm oil plantations*	*Borneo*	*1% (4 species dwelling birds equivalent)*	Koh et al., 2011
	Large-scale palm oil plantations	*Sumatra*	*3.4% (16 species dwelling birds equivalent)*	Koh et al., 2011
	Large-scale palm oil plantations	*Peninsula, Malaysia*	*12.1% (46 species dwelling birds equivalent)*	Koh et al., 2011
	Large-scale palm oil plantations	*Peninsula, Malaysia*	*48-60% of bird species eliminated*	Azhar et al., 2011

Comparison of total species richness with the natural forests	*Palm oil plantations*	*Literature reviews from multiple countries studies*	*Vertebrate/invertebrate species richness in palm oil represents around 38% and 89% (no significant difference) respectively of those in natural forests*	Danielsen et al., 2009
Number of species (species richness)	*Palm oil plantations*	*Literature reviews from multiple countries studies*	*Only around 23% and 31% of vertebrate and invertebrate species, respectively, discovered in forest also occurred in palm oil plantations*	Danielsen et al., 2009
Similarity of community composition	*Palm oil plantations*	*Literature reviews from multiple countries studies*	*Community composition similarity representations of vertebrate and invertebrate species in palm oil were only 29% and 21% of those in natural forest.*	Danielsen et al., 2009

Notes:

Asl = above sea level

M_gCO_{2e} = Mega grams carbon dioxide equivalent

CO-CO_{2e} = 3.667

Mha = million hectares

2.4 Conclusion

Discussions over the drivers and the associated impact of peat swamp forest deforestation and degradation in the South-East Asian region have become contentious topics. It is undeniable that the activities of logging, conversion to industrial agriculture plantation, drainage and repeated fires have a major role in the transformation of peat swamp forest in the region into degraded and fragmented landscapes, resulting in peatland ecosystem decline, biodiversity loss and globally significant volumes of carbon emissions.

This review has highlighted the major drivers of peatland deforestation and degradation in the South-East Asian region and categorised direct and indirect drivers. Direct drivers include logging, conversion to large-scale agriculture including industrial plantations, construction of artificial drainage canals, repeated fires, poverty and fire-based traditional farming practices. Indirect drivers stem from climate change and inconsistent land use policy and weak governance.

To address peatland degradation and its associated impacts in the South-East Asian region, this study recommends that (a) large-scale restoration activities take place on degraded peatland areas, and (b) the existing peatland regulatory and policy measures be reviewed and improved. More research is needed to answer the following questions: (a) what are the key barriers to and techniques for restoring degraded peatland in the tropical region; (b) how can effective peatland restoration be designed and assessed in the tropics; (c) what are the major impacts of industrial plantations on peatlands and what role can those plantations play in restoring degraded peatland and implement wise peatland management; and (d) what regulatory and policy interventions will improve peatland conservation and restoration outcomes in the South-East Asian region?

CHAPTER 3 TECHNIQUES FOR EFFECTIVE PEATLAND RESTORATION IN INDONESIA

Summary

Indonesia’s peatlands cover just 0.14% of the world’s land surface yet contain as much as 7% of the world’s forest-based carbon stocks. They are an ecosystem of global significance—for climate and for biodiversity. They also provide goods and services that sustain the livelihoods of thousands of local people. Despite these substantial values, Indonesia’s peatlands have been subject to extensive deforestation and degradation resulting from logging, drainage, fires and conversion to other land uses.

A number of restoration initiatives have been attempted to address this degradation yet, to date, there has been little coherent or rigorous reflection on the effectiveness of these interventions.

This chapter examines the barriers to peatland restoration in Indonesia and reviews the techniques so far used to restore degraded peatland in the tropics. Direct barriers to peatland restoration in Indonesia include altered peat topography, over-drainage, the presence of invasive ferns and shrub species, repeated fires, and flooding risks. Indirect barriers include climate change, inconsistent land-use policy and lack of alternative livelihood options. It was highlighted that most restoration activities carried out to date have been small-scale trials and the restoration techniques used have included canal blocking, seedling transplantation, and promotion of seed dispersal. I suggest that successful peatland restoration in Indonesia is as much dependent on meaningful land use policy and governance reform as it is on the technical effectiveness of specific restoration methods.

3.1 Introduction

About 47% (21 Mha) of global tropical peatland is located in Indonesia. This carbon-rich resource contains as much as 65% (57 G_tC) of the world’s peat carbon (Page et al., 2011) and 7% of the 861 G_tC of global forest-based carbon stocks, as estimated in 2007 (Pan et al., 2013). Besides being an important as carbon pool, the peatland also supports high biodiversity including endemic and rare species with high conservation value such as the Orangutan and Sumatran tiger (Morrogh-Bernard et al., 2003; Posa et al., 2011; Sunarto et al., 2012). It also provides livelihoods for thousands of local people (Anshari et al., 2005; Noor et al., 2007; Silvius & Diemont, 2007; Suyanto et al., 2009).

The majority of peatland in Indonesia is lowland ombrotrophic, meaning that its primary source of water and nutrient supply comes from atmospheric precipitation or is recycled from decayed plant matter (Rieley & Page, 2008). As a result of these low nutrient and acidic conditions, decomposition of vegetative material is slow (Yule, 2010). This enables peat to form and accumulation to take place.

Despite the value of peatland in Indonesia, the ecosystem has undergone momentous transformation to other land uses and as a result, vast areas of peatland have been left degraded. Logging, conversion to industrial plantations, drainage and fires have been cited as the major drivers of peatland degradation in Indonesia (Hooijer et al., 2006; Koh et al., 2011; Hooijer et al., 2012; Miettinen et al., 2012a; Miettinen et al., 2012c; Margono et al., 2014). Peatland conversion to large-scale industrial plantations, notably oil palm, expanded by around 0.604 Mha between 1990 and 2000 and around 0.612 Mha between 2000–2010. These figures represent annualised growth rates of forest conversion of 42.27% and 13.70% respectively over the two decades (Miettinen et al., 2012a). The extent of artificial drainage development associated with this conversion has also increased significantly (Hooijer et al., 2006; Böhm & Siegert, 2001; Franke et al., 2012). It is estimated that about 12.5 Mha out of the 21 Mha of Indonesia's total former peatland had been drained for agriculture and forestry by 2008 (Joosten, 2010). Fire is also contributing to peatland degradation in Indonesia. Repeated fires limit successful forest regeneration (Page & Waldes, 2008; Page et al., 2009).

In the past two decades, a number of peatland restoration initiatives have been attempted in Indonesia. These initiatives include peatland rewetting through canal blocking (Suryadiputra et al., 2005; Limin et al., 2007; Dohong & Lilia, 2008; Jaenicke et al., 2010; Ritzema et al., 2014), revegetation of bare peatland through the production and transplantation of seedlings (van Eijk et al., 2009; Graham & Page, 2014); promotion of seed dispersal tools (Graham & Page, 2012) and understanding the potential of natural or spontaneous regeneration (Gunawan et al., 2007; van Eijk et al., 2009; Gunawan et al., 2012; Blackham et al., 2013; Blackham et al., 2014).

Despite the initiatives tried by various organisations, there is still a lack of published research that rigorously and coherently reviews peatland restoration issues and techniques in the tropics, particularly with regards to: (a) the types of barriers that have been encountered during the restoration process; and (b) the restoration measures and techniques used as well and their efficacy in addressing peatland restoration. As such, this chapter addresses the questions: (a) what are the principal barriers that may hamper the success of peatland restoration implementation in Indonesia; and (b) what are the restoration measures and techniques that have been used to address peatland degradation in Indonesia? In addition, an evaluation of various peatland restoration techniques is also presented.

3.2 Peatland degradation in Indonesia: scale and principal drivers

Logging, conversion to industrial plantations, drainage and fires have been frequently cited as the major drivers of peatland deforestation and degradation in Indonesia (Böhm & Siegert, 2001; Page et al., 2002; Aldhous, 2004; Koh et al., 2011; Miettinen et al., 2012;). A study by BAPPENAS (Indonesia's National Planning Agency) estimated that by 2006 about 45% of the country's peatland was occupied by shrub/grassland (20%), cropland (15%) and other non-forest vegetation (10%) (BAPPENAS, 2009). In addition, the shrub/grassland cover expanded by 55% (equivalent to 4.4 Mha) during the period 2000–2006, meanwhile forested peatland declined by 15% (remaining 12.0 Mha) during the same period.

Miettinen et al., (2010) reported a dramatic decrease in peat swamp forest cover in Sumatera and Kalimantan during the decades 1990–2000 and 2000–2010. Peat swamp forest cover in both islands reduced significantly from around 8.78 Mha (78%) in 1990 to 5.95 Mha (53%) and 4.21 Mha (38%) respectively in 2000 and 2010 (Miettinen et al., 2012c). These figures represent an annual peat swamp forest loss of 3.40% and 3.82% during the decades of 1990–2000 and 2000–2010 respectively (Figure 3.1).

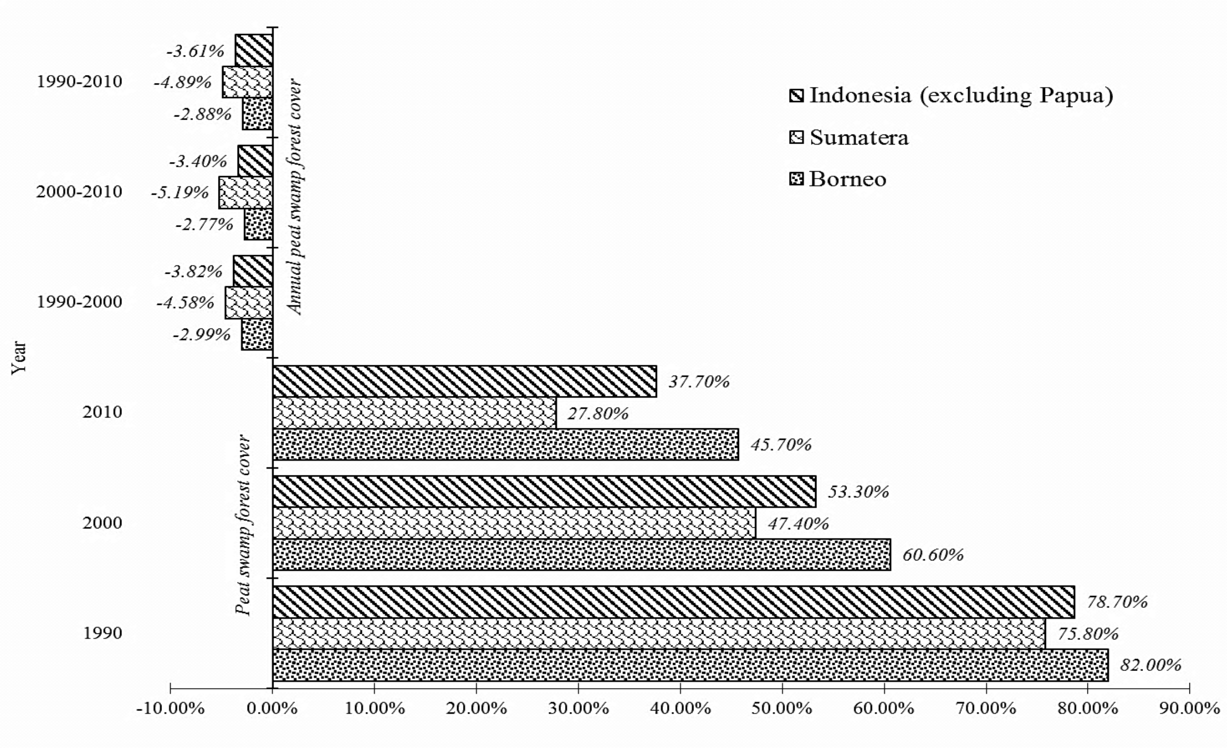


Figure 3.1 Peat swamp forest cover changes (total and annual) in Indonesia and the Islands of Sumatera and Borneo for the periods of 1990, 2000 and 2010 (data adopted from Miettinen et al., 2012c)

Peatland conversion to large-scale agriculture notably to industrial palm oil and pulp timber plantations has become a major concern in the past two decades. The total area of industrial palm oil in Sumatera increased significantly from 0.02–0.26 Mha in 1990 to 0.53–0.70 Mha and 1.05–1.40 Mha in 2000 and 2010 respectively. Similarly, the area of palm oil on peatland in Kalimantan grew significantly from only 0.001 Mha in 1990 to 0.02–0.05 Mha and 0.26–0.31 Mha in 2000 and 2010 respectively (Figure 3.2).

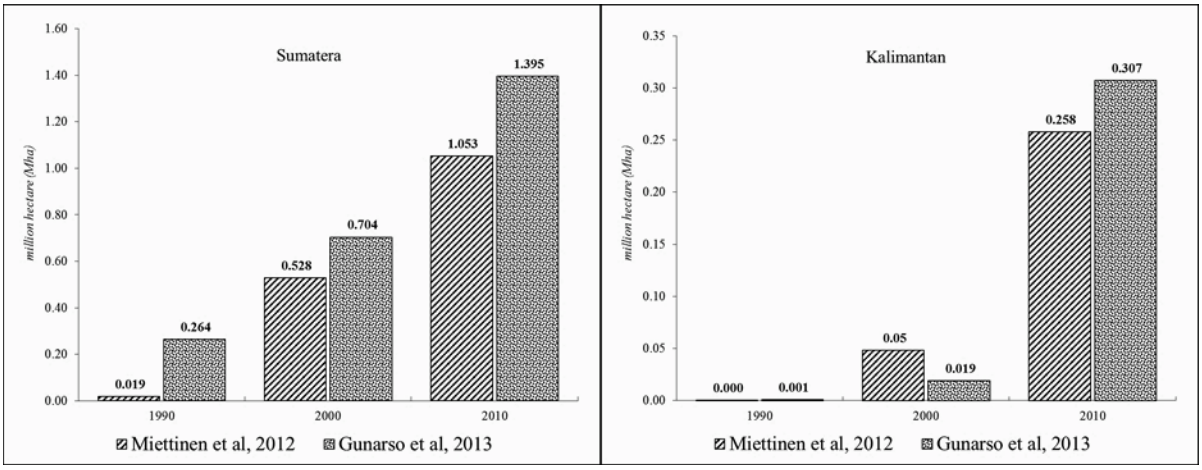


Figure 3.2 Increase in the area of industrial oil palm plantations on peatland in the Islands of Sumatera and Kalimantan

Peatland drainage has enhanced peatland oxidation, compaction, and consolidation, leading to peat subsidence and the release of both atmospheric and fluvial carbon emissions (Hooijer et al., 2006; Hooijer et al., 2012; Jauhiainen et al., 2012). Repeated peatland fires are mostly triggered by both peat forest removal and construction of artificial canals (Hooijer et al., 2006; Hoscilo et al., 2008; Page et al., 2009).

3.3 Peatland restoration barriers

Restoration barriers to wetlands, including peatland ecosystems, are varied and may involve a range of ecological, socioeconomic and policy barriers (Zedler, 2000; Page et al., 2008; Collier, 2011). These barriers may be direct or indirect. The direct barriers may involve ecological (e.g. physical, hydrological conditions) and biological constraints. Meanwhile, indirect barriers may arise from external and socio-political factors such as climate change, lack of enforcement and inconsistency of regulatory measures, and socioeconomic conditions.

3.3.1 Physical-ecological factors

3.3.1.1 Change of peat physical properties and topographical feature

The change of peat physical properties and micro-topography is a result of vegetation removal, artificial drained canals construction, and recurrent fires. Altered peat physical properties and micro-topography may constrain the success of peat forest regeneration due to the changes of microclimate conditions, hydrological fluctuations, peat oxidation and fires leading to peat subsidence, reduction of peat hummock-hollow topography, and increased flooding risk (Page et al., 2009; Graham & Page, 2014).

The removal of peat forest vegetation creates large canopy gaps leading to increased solar radiation input intensity, decreased peat moisture and increased evaporation, and therefore, the peat surface temperature will increase (Page et al., 2008; Gandois et al., 2013; Graham & Page, 2014; Page & Hooijer, 2014;). In turn, the higher temperature affects peat moisture content, evapotranspiration, peat carbon dynamics, and the hydrological balance (Page et al., 2009; Dommain et al., 2011).

The construction of extensive drainage channels in peatland areas can cause changes in peat physical properties and topographical features due to enhanced peat oxidation and increased subsidence, caused by the lowered water table (Rydin & Jeglum, 2013). Peat subsidence will affect peatland micro-topography and hydrology that in turn influences the effectiveness of hydrological and vegetation recovery (Applegate et al., 2012). Moreover, degraded peatland is subject to a high risk of repeated fires. Increased fire frequency not only depletes peat matter, due to combustion leading to the change peatland micro-topography but also has the potential to destroy woody and non-woody vegetation, which is essential for the recovery of degraded peatland (Page et al., 2009; Hoscilo et al., 2011).

3.3.2 Hydrological factors

3.3.2.1 Draught and over drainage

Changed hydrological conditions and repeated fires are the major barriers to peat forest regeneration (Wösten et al., 2006; Page et al., 2008; Wösten et al., 2008; Graham & Page, 2014). Disruptions to the natural hydrological balance caused by peatland drainage are the starting point of peatland degradation. The construction of drainage channels is a common practice associated with the activities of logging, agriculture, plantations and peat swamp forest wood extraction in Indonesia (Hooijer et al., 2006; Jaenicke et al., 2011). The function of the drainage channel depends on the type of land-use being undertaken. For instance, in the agriculture and plantation sector the function of the drainage canals is two-fold: firstly, to lower the water table so that the peat can be planted with crops; and, secondly, the drainage canal may be used to transport agricultural products to the local processing industry or markets (Hooijer et al., 2006; Jaenicke et al., 2010). In forest concession areas, canals are mainly used for transporting felled logs from the interior of the forest to nearest river and so to wood-processing industries downstream (Jaenicke et al., 2010).

During drought events, the drained and degraded peat swamp forest may experience water shortage and faces physiological water deficit (Page & Waldes, 2008). Water deficit during drought events is amplified by the existence of artificial drainage canals, which cause significant water table drawdown and a deepening of the acrotelm (the oxidative upper layer of peat), thereby enhancing peat subsidence (Wosten et al., 2008; Hooijer et al., 2012). The water deficit will affect the growth and mortality of certain seedlings and saplings of forest trees that are intolerant to prolonged drought. Similarly, over-drainage can affect the physical properties and make peat vulnerable to irreversible drying and shrinking and, therefore, succumbing to water resistance, which hampers any attempts at both hydrological and vegetative restoration (Rieley & Page, 2008b; Hooijer et al., 2012).

3.3.2.2 Prolonged flooding and inundation factors

Fluctuation and destabilisation of hydrological regimes between drought and wet seasons can be a major barrier to the success of revegetation. Hydrological regime dynamics are highly dependent upon factors that affect water balance in the peat ecosystem (Ritzema, 2007; Wösten et al., 2007).

Groundwater tables in Central Kalimantan during a prolong drought caused by an El Nino event can be lowered by several metres under the peat surface (Woston et al., 2008; Ballhorn et al., 2009). This excessive drop of the groundwater table during extreme drought periods may expose peat to extreme heat, which can kill seedlings and saplings of forest trees that are very intolerant of these conditions (Page et al., 2008; Page et al., 2009).

On the other hand, excessive precipitation rates during La Nina events can cause other problems for the vegetation and affect peat physical properties. Extended flooding during the rainy season in Indonesia can submerge the peatland under several metres of water and for a number of days or months. This can threaten the longevity of vegetation species that are intolerant to prolonged flooding. For instance, it was noted in a study conducted in Berbak National Park, in Jambi Province, that prolonged and deep flooding in 2004 had killed most of the seedlings planted and the survival rate of seedlings planted remained at 5% (van Eijk et al., 2009).

3.3.3 Biological Factors

3.3.3.1 Emergence of invasive and aggressive of woody and non-woody weeds

The most significant biological barrier that may impede successful peatland vegetation restoration is the presence of invasive and aggressive woody and non-woody weeds. Studies in Central Kalimantan and Sumatera noted that following a peat fire event, dense shrub and fern communities dominated the bare peat, hindering reestablishment of endemic seedlings (Graham et al., 2007; Page et al., 2009; van Eijk et al., 2009). The dense vegetation blocks sunlight, creating deepened shade and the increased competition for nutrients makes it difficult for indigenous plant species to survive. One study indicated that following repeated fires, the colonisation of fern and shrub cover occurred at sufficient density to subdue the regeneration of indigenous tree species (Page et al., 2009).

3.3.3.2 Lack of seed sources and dispersal agent

Fire not only destroys established seedlings and saplings in tropical peatlands but often kills the parent trees, which are valuable on-site seed sources and seed dispersal agents. The lack of seed sources and seed dispersers can hamper natural regeneration of degraded peatland (Graham et al., 2007; D'Arcy & Graham, 2008; Graham & Page, 2014). The protection of remnant natural peat forest patches adjacent to restoration areas is necessary so a source of seed for species recolonisation is available (Hoscilo et al., 2011).

3.3.4 Recurrent fires

Fire is the most significant barrier hindering successful peatland forest restoration in Indonesia (Giesen & Euroconsult, 2004; Page et al., 2008; van Eijk et al., 2009; Hoscilo et al., 2011). Peat fires can seriously limit forest regeneration through impacts on seed banks and reduction in soil fertility, owing to organic matter loss (Giesen & Euroconsult, 2004). Natural or spontaneous regeneration of peat swamp forest following a single fire event is possible. However, multiple fires with frequent intervals may hinder the regrowth of peat forest species. Instead, recurrent fires promote the emergence and dominance of homogeneous and lower non-woody plant communities such as ferns and sedges (Hościło, 2009). Studies in Central Kalimantan show that multiple and repeated fires have hampered forest succession and even contributed to retrogressive succession (Page et al., 2008; Page et al., 2009; Hoscilo et al., 2011). Many studies recommend that fire prevention measures should be put in place to ensure peat forest regeneration can occur.

3.3.5 Regulatory and policy barriers

3.3.5.1 Inconsistent enforcement of land use and peatland conservation policies

Uncertainty surrounding regulatory and policy measures governing peatland use in Indonesia hinders successful restoration initiatives. The legal basis for peatland conservation, protection, and restoration is weak, mainly because the protection of peatland is determined on the basis of peat depth (PORI, 1990). There is no protection for peatland with a peat depth of < 3 m, even though this type of peatland may have crucial socio-ecological and biodiversity value. Despite the 3m regulatory threshold, deep peatland in Indonesia is not free from conversion to other land uses, notably industrial plantations (Silvius & Suryadiputra, 2005; Hooijer et al., 2006).

Another problem with the regulatory measures in Indonesia is the lack of consistency among the ministries and institutions that govern peatland. For example, the Minister for Agriculture Regulation No. 14 of 2009 allows oil palm cultivation on deep peat if the peatland is located outside conservation areas or has been allocated for cultivation under the planning regime (MoARI, 2009). This directly contravenes the Central Government policy for a moratorium on natural forest and peatland conversion to cultivation, regardless of the depth (PORI, 2011, PORI, 2013).

3.3.6 Socio-economic barriers

3.3.6.1 The lack of livelihood options

High levels of poverty and lack of livelihood alternatives are two important issues that face communities residing within peat swamp areas. This may lead local stakeholders to over-utilise, burn or exploit peatland forest resources, which can hamper restoration efforts (Anshari et al., 2005; Noor et al., 2005; Silvius M & Diemont, 2007; Suyanto et al., 2009).

3.3.6.2 Traditional agriculture

Because of its acidity and low nutrient levels, peatland is marginal as a medium for crop cultivation. The only solution used by local subsistence farmers to neutralise peat acidity, and promote peat fertility and increase nutrients, is the use of fire. Fire is used for two purposes in traditional agricultural practices in Indonesia: firstly, to clear weeds, shrubs and other vegetation cover to make way for crop cultivation; and secondly to produce ash, which is used to neutralise peat acidity and act as a fertiliser ameliorant to improve crop productivity (Saharjo, 2007). In addition, the use of fire in traditional agriculture is considered cost-efficient because little effort and labor are needed to clear the land for agriculture (Chokkalingam et al., 2005).

For instance, to improve crop and vegetable productivity, farmers in Kalampangan Village, Central Kalimantan, produce ash fertiliser by burning a combination of peat and post-harvest weeds. This also saves money because they do not need to buy artificial fertilisers (Dohong & Lilia, 2003). The use of fires for clearing weeds and for producing ash fertiliser may affect the peat physical properties and change the micro-topography, which may hinder peat forest regeneration and fires can potentially kill seedlings and saplings, as well as parent trees, which are seed sources.

3.4 Peatland restoration activities in Indonesia: a brief historical overview

Tropical peatland restoration is a new activity and is in its infancy in Indonesia. A number of non-governmental, conservation and research organisations started the peatland restoration initiative in the early 2000s in the Indonesian provinces of Central Kalimantan, Jambi, South Sumatera and Riau as a response to the alarming rate of peatland degradation and its associated impacts in those peatland areas.

Three conservation organisations, namely Wetlands International-Indonesia Programme, Wildlife Habitat Canada and Global Environment Centre, Malaysia under a collaborative programme entitled the Climate Change, Forests and Peatland in Indonesia (CCFPI) introduced, for the first time, peatland rewetting by blocking canals constructed by illegal loggers and also agricultural field drains in Central Kalimantan and South Sumatera from 2003–2005 (Suryadiputra et al., 2005). This peatland rewetting activity is considered as the first peatland rewetting effort in Indonesia and even in the tropical region (Ritzema et al., 2014). Through the CCFPI, about seven large dams were successfully constructed in Block A North-West of the Ex-Mega Rice Project (EMRP), Kapuas District and 73 small dams were successfully built aimed at closing drained canals built by illegal loggers in Muara Puning village, South Barito District, Central Kalimantan from 2003–2004 (Suryadiputra et al., 2005; Dohong & Lilia, 2008; Jaenicke et al., 2011). In addition to these dams, about 12 small dams were successful constructed of an attempt at closing down four illegal loggers' ditches in Merang, South Sumatera in November 2004 (Suryadiputra et al., 2005).

Following the success and experience of the CCFPI canal blocking, an additional 19 large dams were also constructed in Block A North-West of the EMRP under the Dutch Ministry of Foreign Affairs (DGIS)-funded project called the Central Kalimantan Peatland Project (CKPP) in 2007–2008 (CKPP 2008). The CKPP was a partnership project that involved four NGOs (Wetlands International-Indonesia Programme, CARE International-Indonesia Programme, WWF-Indonesia and BOSF) and the University of Palangka Raya (UNPAR). As well as the 19 large dams already mentioned, under the CKPP partnership five big and 263 small dams were successfully built in the Sebangau National Park, Central Kalimantan.

Peatland rewetting activity was also implemented in Block C of the EMRP under the framework of Keys for Securing Tropical Peat Carbon (KEYTROP) and the EU Funded Project called Restoration of Tropical Peatland for Sustainable Use of Renewable Natural Resources (RESTOPEAT). About six dams were finally completed in Kalampangan and Taruna Canals in Block C of the EMRP in 2005 (Jauhiainen et al., 2008; Limin et al., 2008; Ritzema et al., 2014).

The World Wildlife Fund of Indonesia also introduced a peatland rewetting program in Sebangau National Park, Central Kalimantan in 2005. Five large dams were assembled on the SSI canal in 2005 (Panda et al., 2011). In addition, another 263 small dams were constructed in Sebangau National Park by WWF-Indonesia under the partnership of CKPP (CKPP, 2008). Between 2005 and 2009, about 176 illegal logger canals were blocked by WWF-Indonesia in Sebangau National Park (Maya, 2009).

The Orangutan Tropical Peatland Project (OuTrop) constructed 379 small dams (ditch width 1–2 m) by 2010 throughout the Peat Swamp Forest Natural Laboratory in Sebangau (OuTrop, 2010). Rewetting peatland was also implemented in Kampar Peninsula forest, Riau Province initiated by Greenpeace, by blocking artificial open canals in the area (Lisa, 2009a, 2009b). Due to the limitations of information available relating to this canal blocking activity it was not clear how many dams were successfully constructed as part of the organisation’s campaign entitled the Defender Climate Camp, during the period of October–November 2009.

Efforts to revegetate bare peatland have been implemented concurrently with the peatland rewetting activities in many peatland areas in Central Kalimantan and Sumatra since the early 2000s. Seedling nurseries and planting programs have been implemented in the EMRP area of Central Kalimantan (Suryadiputra et al., 2005; CKPP, 2008; Page et al., 2009; Graham & Page, 2014) and Berbak National Park, Sumatra’s province of Jambi (Giesen, 2004; van Eijk & Leenman, 2004; van Eijk et al., 2009). Following the dam building in the main primary canals of the EMRP, Wetlands International carried out seedlings nursery development and seedling plantings aimed at revegetating bare peatland along the canals blocked in the EMRP during the CCFPI program 2003–2005 (Suryadiputra et al., 2005). The CKPP program had also implemented seedlings nursery and seedling transplantation activities in the EMRP and Sebangau National Park under the CKPP program 2007–2008 (CKPP, 2008). It should be noted however, those peatland rewetting and revegetation activities implemented by various organisations are mostly “pilot and trial-based” in terms of their nature and scale.

3.5 Peatland restoration measures and techniques for restoring degraded peatland in Indonesia

Peatland rewetting uses two techniques, namely canal blocking and canal backfilling (Suryadiputra et al., 2005; Dohong & Lilia, 2008; Limin et al., 2008; Houterman & Ritzema, 2009; Jaenicke et al., 2010; Ritzema et al., 2014). Revegetation of bare peatland includes seedlings production, seedlings transplantation, and promotion of seed dispersal techniques (Giesen, 2004; van Eijk & Leenman, 2004; D'Arcy & Graham, 2008; Page et al., 2008; van Eijk et al., 2009; Graham & Page, 2014).

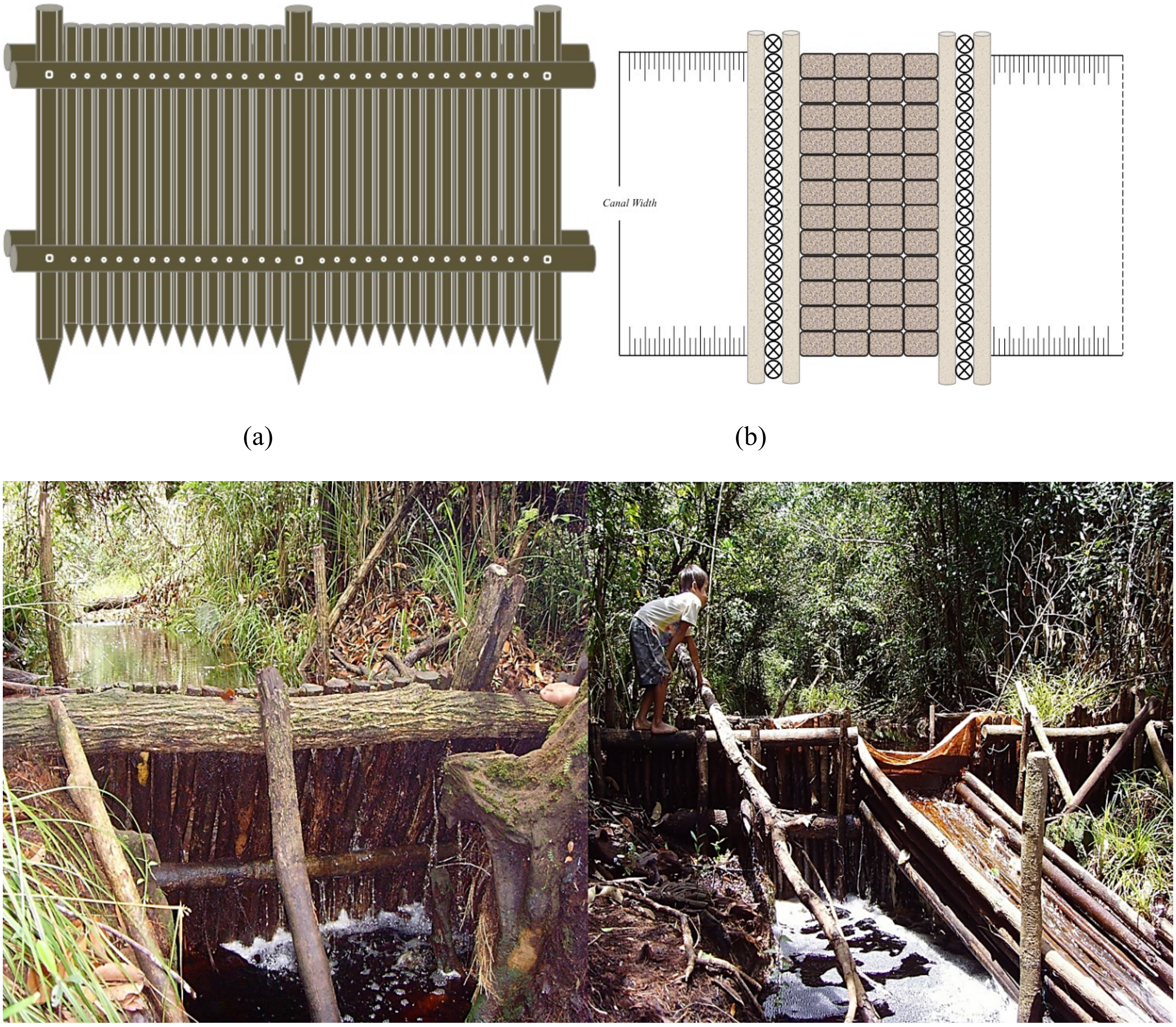
3.5.1 Hydrological restoration through peatland rewetting

Peatland rewetting is a technique used to rewet drained peatland by closing drain canals with dam or weir water, thereby the surface run off outflow is reduced. As a result, the water storage capacity is increased in the canal and its vicinity (Suryadiputra et al., 2005; Dohong & Lilia, 2008; Englhart, 2012; Ritzema et al., 2014). The main goal of peatland rewetting is to improve the peat hydrological properties by means of raising both the surface and groundwater tables so that the hydrological properties of the drained peatland are recovered and stabilised as close as possible to its pre-logging and pre-drainage hydrological conditions. Apart from re-stabilised local hydrological properties, the peatland rewetting also provides benefit in terms of reducing fire occurrences caused by dried out peatlands (Dohong & Lilia, 2008; Page et al., 2009; Panda et al., 2011).

Generally, there are two rewetting techniques that have been practised to rewet drained peatland in Indonesia. These techniques are canal or ditch blocking and canal backfilling. Both rewetting techniques have been widely practised in restoring drained peatland in both temperate and boreal peatlands (Brooks & Stoneman, 1997; Grand-Clement et al., 2013; Lunt et al., 2010; Parry et al., 2014), however, these techniques have only been recently introduced in the tropics (Page et al., 2009; Jaenicke et al., 2010; Ritzema et al., 2014).

3.5.1.1 Canal or ditch blocking

Canal or ditch blocking is a rewetting technique that requires placing dams or water weirs in certain sections of a drained canal so as to reverse surface water outflow and to raise both the surface and groundwater levels along the canal course (Suryadiputra et al., 2005; Dohong & Lilia, 2008; Ritzema et al., 2014;) The type of dam design depends on the size and the availability of materials on site. For small and narrow illegal loggers' ditches, a simple dam design such as the single or composite plank dam can be used and materials for the dam building are locally available (Figure 3.3).



(a) (b)

(c) (d)

Figure 3.3 Dam designs of single plank (a) and composite plank (b). Examples of a single plank (c) and composite plank (d) in Sungai Puning, South Barito District of Central Kalimantan

Wetlands International-Indonesia Programme used simple plank and composite dam designs with blocked illegal logger ditches in Muara Puning, South Barito district in Central Kalimantan and Merang, South Sumatera Province (Suryadiputra et al., 2005). Similarly, the same dam design has been used by the Orangutan Tropical Peatland to block illegal logger canals in the Sebangau Peat Swamp Forest Natural Laboratory (SPSFNL), Central Kalimantan (OuTrop, 2010).

In the meantime, for large canals such as in large-scale irrigation agriculture or industrial plantations, more advanced and stronger dam structure designs have to be employed (Page et al., 2009). The CCFPI and CKPP have developed various designs of the two-sheet pile box dam to block the parent primary and main primary canals in Block A North-West of the EMRP in Central Kalimantan (Figure

3.4; Figure 3.5; Figure 3.6; Figure 3.7; Figure 3.8) (Suryadiputra et al., 2005; CKPP, 2008; Dohong & Lilia, 2008).

Similarly, the KEYTROP and RESTOPEAT applied a similar two-sheet pile box dam model to block Kalampangan and Taruna canals in the Block C of the EMRP (Limin et al., 2008; Ritzema et al., 2014) and WWF Indonesia when blocked the SSI canal in the Sebangau National Park (Suryadiputra et al., 2005; Jaenicke et al., 2010).

There is limited information about the type of wooden structures that have been used in damming artificial canals in other parts of Sumatera Island, such as in Merang REDD Peatland Project, Musi Banyu Asin District, South Sumatera (Barkah & Sidiq, 2009) and Kampar Peninsula, Riau Province implemented by Greenpeace (Lisa, 2009b). However, it seems that the dam designs used are similar to those in Kalimantan.

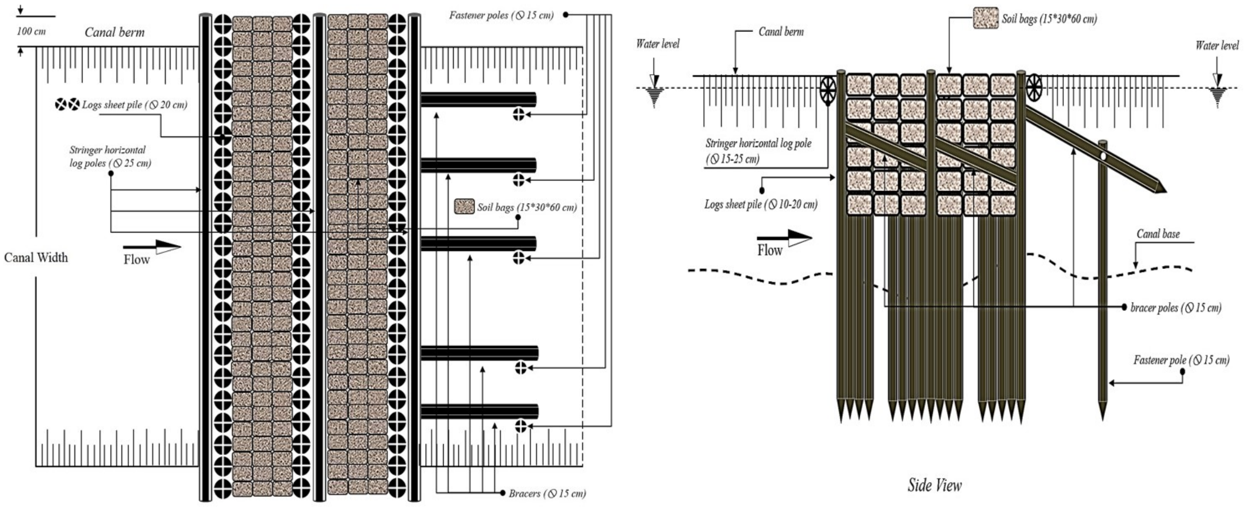


Figure 3.4 Wetlands International’s two sheet piles dam design for canal blocking in the EMRP, Central Kalimantan

Figure 3.5 Canal blocking in the EMRP, Central Kalimantan

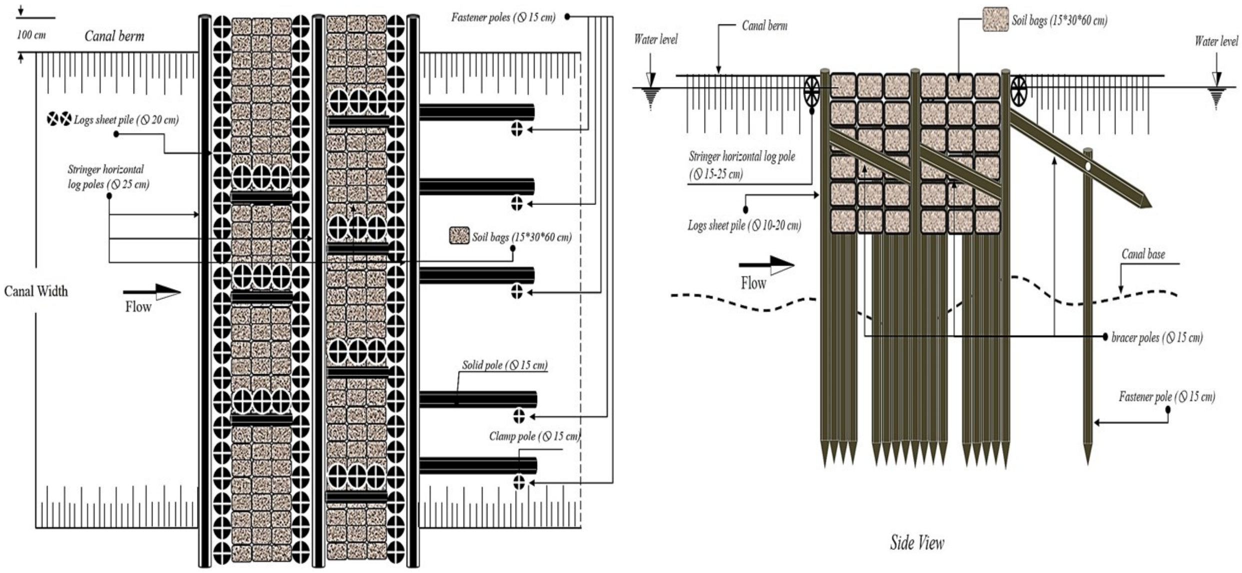


Figure 3.6 Wetlands International's two-sheet pile equipped with chambers dam design for canal blocking in the EMRP, Central Kalimantan

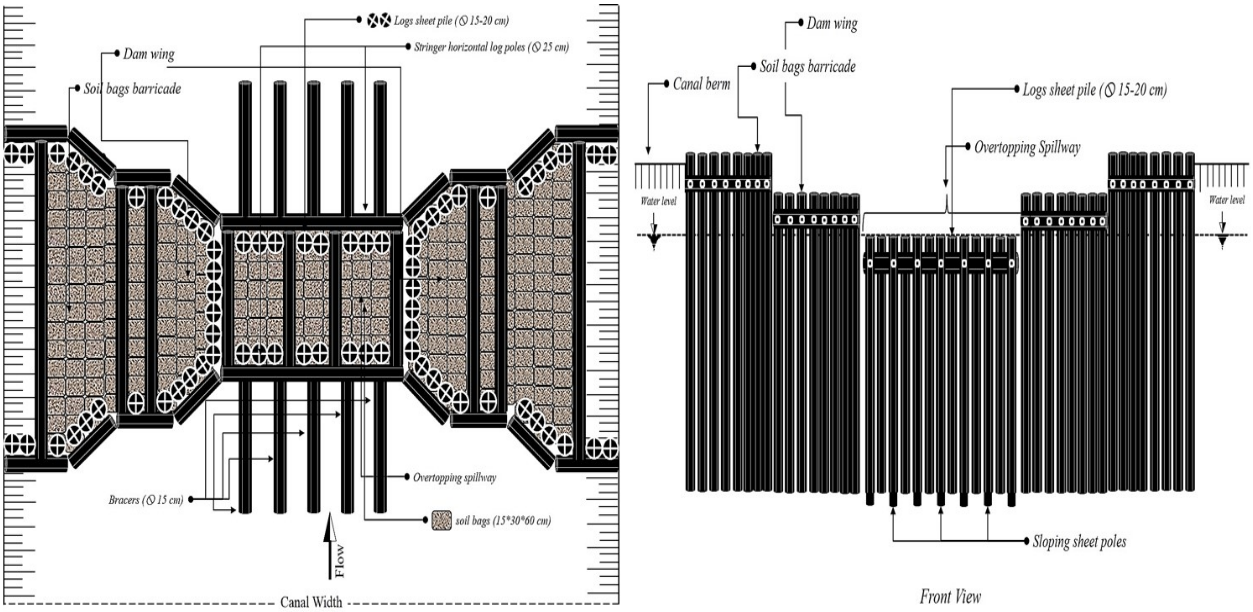


Figure 3.7 Wetlands International's two sheet piles with on top spillway system

Figure 3.8 Dams with spillway system constructed in the EMRP, Central Kalimantan

Canal blocking involves three main stages: (1) pre-construction; (2) construction; and (3) post construction. Each stage consists of a number of activities as summirised briefly in the following diagram (Figure 3.9).

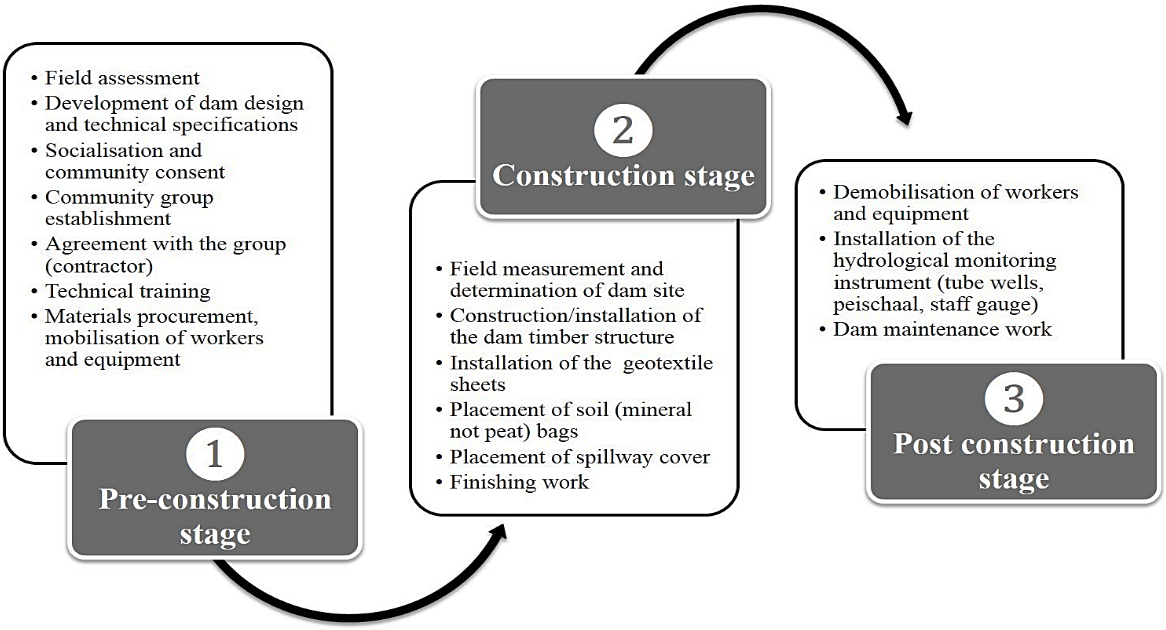


Figure 3.9 Major stages of canal blocking construction implemented by Wetlands International-Indonesia Programme in the EMRP, Central Kalimantan (redrawn from Suryadiputra et al., 2005; Dohong & Lilia, 2008)

3.5.1.2 Canal backfilling

Canal backfilling is commonly practised in restoring peatland hydrology in temperate and boreal regions but this kind of technique has yet to be practised in Indonesia. The canal backfilling technique involves refilling the drained canal with peat berm embankment or other organic material, such as dead wood debris (tree trunks, branches, etc.) and other materials that are available on site or nearby (Euroconsult Mott MacDonald et al., 2009; Houterman & Ritzema, 2009; Applegate et al., 2012). The main aim of canal backfilling is to slow the water flow and to raise the level of organic sediment within the canal or ditch so that the drainability of the canal or ditch can be minimised or even stopped.

The idea of canal backfilling has been proposed in the Master Plan for the Rehabilitation and Revitalisation of the Ex-Mega Rice Project and the Kalimantan Forests and Climate Partnership (KFCP) as a possible peatland rewetting strategy in the EMRP, Central Kalimantan (Euroconsult Mott MacDonald et al., 2008; Euroconsult Mott MacDonald et al., 2009). However, the idea had not been realised up until the KFCP project ended its activities in 2014. Hence, the canal backfilling technique sounds good as a concept but has not yet been proven to effectively rewet drained peatland.

Table 3.1 Summary of canal blocking implemented by various organisations in Indonesia from selected publications

Location	**Timeframe (Year)**	**Type of artificial canal dammed**	**Total dams constructed (unit)**	**Project Initiators Agency/collaborator**	**Reference/Source**
Block A North of the Ex-Mega Rice Project, Kapuas District and Sungai Puning Black Water Ecosystem (Batilap/Bateken, Muara Puning, Batampang villages), Central Kalimantan	2004–2005	• Large irrigation canals (parent primary canals and primary canals) • Illegal logger (small) canals	7 33	Climate Change, Forests and Peatland in Indonesia: Wetlands International, Wildlife habitat Canada, Global Environment Center	Suryadiputra et al., 2005; Dohong & Lilia, 2008
Merang, South Sumatera	2004–2005	• Illegal logger (small) canals	12	Climate Change, Forests and Peatland in Indonesia: Wetlands International, Wildlife habitat Canada, Global Environment Center	Suryadiputra et al., 2005
Block A North and Block E of the Ex-Mega Rice Project, and Sebagau National Park, Central Kalimantan	2007–2008	• Large irrigation canals (parent primary canals and primary canals) • Illegal logger (small) canals	18 263	Central Kalimantan Peatland Project: Wetlands International, WWF-Indonesia, Care International-Indonesia, BOSF foundation and Palangka Raya University	CKPP, 2008; Jaenicke et al., 2011
Block C of the Ex-Mega Rice Project, Central Kalimantan	2005	Large irrigation canals (primary canals)	6	Keys for Securing Tropical Peat Carbon and Restoration of Tropical Peatland for Sustainable Management of Renewable Natural Resources	Limin et al., 2007; Jauhiainen et al., 2008; Page et al., 2009; Jaenicke et al., 2011; Ritzema et al., 2014
Sebangau Natural Peat Swamp Laboratory, Central Kalimantan	2010	Illegal logger canals	379 (1-2 ditch wide range)	The Orangutan Tropical Peatland Project, CIMTROP UNPAR and others	OuTrop, 2010

3.5.2 Vegetation restoration

3.5.2.1 Potential for natural regeneration (self or unassisted regeneration) of degraded peatland in Indonesia

Several studies have examined options for reforestation of degraded peatland areas in Central Kalimantan (Page et al., 2008; Blackham et al., 2014) and Berbak National Park and Riau Sumatera (Giesen, 2004; van Eijk et al., 2009; Gunawan et al., 2012). Regeneration studies have been focused on recolonisation of native forest species, survival rates and recruitment of indigenous species and the role of dispersal mechanisms and disperser agents (D'Arcy & Graham, 2008; Page et al., 2008).

Studies in the Block A North-West of EMRP, Central Kalimantan show that regeneration of peat swamp forest is possible but with a slow pace and limited tree species diversity. Wind-borne and bird dispersers, and sprouting from previous remnant tree cover have played a significant role in this woody species regeneration (Blackham et al., 2014). In addition, a study focused on the potential of seed rain and foreign seed rain in the same site also confirmed that the potential was good for natural regeneration and the role of wind-borne and animal disperser agents in transferring local and foreign seeds to the degraded peatland (Blackham et al., 2013). Despite the potential for unassisted regeneration to occur, these two studies recommend enrichment planting as a means to accelerate the vegetation cover recovery processes and to increase tree diversity.

Other studies in other parts of the EMRP confirmed that the peat forest recovery was feasible through spontaneous regeneration but repeated fires will reverse the regeneration trajectory towards retrogressive (Page et al., 2009). A study in peat forest logged-over area and degraded peatland in Giam Siak Kecil-Bukit Batu Biosphere Reserve in Riau, East Sumatera concludes that forest regeneration in degraded peatland is no longer fruitful for restoring forest vegetation. Human intervention is still required to assist the establishment and recovery of the typical canopy species (Gunawan et al., 2012). In addition, a study in Berbak National Park, in Jambi Province, Sumatera discovered the natural regeneration of certain indigenous peat swamp forests happened even after fire and prolonged flood. The high survival of the indigenous species is due to resprouting from remnant tree covers and aboveground tolerance (van Eijk et al., 2009).

It should be noted that the dominated regeneration of certain indigenous peat swamp species following fire has often occurred. In Central Kalimantan, both *Shorea belangiran* and *Combretocarpus rotundatus* often dominate the colonisation following the fires (Giesen, 2004).

Another effort that has been trialled to promote regeneration of degraded peatland is through the establishment of artificial bird perches aimed at increasing forest seeds dispersal into the degraded peatland site. This technique has been tested in Central Kalimantan to increase the spreading out of seeds and recruitment by fruit eater birds (Graham & Page, 2012). This technique showed a significant result in terms of increasing seed dispersal; yet, with respect to the recruitment of seedlings it has shown the reverse trend. Hence, this study concludes that bird perches yield no significant outcome of transferring seeds from adjacent primary peat swamp forest into its neighboring degraded peatland areas.

3.5.2.2 Re-vegetation of bare peatland (assisted regeneration)

3.5.2.3 Seedlings nurseries

One particular problem with the degraded peatland is the lack of availability of indigenous tree seeds due to many parent trees being removed or dying due to logging and recurrent fires. Thus, seedling procurement is important in the process of bare peatland revegetation.

Generally, there are three techniques used for preparing and recruiting the indigenous peat swamp trees in Indonesia. These techniques include wildings; seeds collected from fruits and then raised in nurseries prior to field transplantation; and stem cuttings (Wibisono et al., 2005; van Eijk et al., 2009). The wildings involve collecting wild seedlings that have already germinated and resprouted in the ground. The main stages in the use of wildings are: wild seedlings are collected from the interior forest where the parent trees are located; the seedlings are put into soil polybags and placed in nurseries; and, the acclimating and hardening off of the seedlings, done prior to transplantation into the ground. “Seeding” produces seedlings from collected fruits from parent trees which are used to grow seedlings in a nursery up until transplantation. Finally, stem cutting is a technique of procuring seedlings by cutting stem tissue from adult or young saplings and putting it into soil polybags in the nursery bank before transplantation into the field (Wibisono et al., 2005; van Eijk et al., 2009).

Other techniques introduced to produce good quality seedling growth include the inoculation of mycorrhiza (either ectomycorrhizal or arbuscular fungus). Studies in Central Kalimantan have shown that inoculation of certain indigenous species with its corresponding mycorrhizas produces better seedling growth and survival rate (Tawaraya et al., 2003; Yuwati et al., 2007; Turjaman et al., 2008; Graham et al., 2013).

3.5.2.4 Seedlings transplanted

Transplantation of indigenous seedlings is one way to accelerate the recovery of bare peatland forest cover. Some trials of transplanted seedlings for indigenous peat swamp forest trees have been planted in Berbak National Park in Jambi Province, Sumatra (Giesen, 2004; van Eijk & Leenman, 2004; van Eijk et al., 2009) and Central Kalimantan province with the aim of reestablishing vegetation on the bare peatland (Suryadiputra et al., 2005; Graham et al., 2007; CKPP, 2008). However, floods and repeated fires are two major factors that challenge the success of seedling transplantation on peatland in Indonesia (van Eijk & Leenman, 2004; Page et al., 2009; van Eijk et al., 2009). To address the flood issue, a mound system has been introduced in Berbak National Park (van Eijk et al., 2009).

Table 3.2 Summary of restoration measures and techniques used for restoring degraded peatland in Indonesia

Management and strategy measures	Restoration technique	Comment	References
I. Hydrological management			
1.1 Peatland rewetting/re-flooding	Canal/ditch/drain blocking/damming	Establishment of water barriers or weirs by placing dam or bund infrastructure; aims to reduce surface run-off and increase water storing capacity within the blocked canals.	Suryadiputra et al., 2005; Dohong & Lilia, 2008; Limin, et al., 2008; CKPP, 2009; Maya, 2009; Panda et al., 2011; Joosten, 2014; Ritzema et al., 2014.
	Canal/ditch infilling	Closing of open canal/ditch by infilling the canal/ditch with peat material, dead wood debris (branches, twigs and trunks) or other suitable material	Houterman & Ritzema, 2009; Applegate et al., 2012
II. Peat forest cover restoration/ rehabilitation			
2.1 Natural regeneration/recolonisation (unassisted regeneration)	Seeds germination and resprouting from remnant trees, tree stumps.	The process of peat swamp forest natural regeneration in Sumatera and Kalimantan can happen through seed germination and resprouting from the remnant vegetation left on the ground	Giessen, 2004; van Eijk & Leenman, 2004; van Eijk et al., 2009; Gunawan et al., 2012.
	Seed rain	Seed rain can be used to predict the potential of natural regeneration of endemic plant species due to the natural seed supply from degraded and adjacent pristine forests	Blackam et al., 2013; Blackam et al., 2014.
	Dispersal systems and dispersers	Seeds dispersal mechanisms and seed dispersers play an important role in promoting the self-regeneration of forest plant species. Natural and artificial bird perches, for instance, can be used to enhance seed rain and distribution from dense seeds sources to scarce ones in the degraded forest	D'Arcy & Graham, 2008; Graham et al., 2012
2.2 Revegetation of bare peatland	Seedling nurseries	• Techniques for seedling procurement entail seed	Wibisono et al., 2005; Page et al., 2009

	germination, wilding and stem cutting • Inoculated seedlings with their corresponding mycorrhizae (e.g. *Shorea balangeran* and *Dyera polyphylla*)	Tawaraya et al., 2003; Yuwati et al., 2007; Turjaman et al., 2008; Graham et al., 2013.
Transplanted seedlings	Proper planting techniques and appropriate planting distances will ensure the successful establishment of seedlings	van Eijk & Leenman, 2004; Page et al., 2008; Page et al., 2009; van Eijk et al., 2009.

3.5.3 Challenges for restoring peatland in Indonesia

3.5.3.1 Peatland restoration performances

3.5.3.1.1 The effect of canal blocking on hydrological properties

Efforts have been made to study the efficacies of canal blocking on hydrological properties with changes such as the ground and surface water fluctuations, water storage, and water retention (Suryadiputra et al., 2005; Dohong & Lilia, 2008; Page et al., 2009; Jaenicke et al., 2010; OuTrop, 2010; Panda et al., 2011; Ritzema et al., 2014). In addition, investigations have also been made to explore the impact of peatland rewetting on peat soil moisture (CKPP, 2008; Jaenicke et al., 2011); and the greenhouse gases (GHGs) fluxes (e.g. CO2 and CH4) (Jauhiainen et al., 2008).

Nearly all studies reported that the surface and ground water levels were immediately increased after dams were placed in the main canals of Block A North and Block C of the EMRP (Suryadiputra et al., 2005; Dohong & Lilia, 2008; Ritzema et al., 2014) and Sebangau National Park (OuTrop, 2010; Panda et al., 2011). For instance, the water table within the dammed sites in the SSI canal, Sebangau National Park remained above the threshold level of 40 cm below the peat surface during the dry year 2006, while the control site (an unblocked canal) fell significantly below the threshold level of 40 cm (Panda et al., 2011). Similarly, the water table within Kalampangan canals in Block C of the EMRP increased up to 151 cm following the canal dam installation in October 2005 (Limin et al., 2007).

The surface water level difference between upstream and downstream from the dam site in the main primary canal of the EMRP was about 60 cm during the period of December 2004–September 2005 and the surface water level upstream was never below than 40 cm compared with the downstream site (Dohong & Lilia, 2008). In addition, it was reported that canal blocking activities carried out within the Peat Swamp Forest Natural Laboratory, Sebangau National Park were successful to slow down and reduce the discharge rate up to 74% following dam construction (OuTrop, 2010). The time spans used for the collection of the surface and groundwater levels for these studies were very short, and therefore, the long-term fluctuations of both the surface and groundwater tables is still unknown.

Studies that used radar satellite image analysis (the Japanese JERS and PALSAR) showed strong results for dams constructed in Block A North and Block C of EMRP, with strong radar signals in the blocked areas compared with those in unblocked areas. This is meant that peat humidity in the blocked areas increased, confirming the effectiveness of canal blocking in rewetting the over-drained areas (CKPP, 2008; Jaenicke et al., 2011).

Problems were also reported with regards to a number of dam structures that experienced technical issues such as collapse, bending, leaning and seepage. A few dams collapsed, due to strong water current and the fragility of the wooden structures used. For example, two out of six dams built in Block C EMRP collapsed due to the fragility of the timber structures used to retain strong water current and high water debit within the dam (Susilo at al., 2013; Ritzema et al., 2014). Similarly, a number of dams built in Block A North-West EMRP and in Sebangau National Park in Central Kalimantan experienced bending, leaning down and breakage owing to strong current, high water debit and excess water seepage, making them dysfunctional for retaining and raising nearby surface and ground water tables (Suryadiputra et al., 2005). Some dams built in the EMRP were also destroyed by illegal loggers, fishers and non-timber forest product collectors as the dams were perceived as hindering their transportation access to the interior forests (CKPP, 2008; Suyanto et al., 2009).

Table 3.3 Reported hydrological property changes following peatland rewetting through canal blocking techniques in several locations in Indonesia, from selected publications

Study	Study site	Canal blocking effects on						Monitoring method/technique used
		Temporary storage	Ground water table (GWL)	Surface water level (SWL) stability	Surface run-off	Flood peak	Peat humidity	
Ritzma et al.,2014	Block C, EMRP, Central Kalimantan	NA	↑	↕	NA	NA	↑	Observation PVC pipes in wells for monitoring the ground water tables
Susilo et al., 2013	Kalampangan dan Taruna canal in Block C of the EMRP, Central Kalimantan	NA	NA	↑	NA	NA	NA	Automatic gauges and loggers
Panda et al., 2012	Sebangau National Park, Central Kalimantan	↑	↑	↑	NA	NA	NA	To monitor ground water table, simple tube wells made from perforated PVC pipes were used; meanwhile, Peischaal measurement tapes were used to measure the surface water fluctuations in the drainage canals
Jaenicke et al., 2010	Block C and A North of EMRP	NA	NA	NA	NA	NA	↑	A combination of remote sensing (radar) and ground checking data
The Orangutan Tropical Peatland Project (OuTrop), 2010	Sebangau National Park	NA	NA	↑	NA	NA	NA	Staff gauges established to monitor surface water fluctuations between locations downstream and upstream of the dams
Page et al., 2009	Block C of EMRP	NA	↕	↑	NA	NA	NA	Remote sensing (ASAR and PALSAR)
Hoekman, 2009	Block E and A North EMRP	NA	NA		NA	NA	NA	A combination of remote sensed (Radar) and ground data

Suryadiputra et al., 2005	Block A North-West of EMRP	NA	↕	↑			NA	Staff gauges established to monitor surface water level fluctuations between downstream and upstream of the dams.
Limin et al., 2007	Sebangau National Park	NA	↑	↑	NA	NA	NA	Staff gauges established to monitor surface water fluctuations downstream and upstream of the dam locations
Limin et al., 2008	Block C of EMRP	NA	↑	↑	NA	NA	NA	
Jauhiainen et al., 2008	Block C of the EMRP	NA	↑	NA	NA	NA	NA	Automated water table level logger (Model DCX-22; Keller Winterthur, Switzerland)
Dohong and Lilia, 2008	Block A North-West EMRP	NA	↕	↑	NA	NA	NA	Staff gauges (surface water levels) and PVC pipes for the ground water tables.

Notes:

↑ = *Increased*

↓ = *Decreased*

↕ = *Increased and decreased (fluctuated) between drought and rainy seasons*

↔ = *No effect*

NA = Data not measured/information not available

3.5.3.1.2 Performance of bare peatland revegetation

A number of studies reported that the performance of seedlings planted on degraded and bare peatland in Sumatra and Kalimantan had shown a promising result in terms of seedling survival rates after a few months planted. For instance, a study in Berbak National Park, Jambi Province reported that the survival rate of transplanted seedlings was relatively high with an average between 65–85% for whole species after 3–5 months of growth. However, the longevity of the planted seedlings reduced significantly, with only 10% left after the area was subjected to prolonged flood and the area was submerged by 100–150 cm for several weeks (van Eijk & Leenman, 2004; van Eijk et al., 2009).

Seedlings planted along the banks of blocked canals had mixed success in the Block A North part of the EMRP. Seedlings planted closer to the dams had higher survival rates (95%) compared with those located a bit further away, which experienced mortality of up to 70% (Suryadiputra et al., 2005). The high mortality of seedlings planted further away from the dam was mainly due to termite attack. In addition, seedlings transplanted in the Sebangau area, Central Kalimantan had a high survival rate with a mortality rate average of 2% (Page et al., 2008).

3.6 Discussion and recommendations

Given the immense scale of peatland degradation in Indonesia, substantial restoration interventions are required to not only reduce the rate of degradation but also repair damage caused by past degradation.

While recognising the strategic value of the restoration trials implemented by various stakeholders, the present restoration practices are mostly "small and pilot-based" in terms of their scale and nature. Our current knowledge and skills are arguably inadequate for the "large and landscape scale" peatland restoration required in Indonesia. Further research is needed into the performance and efficacy of various peatland restoration techniques. There are numerous technical, physical, and social-policy challenges that have to be addressed prior to the peatland rewetting and revegetation being scaled-up and replicated at larger sites in Indonesia.

3.6.1 Peatland rewetting challenges

3.6.1.1 Technical challenges

A proper dam design is the key for peatland rewetting, to effectively raise and retain water levels along the blocked canals and nearby locations. The dam design has to be adaptable and amenable to the main requirements of dam construction in tropical peatland, such as low bearing capacity, high porosity, high permeability, and high hydraulic conductivity (Zakaria, 1992; Page et al., 2009; Ritzema et al., 2014). In addition, the main function of the dam is not to stop totally the water flow but rather to slow down water outflow from the canal (Jauhiainen et al., 2008). The design should be able to raise and retain the desired water table as high as possible, notably during periods of poor precipitation and high evaporation. The dam design depends on the size of the drain canal, water volume, and water velocity. For a small drain canal with little water debit and lower water velocity, a single plank dam or a composite plank dam combined with infill clay soil or compact peat may be suitable and adequate to raise and retain the desired water tables. For giant drain canals such in large-scale agricultural and industrial plantations, a more advanced and stronger dam design is needed (Page et al., 2009). A wooden two-sheet pile box dam design equipped with bracers, chambers and a spillway is highly recommended to address huge water debit and strong water pressure as well as preventing collapse, leaning, and dam dysfunction.

In the meantime, infill material for the dam is crucial for the longevity and effectiveness of the built dam in peat rewetting. It is important to avoid the use of peat soil that has been drained, oxidised, and frequently dried out as infill material. Such kinds of drained and oxidised peat lose their water absorption capacity and become hydrophobic (Landry & Rochefort, 2012). Experience from rewetting of peatland in the EMRP, Central Kalimantan shows that the use of mineral or clay soil as infill material for the dams was more effective compared with peat soil (Dohong & Lilia, 2008). The usage of drained and oxidised peats may not be effective in strengthening the dam timber structure and instead add more pressure to the dam structure. Apart from giving more pressure to the wooden dam structure, the use of drained and oxidised peats for dam infill material may trigger the release of both fluvial carbon loss and increase river pollution.

Dam spacing is also of crucial importance in peatland rewetting. The dam spacing is related to the desired surface water and ground water tables to be elevated, slope gradient and water volume (Armstrong et al., 2009). A larger distance between dams may not effectively raise and retain water as expected and might expose the dam to risks from erosion, seepage, leaning and even collapse. Cascading, closer dams are highly recommended to minimise the risk of dam dysfunction (Houterman & Ritzema, 2009; Page et al., 2009; Ritzema et al., 2014). It is suggested that the optimal water head difference between dams has a maximum depth of 30–40 cm (Houterman & Ritzema, 2009; Kozulin et al., 2010; Landry & Rochefort, 2012; Ritzema et al., 2014).

3.6.1.2 Physical challenges

The use of drained and oxidised peats for the compacted peat dam and canal infilling techniques needs to be carefully considered as it may create two problems. First, the drained and oxidised peats may have lost their water-holding capacity (hydrophobic) and been subject to irreversible shrinking (Rieley & Page, 2008b). Second, the use of dried peat for drainage canal infill may not be successful since it may float and wash away into downstream rivers during the rainy season. This may trigger an increase in Dissolved Organic Carbon and Particulate Organic Carbon concentrations in the river stream, which can exacerbate water pollution.

3.6.1.3 Social challenges

It has been reported that a number of built dams have been destroyed and removed by irresponsible persons who perceived the dams as disruptive to their transportation into the interior forests (Suryadiputra et al., 2005; CKPP, 2008; Suyanto et al., 2009). Certain groups of loggers, fishers and farmers have used drainage canals for transportation of felled logs, non-timber forest products, and fishing activities (OuTrop, 2010; Jaenicke et al., 2011; Chin et al., 2012; Ritzema et al., 2014).

To respond to this social challenge, the dam design has to be reengineered in order to reduce resistance from local communities. A dam design equipped with a spillway device can be used to allow farmers and fisher boats to pass over the dam. Aside from redesigning the dam; socioeconomic interventions have also to be developed to improve economic welfare and to promote the involvement and participation of the locals in the peatland rewetting program (Suryadiputra et al., 2005; Page et al., 2009).

3.6.1.4 Regulatory and Policy challenges

Despite there being only two regulations that currently control the minimum water table threshold for peatland cultivation activities, namely the Minister of Agriculture (MoA) Regulation No. 14 of 2009 and the Government of Indonesian Regulation (GoIR) No. 71 of 2014 (MoARI, 2009; MoLHRRI, 2014), they both stipulate a different minimum water table threshold. The MoA Regulation No. 14/2009 stipulates the water table should be maintained 60–80 cm below the peat surface (for oil palm cultivation), meanwhile, in the GIR No. 71 of 2014 the water table within cultivation areas should be retained at 40 cm below the peat surface. Apart from determining a minimum 40cm water table threshold, the GIR No. 71 of 2014 has also established peatland rewetting through canal blocking as a measure for controlling the water table.

Therefore, there is a need to harmonise and synchronise existing regulations on peatland water table and rewetting to come up with a uniform threshold.

3.6.2 Challenges of bare peatland revegetation

3.6.2.1 The invasive fern and shrub species

The emergence of invasive and dense fern and shrub communities is a substantial challenge to the revegetation of bare peatland. This challenge may hamper the establishment and recolonisation of endemic peat swamp forest due to nutrient competition and over-shading that blocks light penetration needed by indigenous woody species to germinate and sprout (Page et al., 2008; Page et al., 2009).

Another negative impact of dense fern and shrub communities is that they become fuel sources for fire during drought periods (Page et al., 2008; Page et al., 2009). It is recommended to have regular weeding and cutting activities to control invasive and dense fern and shrub communities, to make way for endemic woody species to reestablish and recolonise.

3.6.2.2 Repeated fires

Fire is considered one of the biggest challenges that may hamper the success of bare peatland revegetation in Indonesia (Page et al., 2009; Hoscilo et al., 2011). Repeated fires often destroy both parent trees and established seedlings and saplings on the ground. In addition, apart from hampering both natural and assisted regeneration of peat cover species, fire also will promote the emergence of invasive and dense fern and shrub communities following the fire event that may impede both active revegetation efforts and spontaneous regeneration. Besides, recurrent fires will also destroy and change the physical properties of the peat that may further challenge both active and unaided peat cover regeneration (Hoscilo et al., 2011).

CHAPTER 4 RESEARCH METHODOLOGY

4.1 Summary

This chapter describes the case study approach used for this thesis research. The chapter is divided into two major sections. The first section provides a brief overview of the Ex-Mega Rice Project (EMRP) area including a chronological account of related land use policy, area synopsis of the spatial characteristics of the area, a summary of land cover dynamics, and details of the plans for the area after the termination of the EMRP. A justification is provided for why the EMRP area is an ideal choice as the case study for this thesis. The second section of this chapter describes the three main methodological components of the case study analysis, namely: (1) the study of peatland restoration initiatives already implemented in the area; (2) the study of rewetting as a restoration method tried in the case study area; and, (3) the study of the extent and impact of illegal palm development and implications for peatland restoration.

Importantly, because Chapters 5, 6 and 7 of this thesis (the 'results' chapters) are presented as discrete papers submitted for publication in highly regarded international journals, the specific methods used for those papers are detailed in those chapters, and some parts are also repeated verbatim in this chapter to demonstrate the cogent nature of the overall methodology. Kindly note that this repetition is consistent with acceptable PhD submission format at The University of Queensland.

4.2 Study Site Description

4.2.1 An overview of the Ex-Mega Rice Project (EMRP)

President Soeharto issued the Presidential Instruction on 5 June 1995 regarding the national food security program. This instruction was followed up with the enactment of Presidential Decree No. 82 of 1995 on the development of about 1.46 Mha of peatland for food crops in Central Kalimantan.

The EMRP was then divided into five blocks: Block A with a total area 0.23 Mha (15.59%); Block B with total of 0.16 Mha (11.08%); Block C with a total area of 0.55 Mha (39.03%); Block D with a total area of 0.16 Mha (11.14%); and Block E with total area of 0.337 Mha (23.17%) (Figure 4.1). The development was funded through Presidential Decree No. 83 of 1995, which established a Presidential Assistance Fund for peatland development projects in Central Kalimantan.

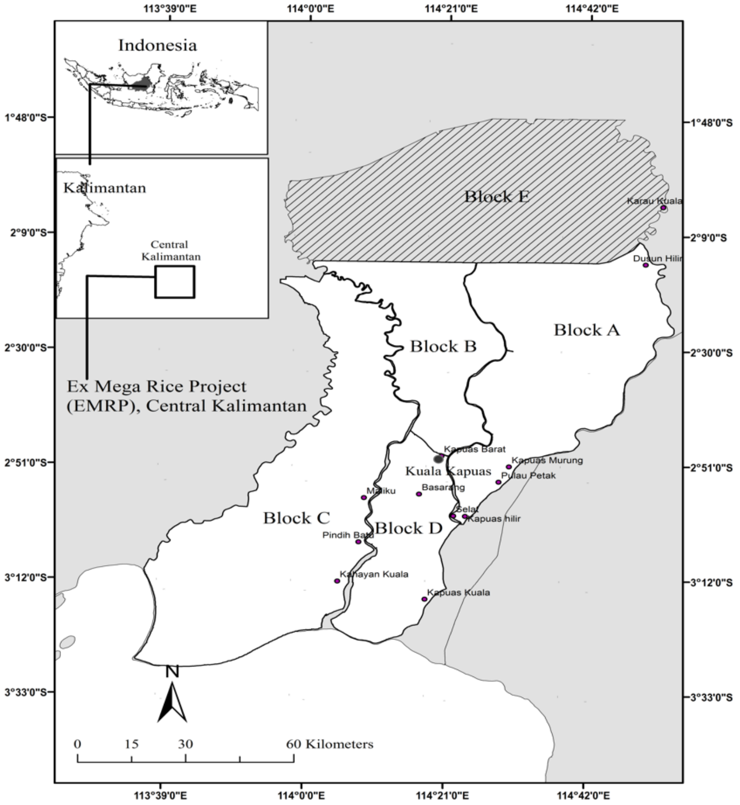


Figure 4.1 Map of research location: EMRP, Central Kalimantan, Indonesia

From 1996 to 1999 work progressed: (a) forest and land clearing began, particularly in the Blocks of A, B, C and D; (b) the main primary, secondary and tertiary drainage canals with a total length of 4,478 km were constructed; (c) there were 358 water gates constructed on the primary, secondary and tertiary canals, mostly in block A; (d) a total of 24,750 ha of rice fields were established in Block A; (e) a total of 16,895 transmigration settlement units and 14,935 transmigrant houses were constructed; and (f) around 14,935 transmigrant families were translocated to the area and mostly located in Block A (Mawardi, 2007).

A series of disastrous and extensive fires occurred in the EMRP area between 1997 and 1998. During that time it also became apparent the peatlands could not sustain rice production (Rieley & Page, 2008b). As a result, the Government of Indonesia enacted President Decree No. 80 of 1999 concerning the general guideline for the planning and management of the EMRP area. This decree marked the official termination of the EMRP.

Following termination, numerous government policies were enacted to attempt to conserve and restore the EMRP. These policies include: the State Minister for the Acceleration of Eastern Indonesia Area Development (MoDAEI) Decree No.4 of 2002 on the establishment of ad hoc teams for the settlement issues of the EMRP; the President Instruction No.2 of 2007 on the rehabilitation and revitalisation of the EMRP; and, MoF Regulation No. 55 of 2008 on the master plan for rehabilitation and conservation of the EMRP.

A chronological account of the land use policies relating to the EMRP are briefly summarised in Table 4.1.

Table 4.1 Governmental policies enacted before, during and after the establishment of EMRP

Development Stage and Issuance agency	**Title, No and Date of Regulation and Policy**
Pre-development stage:	
President Office (Soeharto)	President Instruction concerning National Food Security (dated 5 June 1995)
President Office (Soeharto)	President Decree No. No. 82 of 1995 on the development of peatland for food crops agriculture, in Central Kalimantan
Development/Construction Stage:	
Minister of Forestry (MoF)	MoF Decree No. 166/Menhut/VII/1996 on the allocation of forestland area for food crop agricultural development, in Central Kalimantan.
President Office (Soeharto)	President Decree No. 74 of 1998 on the amendment of President Decree No. 82 of 1995 on the development of peatland for food crop agriculture, in Central Kalimantan.
President Office (Bacharuddin Jusuf Habibie)	President Decree No. 133 of 1998 on the amendment of the President Decree No. 82 of 1995 on peatland development for food crops agriculture in Central Kalimantan.
President Office (Bacharuddin Jusuf Habibie)	President Decree No. 80 of 1999 on General Guideline for Planning and Management of the Peatland Development Area, in Central Kalimantan.
Post Termination Stage:	
The State Minister for the Acceleration of Eastern Indonesia Area Development (MoDAEI)	The MoDAEI Decree No. SK/004/KH.DP-KTI/IX/2002 on the establishment of the Ad Hoc Team for the settlement of the former Peatland Development Project area, in Central Kalimantan.
President Office (Susilo Bambang Yudhoyono President)	President Instruction No. 2 of 2007 on the acceleration of rehabilitation and revitalisation of the peatland development project area, in Central Kalimantan.
Coordinator Ministry for Economic Affairs (CMEA)	CMEA Decree No. Kep-42/M.EKON/08/2007 on the establishment of the Supporting Team and Working Groups within the National Team of Rehabilitation and Revitalisation of the peatland development area, in Central Kalimantan.
Ministry of Forestry (MoF)	MoF Regulation No. P.55/Menhut-II/2008 on the Master Plan for the Rehabilitation and Conservation Peatland Development area, in Central Kalimantan.

The map of land cover changes for the EMRP was processed through steps as depicted in Figure 4.2 The steps are explained as follows. Firstly, cloud-free Landsat images were obtained for each different year. Several of the Landsat images were used for this study including Landsat-5 TM in

1990, Landsat-7 ETM in 2003 and 2009, and Landsat-8 in 2013. The same spectral band was used in this experiment processes.

Secondly, metadata generated from each of the images was used to perform radiometric correction. The purpose of this correction was to obtain reflectance that has the nearest range value to the real value. The advantage of this stage was that the visualisation of each data was nearly same. It was useful for the visual interpretation so as to obtain land cover classification.

Thirdly, geometric correction was performed by using an image-to-image method so as to generate images that were uniformly geometric. The purpose of this stage was to correct the coordinates and position of the objects in the image geometrically.

Fourthly, all data for same year were gathered through the mosaic process. The next process was that all the secondary data, such as peat swamp forest maps, plantation maps, integrated intervention for farming maps, and Area of Interest (AoI) were used to define land cover classification. A visual interpretation method was used in this stage to acquire good accuracy with the results.

In the final step, the land cover area was calculated. The purpose of this stage was to analyse land cover changes in each year, notably with the area of peat swamp forest.

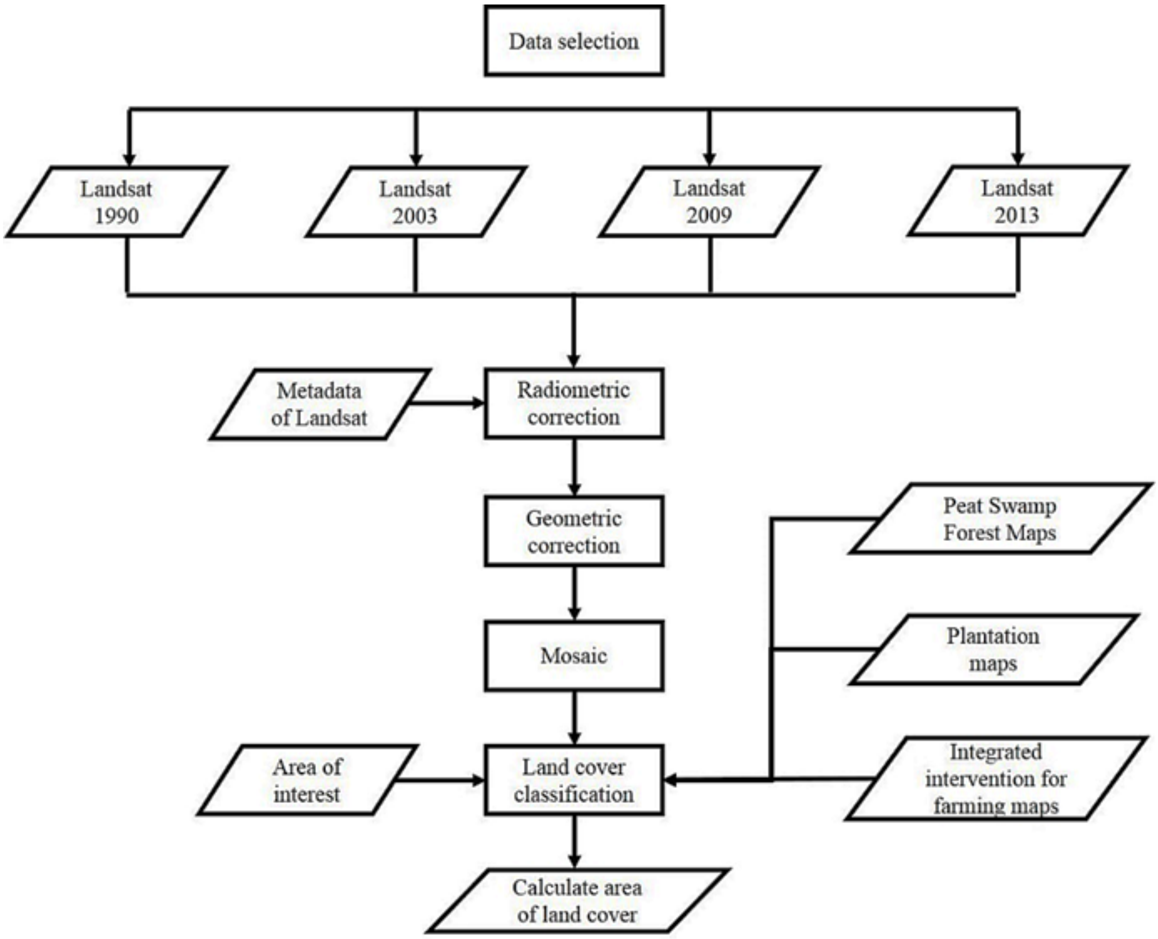


Figure 4.2 Flowchart of land cover processes and analysis

The land cover changes in the EMRP between 1990 and 2013 are shown in Figure 4.3 and Figure 4.4. In 1990, nearly 85% of the area was covered by peat swamp forest, whereas only small areas were covered by rice fields, open land and a mosaic of wetland areas. By 2003, forest cover had been reduced to 67% (mostly in the Block E and C) and the rice fields and fern/shrub communities had increased substantially. By 2009, peat swamp forest cover had been reduced to around 55%, while the fern/shrubs, rice fields, oil palm plantations and open land increased to about 17%, 13%, 6.3%, and 6.2% respectively. Finally, the peat swamp forest cover made up 49% and in the meantime, the industrial oil palm plantation, fern/shrub communities and rice fields made up 23%, 12% and 11% respectively of the total EMRP area.

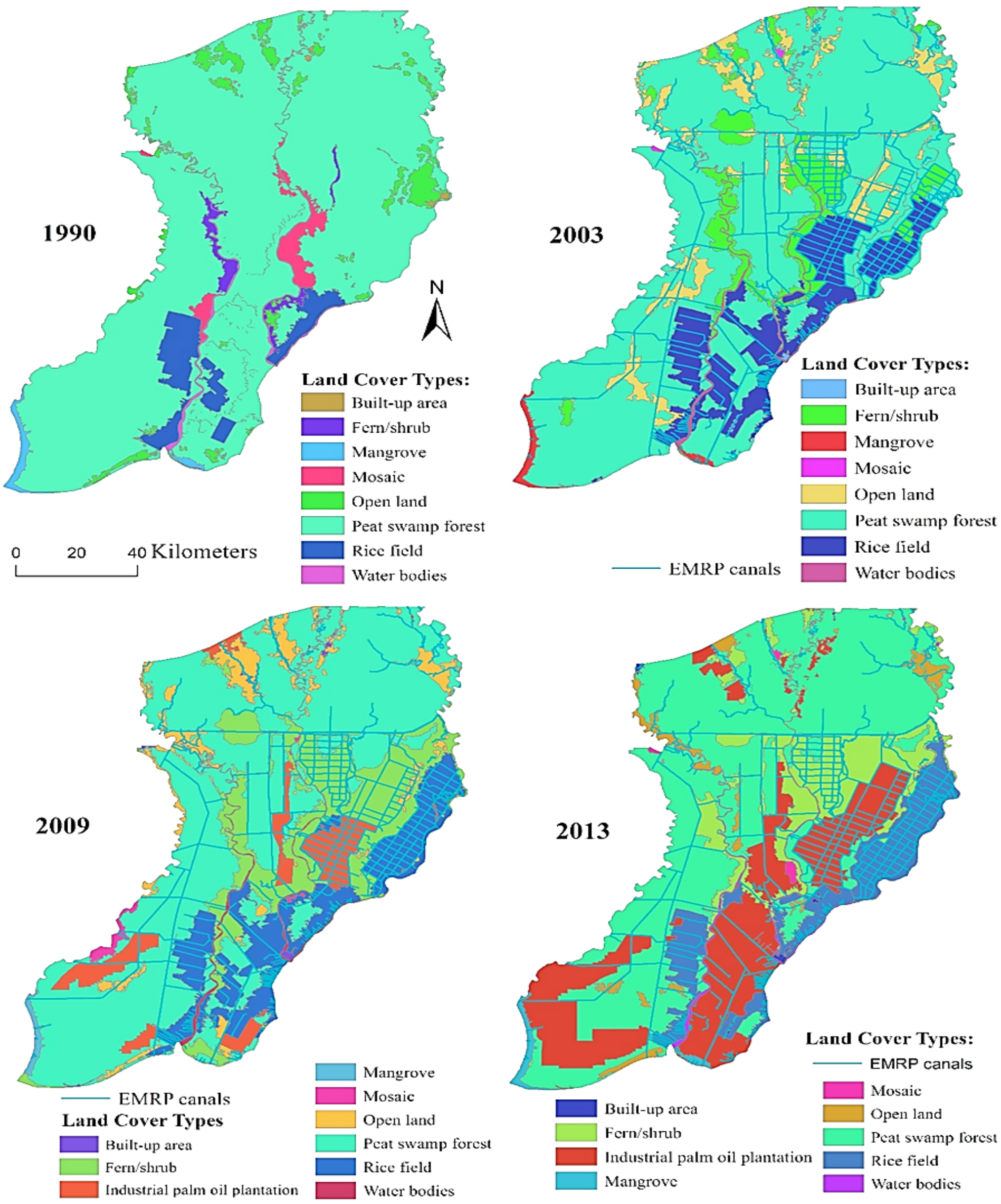


Figure 4.3 Land cover compositions and changes in the EMRP in 1990, 2003, 2009, and 2013

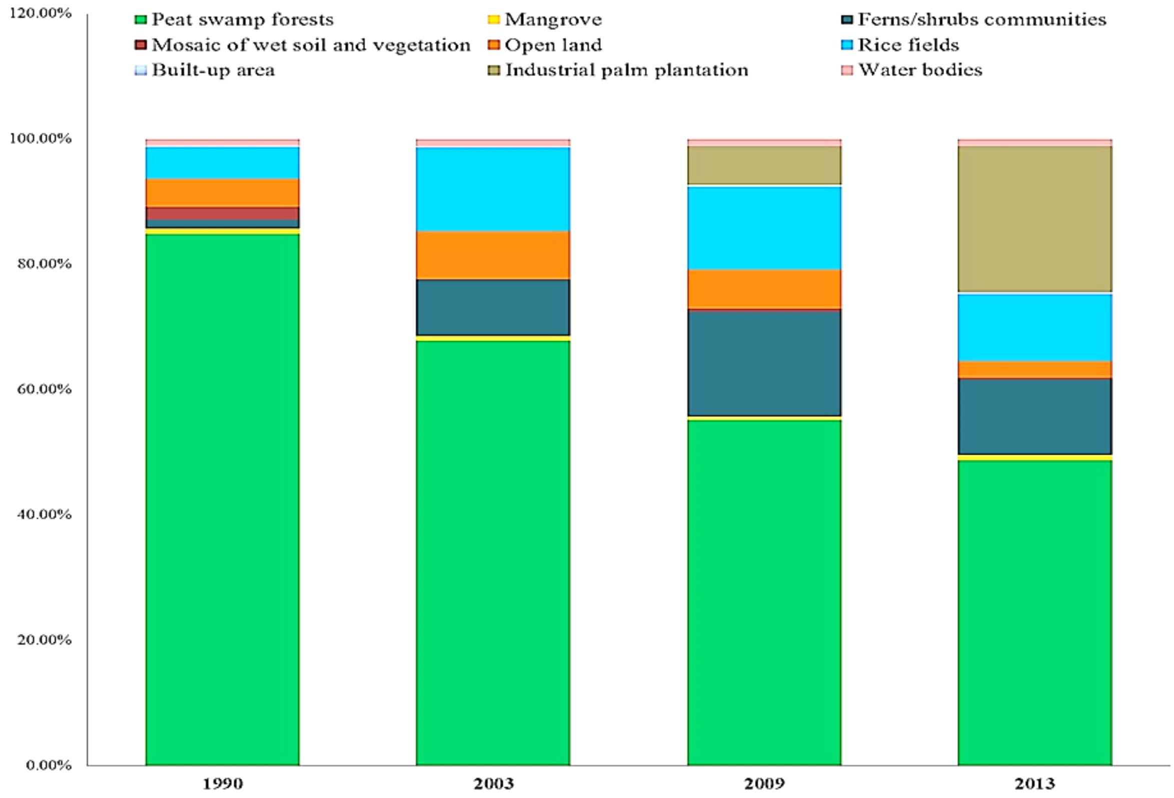


Figure 4.4 The composition of land covers of the EMRP in 1990, 2003, 2009 and 2013

In the meantime, over 64% of the 1.46 Mha EMRP area is constituted peatland area, whereas, the remaining area is mineral soil (Table 4.2). Of the 0.93 Mha of peatland area in the EMRP, about 0.32 Mha (21.92%) is classified as non-deep peat (< 300 cm peat thickness), while, around 0.61 Mha (41.78%) classified as deep peat (> 300 cm thickness). The spatial distribution of peatland based on peat thickness class is given in Figure 4.5. According to Indonesian laws, deep peat must be conserved and is not allowed for conversion to other land uses.

Table 4.2 Total area of EMRP based on peat depth class

Peat depth class	Total area (Mha)	Percentage
Mineral	0.53	36.30%
Peatland with depth <300 cm	0.32	21.92%
Peatland with depth >300 cm	0.61	41.78%
Total	1.46	100.00%
Data source: extracted from WIIP peatland atlas (Wahyunto et al 2004)		

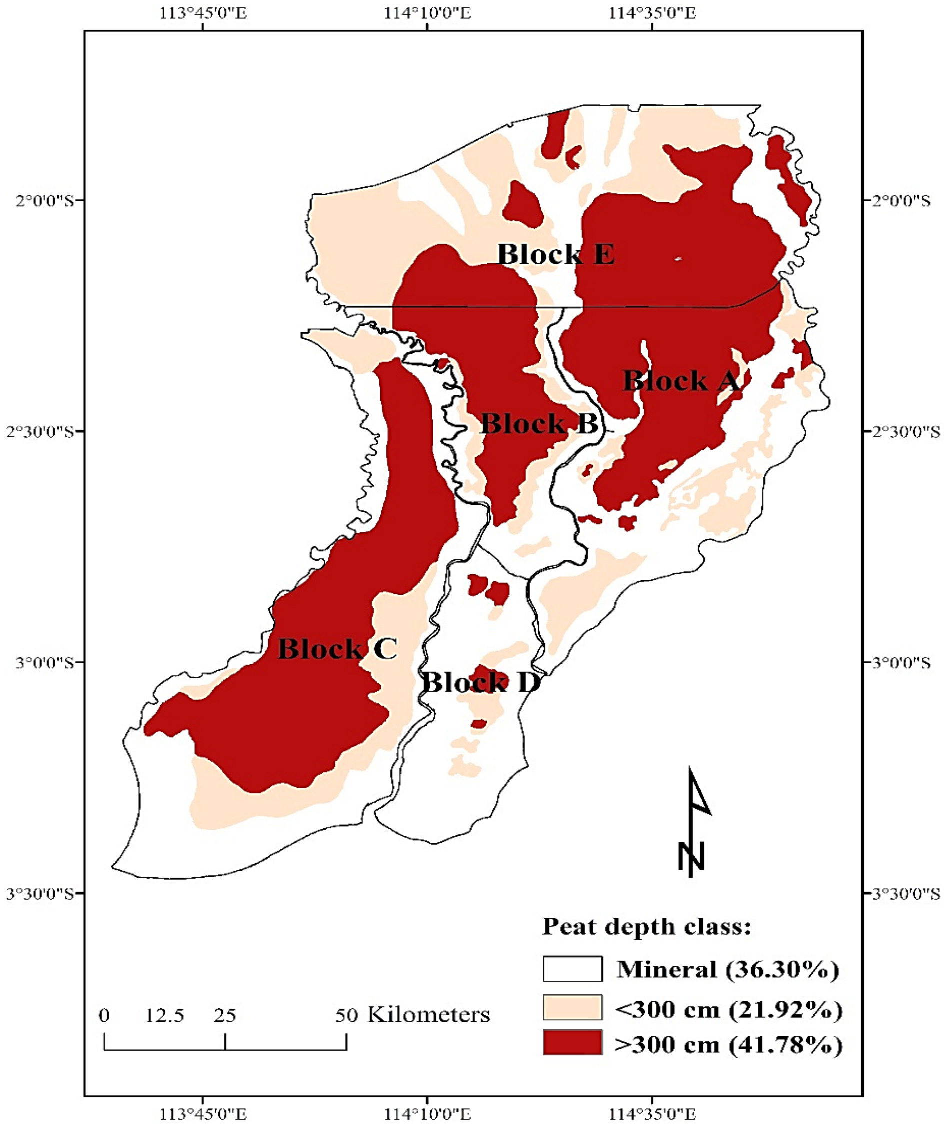


Figure 4.5 Peatland spatial extent and peat depth class in the EMRP

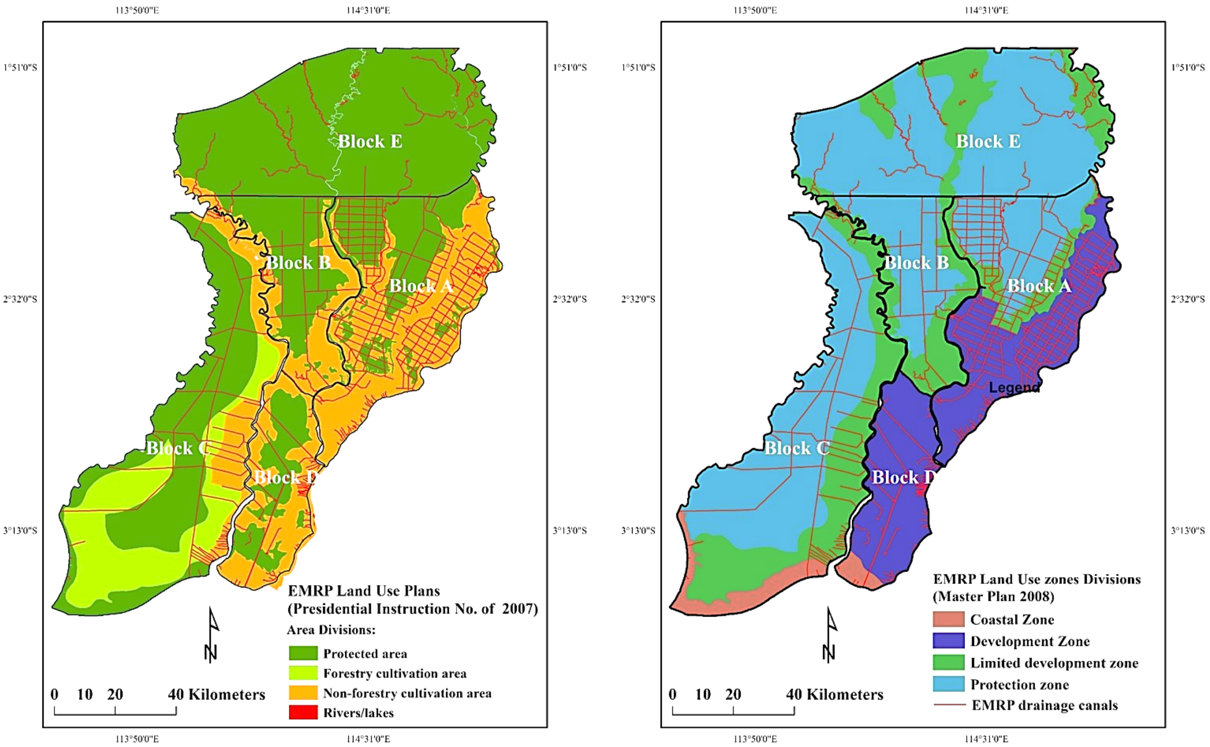
Several strategic plans have been developed for the rehabilitation and conservation of the EMRP following the termination of the EMRP in 1999. These land use plans are briefly discussed, as follows.

Firstly, under the coordination of the Minister for the Development Acceleration of Eastern Indonesia (MoDAEI), an ad hoc team was established and tasked to develop the strategic action plan for rehabilitation of the EMRP (Setiadi 2005). The team eventually completed a planning document entitled: "Plan for Rehabilitation of the Ex-One Million Hectares Peat Development Area in Central Kalimantan". The document has provided general guidelines for the conservation and development of the EMRP as the follows: 1) The reallocation of peatland area in the EMRP for conservation purposes has to be allocated on the basis of the 3 m depth threshold; 2) Conservation and protection activities should be targeted for water management, carbon sink as well as for wildlife nature conservation; 3) the EMRP was divided into two principal zones for conservation and utilisation. The ad hoc team document was not institutionalised and implemented on the ground and the document ended up as paper planning only.

Secondly, through the Presidential Instruction (INPRES) No. 2 of 2007 concerning the revitalisation and rehabilitation of the EMRP area; the area was allocated for three major uses including a protected area, forestry cultivation area, and non-forestry cultivation area (Figure 4.6). In addition, as one of the outcomes of the INPRES No. 2 of 2007, the Ministry of Forestry developed a master plan for rehabilitation and conservation of the EMRP and the master plan was legalised through the issuance of the Minister of Forestry Regulation No. 55 of 2008, which allocated about 1.05 Mha of EMRP area for protection (85.42%) and forestry cultivation areas (14.57%).

Finally, under the collaborative work of BAPPENAS, the Dutch Government and the Provincial Government of Central Kalimantan, the Master Plan for the rehabilitation and revitalisation of the EMRP area was completed in 2008. This master plan divided the EMRP into four main zones that are: protection 0.77 Mha (52.95%); development 0.30 Mha (20.21%); limited development 0.35 Mha (23.70%); and coastal 0.05 Mha (3.15%)(Figure 4.6).

It should be noted however, none of these planning documents have been used as a guide when allocating and utilising the EMRP area for production, conservation and restoration activities. Much of the activity currently under way in the field just simply ignored these documents.



(a) (b)

Figure 4.6 Land use plans/zoning of the EMRP based on INPRES No. 2 of 2007 (a) and Master Plan (b)

4.2.2 Problems caused by the Ex-Mega Rice Project (EMRP)

The EMRP has caused many environmental problems. There is an urgent need to fix these problems. The degree, extent and complexity of these problems and the related causes and influencing factors, make the EMRP project area a very useful case study through which to examine how to achieve successful peatland restoration. The following section outlines these problems in the context of justifying the EMRP as a good case study area for this thesis.

A total of 4,478 km of main primary, primary, secondary, and tertiary drainage canals were constructed in the area (Figure 4.7). In addition to this there were irrigation canals and about 358 units of primary, secondary and tertiary water gates constructed mainly in the block A. These drainage canals have disrupted the hydrological balance in the EMRP area owing to the increased water outflow run-off and reduced water storage capacity. As a result, the surface and groundwater tables drawdown during the drought periods and trigger peat oxidation and subsidence (Page et al., 2009; Hoscilo et al., 2012).

The EMRP drainage canals create major problems for the area as the peat dries out and is exposed to oxidation, which in turn leads to greater vulnerability in the area to fire events. Over-drainage and fire events together are the major source of CO2 emissions, which exacerbates climate change.

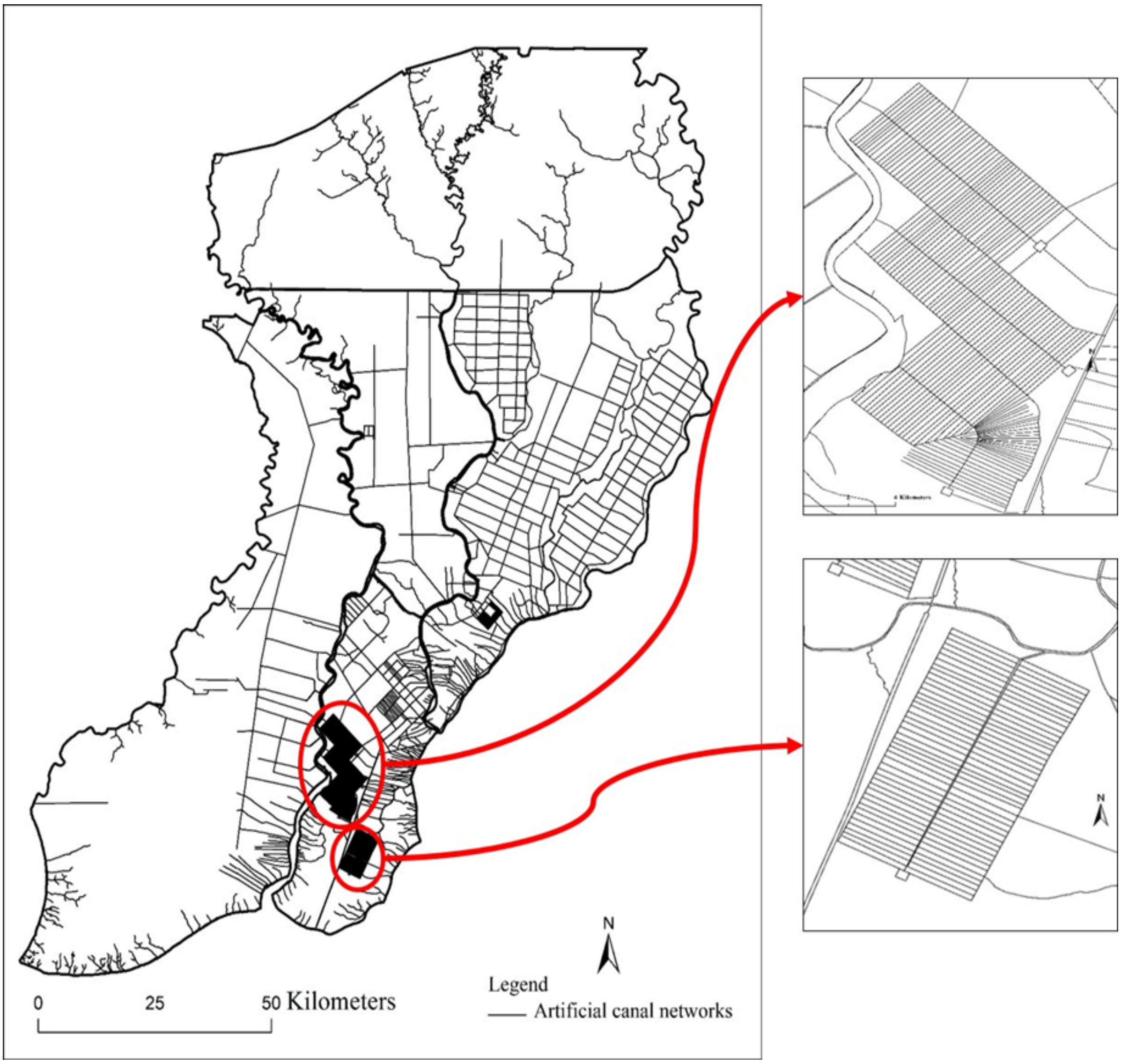


Figure 4.7 The network of artificial drainage canals in EMRP

Fire is one of the biggest contributors to peatland degradation in EMRP. Devastating fires occur nearly every dry season and produce thick smog that creates human health problems as well as releasing substantial CO2 emission to the atmosphere (Page et al., 2002; Aldhous, 2004; Hoscilo et al., 2011).

To understand the spatial distribution pattern of fires in the EMRP area over the period of 2001-2013, the time series hotspot data from MODIS (Terra and Aqua Satellites) were acquired and processed through the following steps.

First, the freely available MODIS (Terra and AQUA) hotspot data for the years 2001 to 2013 were acquired and downloaded from the NASA FIRMS Archive in the following website address: https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data). Second, all annual hotpot data of with a level of confidence above 50% were retrieved and classified by year (2001-2013). Third, annual hotspot data (2001-2013) were then overlaid with mineral soil and two different peat depth classes; peat depth less than 300 cm and the peat depth more than 300 cm. Fourth, the number of hotspots per year was then classified and totalled based on mineral and peat soil classes. Finally, total hotspots per annum during the period 2001 to 2013 were presented in a table to distinguish their locations on the basis of mineral and peat depth classes.

The analysis of times series hot spot data over the period 2001–2013 shows that hot spot frequencies are higher in the peatland areas compared with those in mineral soil (Table 4.3; Figure 4.8; Figure 4.9).

Table 4.3 Frequency distribution of hot spots in EMRP during period 2001–2013

Year	No of hot spots on mineral soil	No of hot spots on peat (depth < 300 cm)	No of hot spots on peat (depth > 300 cm)	Total No of hot spots on peat	Total No of hot spots on EMRP
2001	144	95	923	1,018	1,162
2002	1,065	1,560	3,352	4,912	5,977
2003	606	446	1,299	1,745	2,351
2004	839	650	2,224	2,874	3,713
2005	327	537	1,068	1,605	1,932
2006	1,125	955	3,779	4,734	5,859
2007	131	102	157	259	390
2008	64	53	21	74	138
2009	930	1,099	3,028	4,127	5,057
2010	8	4	6	10	18
2011	528	537	359	1,076	1,604
2012	224	349	1,275	1,624	1,848
2013	144	319	296	615	759

Source of data:

Hot spots data acquired, processed and analysed from MODIS (Terra and Aqua) with level of confidence > 50% (downloaded from NASA FIRMS Achieve at https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data)

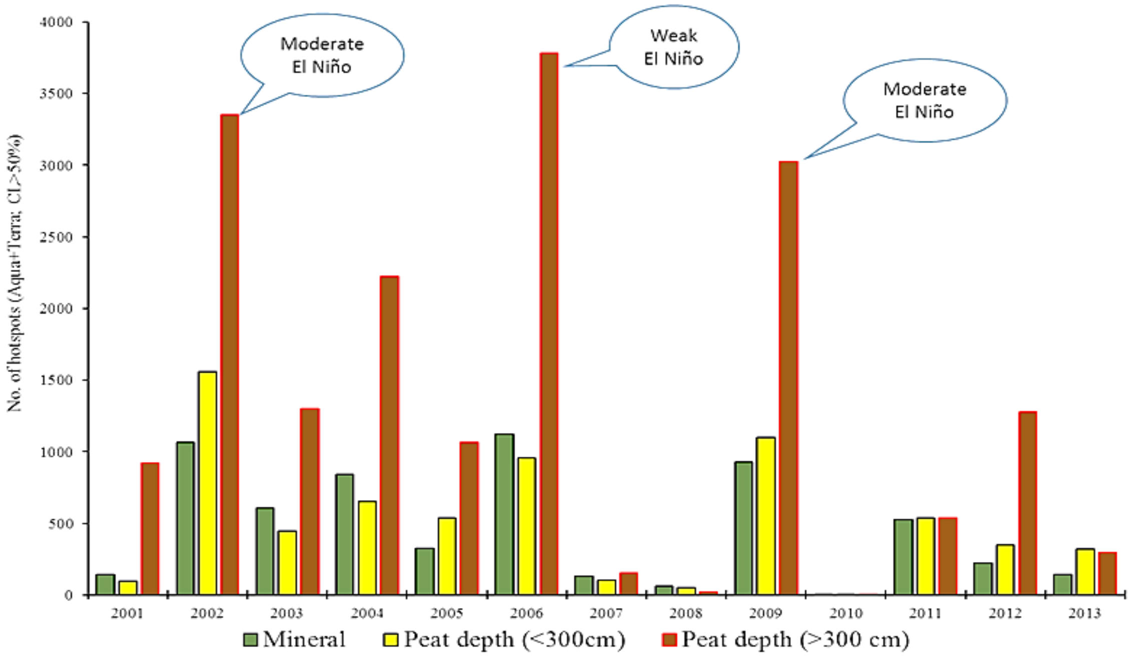


Figure 4.8 The distribution of hot spots according to peat depth class in EMRP 2001–2013

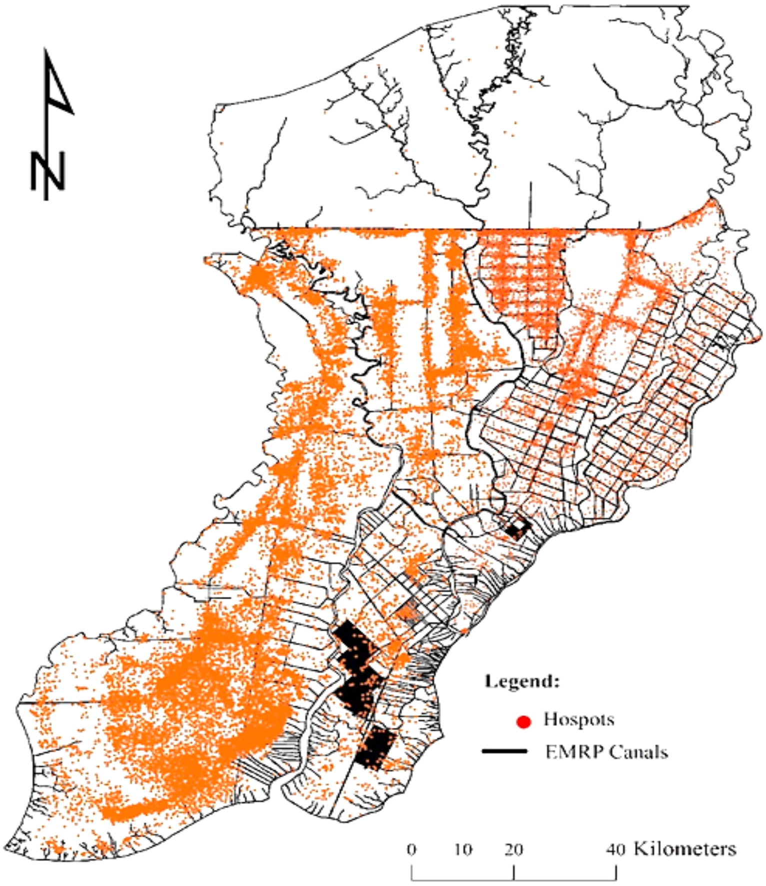


Figure 4.9 Cumulative hot spots (MODIS-Terra & AQUA CL > 50%) 2001–2013 in the EMRP

The increased expansion of industrial oil palm plantation is of particular concern in the EMRP. By 2012, there were about 0.199 Mha subject to palm oil permits allocated in the EMRP area and more than 44% of these palm oil concessionaires were allocated on deep peat (> 300 cm thickness), which is against existing regulations and renders them technically illegal (Figure 4.10).

Cultivating palm oil on peatland has been a major global concern due to its potential impact on the release of CO2 due notably to peat oxidation caused by peat drainage and fires

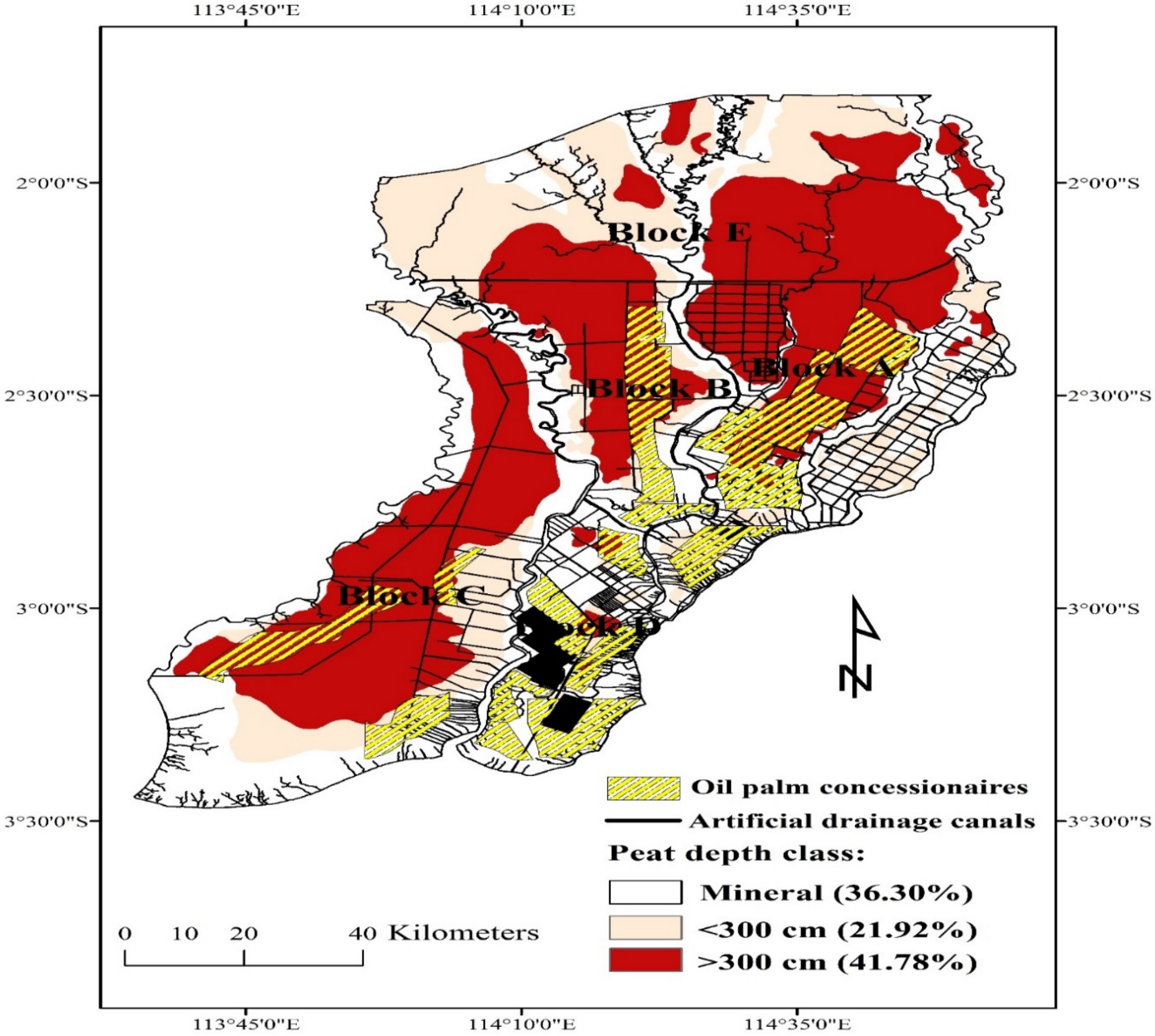


Figure 4.10 Spatial distribution of industrial palm oil concessionaires in EMRP (the oil palm concessionaires data (both database and georeferenced boundaries) were obtained from the Provincial Plantation Office of Central Kalimantan.

The socioecological problems associated with this mega project persist and a study reported that by 2005, about 54% out of 15,600 migrant families located in the area up to 1999/2000 had pulled out and fled their settlements and agricultural properties due to difficulty in growing crops to fulfil their subsistence needs (Mawardi, 2007).

4.3 Case Study Analysis

This thesis used a variety of data sources. These are listed in Table 4.4.

Table 4.4 Type, form, source and location of research data

Type of Data	Form of Data	Data Location
I. Biophysical/ecological data:		
• Land cover maps of Ex-Mega Rice Project (EMRP)	Paper and digital/remote sensing data (satellite images, aerial photographs)	Provincial Planning Agency; Provincial Forestry Agency, Provincial plantation office Landsat images from USGS (earthexplorer.usgs.gov)
• Land use maps of EMRP	Paper and digital/remote sensing data (satellite images, aerial photograph)	Provincial Planning Agency; Provincial Forestry Agency, Provincial Plantation Office
• Oil palm plantation concessionaires per district and the EMRP	Dataset (non-digital/digital)	Provincial plantation office and Kapuas district plantation office
• Peat distribution and peat depth for Central Kalimantan and the EMRP	Dataset/digital	Wetlands International-IP, World Resource Institute (www.wri.org/resources)
• Biophysical data (soil, biomass, rainfalls, elevation, slope, nutrient, etc.) of the EMRP	Dataset and processed/digital	Provincial Planning Agency; Provincial Forestry Agency, Provincial Plantation Office BOSF, CIMTROP, Wetlands International
II. Socio-economic Data:		
• Population, economic growth, export-import (CPO, PKO), oil palm data with regards to total area, productivity, labour and price.	Dataset and published data	Interview, provincial/district statistical offices, Provincial Planning Agency; Provincial/district plantation offices, NGOs (BOSF, WWF, CIMTROP), Directorate General of Plantation, Ministry of Agriculture, FAOSTAT of Food and Agriculture Organisation (FAO) at www.fao.org/statistics/en
• Other socioeconomic data relevant to the studies	Dataset and processed data	Interview, provincial/district statistical offices, oil palm plantation companies

Detailed descriptions of how this data was used and analysed is provided in the methods sections of Chapters 5, 6 and 7 of this thesis. In summary, the analysis methods used included descriptive and inferential statistical methods, remote sensing processing and interpretation methods and Geographical Information Systems (GIS) using ArcGIS 10.2 software. A descriptive statistical approach was used to classify, present and analyse the primary data. Cross tabulation and simple descriptive statistical technique were used such as distribution frequency, median, mode and average values of the data set and all data sets were stored in the form of excel files. All digital and spatially remote sensing data (land use classification, oil palm concessionaires' distribution, peat extent and depth) were classified, processed, mapped and presented by using ArcGIS Software version 10.2

The research analysis consists of three main components: (a) all restoration activities implemented in the EMRP (presented in Chapters 3 and 5); (b) looking critically at rewetting in the EMPR (presented in Chapter 6; and (c) I looked at the illegal palm oil in the EMRP (presented in the Chapter 8).

CHAPTER 5 REWETTING OF DEGRADED PEATLAND: A CASE STUDY FROM THE EX-MEGA RICE PROJECT, CENTRAL KALIMANTAN, INDONESIA

Summary

From 1995 to 1999, the Government of Indonesia attempted to convert more than one million hectares of peatland (mostly covered by peat swamp forests) in Central Kalimantan province to rice farms. Tragically, the targeted peatlands were not capable of sustaining rice production and the initiative, which subsequently became known as the Ex-Mega Rice Project, was a tremendous failure. The initiative was officially terminated in 1999 and since then the Ex-Mega Rice Project area has been a hot spot of environmental problems. Recurrent fires of semi-drained peat have resulted in globally significant volumes of greenhouse gas emissions and smoke pollution across the region has caused major public health problems and political controversy.

Various restoration initiatives have been attempted to address these problems but effectively all have been small-scale, demonstration-like in nature and lacking in wider impact. Arguably the most common restoration method tried has been peatland re-wetting, a technique in which drainage canals are blocked with rudimentary dams so that the depth of the watertables of the peatlands are somewhat restored and the burning potential of the peat retarded. Little research has been published on what constitutes and influences successful tropical peatland restoration techniques such as rewetting. This chapter address this gap in the ecological restoration literature by analysing a collection of peatland rewetting initiatives used by Wetlands International in the Ex-Mega Rice Project area between 2003 and 2008. Analysis reveals that effective rewetting can be achieved, with or without spillways on "dam box" designs, if special design consideration is given to dam crest elevation and dam spacing, and if the materials used to construct the dams are sufficiently durable and appropriate. The analysis also revealed that rewetting dams built for restoration are frequently damaged, apparently by loggers and fishermen opposing the restoration intervention in the area. This chapter makes several recommendations for how these lessons can be incorporated into larger-scale restoration intervention plans, so that future restoration activities have a greater probability of success.

5.1 Introduction

Approximately one-fifth of the 21 Mha peatland in Indonesia is located in Central Kalimantan province (Page et al., 2011). Peatlands in Central Kalimantan hold globally significant carbon stocks (holding over 11% of 57 GtC of the country's peats carbon), provide habitat for iconic species such as the Orangutan and Proboscis monkey, and sustain the livelihoods of thousands of local people (Wahyunto et al., 2004; Jaenicke et al., 2008; Wahyunto et al., 2010).

Central Kalimantan's peatland is mostly classified as ombrotrophic (rain-fed). These sorts of peatlands formed across hundreds of kilometres of inland freshwater river valleys. Some peatlands in Central Kalimantan are minerotrophic (receiving surface run-off or groundwater inflow) and are located along the fringe of coastal lagoons, the banks and flood zones of rivers and the margin of upland lakes (Rieley & Page, 2008b). Peatland that is in a pristine state is an effective hydrological regulator, controlling excess water during the rainy periods and retaining and slowly releasing water back into rivers during drought periods (Wösten et al., 2008; Jaenicke et al., 2010).

Between 1995 and 1998 the Government of Indonesia, under the Soeharto regime, attempted to convert around 1.46 Mha of peatland in Central Kalimantan to rice farms (Mawardi, 2007; Rieley & Page, 2008b). The area of this initiative became known as the Ex-Mega Rice Project (EMRP). Hundreds of thousands of hectares of peat swamp trees were cut down and removed and more than 4,700 km of drainage canals were constructed (Ritzema et al., 2014). The main drains were large and deep and were constructed by cutting through the peat domes. This led to the disruption of the hydrological balance over the whole area, owing to excessive outflow and water run-off, which in turn caused long-term over-drainage problems (Page et al., 2009; Ritzema et al., 2014). Because of this, the EMRP area now experiences over-drainage and extensive fires occur almost every year.

The EMRP was terminated in 1999 through President Decree No. 80 (PORI, 1999). Despite the few master plans prepared by the Indonesia Government for the rehabilitation and restoration of the EMRP, little has been done on the ground to address the rate of peatland degradation and restore already degraded areas.

A handful of conservation and research organisations have introduced peatland rewetting programs aimed at restoring the hydrological properties of the EMRP area. Peatland rewetting, by blocking the drainage canals, was introduced in Block A North-West of the EMRP between 2003 and 2008 under the programs called the Climate Change, Forests and Peatland in Indonesia (CCFPI) and the Central Kalimantan Peatland Project (CKPP)(Suryadiputra et al., 2005; CKPP, 2008; Dohong & Lilia, 2008). Under the CCFPI program, seven large dams were successfully constructed between 2003 and 2004 (Suryadiputra et al., 2005). Under the CKPP initiative, 19 large dams were successful built between 2007 and 2008 (CKPP, 2008). A similar rewetting activity was also introduced in Block C under two partnership flags called the Keys for Securing Tropical Peat Carbon (KEYTROP) and the Restoration of Tropical Peatland for Sustainable of Renewable Natural Resources (RESTORPEAT) in 2005. Under these two initiatives, six dams were finally completed to block the drain canals in Block C of the EMRP in 2005 (Limin et al., 2007; Jaenicke et al., 2011; Ritzema et al., 2014).

Despite the use of rewetting in the EMRP area and the sound logic behind the technique, little is known about the elements of the method that are most likely to support effective restoration in practice. There are no accepted guidelines for “good” rewetting practice. In the following sections of chapter, This Chapter presents a case study of the rewetting activities tried by Wetlands International Indonesia Programme (WI-IP) in Block A North-West of the EMRP. The study findings were coherently analysed and presented so they might be used to inform better rewetting and restoration practices in Central Kalimantan and tropical peatlands more widely.

5.2 Method

5.2.1 Study site

This chapter presents analysis of the rewetting activities carried out by WI-IP in Block A of the EMRP from 2003 to 2015. The study area covers approximately 49,000 ha (Figure 5.1). The following section describes the case study area and the broader context of the case study analysis.

The EMRP was developed with the aim of securing and boosting national rice production during the Soeharto Presidential era. To realise this objective, President Soeharto issued the Presidential Instruction on 5th June 1995 concerning the national food security program. This instruction was then strengthened through the enactment of President Decree No. 82 of 1995 regarding the development of peatland for food crops in Central Kalimantan.

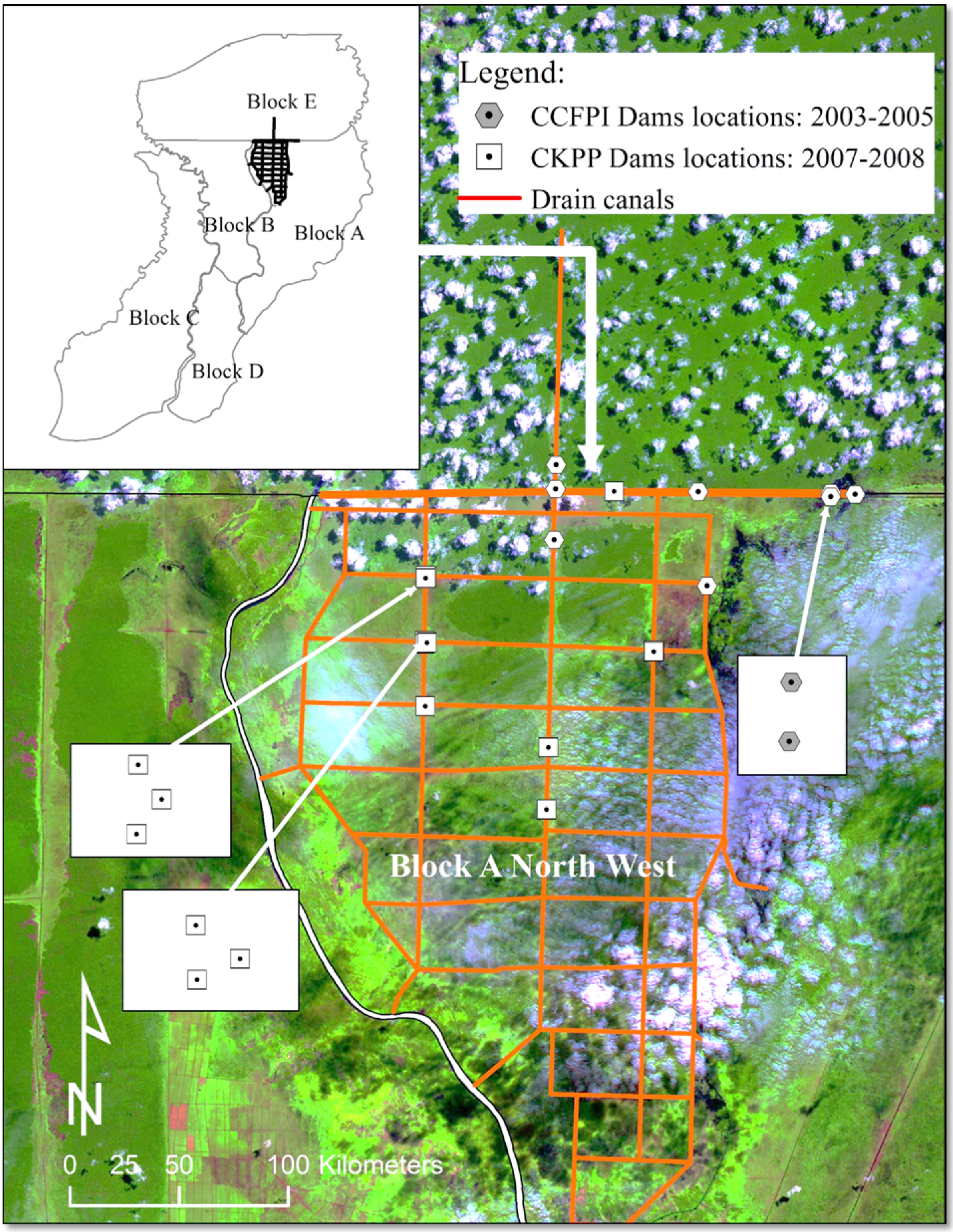


Figure 5.1 Study site: Block A North-West, the EMRP

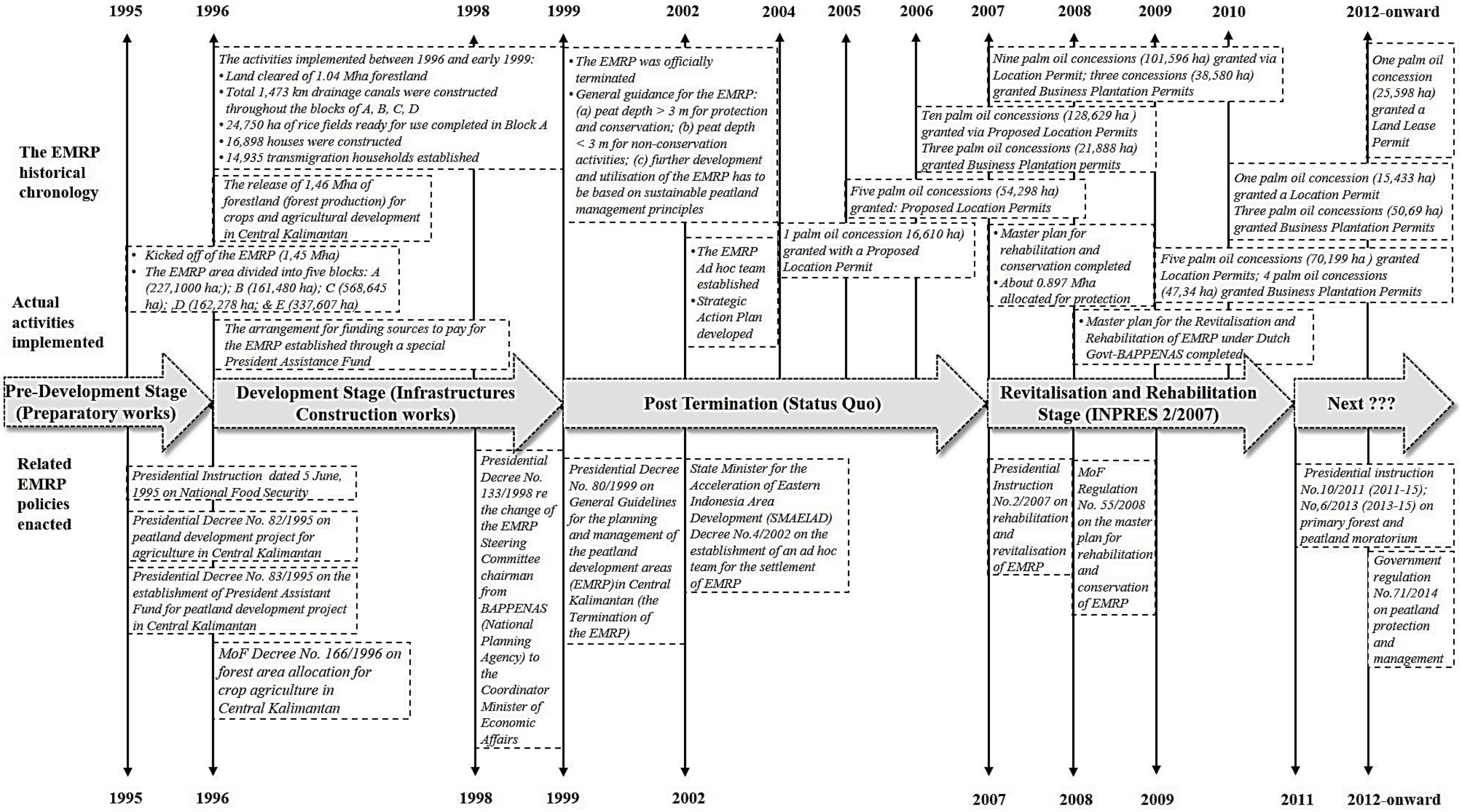
To legalise the conversion of peat forestland to agriculture land, the Minister of Forestry changed and relinquished the forestland status of the EMRP through Ministerial Decree No. 166/1996 concerning the allocation and delineation of around 1.45 Mha forest land for agriculture. The EMRP was then divided into five blocks: Block A with a total area 0.23 Mha (15.59%); Block B with total of 0.16 Mha (11.08%); Block C with a total area of 0.55 Mha (39.03%); Block D with a total area of 0.16

Mha (11.14%); and Block E with total area of 0.337 Mha (23.17%). The development was funded through President Decree No. 83 of 1995, which established a Presidential Assistant Fund for peatland development projects in Central Kalimantan.

From 1996 to 1999 work progressed: (a) forest and land clearing occurred, particularly in the Blocks of A, B, C and D; (b) the main primary, secondary and tertiary drainage canals with a total length of 4,478 km were constructed throughout the area; (c) 358 water gates were constructed on the primary, secondary and tertiary canals, mostly in block A; (d) a total of 24,750 hectares of rice fields were established in Block A; (e) a total of 16,895 transmigration settlement units and 14,935 transmigrant houses were constructed; and (f) around 14,935 transmigrant families were translocated to the area and mostly located in Block A (Mawardi, 2007).

A series of disastrous and extensive fires occurred in the EMRP area between 1997 and 1998. During that time it also became apparent the peatlands could not sustain rice production. As a result, the Government of Indonesia enacted President Decree No. 80 of 1999 concerning the general guideline for the planning and management of the EMRP area. This decree marked the official termination of the EMRP.

Following termination, numerous government policies were enacted to attempt to conserve and restore the EMRP. These policies include: the State Minister for the Acceleration of Eastern Indonesia Area Development (MoDAEI) Decree No.4 of 2002 on the establishment of Ad Hoc teams for the settlement issues of the EMRP; the President Instruction No.2 of 2007 on the rehabilitation and revitalisation of the EMRP; and, MoF Regulation No. 55 of 2008 on the master plan for rehabilitation and conservation of the EMRP. The chronological historical policies relating to the EMRP are shown in Figure 5.2.



The activities implemented between 1996 and early 1999:

- *Land cleared of 1.04 Mha forestland*
- *Total 1,473 km drainage canals were constructed throughout the blocks of A, B, C, D*
- *24,750 ha of rice fields ready for use completed in Block A*
- *16,898 houses were constructed*
- *14,935 transmigration households established*

The release of 1,46 Mha of forestland (forest production) for crops and agricultural development in Central Kalimantan

- *Kicked off of the EMRP (1,45 Mha)*
- *The EMRP area divided into five blocks: A (227,1000 ha;); B (161,480 ha); C (568,645 ha); ,D (162,278 ha; & E (337,607 ha)*

The arrangement for funding sources to pay for the EMRP established through a special President Assistance Fund

- *The EMRP was officially terminated*
- *General guidance for the EMRP: (a) peat depth > 3 m for protection and conservation; (b) peat depth < 3 m for non-conservation activities; (c) further development and utilisation of the EMRP has to be based on sustainable peatland management principles*

- *The EMRP Ad hoc team established*
- *Strategic Action Plan developed*

1 palm oil concession 16,610 ha) granted with a Proposed Location Permit

Five palm oil concessions (54,298 ha) granted: Proposed Location Permits

Ten palm oil concessions (128,629 ha) granted via Proposed Location Permits Three palm oil concessions (21,888 ha) granted Business Plantation permits

Nine palm oil concessions (101,596 ha) granted via Location Permit; three concessions (38,580 ha) granted Business Plantation Permits

- *Master plan for rehabilitation and conservation completed*
- *About 0.897 Mha allocated for protection*

- *Master plan for the Revitalisation and Rehabilitation of EMRP under Dutch Govt-BAPPENAS completed*

Five palm oil concessions (70,199 ha) granted Location Permits; 4 palm oil concessions (47,34 ha) granted Business Plantation Permits

One palm oil concession (15,433 ha) granted a Location Permit Three palm oil concessions (50,69 ha) granted Business Plantation Permits

One palm oil concession (25,598 ha) granted a Land Lease Permit

Presidential Instruction dated 5 June, 1995 on National Food Security

Presidential Decree No. 82/1995 on peatland development project for agriculture in Central Kalimantan

Presidential Decree No. 83/1995 on the establishment of President Assistant Fund for peatland development project in Central Kalimantan

MoF Decree No. 166/1996 on forest area allocation for crop agriculture in Central Kalimantan

Presidential Decree No. 133/1998 re the change of the EMRP Steering Committee chairman from BAPPENAS (National Planning Agency) to the Coordinator Minister of Economic Affairs

Presidential Decree No. 80/1999 on General Guidelines for the planning and management of the peatland development areas (EMRP)in Central Kalimantan (the Termination of the EMRP)

State Minister for the Acceleration of Eastern Indonesia Area Development (SMAEIAD) Decree No.4/2002 on the establishment of an ad hoc team for the settlement of EMRP

Presidential Instruction No.2/2007 on rehabilitation and revitalisation of EMRP

MoF Regulation No. 55/2008 on the master plan for rehabilitation and conservation of EMRP

Presidential instruction No.10/2011 (2011-15); No,6/2013 (2013-15) on primary forest and peatland moratorium

Government regulation No.71/2014 on peatland protection and management

Figure 5.2 Governmental policies enacted during the development stages of the EMRP

The land cover changes in the EMRP between 1990 and 2013 are shown in Figure 5.3 and Figure 5.4 and

Table 5.1. In 1990, nearly 85% of the area was covered by peat swamp forest, whereas only minor areas were covered by rice fields, open land and a mosaic of wetland areas. By 2003, forest cover had been reduced to 67% (mostly in the Block E and C) and covers of rice fields and fern/shrub communities had increased substantially. By 2009, peat swamp forest cover had been reduced to around 55%, while covers of the fern/shrubs, rice fields, oil palm plantations and open land increased to about 17%, 13%, 6.3%, and 6.2% respectively. Finally, the peat swamp forest cover made up 49% and in the meantime, covers of industrial oil palm plantation, fern/shrub communities and rice fields made up 23%, 12% and 11% respectively of the total EMRP area.

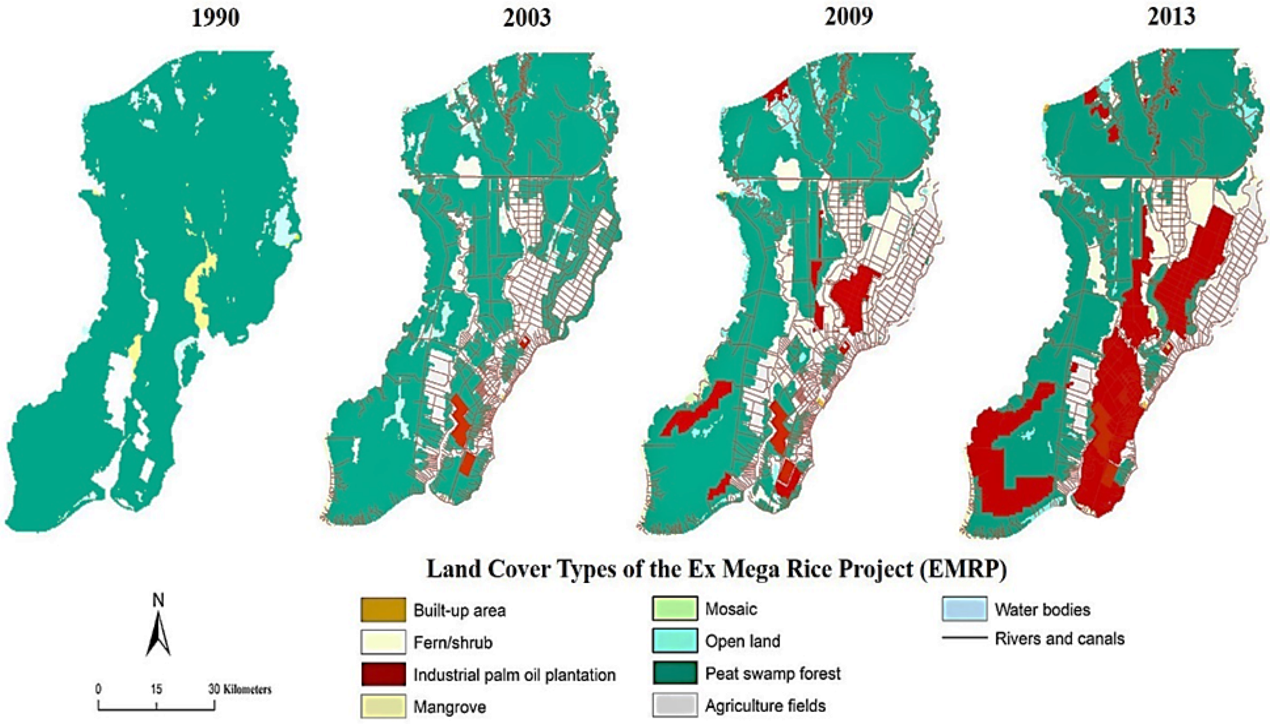


Figure 5.3 The state of land cover of the EMRP in 1990, 2003, 2009, and 2013

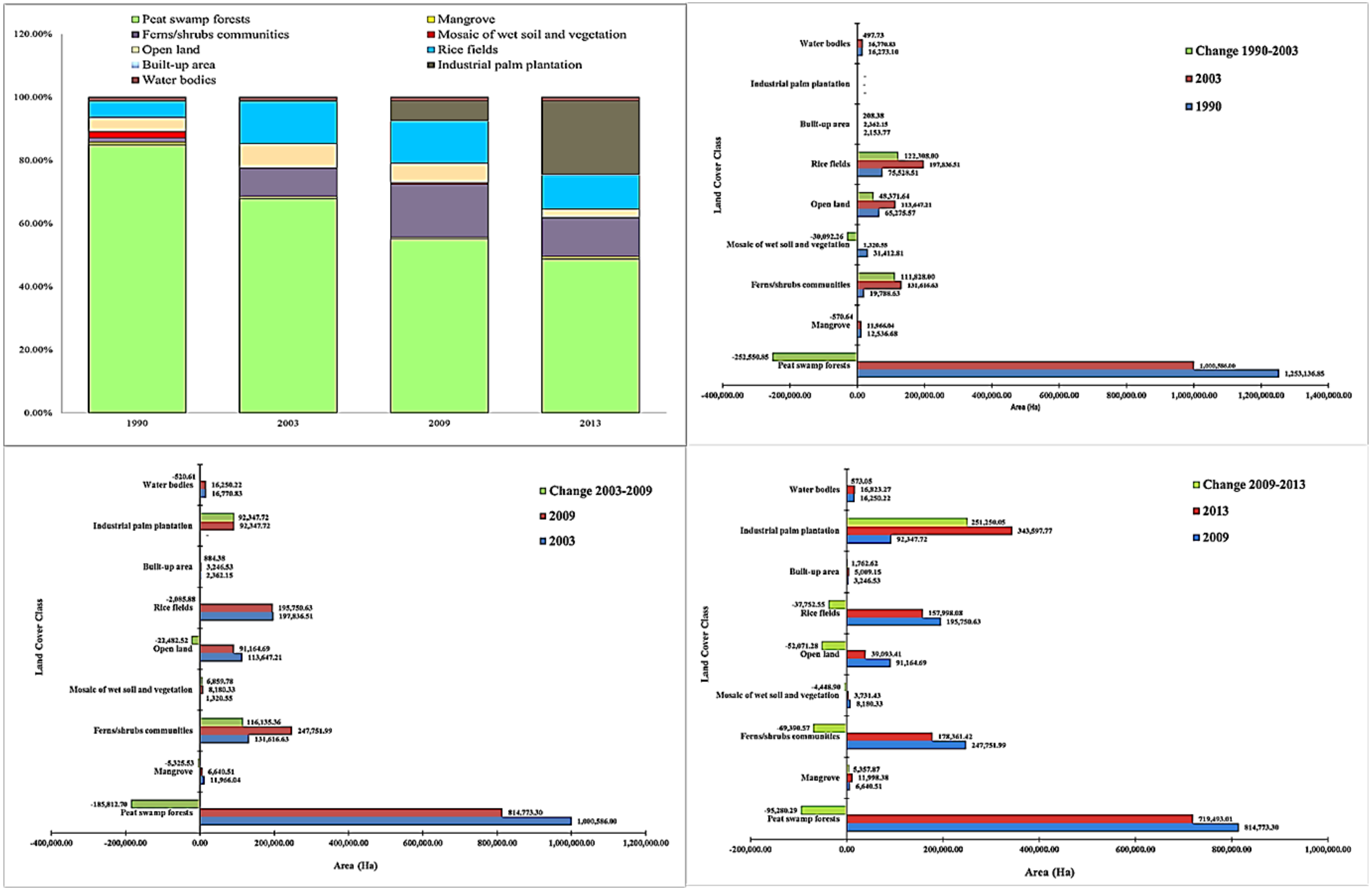


Figure 5.4 Land cover compositions and land cover changes in the EMRP in 1990, 2003, 2009, and 2013

Table 5.1 The composition of the EMRP land cover in 1990, 2003, 2009 and 2013

Land cover class	**1990**		**2003**		**2009**		**2013**	
	Absolute	**(%)**	**absolute**	**(%)**	**absolute**	**(%)**	**absolute**	**(%)**
Peat swamp forests	1,253,136.85	84.89%	1,000,586.00	67.79%	814,773.30	55.20%	719,493.01	48.74%
Mangrove	12,536.68	0.85%	11,966.04	0.81%	6,640.51	0.45%	11,998.38	0.81%
Ferns/shrubs communities	19,788.63	1.34%	131,616.63	8.92%	247,751.99	16.78%	178,361.42	12.08%
Mosaic of wet soil and vegetation	31,412.81	2.13%	1,320.55	0.09%	8,180.33	0.55%	3,731.43	0.25%
Open land	65,275.57	4.42%	113,647.21	7.70%	91,164.69	6.18%	39,093.41	2.65%
Rice fields	75,528.51	5.12%	197,836.51	13.40%	195,750.63	13.26%	157,998.08	10.70%
Built-up area	2,153.77	0.15%	2,362.15	0.16%	3,246.53	0.22%	5,009.15	0.34%
Industrial palm plantation	-	0.00%	-	0.00%	92,347.72	6.26%	343,597.77	23.28%
Water bodies	16,273.10	1.10%	16,770.83	1.14%	16,250.22	1.10%	16,823.27	1.14%
Total Area	1,476,105.92	100.00%	1,476,105.92	100.00%	1,476,105.92	100.00%	1,476,105.92	100.00%

Data source: Estimated from time series satellite images Landsat-5 TM (1990), Landsat-7 ETM (2003, 2009), and Landsat-8 (2013)

A total of 4,478 km of main primary, primary, secondary, and tertiary drainage canals constructed in the area (Figure 5.5). These drainage canals have disrupted the hydrological balance in the EMRP area owing to the increased of water outflow run off and reduced water storage capacity. As a result, the surface and groundwater tables drawdown during the drought periods and trigger peat oxidation and subsidence (Page et al., 2009; Hoscilo et al., 2012).

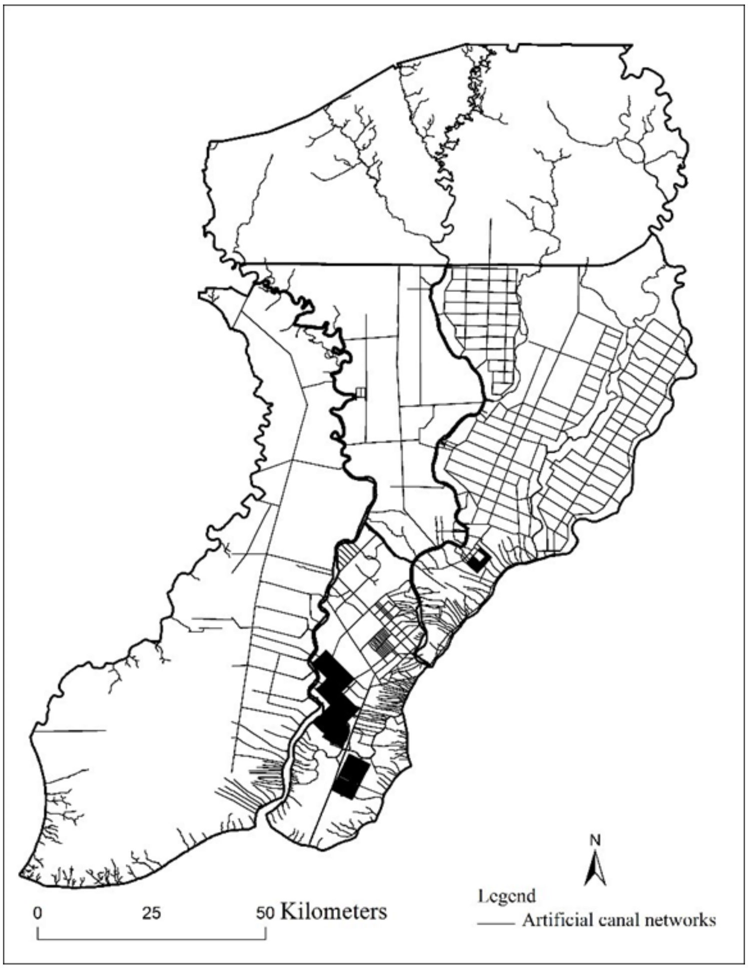


Figure 5.5 The network of artificial drainage canals in the EMRP

5.2.2 Measurement dams constructed on surface water level fluctuations

To check the effectiveness of the constructed dams in the study site, three dams were selected to analyse the effectiveness of damming on the raised surface water results the blocked canal sections. These dams were the ones denoted by CFPPI-01 (-2.23098, 114.55541), CCFPI-02 (-2.23148, 114.60191), and CKPP-08 (-2.23086, 114.52594).

Each constructed dam was equipped with two staff gauges located at the downstream and upstream sides. The name codes, altitudes, coordinate points and locations of these staff gauges as well as the frequency of data collected are presented in the following Table 5.2.

Table 5.2 Selected staff gauges for measuring surface water level fluctuations at three selected constructed dams

Dam Name	Staff Gauge Number	Altitude (msl)	Coordinate points		Frequency of data collected and measured
			Latitude	Longitude	
CCFPI-01	SG03 (upstream)	3.74	-2.23138	114.60177	Weekly (July 2005 to June 2008
	SG04 (downstream)	3.74	-2.23139	114.60193	Weekly (July 2005 to June 2008
CCFPI-02	SG07 (upstream)	5.43	-2.22992	114.50543	Daily (July 2007 to June 2008
	SG08 (downstream)	5.93	-2.23017	114.50544	Daily (July 2007 to June 2008
CKPP-08	SG20 (upstream)	4.63	-2.23083	114.52594	Weekly (July 2007 to June 2008
	SG21 (upstream)	4.49	-2.23083	114.52598	Weekly (July 2007 to June 2008

Source: Central Kalimantan Peatland Project (CKKP) Report, Wetland International-IP, 2008 (with permission)
Note:
msl = mean sea level

5.3 Results

5.3.1 Overview of rewetting activities and techniques

Wetlands International Indonesia (WIIP), via the CCFPI and CKPP programs, carried out peatland rewetting activities in the Block A North-West of the EMRP from 2003 to 2008. About 26 large dams were built in the area (CKPP 2008; Suryadiputra et al. 2005). The principal process of peatland rewetting implemented by WIIP (both CCFPI and CKKP programs) entailed three major stages (Suryadiputra et al., 2005; CKPP, 2008; Dohong & Lilia, 2008). These three stages were: pre-construction; construction; and post construction (Figiure 5.5).

In the pre-construction stage, the main activities included: (a) field assessment to collect the baseline information about the site (hydrological, bio-physical, soil condition, land cover); (b) development of the dam model design and its technical specifications based on initial assessment information (baseline); (c) communicating about the rewetting activity plan with the local communities and seeking community consent for the rewetting program; (c) the establishment of community groups as principal partners to carry out the dam construction; (d) contract agreement with the elected community group; (e) technical training for the elected community group: and (f) procurement of the materials required and mobilisation of workers and equipment needed for the dam construction.

Meanwhile, the construction stage involves: (a) field measurement and assessment of the target site for the dam placement; (b) construction of the mainframe structure of the box dam as well as its equipment structure facilities; (c) installation and placement of the geotextile; (d) placement of the soil bags; (e) the installation of the spillway cover; and (f) finishing the work. Finally, the activities in the post construction stage entail: demobilisation of the workers and equipment; the installation of hydrological monitoring system such as tube wells, peilschaal and staff gauge; and dam maintenance activities.

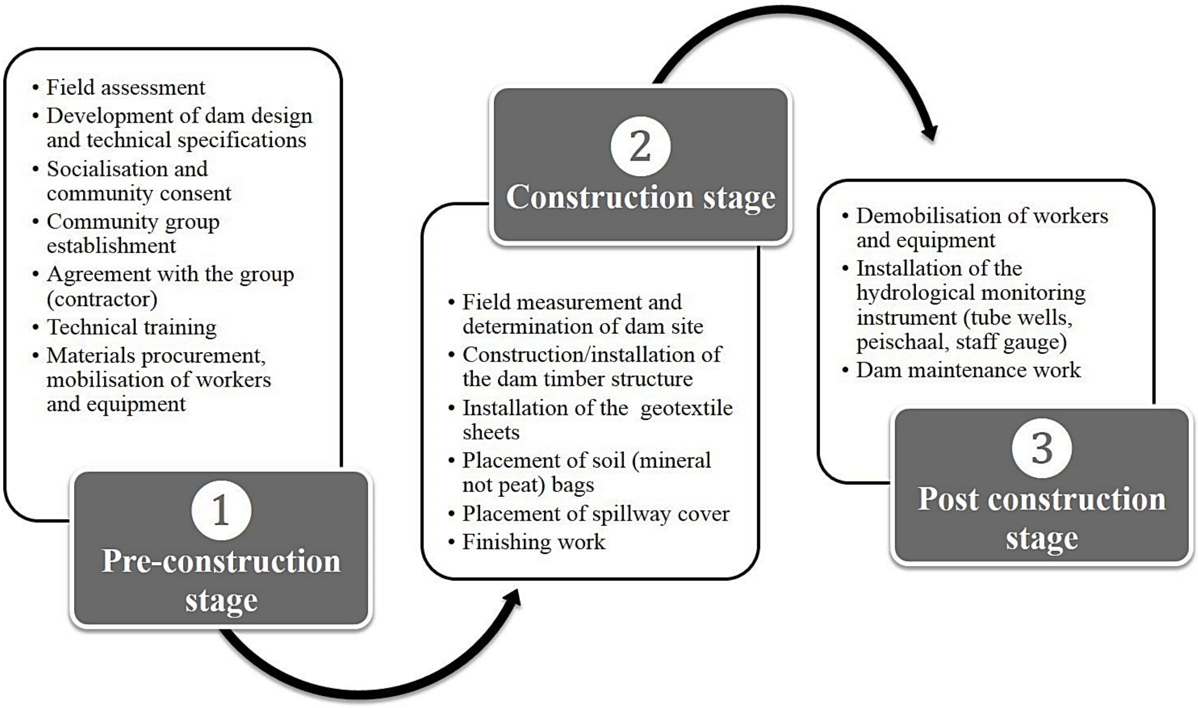


Figure 5.6 Major processes and stages of peatland rewetting activities (adopted and modified from Suryadiputra et al., 2005; Dohong & Lilia, 2008; CKPP, 2008)

5.3.1.1 Dam designs and general technical specifications

There were four types of box dam designs that had been used by WIIP to block drainage canals in Block A North-West of EMRP. Three box dam models were designed and tested during the CCFPI in 2003–2005 and one model designed and tested under the CKPP program in 2006–2008.

The features and specifications of those box dam designs are briefly presented in subsequent Table 5.3. Meanwhile, the basic drawings of the box dam models used are presented in Figure 5.7; Figure 5.8; Figure 5.9; and Figure 5.10 respectively.

Table 5.3 The design models, structure descriptions and specifications of the CCFPI and CKPP

No	Dam design model	Structure description and specification
1.	CCFPI Dam Model 1	• The mainframe structure of the box dam is made of local log pole (*Shorea belangiran*) (20–25 cm diameters); • The mainframe of the timber structure consists of three row of log sheet piles (15–20 cm diameters); • The log bracing system is attached at the downstream (rear) side of the dam structure; • The mineral soil bags are placed in between the columns of the log sheet piles; • Geotextile sheeting is placed at the bottom of the canal basin prior to soil bags being placed.
2.	CCFPI Dam Model 2	• The mainframe structure of the box dam is made of local log pole (*Shorea belangiran*) (20–25 cm diameters); • The mainframe of the timber structure consists of three rows of log sheet piles equipped with chambers in between (15–20 cm diameters); • The log bracing system is attached at the downstream (rear) side of the dam structure; • The mineral soil bags are placed in between the columns of the log sheet piles; • Geotextile sheet is placed at the bottom of the canal basin prior to soil bags being placed.
3.	CCFPI Dam Model 3	• The mainframe structure of the box dam is made of local log pole (*Shorea belangiran/or Melaleuca cajuputi*) (20–25 cm diameters); • The mainframe of the timber structure consists of two rows of log sheet piles equipped with no chambers in between (15–20 cm diameters); • Two narrow rows of log sheet piles are established at the rear side aimed at strengthening the box dam mainframe against strong water pressure; • The overflow inclined spillway is built at both upstream and downstream sides of the box dam; • The mineral soil bags are placed in between the sheet pile columns.

4.	CKPP Dam Model 1	• The mainframe structure of the box dam is made of local log poles (*Melaleuca cajuputi* with diameter size of 20–25 cm; • The mainframe of the timber structure consists of two rows of log sheet piles equipped with no chambers in between (15–20 cm diameters); • The mainframe structure of the box dam is divided into two segments, which are the wing and the spillway; • The mainframe of spillway segment is made square or rectangular and is positioned at the centre of the canal section; meanwhile, the wing segment is constructed of two sub-segment wings (attached to the two canal banks); • The spillway segment is constructed a bit lower than the wing segment and the crest elevation of the spillway is 20-40 cm lower than the crest elevation of the wings or canal banks; • The wing is made to widen out from the spillway frame towards the canal banks; • A log bracing system is established both upstream and downstream of the box dam mainframe, aimed at adding strength to the dam main structure against strong water pressure.

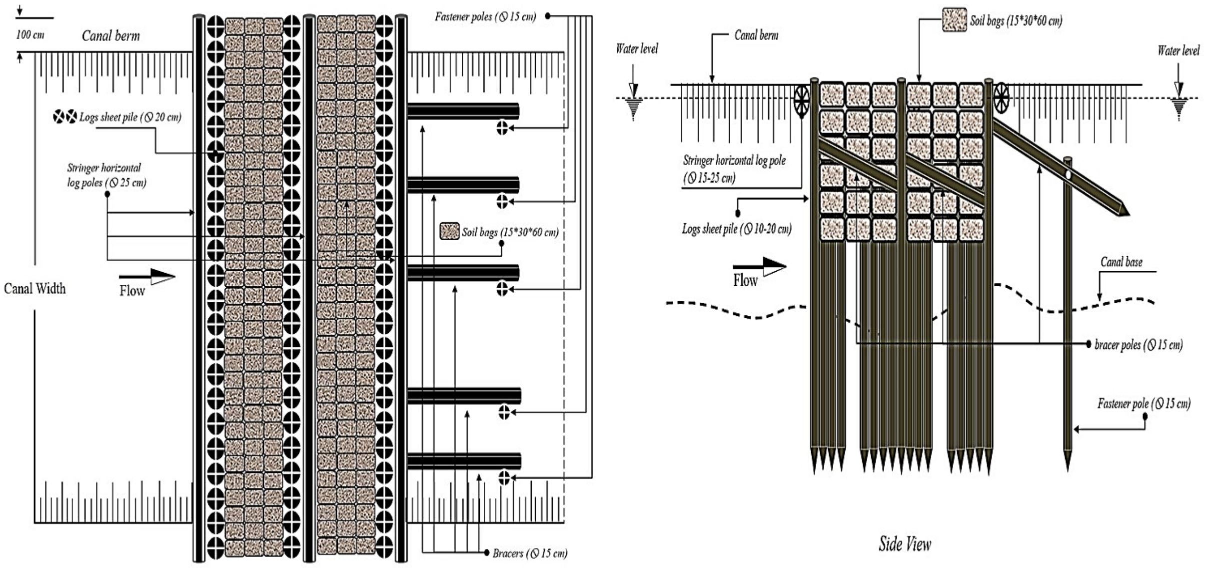


Figure 5.7 Three sheet pile box dam (CCFPI Dam Model 1)

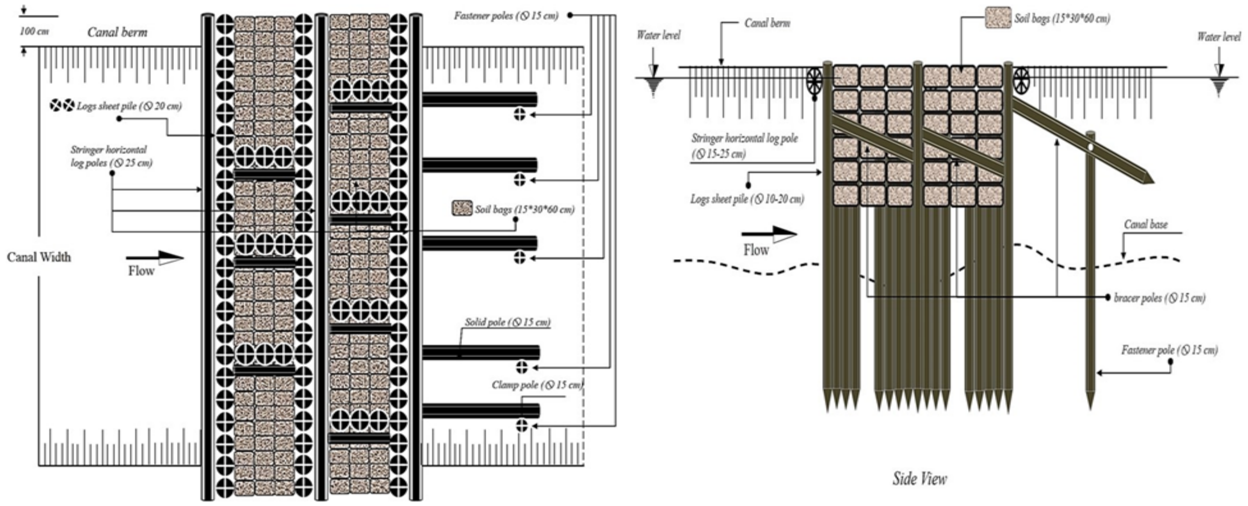


Figure 5.8 Three sheet pile box dam with chambers in between (CCFPI Dam Model 2)

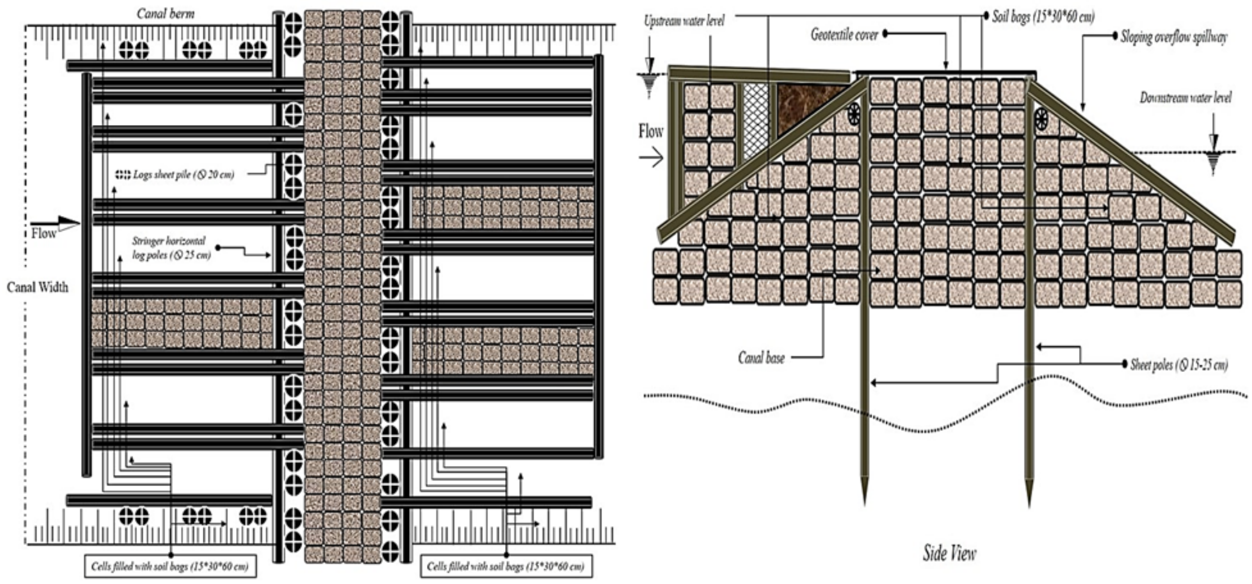


Figure 5.9 Two sheet pile box dam equipped with inclined overflow spillway (CCFPI Dam Model 3)

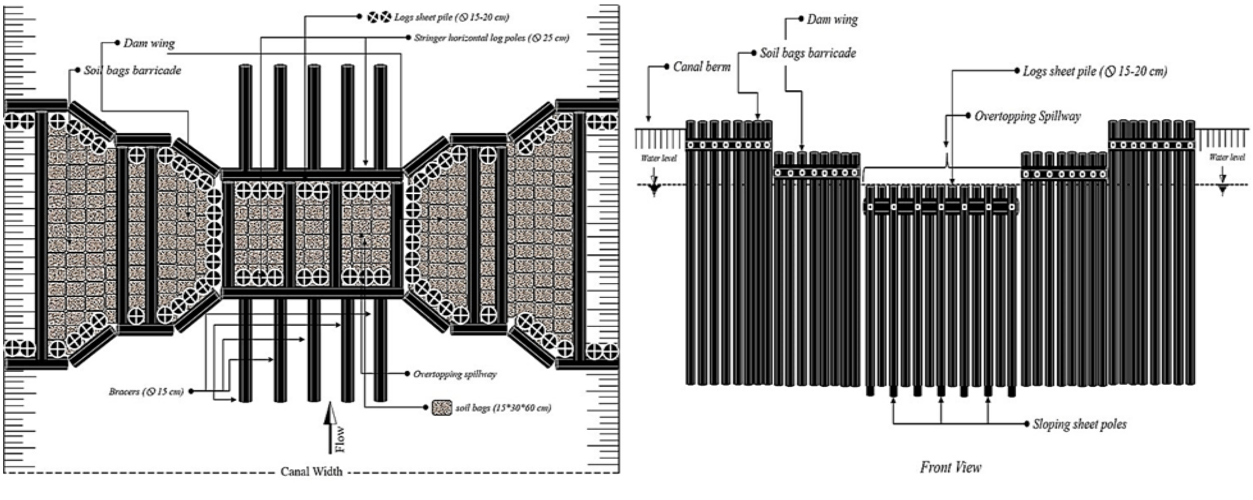


Figure 5.10 Two sheet pile box dam equipped with lowered middle crest spillway (CKPP Dam Model 1)

5.3.1.2 Total dams built, dam design used and locations

There were eight large dams (CCFPI-01—CCFPI-08) successfully constructed under the CCFPI during 2003–2006 and 12 large dams effectively built in 2006–2008 (CKPP-01 – CKPP-12). The details of the locations, dam design models and the matrix distance of these dams are presented in the followings tables (Table 5.4; Table 5.5; and Table 5.6).

Table 5.4 Total large dams constructed, locations, and dam design models used in the Block A North-West, EMRP

Dam Name	Coordinate points		Canals locations and community groups	Dam design model used
	Latitude	Longitude		
CCFPI-01	-2.23098	114.55541	SPI-1 Utara (jambek)	CCFPI Dam Model 1
CCFPI-02	-2.23148	114.60191	SPI-1 Utara (basecamp)	CCFPI Dam Model 2
CCFPI-03	-2.22999	114.50549	SPU-7 (Kanal Nereka)	CCFPI Dam Model 2
CCFPI-04	-2.22150	114.50570	SPU-7 (Kanal Nereka)	CCFPI Dam Model 2
CCFPI-05	-2.24780	114.50497	SPU-7 (Kanal Nereka) Southern SPI-2	CCFPI Dam Model 2
CCFPI-06	-2.23270	114.60187	SPI-2 (dibelakang camp)	CCFPI Dam Model 2
CCFPI-07	-2.23185	114.61037	SPI-2 (Sungai Mantangai)	CCFPI Dam Model 2
CCFPI-08	-2.26395	114.55848	SPU-7 right (Danau Uju)	CCFPI Dam Model 3
CKPP-01	-2.26131	114.45985	Katunjung (Kel. Isen Mulang)	CKPP Dam model 1
CKPP-02	-2.26088	114.46016	Katunjung (Kel. Hapakat)	CKPP Dam model 1
CKPP-03	-2.26045	114.45987	Katunjung (Kel. Penyang Kasimpei)	CKPP Dam model 1
CKPP-04	-2.28335	114.45960	Sei Ahas (Kel. Tekad Bersatu)	CKPP Dam model 1
CKPP-05	-2.28425	114.45962	Sei Ahas (Kel. Karya Bersama)	CKPP Dam model 1
CKPP-06	-2.28390	114.46033	Sei Ahas (Kel. Lestari Alam)	CKPP Dam model 1
CKPP-07	-2.30618	114.45975	Sei Ahas (Kel. Suka Maju)	CKPP Dam model 1
CKPP-08	-2.23086	114.52594	SPI-1 Utara (kel. Bersama/gabungan)	CKPP Dam model 1
CKPP-09	-2.28663	114.53999	Danau Uju (Kel. Sama Kahandak)	CKPP Dam model 1
CKPP-10	-2.28700	114.53983	Danau Uju (Kel. Teras Pandehen Gawi)	CKPP Dam model 1
CKPP-11	-2.32059	114.50292	Kalumpang (Kel.Batuah Hampumpung)	CKPP Dam model 1
CKPP-12	- 2.34240	114.50226	Kalumpang (Kel. Penyang Hinje Simpei)	CKPP Dam model 1

Table 5.5 The distance locations matrix of the CCFPI dams (Km)

	CCFPI-1	CCFPI-2	CCFPI-3	CCFPI-4	CCFPI-5	CCFPI-6	CCFPI-7	CCFPI-8
CCFPI-1		5.169	5.549	5.625	5.910	5.167	6.109	3.683
CCFPI-2			10.718	10.751	10.926	0.136	0.941	6.029
CCFPI-3				0.945	1.982	10.716	11.659	6.997
CCFPI-4					2.926	10.761	11.690	7.530
CCFPI-5						10.900	11.848	6.213
CCFPI-6							0.949	5.945
CCFPI-7								6.783
CCFPI-8								

Table 5.6 The distance locations matrix of the CKPP dams(Km)

	CKPP-1	CKPP-2	CKPP-3	CKPP-4	CKPP-5	CKPP-6	CKPP-7	CKPP-8	CKPP-9	CKPP-10	CKPP-11	CKPP-12
CKPP-1		0.059	0.096	2.452	2.552	2.513	4.991	8.089	9.342	9.337	8.148	10.177
CKPP-2			0.058	2.500	2.600	2.561	5.039	8.038	9.323	9.319	8.167	10.204
CKPP-3				2.547	2.647	2.609	5.087	8.047	9.369	9.365	8.224	10.261
CKPP-4					0.100	0.102	2.539	9.405	8.942	8.926	6.351	8.101
CKPP-5						0.088	2.439	9.466	8.936	8.920	6.285	8.018
CKPP-6							2.479	9.380	8.859	8.843	6.250	8.004
CKPP-7								11.149	9.179	9.152	5.059	6.209
CKPP-8									6.397	6.432	10.303	12.683
CKPP-9										0.045	5.590	7.488
CKPP-10											5.549	7.444
CKPP-11												2.427
CKPP-12												

5.4 The impact of dam constructed on surface water level fluctuations

The main objective of blocking the drainage canals is to reduce the water outflow run-off and to raise both the surface and groundwater levels along the blocked canal as well as its nearby sites. The effectiveness of dams built to rewet the drained peat can be monitored from the fluctuations of the surface and groundwater table within the blocked canal.

The fluctuations of the surface water levels within the CCFPI-01, CCFPI-2, and CKPP-08 are presented in the Figure 5.11; Figure 5.12; Figure 5.13 respectively. It is clear that the three dams were effective in raising surface water levels in the blocked canals. The surface water level differences in the CKPP-08 were higher compared with CCFPI-01 and CCFPI-02. The CKPP-08 was equipped with spillway devices; whereas, both CCPFI-01 and CCFPI-02 had no spillway devices. This means that the box dam equipped with a crest spillway system may be more effective in raising water levels. However, further investigation is needed to come up with precise determinant factors.

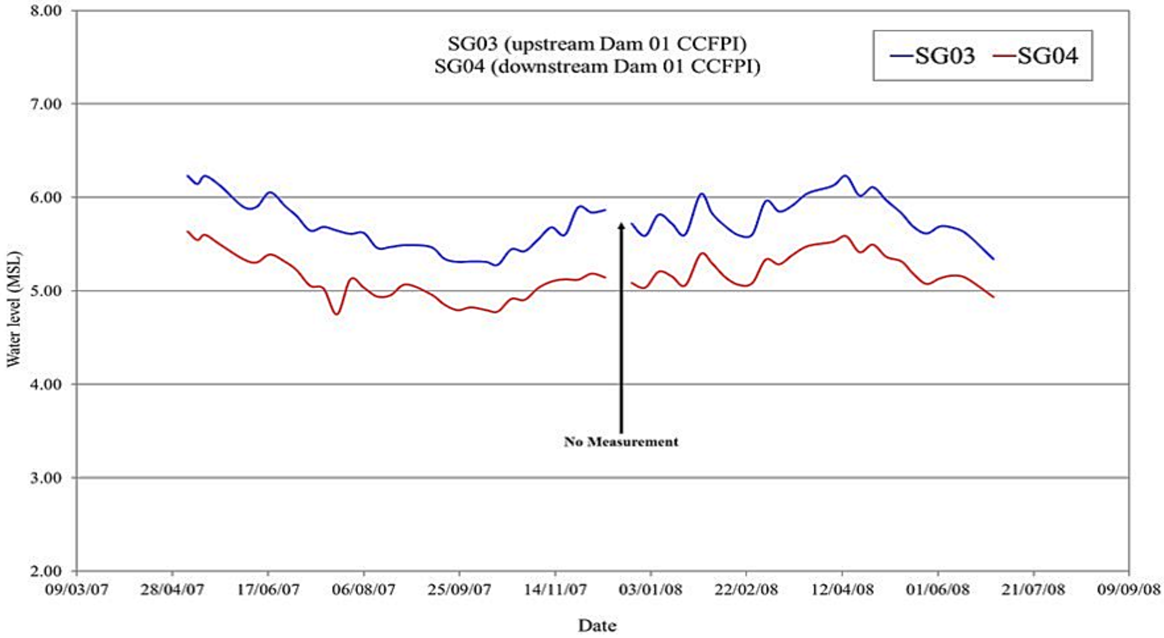


Figure 5.11 Surface water levels differences between downstream and upstream sides of the CCFPI-01 dam during April 2007–July 2008

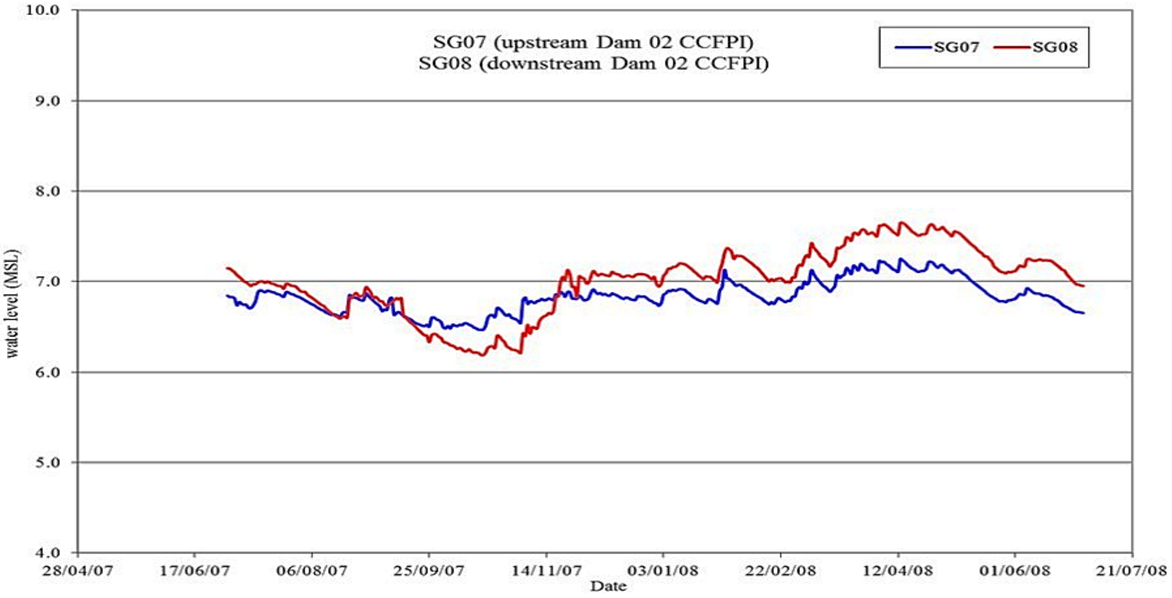


Figure 5.12 Surface water level differences between downstream and upstream sides of the CCFPI-02 dam during June 2007–July 2008

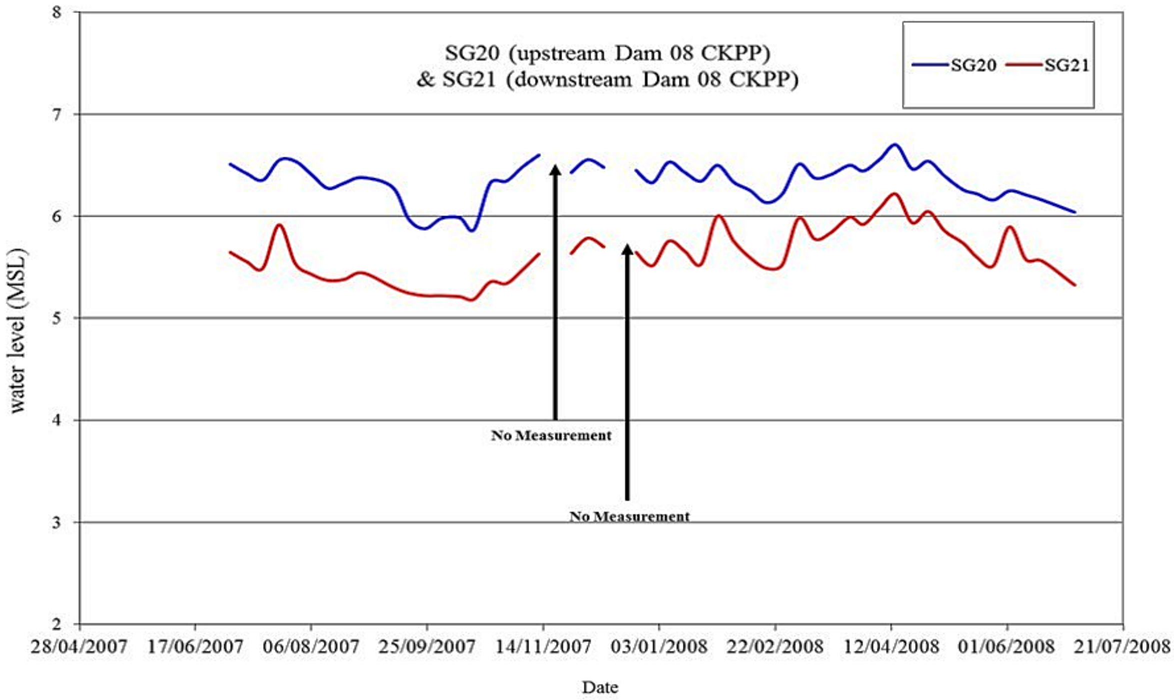


Figure 5.13 Surface water level differences between downstream and upstream sides of the CKPP-08 dam during June 2007–July 2008

5.5 Discussion and Concluding Remark

The peatland rewetting activities carried out by WI-IP from 2003–2008 in Block A North-West, EMRP resulted in a positive impact in terms of reduced outflow run-off and raised surface water levels along the blocked canals in the EMRP. There were significant differences between surface water levels at the downstream and the upstream sides of the dams. It means that those installed dams were effective in raising water levels higher than if the canals remained unblocked.

To determine the optimal amount of spacing between dams, the surface gradient needs to be determined. The maximum water head difference is recommended at 30–40 cm in the boreal and temperate region (Kozulin et al., 2010; Landry & Rochefort, 2012). Meanwhile, in the tropical region, the recommended water head differences are 20–25 cm (Jaenicke et al., 2010; Ritzema et al., 2014). The higher water head difference between dams will potentially risk bottom and rear dam erosion. The space between dams is also very much dependent upon the size of the drainage canal.

It should be noted that the major dam function is reducing the surface run-off and therefore slowing the water as it flows out through the canal course rather than totally stopping the water outflow. Hence, the dam design should not be rigid and the construction processes should be simple (Jaenicke et al. 2010).

Some technical, ecological and social challenges are emerging from the implementation of peatland rewetting activities in the EMRP area of Central Kalimantan. In terms of technical aspects, the dam design used is of particular importance and needs to be considered when implementing peatland rewetting programs in the EMRP. The use of box dams without the overflow spillway device seems less effective in raising and maintaining desired water levels, due mostly to seepage from beneath the canal base and the canal banks. This is of particular importance when the dam crest elevation is higher than the elevation of the canal levee. The higher water level and water debit in the upstream side of the dam tend to give strong pressure towards the canal banks, and there is potential for a new waterway to result from bank seepage.

In addition, water seepage is also possible from underneath of the dam base if the infilling soil bags do not properly penetrate up to the mineral/clay soil subsoil at the bottom. Both the base and bank seepages can make the dam dysfunctional by slowing down outflow run-off and raising the water table to a desired level. This seepage will also place the timber structure at further risk of collapse and malfunction. Hence, it is recommended that the type of box dam equipped with an overflow spillway (e.g. CKPP Dam Model 1) is installed so as to prevent potential bottom and bank seepages.

Finally, materials used for infill in the chambers or columns of the dam timber structure are another important consideration. The use of peats that have already experienced excessive or frequent drying are not recommended as dam infill materials. This type of dried peat has a hydrophobic (water resistant) character and irreversible shrinking characteristics and is not suitable for use as dam infill material (Holden et al., 2004; Holden et al., 2006; Rieley & Page, 2008; Landry & Rochefort, 2012).

CHAPTER 6 CARBON EMISSIONS FROM ILLEGAL PALM OIL DEVELOPMENT ON PEATLAND IN CENTRAL KALIMANTAN INDONESIA

Summary

Of the 44 million hectares of peatland in the tropics, Indonesia has proportionately the largest area (45%) and carbon content (64%). These carbon-rich peat ecosystems play an important role in regional climate stabilisation and biodiversity conservation. The Indonesian Government has enacted numerous regulatory measures since the 1990s aimed at boosting protection of the remaining intact peatland, with a threshold that peat deeper than 3 m must be conserved and cannot be cultivated. Despite these regulatory measures there has been extensive conversion of peatland to other land uses, especially large-scale palm oil plantations.

This study shows that over 40% of palm oil plantations located in the former Ex-Mega Rice Project (EMRP) area (of some 1.46 million hectares) in Central Kalimantan are situated in deep peat areas and are not compliant with existing peatland conservation regulations, laws or ordinances. We estimate that continuing the present palm oil development practices on deep peat in the EMRP area will result in the release of between 93 and 217 M_tCO_{2e} over the next 25 years.

6.1 Introduction

Indonesia's peatland accounts for the largest proportion of carbon in terrestrial peat in the tropics (Page et al., 2011). This carbon-rich ecosystem plays an important role, contributing economic value and providing beneficial ecological services, including controlling and mitigating global climate change (Jaenicke et al., 2008). Because of this, during the past two decades the Government of Indonesia has enacted various regulatory and policy measures concerning peatland, aimed at conserving and protecting the remaining intact peat forest and carbon-rich peat. These regulatory and policy measures are at the national, sectoral and local levels, and require deep peat to be protected and conserved; therefore, no cultivation is allowed within areas containing deep and very deep peat (PORI, 1990, PORI, 1999). The regulatory measures were further strengthened through the enactment of recent Presidential instructions (number 10 of 2011 and number 6 of 2013): policies that place a moratorium on developing primary natural forest and peatland (PORI, 2011b, PORI, 2013).

However, despite these regulatory measures, peatland in Indonesia is under severe threat of conversion to other land uses, notably to large-scale palm oil plantations. The rapid expansion of the palm oil plantation industry in Indonesia and Malaysia in the past two decades has come partly at the expense of peat swamp forest (Koh et al., 2011; Miettinen et al., 2012). The area of large-scale palm oil plantations on former peat swamp forests in the Malaysian Peninsula and in Borneo increased from around 0.880 million hectares in the early 2000s (Koh et al., 2011) to 2.14 million hectares in 2010 (Miettinen et al., 2012), with an average annual growth of over 14%. If the current rate of peat swamp forest conversion continues, and no appropriate land-use policy is adopted, it is predicted that the primary peat swamp forests of South-East Asia will completely disappear by 2030 (Miettinen et al., 2012). Despite the lucrative short-term financial benefits that Indonesia has gained from its palm oil industry, the development has led to widespread deforestation (Carlson et al., 2012; Miettinen et al., 2012; Lee et al., 2014), resulting in biodiversity decline (Fitzherbert et al., 2008; Koh & Wilcove, 2008; Koh et al., 2011; Savilaakso et al., 2014), and immense CO_2 emissions via the removal of above-ground biomass and peat oxidation resulting from peat drainage (Hooijer et al., 2010; Murdiyarso et al., 2010; Hergoualc'h & Verchot, 2011; Hooijer et al., 2012). A recent estimate suggests that over a quarter of Indonesia's palm oil plantations are located on peatlands (Varkkey, 2012).

Between 1995 and 1998, the Indonesian Government allowed almost one-third of Central Kalimantan's 3 million hectares of peatland to be cleared for rice fields. The project, now renown as the Ex Mega Rice Project (EMRP), was eventually terminated in 1999 as a failure through the enactment of a presidential decree (PORI, 1999). The EMRP was abandoned for more than a decade, with no clear policy guidance or attempts at physical rehabilitation or restoration. This area has been the source of massive annual CO_2 emissions resulting from recurrent fires and peat oxidation and subsidence caused by peat drainage.

Since 2004, the vagueness in governance for the area was exploited by district leaders who granted licences to the private sector to develop palm oil estates, with scant regard for the existing peatland regulatory measures or the planning guidance that had been provided for the revitalisation and restoration of the peatlands (Euroconsult Mott MacDonald et al., 2008; MoFRI, 2008). Despite their non-compliance with existing ordinances, the granting of new permits for palm oil plantations in the EMRP has somewhat complicated the current land-use plan, and may impede the implementation of rehabilitation and restoration plans that have been designated for the area.

This chapter aims to: (a) summarise the regulatory measures that apply to peatland conservation and protection in Indonesia and cross-reference those regulations with a reliable estimate of palm oil development in the EMRP, thus allowing a reasonable estimate of the extent of illegal palm oil development in the region over the past 10 years; (b) estimate the potential CO_2 emissions resulting from peat oxidation caused by drainage, with and without palm oil plantations; and (c) calculate the potential CO_2 emission reductions contribution from three different scenarios towards the country's greenhouse gases emissions reduction target by 2020.

6.2 Method

6.2.1 Study Location.

The study took place in the EMRP of Central Kalimantan, Indonesia. The study site encompasses 1.04 million hectares and comprises blocks A, B, C and D (Figure 6.1). Of this area, around 0.427 million hectares (41.09%) comprises mineral soil, about 0.173 million hectares (16.66%) comprises peat with a thickness of < 200 cm, and about 0.439 million hectares (42.24%) comprises peat with thickness > 200 cm (Table 6.1).

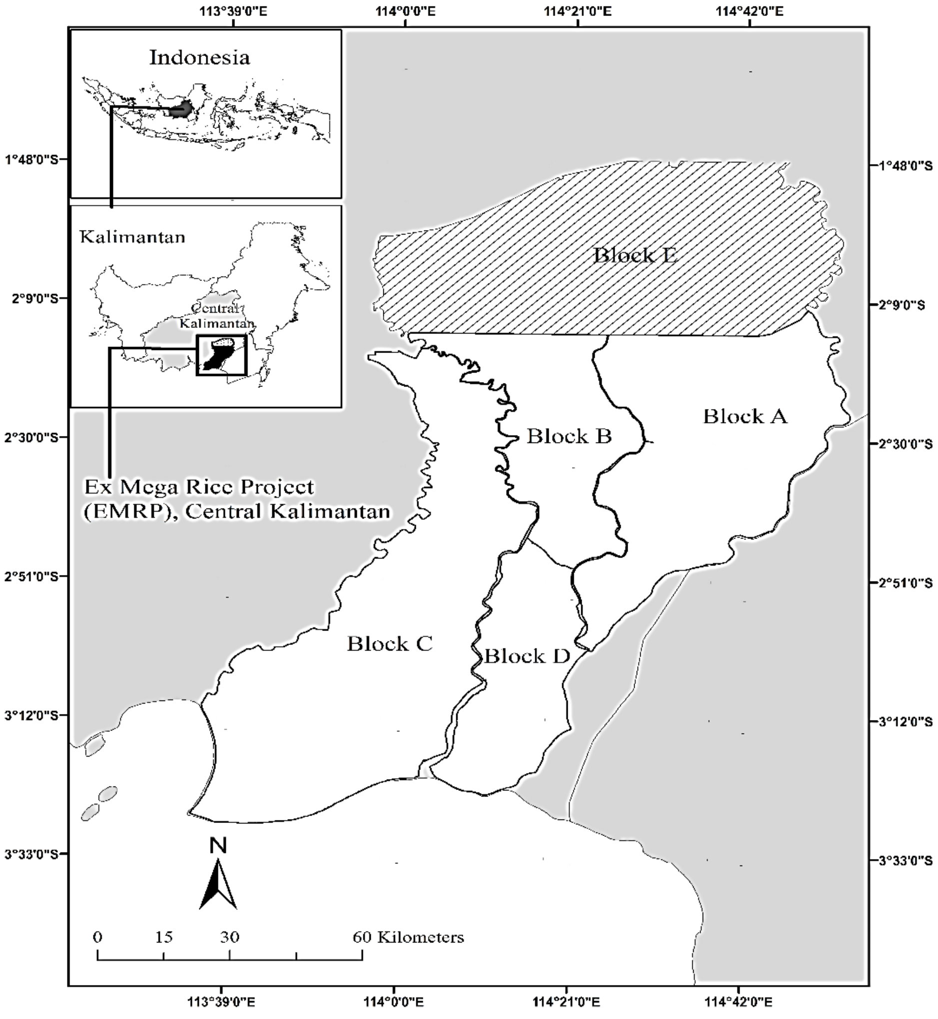


Figure 6.1 Map of research location: EMRP, Central Kalimantan, Indonesia

Table 6.1 Total EMRP (Block A, B, C and D) based on peat depth class

Peat Depth Class	Block A (Ha)	Block B (Ha)	Block C (Ha)	Block D (Ha)	Total (Ha)
Non-Peat (mineral)	121,930.93	46,483.62	142,896.59	116,216.70	427,527.84
< 300 Cm	53,945.93	26,258.93	80,316.24	12,892.39	173,413.40
> 300 Cm	133,215.35	84,902.14	213,285.00	8,206.99	439,609.50
Total	**309,092.12**	**157,644.71**	**436,497.83**	**137,316.08**	**1,040,550.73**

Source: Extracted using ArcGIS 10.3 from Wahyunto et al., 2004.

6.2.2 Indonesia's regulatory measures on peatland conservation, protection and restoration

Information about Indonesian laws and policies on peatland conservation, protection and restoration was collected and compiled from secondary sources through a desktop study.

6.2.3 Calculating the total area of oil palm plantations on deep and non-deep peats and mineral soil

The total area of palm oil cultivation on mineral soil, non-deep and deep peats was determined by overlaying the palm oil concessionaires georeferenced locations and the peat data (total area and depth class) using ArcGIS 10.2 (ESRI, 2013) The palm oil concessionaires' data (database and georeferenced boundaries) for the EMRP area were obtained and extracted with permission from the Provincial Plantation Office of Central Kalimantan. Peatland data (peat extent and peat depth class) for the EMRP were extracted with permission from Wetlands International's Central Kalimantan peat Distribution Map 2004 (Wahyunto et al., 2004). For simplicity of analysis, I condensed Wetlands International's six peat depth classes into three: (a) mineral soil; (b) peat with a thickness of < 300 cm (non-deep peat); and (c) peat with a thickness of > 300 cm (deep peat).

6.2.4 Calculation of CO_2 emission from palm oil drainage

Before calculating the potential CO_2 emissions caused by drainage for palm oil plantations, three default CO_2 scenario emission ($tCO_{2e}ha^{-1}year^{-1}$) values were determined. The maximum default value of 100 $tCO_{2e}ha^{-1}year^{-1}$ was adopted from Hooijer, et al. (2012) the minimum default value of 43 $tCO_{2e}ha^{-1}year^{-1}$ adopted from Agus et al. (2013), and the mean value of 71.5 tCO_{2e}/ha/year was calculated from taking the average of the maximum and minimum values above. Total annual CO_2 emissions from peat oxidation caused by drainage for palm oil plantations on deep and non-deep peats were calculated by multiplying respective default values (maximum, minimum and mean) by the total area of palm oil plantations located on deep and non-deep peats. Similarly, total potential CO_2 emissions during the 25-year palm oil operational cycle were calculated by multiplying annualised CO_2 emissions (maximum, minimum and mean) by 25 for both deep and non-deep peats.

6.2.5 The potential contribution towards CO_2 emission reduction and achieving the national CO_2 emission reduction target on forestry and peatland by 2020, if drainage for palm oil plantations is avoided.

Three scenarios were proposed to estimate the potential contribution towards CO_2 emissions reduction that would be made by avoiding drainage on deep and non-deep peatlands for palm oil plantations, thereby helping to meet the national CO_2 emission reduction target for the forestry and peatland sector by 2020. The scenarios were: (a) the "business as usual" (BAU) scenario, meaning the palm oil plantations on peatland in the EMRP would continue in the current manner; (b) the "enforce peat laws" scenario, meaning that all palm oil plantations currently operating on deep peat areas (peat thickness > 200 cm) must be closed down and/or moved out to mineral soil areas; and (c) the "no palm oil on peat" scenario, meaning that all palm oil plantations on peat should be closed down and no further palm oil cultivation on peat be planned. The CO_2 emissions reduction potential (minimum, mean and maximum) from each scenario were then calculated by multiplying the total CO_2 emission that would be released over the palm oil operational cycle (25 years) by total area palm oil plantations on peatland. Under the BAU scenario, there would be no CO_2 emissions reduction. If the "enforce peat laws" scenario was implemented, the potential reduction of CO_2 emissions would be calculated by multiplying the total area of palm oil cultivated on deep peat with the CO_2 default values (minimum, mean and maximum) over 25 years. Finally, if the "no palm oil on peat" scenario was adopted, the potential CO_2 emission reduction is estimated by multiplying the total area of palm oil cultivated on peatland by the CO_2 default values (minimum, mean and maximum) over 25 years.

6.3 Results and Discussion

6.3.1 Regulatory and policy measures on peatland conservation, protection and restoration in Indonesia

Our study identified 13 national regulations or policies that directly and indirectly regulated peatland conservation, protection and restoration in Indonesia (Table 6.2). These regulations include national acts, Government regulations, presidential decrees and instructions, and other ministerial regulations. Some of these regulations are not aimed specifically at peatland conservation and protection but most cite the principal function of peatland as protecting the underlying subsoil. They also provide a rather narrow definition of peatland on the basis of peat depth. For instance, Presidential Decree No. 32 year 1990 (PORI, 1990), Indonesian Law No. 26 year 2007 (MoLHRRI, 2007), and Minister for Agriculture Regulation No. 14 year 2009 (MoARI, 2009) classify peatlands as areas to be protected where their main function is to protect the subsoil. In these regulations, peatland is defined as an area with peat with a minimum thickness of 3 m. The use of this criteria for defining peatland for conservation and protection purposes has implications for peatland management and conservation practices in Indonesia. Firstly, peatland < 3 m deep is not protected by law, and hence can be used for cultivation and, secondly, other economic and ecological functions and values that peatlands provide are omitted from the decision-making process when an area is proposed for conservation or protection.

Table 6.2 National and sectorial regulatory measures related to peatland conservation/protection and restoration

Governmental Level/Regulatory & Policy Measurer	**Brief Description**	**Note (relevancy to peatland conservation and restoration activities)**
Presidential Decree No. 32 of 1990 on Protected Area Management	This decree stipulates general guidance on management of protected areas including objectives, scope, basic policy for protected areas, designation of protected areas, and oversight of protected areas	Peatland is one of the protection areas, which provides protection unto its sub-layer underneath. Peatland area is defined as peat area with a minimum thickness of 3 m
Indonesian Law No. 5 of 1994 on the Ratification of the United Nations Conventions on Biological Diversity	National law that binds Indonesia to the implementation of the United Nations Conventions on Biological Diversity	Several peatland endemic flora and fauna species are of local, regional and internationally importance
Presidential Decree No. 48 of 1991 on the Ratification of United Nations Convention on Wetlands of International Importance, especially as Waterfowl Habitat (RAMSAR Convention)	Government of Indonesia ratifies the United Nations convention on wetlands habitat as major habitat notably for waterfowl habitat	Peatland is part of the wetlands ecosystem that provides habitat protection for waterfowl or fresh water birds
Indonesian Law No. 26 of 2007 on Spatial Planning	National law that regulates and guides the national spatial plan policy including principles and goals, classification of spatial plan, tasks and responsibilities of related parties, spatial arrangement and control; implementation of spatial plans; spatial utilisations, oversight of spatial plans, community's rights and responsibilities, conflict resolution, and inquiries and criminal acts	Explanation of the Article 5 (2) states an area which provides protection to its subsoil, including forest protection area and peatland
Presidential Decree No. 80 of 1999 on General Guidance on Planning and Management of Peatland Development Area in Central Kalimantan	The decree provides principles and guidance for the post planning of the EMRP with respect to: (a) the adoption of sustainable peatland principles in designing the rehabilitation of the area; (b) shallow peat (< 3 m) can be used for activities of forestry, agriculture, fishery and plantation activities; (c) deep peat (> 3 m) must be conserved and protected; (d) all activities in the area should be carried out on the basis of recommendations provided in the Integrated Environmental Impact Assessment study; and (e)	The decree instructed that all deep peats (> 3 m) must be protected and conserved, hence, no cultivation activity is allowed.

	revocation of previous presidential decree on the mega rice project (termination of the EMRP)	
Presidential Instruction No. 2 of 2007 on the acceleration of rehabilitation and revitalisation of the peatland development project area in Central Kalimantan	President instructed his 10 line ministries, governor of Central Kalimantan and four district heads (Barito Selatan, Kapuas, Pulang Pisau and Palangka Raya) to carry out revitalisation and rehabilitation activities within the EMRP area. The instruction also established a national and provincial team to implement and govern the presidential instruction as well as citing the budget sources that could be used to expedite the activities	One of the obvious outcomes of this presidential instruction is the completion of the Master Plan for Rehabilitation and Conservation of the EMRP document. The master plan document has allocated and designed around 874,453 ha (60.12%) of the EMRP as conservation and protection areas (including block E) and those degraded deep peat (> 3 m depth) areas have to be restored
Governmental Regulation No. 26 of 2008 on National Spatial Plan	Government regulation on detailing the implementation of Law 20 of 2007 on Spatial Planning	Explanatory note of the Article 52 (1b) states that an area that provides protection to the layer underneath including a forest protection area, peatland and water catchment area, must be protected. Article 55 (2) indicates that peatland areas deeper than 3 m must be protected
Presidential Instruction No. 10 of 2011 on suspension of granting new licences on natural primary forest and peatland areas (primary forest and peatland moratorium policy phase-1)	President instructed his eight line ministries, all governors and head of whole districts in Indonesia to implement the suspension of giving out new licences within primary forest production and peatland for a 2-year period (2011-2013)	All proposed new licences on primary forest production and peatland areas should be suspended for 2 years (2011-2013)
Presidential Instruction No. 6 of 2013 on suspension of granting new licences on natural primary forest and peatland areas (primary forest and peatland moratorium policy phase-2)	President extended his instruction on primary production forest and peatland moratorium for another 2-year period (2013-2015)	All proposed new licences on primary forest production and peatland areas should be suspended for another 2 years (2013-2015)
Minister for Forestry Regulation No. 55 of 2008 on Master Plan for Rehabilitation and Conservation of Peatland Development in Central Kalimantan	This regulation is enacted as the basis of the implementation of the master plan for rehabilitation and conservation of the EMRP in Central Kalimantan. This master plan was one of the outputs produced under the working group of conservation and rehabilitation of the EMRP team under Presidential Instruction No.2 of 2007	This master plan has allocated about 874,453 ha (60.12%) of the EMRP area (mostly deep peats) as rehabilitation and conservation areas (including block E area)
Minister for Agriculture Regulation No. 14 of 2009 on Guidelines on the utilization of peat for Palm Oil Cultivation	Provide regulatory and technical requirement thresholds for cultivating palm oil on peat	The regulation stipulates that palm oil cultivation in peatland areas can only be carried out when the following criteria are met: (a) the peatland area has been allocated and designated as a cultivation area within the jurisdiction of the spatial plan; (b) the thickness of the peat is < 3 m; (c) the substratum of the peat layer is not quartz sand and pyrite; (d) the peat decomposition rate is varied between sapric (highest decomposition rate) and hemic (medium

		decomposition); and peat with eutrophic fertility rate
Minister for Agriculture Regulation No. 19 of 2011 on Indonesian Sustainable Palm Oil Plantation (ISPO)	The regulation provides guidance on the implementation of the Indonesian Sustainable Palm Oil Plantations, with particular emphasis on the compliance of palm oil companies with existing regulatory and policy measures in relation to palm oil cultivation and business activities in Indonesia	All palm oil plantations operating in Indonesia must comply with existing regulations and policies including those on peatland conservation and protection activities
Government Regulation No. 27 of 2014 on Environmental License	Government regulation that obliges all businesses to undertake an Environmental Impact Assessment and/or Environmental Management and Monitoring Report to obtain an environmental licence	A study on the Environmental Impact Assessment and/or Environmental Management and Monitoring Report should be undertaken in accordance with existing regulatory and policy measures including peatland regulations

6.3.2 Large-scale palm oil plantations and peat thickness in the EMRP of Central Kalimantan

By early 2013, it was identified about 16 large-scale oil palm plantations actively operating within the EMRP site. These plantations cover a total area of 0.199 million ha, which is equivalent to 19.17% of the EMRP area, and they are distributed across blocks D (33.33%), A (25.41%), B (23.09%) and C (8.8%) (Table 6.3).

Table 6.3 Total Area of EMRP and Total Area of Large-scale Palm Oil Plantations within the EMRP Area

Peat depth class	Total area of EMRP*)		Total palm oil in EMRP		
	(ha)	(%)	(ha)	(%)#)	(%)##)
Mineral (non-peat)	427,643.42	41.09%	75,528.59	37.85%	17.66%
< 300 cm	173,413.39	16.66%	37,292.99	18.69%	21.51%
> 300 cm	439,609.50	42.24%	86,716.40	43.46%	19.73%
Total	**1,040,666.31**	**100.00%**	**199,537.98**	**100.00%**	**19.17%**

Notes and abbreviation:

**) Consist of block A, B, C and D (excluding block E)*

#) Percentage against total palm oil area in the EMRP

##) Percentage against total area of each respective peat depth class in EMRP

EMRP = Ex-Mega Rice Project

These 16 companies were granted location permits (Ijin Lokasi) between 2004 and 2009. Fifteen of the companies obtained their plantation business permits (Ijin Usaha Perkebunan) between 2006 and 2012, with only one further land lease permit (Hak Guna Usaha) for cultivating palm oil granted by the end of 2013. In terms of areas under cultivation, six companies own less than 10,000 ha, eight companies own 10,000–20,000 ha and two companies own more than 20,000 ha.

Based on analysis of peat thickness, 0.086 million ha (43.46%) of plantations are located on deep peat (thickness > 300 cm), 0.037 million ha (18.69%) are on peat of < 300 cm deep and the remaining 0.075 million ha (37.85%) are on mineral soil (non-peat) (Figure 6.2).

Our analysis found that around 44% of existing palm oil has been cultivated on deep peat. This is not permitted under the regulations outlined above and therefore is technically illegal. This lack of compliance could have both financial and administrative consequences for these palm oil companies because the penalties set forth in the laws on protected area management (PORI, 1990), spatial plans (PORI, 2008) and environmental management and protection (MoLHRRI, 2009, 2012) include potentially closing down the operation, imprisonment and heavy fines. In addition, palm oil cultivation on deep peat is also totally inconsistent with the land-use planning scenarios detailed in the master plans for rehabilitation and restoration of the EMRP, of which over 60% has been designated for peatland conservation and restoration activities (Euroconsult et al., 2008; MoFRI., 2008).

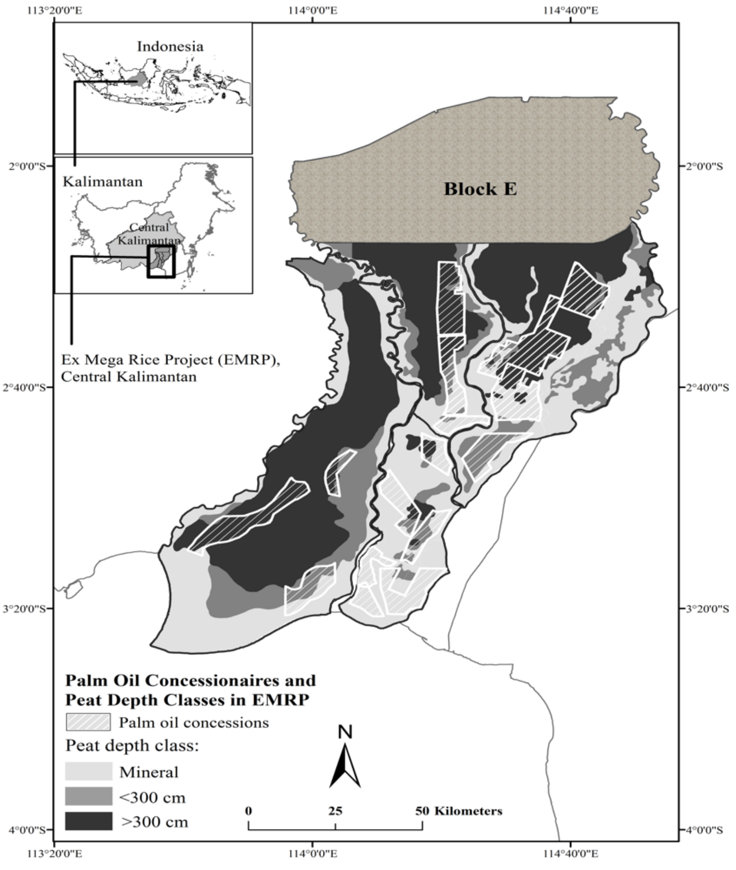


Figure 6.2 Spatial distribution of palm oil concessionaires and peat depth class in the EMRP as June 2012

6.3.3 Carbon Dioxide emission from peat oxidation caused by palm oil drainage in EMRP

Various studies have reported that palm oil cultivation on deep peat would increase the rate of peat subsidence caused by peat oxidation and compaction, leading to the release of carbon dioxide (CO_2) to the atmosphere, thus exacerbating climate change (Murdiyarso et al., 2010; Hooijer et al., 2012). Studies have estimated that the potential CO_2 emission resulted from peat oxidation caused by drainage in the palm oil plantations in Indonesia and Malaysia range from 43 (Agus et al., 2013) to 100 $M_tCO_{2e}ha^{-1}year^{-1}$ (Hooijer et al., 2012) during the first 25 years of operations.

By using values of CO_2 emissions from peat oxidation of 43 $M_tCO_{2e}ha^{-1}year^{-1}$ (minimum), 71.7 $M_tCO_{2e}ha^{-1}year^{-1}$ (mean) and 100 $M_tCO_{2e}ha^{-1}year^{-1}$ (maximum), I estimate that continuing the present palm oil plantation activities in the EMRP would result in annual CO_2 emissions of 5.33 M_tCO_{2e} (minimum), 8.87 M_tCO_{2e} (mean) and 12.40 M_tCO_{2e} (maximum). Over the 25-year palm oil plantation operational cycle, the potential CO_2 release from peat oxidation caused by drainage for oil palm cultivation in the EMRP is 133.31 M_tCO_{2e} (minimum), 221.67 M_tCO_{2e} (mean) and 310.02 M_tCO_{2e} respectively. On the other hand, if the peat regulatory thresholds were to be strictly enforced in the EMRP, the potential annual CO2 emissions could be reduced to 3.73 M_tCO_{2e} (minimum), 6.20 M_tCO_{2e} (mean) and 8.67 M_tCO_{2e} (maximum) or total emissions of 93.22 M_tCO_{2e} (minimum), 155.01 M_tCO_{2e} (mean) and 216.79 M_tCO_{2e} over the 25-year operational cycle. Finally, if no palm oil is allowed on peatlands, the potential CO_2 emissions released from peat oxidation caused by drainage would be zero (Table 6.4 and Figure 6.3).

Table 6.4 Calculation of CO_2 emission from peat oxidation caused by drainage of palm oil plantation activities in EMRP

Oil Palm Plantation Life Cycle Operation	CO_{2eq} emission unit (ton $ha^{-1}yr^{-1*)}$	Total Oil Palm Area on Peatland (ha)			Expected CO_2 emission release ($M_tCO_{2e}yr^{-1}$)			Total Year	Total CO_{2eq} emitted during Operation Cycle ($MtCO_{2eq}$)	
		Deep#)	Non-deep ##)	Total	Deep peat	Non-Deep	Total		Only from Deep-peat	Total peat
First 5 Year (Year 1-5)*)	178	86,716.40	37,292.99	124,009.39	15.44	6.64	22.07	5	77.18	110.37
After 5 year (Year 6-25)*	73	86,716.40	37,292.99	124,009.39	6.33	2.72	9.05	19	120.28	172.00
Total 25 Years of plantation cycle (Maximum)*	100	86,716.40	37,292.99	124,009.39	8.67	3.73	12.40	25	216.79	310.02
Total 25 Years of plantation cycle (Mean)**	71.5	86,716.40	37,292.99	124,009.39	6.20	2.67	8.87	25	155.01	221.67
Total 25 Years of plantation cycle (Minimum)***	43	86,716.40	37,292.99	124,009.39	3.73	1.60	5.33	25	93.22	133.31

Abbreviations and notes:

$M_tCO_{2e}yr^{-1}$ = Megaton carbon dioxide equivalent per year

Notes on CO_2 emissions default values used:

- Default values for the calculation of expected CO_2 emissions from peat oxidation caused by palm oil drainage were adopted from the following publications:
  - * Hooijer et al., 2012 (with average water table depth at 0.75 m)
  - ** Mean value calculated by authors by taking average values from Hooijer et al., 2012 and Agus, et al., 2013
  - *** Agus, et al., 2013
- Peat depth class:
  - # peat with depth < 3 m
  - ## peat with depth > 3 m
- Assumptions used in CO_2 calculation:
  Source of CO_2 emission is calculated from peat oxidation caused by drainage only, thus, above ground carbon and Below Ground Carbon generated from palm oil plants were omitted and excluded from calculation

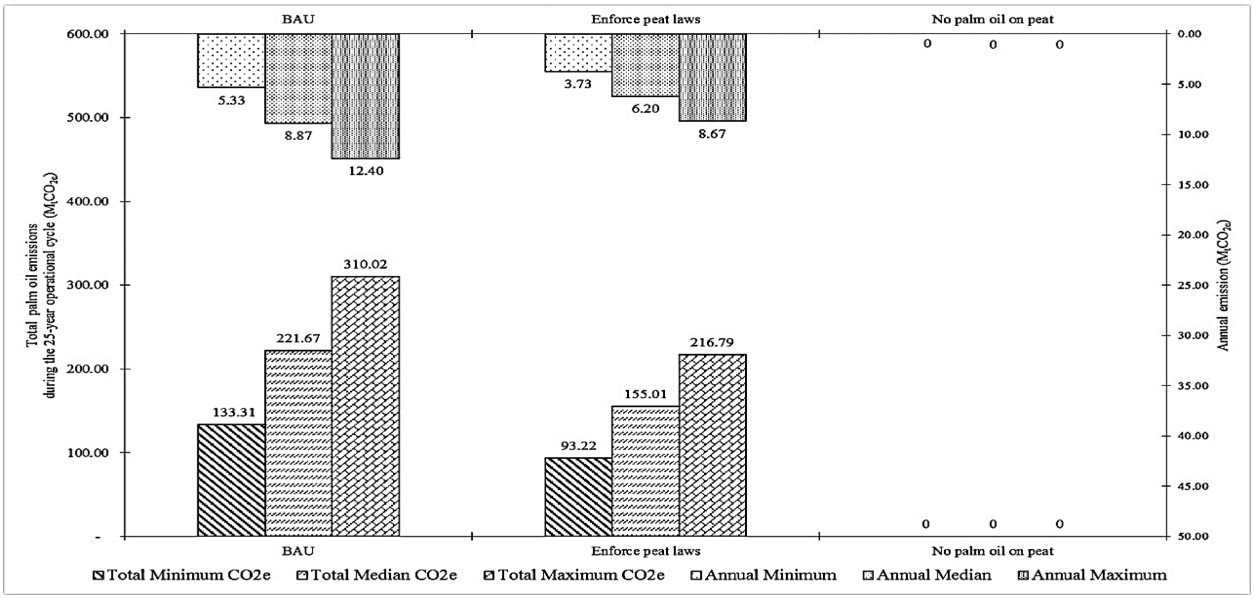


Figure 6.3 The potential CO_{2e} emissions from peat oxidation caused by drainage for palm oil plantations (annual CO_{2e} emission and total CO_{2e} emission during the 25-year palm oil operational cycle) in the EMRP

6.3.4 The potential contribution of "peatland law enforcement" and "no palm oil on peat" scenarios to achieve the national emission reduction target in the forestry and peatland sector

I estimate the potential contribution of banning palm oil plantations on deep peat in the EMRP (the "enforce peat laws" scenario) could reduce greenhouse gas emissions in the forestry and peatland sector by 13.87% (minimum) to 32.26% (maximum) by 2020 (Table 6.5 and Figure 6.4), compared with the national target of 26% (Table 6.5). If no palm oil cultivation is allowed on peatlands (no peat scenario) in the EMRP, there would be potential CO_2 emission reduction of 19.84% (minimum) to 46.13% (maximum), in the forestry and peatland sector by 2020.

Table 6.5 Indonesia's National Action Plan on the greenhouse gases reduction target by 2020 with 26% (own effort) and 41% (international assistance) reduction scenarios

Sector	26% Reduction target		41% Reduction target	
	(M$_t$CO$_{2e}$)	(%)	(M$_t$CO$_{2e}$)	(%)
Agriculture	8.00	1.04%	11.00	0.93%
Forestry & Peatlands	672.00	87.61%	1,039.00	87.38%
Energy & Transportation	38.00	4.95%	56.00	4.71%
Industry	1.00	0.13%	5.00	0.42%
Waste Management	48.00	6.26%	78.00	6.56%
Total	767.00	100.00%	1,189.00	100.00%

Source: *President Regulation No. 61 of 2011 on the National Action Plan on Greenhouse Gases Emissions Reduction*

Table 6.6 Minimum, mean and maximum contributions of (i) the "enforce peat laws" scenario and (ii) "no palm oil on peat" policy options on the national greenhouse gas emissions reduction target by 2020

Sector	Scenario and emission reduction target	Potential CO_2 reduction per scenario			Initial NAP balance (M$_t$CO$_{2e}$)	Minimum NAP balance (M$_t$CO$_{2e}$)	Mean NAP balance (M$_t$CO$_{2e}$)	Maximum NAP balance (M$_t$CO$_{2e}$)
		Min	Mean	Max				
Forestry and peatland (26% reduction target)	Enforce peat laws	93.22	155.01	216.79	672.00	578.78	516.99	455.21
	No palm oil on peat	133.31	221.67	310.02	672.00	538.69	450.33	361.98
Whole economy sectors (26%	Enforce peat laws	93.22	155.01	216.79	767.00	673.78	611.99	550.21
	No palm oil on peat	133.31	221.67	310.02	767.00	633.69	545.33	456.98

reduction target)								
Forestry and peatland (41% reduction target)	Enforce peat laws	93.22	155.01	216.79	1,039.00	945.78	883.99	822.21
	No palm oil on peat	133.31	221.67	310.02	1,039.00	905.69	817.33	728.98
Whole economy sectors (41% reduction target)	Enforce peat laws	93.22	155.01	216.79	1,189.00	1,095.78	1,033.99	972.21
	No palm oil on peat	133.31	221.67	310.02	1,189.00	1,055.69	967.33	878.98

Abbreviations and notes on scenarios:

- *M_tCO_{2e} =Megaton carbon dioxide equivalent*
- *NAP = National Action Plan*

Scenario definitions:

- ***Enforce peat laws**: meaning strictly enforcing the existing regulatory threshold that deep peat much be conserved and protected, so no cultivation is allowed (including palm oil plantations) on deep peat in the EMRP.*
- ***No palm oil on peat**: meaning that palm oil cultivation is banned from all peatland areas (deep and non-deep peats). Therefore, existing palm oil plantations must be closed down, and no further palm oil plantations will be established on peatlands in the EMRP*

There are numerous uncertainties, such those outlined in earlier parts of this Chapter, that should be taken into consideration before directly applying the information provided in Table 6.6 to national peatland management policies and related emissions reduction targets'.

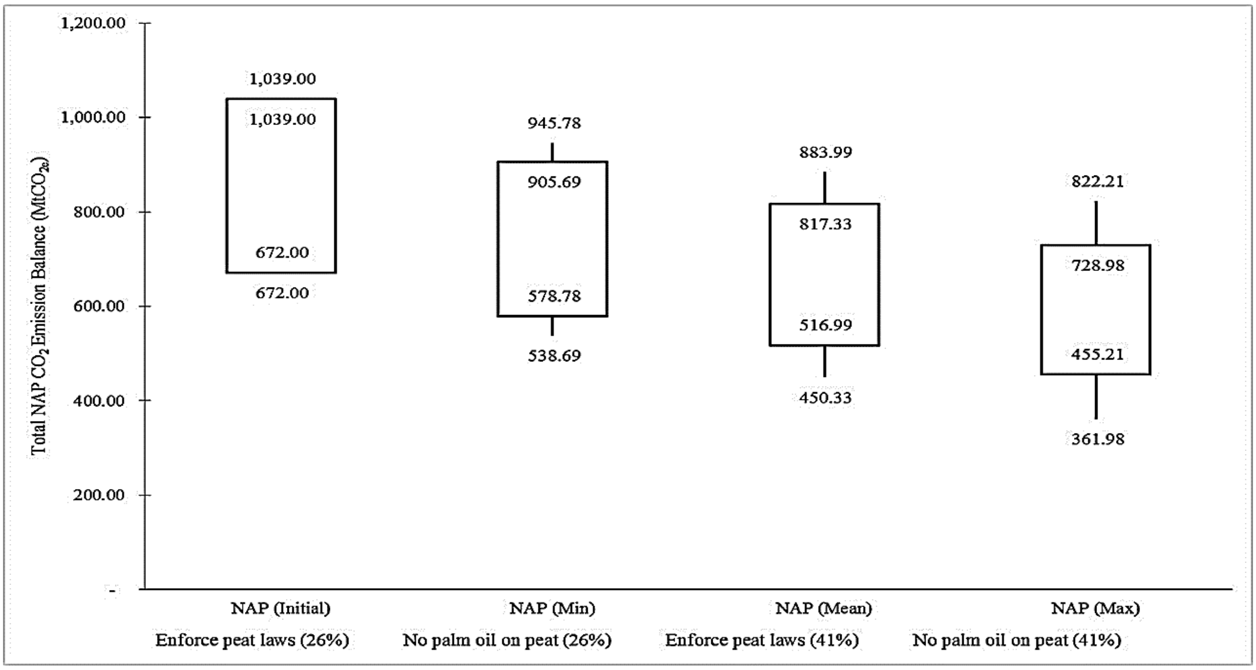


Figure 6.4 Contributions of (i) the "enforce peat laws" scenario, and (ii) "no palm oil on peat" policy options on the forestry and peatland greenhouse gas emissions reduction targets (26% and 41%) balance by 2020

6.4 Conclusion

This study identifies 13 national regulatory and policy measures that are directly and indirectly regulated in peatland conservation, protection and restoration in Indonesia. These law measures vary from national acts, government regulations, presidential regulation and instructions, and related ministerial regulations. These peatland ordinances oblige peatland with a minimum 3 m thickness to be conserved, protected and restored and, therefore, any cultivation or peat exploitation activities on this thick peatland are considered illegal.

Despite the 3 m peat depth regulatory threshold, however, this study found that around 44% (equivalent to 0.086 million hectares) of 16 large-scale palm oil plantations operating in the EMRP were cultivated on deep peat. They were not permitted by existing peatland regulatory measures and are operating on an illegitimate basis.

Continuing the present practice of cultivating palm oil on deep peat in the EMRP, may bring legal and economic consequences to the palm oil companies, as well as an ecological problem to the peatland ecosystem. Besides the potential of both financial and administrative penalties, cultivating palm oil within deep peat in EMRP will exacerbate peatland oxidation caused by peatland drainage leading to the release of substantial CO_2 emission into the atmosphere. This study concludes that there will be 93.22–310.02 M_tCO_{2e} of carbon dioxide potentially released from peat oxidation caused by palm oil drainage during the first 25-year plantation cycle. However, this potential CO_2 emission release can be reduced to 93.22–216.79 M_tCO_{2e} if those palm oil plantations on deep peat are stopped. The potential CO_2 emission release from peat oxidation would be zero if all palm oil plantations were displaced from peatland in the EMRP.

Based on findings of this study, we recommend the followings policy options in regards to palm oil plantation development and management in the EMRP.

First, the central, provincial and local governments need to consistently enforce the existing peatland regulatory threshold with regards to illegal palm oil plantations practices in the EMRP area. This policy would contribute significantly (13.87–32.22%) to the achievement of the national greenhouse gases emissions reduction target for the forestry and peatland sectors by 2020.

The second (and the best) option to maximise the avoidance of potential CO_2 emission release, is that all peatland in the EMRP should be free from palm oil cultivation, avoiding CO_2 emission release from peat oxidation caused by peat drainage.

Third, a land swap policy should be implemented to enable those plantations located on deep peat to move to mineral lands or shallow peat within the EMRP or to other areas in Central Kalimantan. Our analysis showed that more than 41% of the total 1,040,666 ha of the EMRP comprises mineral soil.

Therefore, there is space available to accommodate the shift of palm oil cultivations from deep peat to mineral soil. In addition, a recent study reported that there are 1,800,000–1,100,000 ha of land suitable for palm oil development available in Central Kalimantan (Sumarga et al., 2015).

Finally, it is important that palm oil companies operating in the EMRP adopt the best management practices when cultivating palm oil on peat in order to minimise the ecological impacts of their operations on communities and peat ecosystems. Roundtable Sustainable Palm Oil has developed two best management practice manuals on cultivating palm oil on peat (Lim et al., 2012) and the management and rehabilitation of natural vegetation in association with palm oil cultivation on peat (Parish et al., 2012); these should be used for practical guidance.

CHAPTER 7 ASSESSING THE SUCCESS OF TROPICAL PEATLAND RESTORATION

Summary

Indonesia's peatland ecosystems have globally significant carbon stocks and play an important role in regional and global climate systems. Despite their values, these peatlands have been subject to extensive degradation over the past two decades, such that now, more than 50% of the nation's 21 million hectares of peatlands are considered degraded. This degradation needs to be addressed in order to mitigate climate change and control the related peatland fires that are causing widespread smoke pollution and public health problems in the region. As part of these actions, degraded areas need to be effectively restored. Most peatland restoration activities carried out in Indonesia to date have been ad hoc demonstration projects and involved techniques such as blocking drainage canals, planting trees, conserving remnant forest areas and creating livelihood alternatives for local people. In this chapter I proffer a framework that can be used by policy makers, funding agencies and land managers to assess the effectiveness of alternative peatland restoration plans. The framework includes five elements of restoration outcomes; aspects, attributes, principal indicators, standard for comparison, and decision criteria. I also present a stepwise protocol for monitoring the performance of tropical peatland restoration activities.

The guideline I present facilitate better decision making and implementation of restoration activities that are likely to be more successful and wider impact in the future

7.1 Introduction

Tropical peatland in Indonesia is of a global importance for its terrestrial carbon pool and biodiversity conservation values. The peatland also provides valuable goods and ecosystem services, including the provisioning and production services (e.g. timbers and non-timber products); environmental regulation services (e.g. climate change, flood control and prevention); cultural/informational services (e.g. ecotourism, education, religious practices), and supporting services (e.g. biodiversity, nutrient cycling) (Joosten & Clarke, 2002; Kimmel & Mander, 2010). Despite these substantial values and ecosystem services, peatland in Indonesia is undergoing rapid degradation owing to conversion to other land uses such as large-scale agriculture and industrial plantations (Koh et al., 2011; Carlson et al., 2012; Miettinen et al., 2012; Miettinen et al., 2012a; Miettinen et al., 2013), artificial drainage canal development (Hooijer et al., 2006; Hooijer et al., 2012;), and recurrent fires (Page et al., 2002; Aldhous, 2004; Hoscilo et al., 2011).

Peatland degradation has brought negative consequences including the disappearance of peat swamp forest cover (Hooijer et al., 2006; BAPPENAS, 2009; Miettinen et al 2012; Margono et al., 2014), the release of immense CO2 emissions into the atmosphere (Page et al., 2002; Hooijer et al., 2006; Koh et al., 2011; Carlson et al., 2012), and the near extinction of endemic and iconic species such as the orangutan and Sumatran tigers (Byrne & Farrell, 1997; Felton et al., 2003; Danielsen et al., 2009; Quinten et al., 2010; Azhar et al., 2011; Posa, 2011; Sunarto et al., 2012).

Numerous peatland restoration activities have been attempted to reverse the rate of degradation. These restoration initiatives have embodied various activities such as damming drainage channels (Suryadiputra et al., 2005; Dohong & Lilia, 2008; Page et al., 2009; Jaenicke et al., 2010; Ritzema et al., 2014;); revegetation of bare peatland through planting trees, seedling provision, and artificial seed dispersal promotion (Giesen, 2004; van Eijk & Leenman, 2004; Graham et al., 2007; Page et al., 2008; van Eijk et al., 2009; Graham & Page, 2012; Graham & Page, 2014); and developing livelihood options for locals (Noor et al., 2005; Noor et al., 2007; Silvius & Diemont, 2007; Suyanto et al., 2009; Gillespie, 2012; Jewitt et al., 2014).

There is a clear need to assess the efficacy of peatland restoration activities. Successful assessment monitors and evaluates the successional trajectories of the restorative measures and techniques used against a specific criteria or standard (SER, 2004). In addition, the results of a successful assessment will inform whether or not the hydrological, biological and biogeochemical characteristics of a restored site have been moved toward its previous undisturbed condition or have moved more towards an alternative state.

To perform a better evaluation of restoration success, a proper assessment framework is needed, which provides sets of comprehensive aspects, attributes, indicators, standards for evaluation, and decision criteria. The processes of implementing assessment activities should be completed step-by-step from identifying restorative measures and techniques used, to developing success indicators, monitoring and measuring implementation, analysing the results, comparing the monitored results with the standard values obtained from reference sites, and assessing the success of the restored site.

7.2 The major processes and steps of peatland restoration

Generally, peatland restoration involves five major processes and steps. These are: (a) understanding the main restoration barriers; (b) setting the restoration goals; (c) identifying and determining restoration strategies and techniques; (d) implementing the elected restoration strategies and techniques; and (e) monitoring and assessing the success of restoration measures and techniques used (Hobbs & Norton, 1996; Greipsson, 2011). These processes and steps are depicted briefly in Figure 7.1.

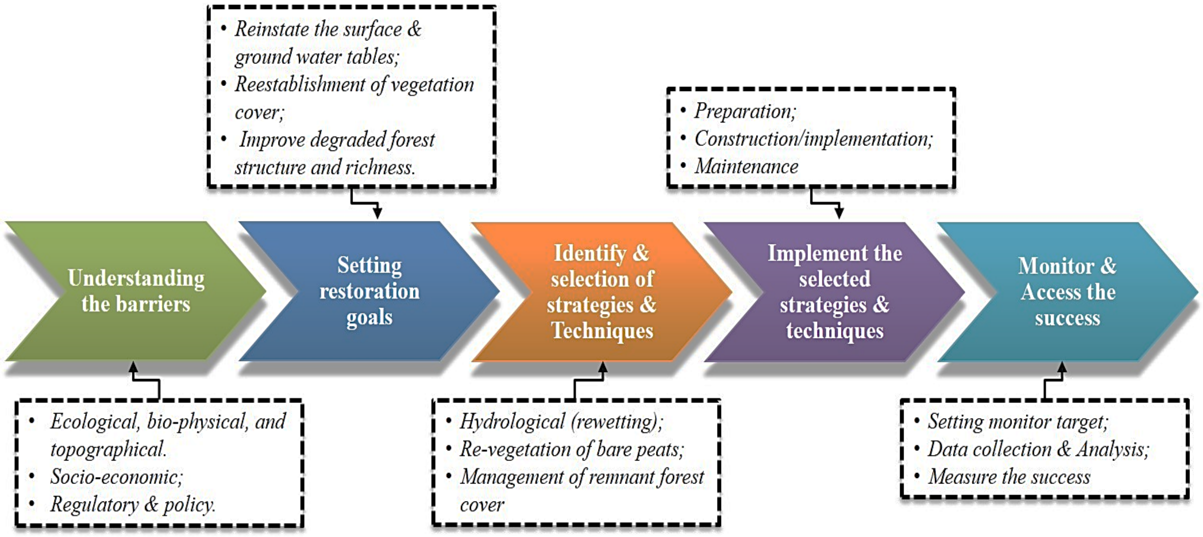


Figure 7.1 Major processes and steps of peatland restoration

The first step in restoration is identifying and understanding restoration barriers that can potentially hamper the success of peatland restoration. The barriers may include the hydrological, biological, topographical, socioeconomic and regulatory policies. For instance, frequent fires and flooding have been reported as the major barriers for both natural regeneration and bare peatland revegetation in Central Kalimantan and in Berbak National Park, Jambi (van Eijk & Leenman, 2004; Wösten et al., 2006; Page et al., 2009; van Eijk et al., 2009; Hoscilo et al., 2012).

The second step in restoration is to set the goals of peatland restoration. The restoration goal is the achievement of the desired conditions after the restoration measures and techniques are deployed. Determination of restoration goals is critical in defining proper restoration strategy, measures and techniques. Generally, the end point of peatland restoration is the return of the hydrological, biological, and biogeochemical characteristics of a degraded peatland to a condition as similar as possible to their prehistoric levels.

The next process and step in peatland restoration is to identify and to select appropriate restoration measures and techniques. These measures and techniques range from interventions on hydrological, biological, socioeconomic, and even regulatory policy. The fourth process and step in peatland restoration is the implementation of the elected restoration measures and techniques on the ground. Finally, monitoring and assessing the success of the restoration activity is constituted the final step in the restoration processes.

7.3 Peatland restoration goals

The goals of ecological restoration activities are the recovery of structural and functional characteristics of a degraded ecosystems and the reestablishment of prehistorical undisturbed characteristics (SER, 2004; Hobbs, 2007; Hobbs et al., 2007). In addition, restoration goals may also encompass broader perspectives such as the restoring and maintaining of both local and global biodiversity, as well as the improvement of ecosystem services (Allison, 2012).

To contextualise, the common definition of the tropical peatland restoration goal is the recovery of hydrological, biological, and biochemical characteristics of a degraded peatland to its prevous undisturbed condition and/or being as close as possible to its reference site attributes (Page et al., 2008; Page & Rieley, 2008; Ritzema et al., 2014).

However, debate upon restoration goals has become contentious with discussions among ecologists and conservationists. The debate is contested between the supporters of idealistic and purist goals and those urging for more pragmatic and realistic goals. The idealistic and purist groups argue that the goal of restoration should be brought back of the structural and functional characteristics of a degraded ecosystem to its original condition. These goals have been criticised as unrealistic and retrospective (Choi, 2007). In the meantime, the supporters of pragmatic and realistic goals suggest that the formulation of restoration goals should be based on factors such as resources availability, time limitations, and other external determinants, including climate change, socioeconomic and policy dynamics (Ehrenfeld, 2000; Choi et al., 2008; Suding, 2011). Setting a realistic goal is a crucial step so as to ensure the restoration targets will be successfully achieved (Hobbs & Norton, 1996).

Due to broad targets in restoration goals, the followings four paradigms of setting restoration goals have been suggested: restoration to guide recovery; restoration to compensate habitat loss; restoration to deliver ecosystem services, and restoration to enhance resilience (Suding, 2011).

It should be remembered that successional trajectories of ecological restoration activities are dynamic and non-linear towards the desired goals. Numerous studies have shown that the end outcomes of restoration activities could result in three possible successional trajectories: convergence toward a desired target goals; unplanned divergence across restoration sites; and deviation from the target goals or creation of a novel ecosystem (Figure 7.2)(Matthews & Spyreas, 2010; Suding, 2011; Aronson & van Andel, 2012; Moreno-Mateos et al., 2012). Therefore, to anticipate potential deviance of restoration outcomes against the desired goals, monitoring activity is necessary at an early stage of restoration, so as to recognise as early as possible the directional trends of the successional trajectory.

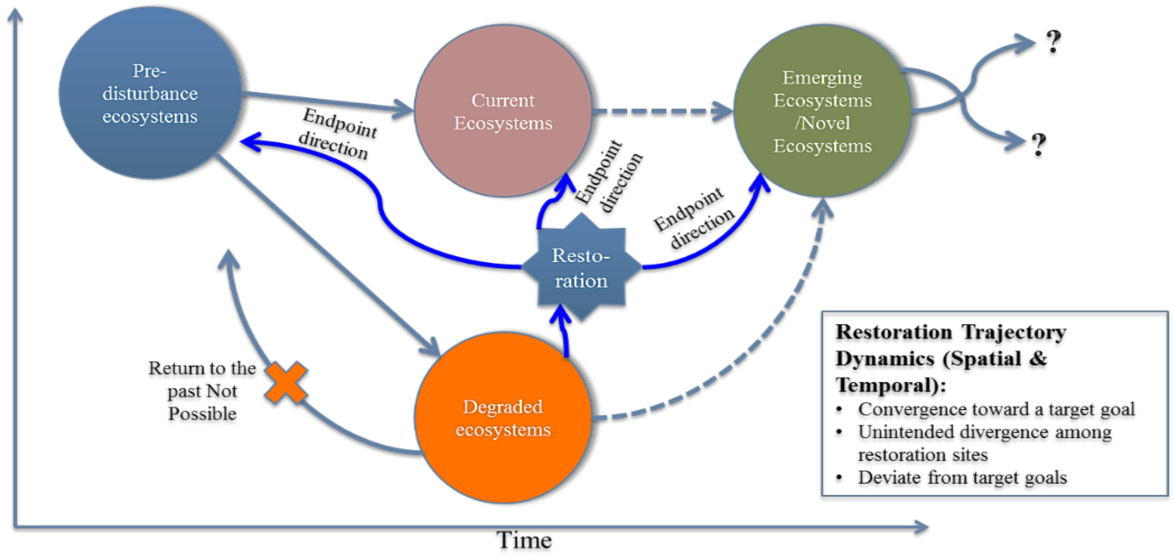


Figure 7.2 Restoration goals endpoint possibilities (redrawn & modified from Suding, 2011 and Aronson & van Andel, 2012)

7.4 Defining peatland restoration success

Generally, the main goal of peatland restoration is the reestablishment of hydrological, biological, and biogeochemical properties of a degraded peatland. The fulfilment of the intended restoration goal is commonly concluded as restoration success (Moreno-Mateos et al., 2012). In other words, peatland restoration is considered a success when the established success criteria (hydrological, biological, and biogeochemical/functional characteristics) are significantly represented in the restoration site. It should be noted that the current conceptual definition of "success" is merely narrowed and biased towards structural and functional success criteria, whereas socioeconomic and policy aspects have been ignored in calculation of the success definition. These socioeconomic and policy aspects are important components that should be included in any evaluations (Bonnett et al., 2011).

The definition of restoration success can be multifaceted and it is very much dependent upon geographical, technical, social, political and time contexts (Kentula, 2000). Kentula (2000), for, instance, it has been proposed there are three conceptual definitions of "success". These are: compliance success, functional success, and landscape success. Compliance success is achieved by evaluating whether the restoration activity has complied with the terms of an agreement (e.g. permit, contract, regulatory plan). Functional success is decided on whether or not the ecological functions of the ecosystem have been recovered. Landscape success is judged on the restoration's contribution to the enhancement of landscape integrity, including biodiversity.

7.5 Measuring tropical peatland restoration success

Measuring restoration success is one of the key elements in ecological restoration. Success measurement aims to present whether or not sets of intended success criteria have been fulfilled and achieved in the restoration site. In other words, measuring success is an effort to understand the successional trajectories of a degraded ecosystem after the restoration measures and techniques are put in place (Suding, 2011).

Efforts to evaluate restoration success are often hampered by several fundamental factors including data inaccessibility, inadequate resources, limited and very short timeframes, absence of monitoring frameworks, lack of appropriate and quantified success criteria, and the dynamics of reference sites (Cairns & Heckman, 1996; Suding, 2011; Suding & Leger, 2012). To measure restoration success, an assessment framework and protocol are required (Cairns & Heckman, 1996; Hobbs & Norton, 1996; Suding, 2011).

7.5.1 Aspects and ecosystem attributes to be measured

Peatland restoration involves numerous and simultaneous objectives ranging from hydrological, biological, biogeochemical, socioeconomic and regulatory policy aspects. When measuring the success of peatland restoration, these objectives have to be included in the assessment framework.

In the meantime, the measurement of ecological restoration success has been carried out on the basis of three ecosystem attributes. These attributes are diversity, vegetation, and ecological processes (Ruiz-Jaen & Mitchell, 2005). The Society of Ecological Restoration International (SER,2004) has developed a more comprehensive and integrated assessment tool for measuring restored ecosystems, which comprises the following nine attributes: (a) similarity in terms of species characteristics and community structures with the reference site; (b) presence of indigenous species; (c) existence of functional groups needed for long-term stability; (d) ability of the physical environment to support reproducing populations; (e) normal functions; (f) integration with the landscape; (g) removal of potential barriers (h) resilience to the natural perturbations; and (i) self-sustainability as its reference ecosystem. Despite its comprehensive assessment attributes, no study has reported applying these SER ecosystem attributes, owing to various limiting factors such shortfalls in budget and resources, and the monitoring timeframe being very short (Ruiz-Jaen & Mitchell, 2005).

In evaluating peatland restoration success, a broader group of attributes should be considered that include hydrological, biological (structural and diversity), and biogeochemical attributes.

The structural attribute is normally determined by measuring diversity and structure of the vegetation or faunal communities. In the meantime, the diversity attribute is commonly actuated by measuring species richness and species abundance of the target communities. Finally, the ecological processes attributed are normally identified through characterisation of the nutrient cycling dynamics of the soil and biological interactions. It should be noted that socioeconomic and policy aspects have been so far neglected in calculating successional measurement attributes. Owing to the importance the socioeconomic and policy factors in restoration activity, there is a necessity for incorporating these aspects within restoration success measurement (Aronson et al., 2010; Collier, 2011; Schultz et al., 2012).

The measurement of restoration success has been so far focused on the successional dynamics and trajectories of the structural and functional components of the restored ecosystem, whereas, the socioeconomic and policy aspects have been neglected (Aronson et al., 2010; Collier, 2011).

7.5.2 Reference sites

One important aspect in measuring restoration success is the selection of appropriate reference sites, which can be used as a criteria or benchmark for reflecting the success of restoration measures and techniques applied. The criteria is generally built from the result of monitoring conducted in reference sites and the criteria offers an empirical basis for judging whether or not restoration goals and objectives have been attained (Bonnett et al., 2011).

The selection of a reference site has to be done in a proper manner and should satisfy the following requirements and characteristics: (a) occurs in the same life zone or landscape; (b) is relatively close to the restoration site; (c) is exposed to similar natural perturbations as in the restoration site; and (d) is relatively pristine or undisturbed in condition (Cairns & Heckman, 1996; SER, 2004; Ruiz-Jaen & Mitchell, 2005). In addition, it is of critical importance to understand the potential variations within reference sites, therefore, it is necessary to have more than single reference sites to evaluate the success of restoration (Hobbs & Norton, 1996). However, the selection of idealistic reference sites, which fulfil these characteristics is very difficult in reality, due to factors such as the dynamics of the ecosystem (which change over time), climate change, socioeconomic dynamics of anthropogenic disturbances, and lack of recorded data of the previous ecosystem.

7.5.3 Success criteria and decision strategy

To estimate the success level of restored ecosystems, the following two strategies are commonly used: direct comparison and trajectory analysis (SER, 2004; Ruiz-Jaen & Mitchell, 2005; Bonnett et al., 2011). Direct comparison is done by comparing the aspects and attributes as well as performance indicators of both the restored site and its reference sites. Meanwhile, trajectory analysis is done by comparing recovery trajectories of different variables through time with the reference sites.

The common approach in measuring the degree of success of a restored ecosystem is via comparing the ecological (structural and functional) properties in the restored site with those in the reference sites (Ruiz-Jaen & Mitchell, 2005). In the context of peatland restoration, the comparison should be focused on hydrological, biological (vegetation and faunal), and biogeochemical properties.

7.5.4 Potential indicators of success

There has been a handful of studies conducted to measure the success of peatland restoration in Indonesia in recent years. As a result, scant literature is available that discusses the potential indicators useful for measuring successful peatland restoration activities. Advanced and numerous studies have been conducted in temperate and boreal regions to evaluate the impact of peatland restoration activities. So, success indicators that have been used in temperate and boreal areas can be useful as a basis for developing similar success indicators for peatland restoration in the tropics.

The potential indicators for measuring tropical peatland success can be classified into four principal groups of potential indicators measuring: hydrological recovery; biological recovery; biogeochemical recovery, and socioeconomic and policy success. These four groups are further detailed in the subsequent sections.

7.5.4.1 Potential indicators for measuring hydrological recovery

Peatland rewetting via canal blocking techniques aims to increase surface water levels and storage within the blocked canals (Suryadiputra et al., 2005; Limin et al., 2007; Dohong & Lilia, 2008; Page et al., 2009; Landry & Rochefort, 2012; Parry et al., 2014;). In addition to these, canal blocking is expected to reduce outflow run off and increase the capacity of water retention as well as increase the stability of water levels (Lunt et al., 2010; Jaenicke et al., 2011; Susilo, 2013; Ritzema et al., 2014). Hence, increased surface water levels (SWL), increases ground water levels, water level stabilisation and water retention, and decreases outflow run off that can be potentially used as predictors for the recovery of hydrological features resultant from peatland rewetting (Table 7.1).

Table 7.1 Hydrological recovery indicators

Hydrological recovery indicators	**References**
Surface water level	Suryadiputra et al.,2005; Limin et al., 2007; Dohong & Lilia, 2008; Lunt et al., 2010; Jaenicke et al., 2011; Page et al., 2011; Landry & Rocherfort, 2012; Ritzema et al., 2014
Ground water level	Limin et al., 2007; Lunt et al., 2010; Page et al., 2011; Landry & Rocherfort, 2012; Susilo, 2013; Ritzema et al., 2014
Stabilisation of water level	Amstrong et al., 2009; Lunt et al., 2010; Landry & Rocherfort, 2012; Ritzema et al., 2014
Water Retention (increase)	Amstrong et al., 2009; Lunt et al., 2010; Landry & Rocherfort, 2012; Ritzema et al., 2014
Run off (decrease)	Amstrong et al., 2009; Lunt et al., 2010; Landry & Rocherfort, 2012; Ritzema et al., 2014

7.5.4.2 Indicators for measuring biological recovery

7.5.4.2.1 Plants

Numerous studies have been done to measure the success of reforestation in the tropical region. For instance, Le et al., (2012) carried out a comprehensive literature review on the success of reforestation in the tropics, and outlines four principal success indicators for assessing reforestation. These success indicators include: establishment, forest growth, environmental, and socioeconomic success (Le et al., 2012).

Furthermore, a literature study has been done to shed light on the performance of global wetlands restoration activities in recovering the structural and functional aspects of restored wetlands (Moreno-Mateos et al., 2012).

The success of peatland restoration can be perceived from the presence of recolonisation and reestablishment of indigenous plant covers, in both woody and non-woody species. These recolonisation and reestablishment activities can further be evaluated in term of richness, diversity, and abundance.

In the meantime, vegetation establishment success can be judged from the survival rate of the seedlings and trees planted, or naturally generated, as well as the total area being rehabilitated (Le et al., 2012).

The potential success indicators for peatland revegetation include the subsequent attributes: vegetation establishment, plan cover, species richness, species abundance, and biomass Table 7.2)

7.5.4.2.2 *Vertebrates and macroinvertebrates*

The potential success indicators for the existence of vertebrates and macroinvertebrate communities as result of peatland restoration can be measured through their species richness, abundance, density, and occupancy (Table 7.2).

Table 7.2 Biological recovery indicators

Biological recovery indicators	References
Vegetation/plants recovery indicator:	
Vegetation establishment (survival rate, area planted)	Ruiz-Jaen & Aide, 2005; Graham et al., 2007; Le et al., 2011; Moreno-Mateos et al., 2012.
Plant covers (ground cover type, height, canopy diameter, vertical stratification, dominant species)	Ruiz-Jaen & Aide, 2005; Graham et al., 2007; Murdiyarso et al., 2010; Le et al., 2011; Moreno-Mateos et al., 2012.
Species richness	Ruiz-Jaen & Aide, 2005; Graham et al., 2007; Murdiyarso et al., 2010; Le et al., 2011; Moreno-Mateos et al., 2012.
Species abundance	Ruiz-Jaen & Aide, 2005; Graham et al., 2007; Murdiyarso et al., 2010; Le et al., 2011; Moreno-Mateos et al., 2012.
Biomass	Murdiyarso et al., 2010; Moreno-Mateos et al., 2012.
Vertebrates:	
Abundance	Ruiz-Jaen & Aide, 2005; Graham et al., 2007; Le et al., 2011; Moreno-Mateos et al., 2012.
Density	Ruiz-Jaen & Aide, 2005; Graham et al., 2007; Le et al., 2011; Moreno-Mateos et al., 2012.
Species richness	Moreno-Mateos et al., 2012
Occupancy	Moreno-Mateos et al., 2012
Macroinvertebrates:	Moreno-Mateos et al., 2012
Density	Moreno-Mateos et al., 2012
Abundance	Moreno-Mateos et al., 2012
Species richness	Moreno-Mateos et al., 2012

7.5.4.3 *Potential indicators for measuring biogeochemical processes*

Potential indicators for measuring the success of peatland restoration-related biogeochemical processes can be included as follows: carbon storage and cycling; nitrogen storage and cycling; phosphorous storage and cycling; organic matter accumulation; and other elementals storage

(Armstrong et al., 2010; Jauhiainen et al. 2008; Moreno-Mateos et al. 2012; Murdiyarso et al. 2010) (Table 7.3).

Table 7.3 Biogeochemical recovery indicators

Biogeochemical recovery indicators	References
Carbon storage and cycling (soil total and organic carbon, respiration rate, mineralisation rate)	Jauhiainien et al., 2008; Murdiyarso et al., 2010; Agus et al., 2011; Moreno-Mateos et al., 2012; Grand-Clement et al., 2013
Nitrogen storage and cycling (soil and total organic nitrogen)	Moreno-Mateos et al., 2012
Phosphorus storage (soil total and organic phosphorous, Ca-Fe-Al bounded phosphorous)	Moreno-Mateos et al., 2012
Organic matter accumulation (soil organic matter, bulk density, soil texture, and soil moisture)	Agus et al., 2011; Moreno-Mateos et al., 2012
Other elementals storage (salinity, soil Fe, Al, Ca, Mn, Mg, water dissolved oxygen)	Amstrong et al., 2010; Moreno-Mateos et al., 2012; Grand-Clement et al., 2013

7.5.4.4 Indicators for measuring socio-economic and policy success

Aside from creating positive impacts to the hydrological, biological and geochemical properties, peatland restoration is expected to have positive implications in terms of socioeconomic improvement, notably to the local communities (Anshari et al., 2005; Chokkalingamet al., 2005; Page et al., 2009; Jewitt et al., 2014).

The potential indicators that can be used to measure the impact of peatland restoration on socioeconomic factors entail: income sources, income structure composition, employment options, employment opportunities, and business expansion opportunities (Table 7.4).

In the meantime, institutional and policy improvement, clarity of tenure systems, improved community participation, a special agency to handle peatland management and restoration, and harmonised inter-sector policies on peatland management and conservation can be used as potential success indicators from institutional and policy perspectives (Table 7.4).

Table 7.4 Socioeconomic and policy success indicators

Socioeconomic and policy success indicators	References
Income and alternative livelihood options:	Anshari et al., 2005; Chokkalingam et al., 2005; Chokkalingam et al., 2007; Jewitt, 2008; Suyanto et al., 2009; Page et al., 2009; Jewitt et al., 2014
Income sources (increases in variety of sources of income)	Anshari et al., 2005; van Beukering et al., 2008; Suyanto et al., 2009
Income structure composition (agriculture, non-agriculture, industry, public services)	Anshari et al., 2005; van Beukering et al., 2008; Suyanto et al., 2009
Employment:	
Increased job opportunities	Suyanto et al., 2009
Type of jobs offered, increased and varied	Suyanto et al., 2009
Business opportunities improved	Suyanto et al., 2009
Institutional and regulatory policy:	
Special institution to handle peatland conservation and restoration present	Silvius & Suryadiputra, 2005; Galudra et al., 2011
Clarity in land tenure system	Galudra et al., 2011, van Noordwijk et al., 2014
Community participation increased	
Regulatory and policy measures and guidance on sustainable peatland management, conservation, and restoration available	Silvius & Suryadiputra, 2005; Chin & Parish, 2013; Guzick & Robinson, 2013; Koh, 2013
Inter-sector policies harmonised and enforced consistently	Silvius & Suryadiputra, 2005; Galudra et al., 2011; Murdiyarso et al., 2011

7.6 Proposed framework for assessing tropical peatland restoration success

The proposed assessment framework for measuring success of tropical peatland restoration is briefly depicted in Figure 7.3. The basic skeleton of the assessment framework comprises of five elements that are: aspects, attributes, principal indicators, standard for comparison, and decision criteria.

There are four main aspects of restoration that have to be measured, these aspects are biological, hydrological, biogeochemical, and socioeconomic and policy. Each individual aspect embraces relevant attributes. For instance, the biological aspect has two attributes in diversity and structure. In the meantime, all aspects and attributes have potential success indicators. The potential indicator is derived from monitoring the results of the reference sites and can be obtained from relevant literature review data.

The next component of the assessment framework is the standard for comparison. There are two strategies which can be used in evaluating the success of restoration. These are: the direct comparison; and the trajectory analysis (SER, 2004; Ruiz-Jaen & Mitchell Aide, 2005; Bonnett et al., 2011). The direct comparison is achieved by measuring and comparing the values of selected parameters of the hydrological, biological, and geochemical properties both in restoration and reference sites. Meanwhile, the trajectory analysis is determined through the analysis of data obtained from periodical monitoring activities in the restoration sites, with these data plotted so as to illustrate the successional trends of selected parameters (SER, 2004; Bonnett et al., 2011).

The final element of the assessment framework is successful decision criteria. There are three decision criteria, which can be used to judge the success of peatland restoration. These criteria are success, partial success and failure; or the success level can also be determined through the success ratio method (Short et al., 2000).

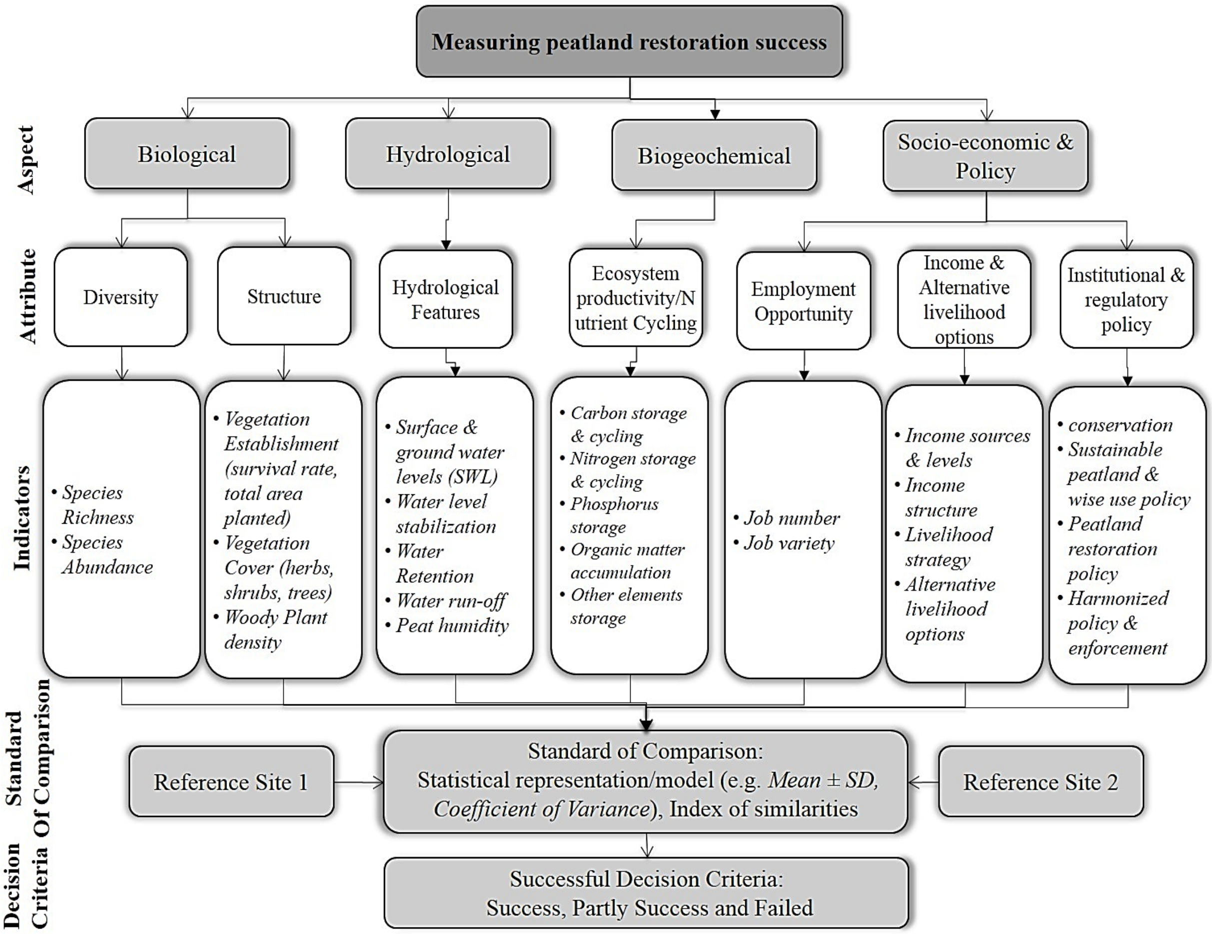


Figure 7.3 Conceptual framework for assessing the success of tropical peatland restoration

Monitoring activity is a critical step in measuring the success of peatland restoration. In order to achieve better monitoring results there should be a monitoring protocol as a guide to the success indicators of elected parameters. This study proposes the basic monitoring protocol for evaluating peatland restoration success as presented in the Figure 7.4.

The monitoring protocol comprises the followings six sequential steps: (1) identifying the restorative measures and techniques employed at the restoration site; (2) developing success indicators; (3) monitoring the elected parameters for aspects and attributes both in restoration and reference sites; (4) performing collected data analysis and presenting the results; (5) comparing monitoring results with the success benchmark indicators; and (6) assessing and judging the successional trends (success, partial success, and failure).

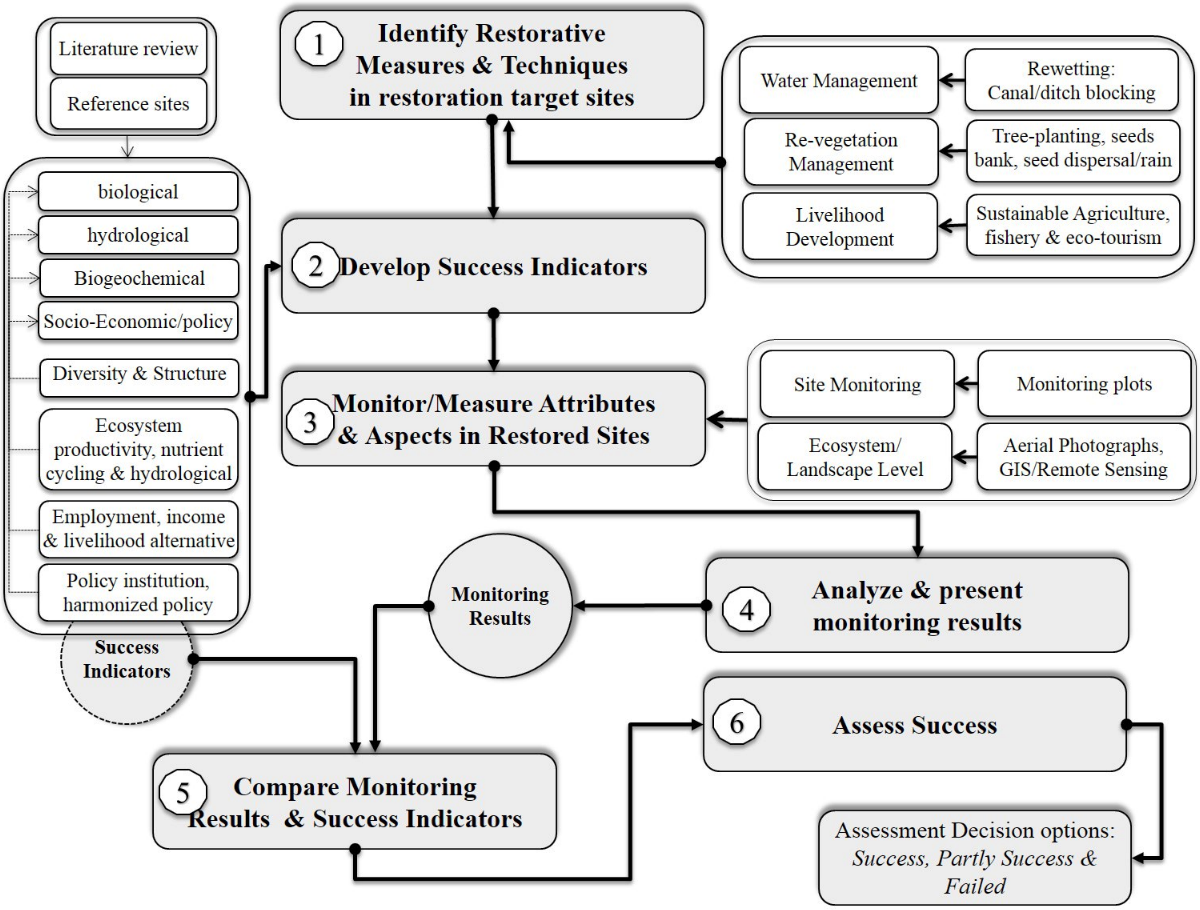


Figure 7.4 Principal steps for monitoring peatland restoration success

CHAPTER 8 CONCLUSION

8.1 Summary of thesis

The first research question of the thesis called for a review of the drivers of tropical peatland degradation, with particular attention focusing on Indonesia, in order to better understand the broader socioecological context in which restoration activities take place. The review presented in Chapter 2 established three significant concepts. First, the direct drivers of tropical peatland degradation included logging, industrial oil palm plantation development, drainage, and recurrent fires (mostly caused by large- and small-scale land use activities), and the indirect drivers included climate change, poverty and livelihood needs of local people, and the ineffective and sometimes perversely counter-productive land use governance systems. Second, it was found peatland degradation had resulted in peatland forest cover loss, carbon emissions and severe threats to biodiversity. Third, the peatland forest cover in Indonesia had been reduced to 38% by 2010, with oil palm development the largest contributor to forest loss and land use change.

The review reinforced the urgent need for effective large-scale peatland restoration initiatives and the revision of peatland regulatory measures, to make them more effective. The second research question required an analysis of previous and current peatland restoration practices in Indonesia in order to better understand the techniques used and the factors limiting their relative effectiveness. The analysis presented in Chapters 3 and 5 highlighted that: 1) the principal factors that hindered the success of peatland restoration in Indonesia included physical and hydrological site conditions, recurrent fires, counter-effective land use policies and the socioeconomic context of the challenge; 2) the principal techniques used to restore peatlands in Indonesia included rewetting through canal blocking, re-forestation through seedling transplantation, the development of seed-based tree seedling nurseries, and measures that supported natural regeneration such as the strategic planting of seed trees and additional seed dispersal; and, 3) the previous restoration measures in the case study area were typically “small and pilot-based” and, as such, had a limited impact. Despite the small size of the projects, it clearly emerged that of the techniques used, rewetting appeared to be the most common and the most likely to result in larger-scale successful peatland restoration.

The second research question was also addressed through an analysis of illegal oil palm development in the case study area presented in Chapter 6. Spatial analysis and emissions calculation indicated that around 86,700 ha of palm oil plantations had been developed on “deep” peatland in the case study area (2004–2012) in direct contravention of a range of applicable laws, rules, decrees and ordinances aimed at conservation of deep peatland. Modelling presented in Chapter 6 suggested that these oil palm plantations had directly resulted in between 3.73 M_tCO_{2e} (minimum) to 8.67 M_tCO_{2e}

(maximum) of emissions annually between 2004 and 2012. This illegal oil palm development was a critical factor limiting the effectiveness of restoration activities in Central Kalimantan. As such, several recommendations are made in Chapter 6 to improve the enforceability of laws and policies protecting peatlands in Indonesia, and to allow restoration activities to be enacted with a reasonable chance of success.

The third research question of this thesis was also addressed in Chapter 5 through a study of the specific restoration technique of "rewetting". The rewetting study highlighted that: 1) effective rewetting and peatland restoration can be achieved with or without spillways on "dam box" designs, and if special design consideration is given to dam crest elevation and dam spacing, and if the materials used to construct dams are sufficiently durable and appropriate. The dams studied are to the best of my knowledge still in existence; and 2) rewetting dams built for restoration are frequently damaged, apparently by loggers and fishermen opposed to the restoration intervention in the area. Using the insights gained from the analysis of previous rewetting projects carried out in the case study area, a series of recommendations was made in Chapter 5 to improve the effectiveness of rewetting techniques.

The fourth research question was addressed in Chapter 7 through the presentation of an overarching conceptual framework for evaluating the success of effective peatland restoration. This framework can be used by policy makers to devise restoration interventions that should have a greater probability of success. In addition, a monitoring protocol is proffered in Chapter 7 to assist with the implementation of peatland restoration evaluation activities.

8.2 Limitations

The research involved a case study approach. The case study area used was the EMRP area of Central Kalimantan. This case study area provided a very interesting and data rich setting for the study of peatland restoration, given the extent of past ecological degradation in the area and the fact that some restoration activities had been tried. While useful, the circumstances of the case study area are specific to that area. This means that the results of the analysis presented in this thesis are primarily applicable to the case study area, but may have limited validity in other areas faced with different circumstances. In my view and experience, the results of this thesis are broadly applicable to peatland restoration across South-East Asia, but some of the recommendations, such as those related to rewetting and some aspects of policy reform needed to halt illegal peatland degradation should be taken into consideration and further tested before broader-scale application in other contexts. The policies synthesised in Chapters 2 and 6 of this thesis, are specific to Indonesia. While they have similarities with countries such as Malaysia, there are also distinct differences.

The advantage of using a regional-level case study area like the EMRP was that it offered the opportunity to consider drivers of degradation and past restoration activities at a scale that was useful for policy considerations. It also meant that analysis was mostly aggregative and reliant on primary data, sourced from other parties (e.g. Wetlands International). The methods presented in this thesis outline the steps taken to address these issues and support the validity and reliability of data collection and the analysis methods used.

This thesis makes an important contribution to what is a relatively new area of ecological restoration and scientific inquiry. As a new field of scientific inquiry, little has been previously published on what factors influence and constitute successful tropical peatland restoration. Much research and writing has explored temperate peatland restoration but little robust research has been published on tropical peatland restoration. This meant there was sparse research available in the public domain to use for comparison purposes with the results presented in this thesis. It also meant that the regional-level and aggregative nature of the EMRP case study had mixed primary data available on various important issues. The methods presented in this thesis, and the major results papers presented as Chapters 5, 6 and 7, were designed with this constraint in mind. The recommendations for future research listed in the following section also presents a wish-list of sorts for the types of primary empirical research needed to support improved aggregative regional-level studies in the future.

8.3 Future research

Given the findings of this thesis, I recommend three main projects for future research. First, more data are needed on the longer-term effectiveness of larger-scale tropical peatland restoration activities. Hydrological studies are needed at dam-site specific scales that expand on and test some of the findings and recommendations made in Chapters 3 and 5 of this thesis. Botanical and ecological students are needed on a similar scale to study responses to restoration interventions over time. Similarly, more research is needed into the responses of these hydrological and ecological features include surface and ground water levels behaviours, run-off level, evaporation rate, ecosystem respiration and so forth of the peatland areas to a combination of restoration measures, and consideration should be given to whether a certain combination of restoration techniques is more or less likely to result in better outcomes than the predominant use of one or another of the techniques.

Second, more research is needed on the socioeconomic factors that constrain and enable successful peatland restoration. This thesis presented evidence of rewetting restoration activities being damaged by local stakeholders because, apparently, they were opposed to the restoration. The question needs to be asked; what is the aggrieved of the stakeholders that justifies such damage and how widespread is that risk? The economics of restoration activities would benefit from further research too. Research into the comparative costs and returns (financial and non-financial) of different restoration techniques should support better longer-term decision-making and resource allocation. Such research could also help better formulate strategies that enable restoration activities to be used as a green business opportunity and livelihood improvement by local communities.

Third, more research is needed on how to use initiatives like oil palm product certification to systematically create opportunities to effectively limit illegal oil palm plantation development and support forms of oil palm development that enable better peatland restoration outcomes. For example, can oil palm development carried out in specific regions, and using certain agronomic methods, help reduce the incidence and extent of recurrent fires at regional scales? How can restoration activities be either funded or economically supported (e.g. through common use of equipment and resources) by oil palm plantation development companies and how can those companies be effectively enlisted to support larger-scale successful restoration. These sorts of research questions will help extend and enable the results of this thesis to hopefully contribute to the urgent need for better, larger-scale peatland restoration in Indonesia.

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