博士論文 (要約)

Landscape Strategies of Forest Restoration and Management to Reduce GHG Emissions Using Time-Series Land Cover Maps in East Kalimantan Province, Indonesia

(インドネシア東カリマンタン州における時系列土地被覆図を用いた温室効果ガス排出削減のための森林回復および管理の景観戦略)

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by

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KISWANTO

Abstract

Deforestation and forest degradation in the tropics are the substantial problems in the world because they have occurred at the highest rates and contribute to rapid forest loss, biodiversity damage, and climate changes. The international agreement for reducing emissions from deforestation and forest degradation (REDD+) arranges the leading strategy for mitigating climate changes, mainly in the forest-rich developing countries, including Indonesia. The government of Indonesia had pledged to reduce emissions by 26% on its efforts and up to 41% with international support by 2020 which was submitted to the UNFCCC (the United Nations Framework Convention on Climate Change) in January 2010. Beyond 2020, Indonesia imagines the higher pledge to reduce greenhouse gas (GHG) emissions in 2030 by 29% below its BAU (business as usual) unconditionally and up to 41% conditionally which was also submitted to the UNFCCC on 24 September 2015. East Kalimantan Province has been selected as one of the target provinces for implementing Indonesia's commitment in synergy with its low carbon use economic strategy.

This research mainly aimed to formulate landscape strategies for restoring and managing forests to reduce GHG emissions using time-series land cover maps and spatial datasets in the context on assisting the Government of East Kalimantan Province for applying REDD+ at the provincial level. To address the main objective, this research developed the specific objectives represented by six main chapters in this thesis. Since the existing spatial datasets published by the Indonesian government were not completely available, this research was begun by completing the yearly land cover maps in East Kalimantan from 2000 to 2016 using the existing land cover maps

in combination with the visual interpretation of Landsat imageries. The spatial dataset produced in this study was used for analyzing annual land cover changes (Chapter 4), deforestation and forest degradation (Chapter 5), and annual GHG emission (Chapter 6). This study investigated the current land cover conditions within and outside the forest area (Chapter 7) and formulated restoration of the deforested and degraded forests (Chapter 8) as well as silvicultural systems for managing forests (Chapter 9).

This doctoral thesis described research background and objectives in Chapter 1, literature review of related topics in Chapter 2, and the overview of the study area and REDD+ program in Chapter 3. According to the yearly land cover map dataset, East Kalimantan was dominated by forests covering more than half of the total province. However, the total area of land cover change increased every year (Chapter 4) with overall changes from natural forests to shrubland, estate cropland, and plantation forest. Forest cover changes illustrated by deforestation and forest degradation also increased every year (Chapter 5). This study reported that deforestation occurred in all natural forests:12.77% of primary dryland forest, 24.71% of primary mangrove forest, 15.06% of primary swamp forest, 12.15% of secondary dryland forest, 27.24% of secondary mangrove forest, and 17% of secondary swamp forest. The largest degradation occurred in the primary dryland forest that frequently degraded into the secondary dryland forest, while the largest deforestation occurred in secondary dryland forest which contributed to the increase of dry shrubland and estate cropland. Deforestation and forest degradation contributed to the accelerated GHG emissions in East Kalimantan from 2000 to 2016 (Chapter 6). The predicted GHG emission for 2030 showed that REDD+ applied in East Kalimantan could reduce emission by 18.89% from the historical baseline. However, this progress was smaller than the target written in the provincial action plan (by 22.38% from BAU for 2020). This condition revealed that the provincial government needs to formulate the further strategies to reduce GHG emission more effectively.

Using the 2016 land cover map overlaid with the forest area designated by the government, this study reported that the potential forests (Chapter 7) categorized as the forest area (89.49%) and forests covered non-forest area (10.51%). The potential forests exposed to deforestation and forest degradation were firstly planned for forest restoration (Chapter 8), while the forests functioned well were directly planned for forest management activities (Chapter 9). This study formulated landscape strategies for forest restoration in Chapter 8 classified as reforestation and forest rehabilitation activities with three priorities (1st priority, 2nd priority, and 3rd priority). Reforestation was planned for restoring the deforested area, while forest rehabilitation was planned for restoring the degraded forest area. The restoration priorities were formulated by considering forest vulnerability illustrated by the combination of slope and soil risk erosion level. In Chapter 9, this study formulated the silvicultural systems for managing forests sustainably by combining timber harvesting practices and forest regeneration approaches to reach various forest management objectives.

The overall research results summarized in Chapter 10 highlighted that spatial information and landscape strategies resulted in this study could assist the national and provincial governments for making political decisions and designing the further strategies for restoring and managing forests to reduce emissions from deforestation and forest degradation at the province level. However, these research findings need to be continued by focusing on the finer-scale and adding the comprehensive datasets for informing in-depth technical procedures for specific forest landscapes.

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List of Abbreviations

AFOLU	Agriculture, Forestry, and Other Land Use
ALOS	Advanced Land Observation Satellite
Bappeda	*Badan Perencanaan Pembangunan Daerah* (Regional Development Planning Agency)
BAU	Business As Usual
CNES	The Centre National d'Études Spatiales
CO_2	Carbon dioxide
COP	Conference of Parties
DDPI	*Dewan Daerah Perubahan Iklim* (Regional Council on Climate Change)
DEM	Digital Elevation Models
DN	Digital Number
DOS	Dark Object Subtraction
ENSO	The El Niño Southern Oscillation
ENVI	Environment for Visualizing Images
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
FCPF	The Forest Carbon Partnership Facility
FMU	Forest Management Unit
FRA	Forest Resource Assessment
FREL	Forest Reference Emission Level
GCF	Governors Climate and Forests Task Force
GGC	Green Growth Compact
GHG	Greenhouse Gas
GIS	Geographical Information Systems
GRDP	Gross Regional Domestic Product
IP	Indigenous Peoples
IPCC	Intergovernmental Panel on Climate Change
ITTO	The International Tropical Timber Organization

IUCN	International Union for the Conservation of Nature
LULC	Land Use and Land Cover
LULUCF	Land Use, Land-Use Change and Forestry
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEF	Ministry of Environment and Forestry
MoF	Ministry of Forestry
MSS	Multispectral Scanner
NAMA	Nationally Appropriate Mitigation Actions
NDC	The Nationally Determined Contribution
NFMS	The National Forest Monitoring System
NGO	Non-Governmental Organization
NYDF	New York Declaration on Forests
OLI	Operational Land Imager
PHPL	*Pengelolaan Hutan Produksi Lestari* (Sustainable Production Forest Management)
PPIIG	*Pusat Pengembangan Infrastruktur Informasi Geospasial* (the Center for Geospatial Infrastructure Information Development)
RED	Reducing Emission from Deforestation
REDD+	Reducing Emissions from Deforestation and Forest Degradation
REL	Reference Emission Level
RIL	Reduced-Impact Logging
SAR	Synthetic Aperture Radar
SFM	Sustainable Forest Management
SLC	Scan Line Corrector
SNI	*Standar Nasional Indonesia* (Indonesia National Standard)
SPOT	Satellite Pour l'Observation de la Terre
SVLK	*Sistem Verifikasi Legalitas Kayu* (Wood Legality Verification System)
THPB	*Tebang Habis Permudaan Buatan* (Clear-Cutting with Intensive Planting)
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of the Atmosphere

TPTI	*Tebang Pilih Tanam Indonesia* (Selective Cutting with Enrichment Planting of Indonesia)
TPTJ	*Tebang Pilih Tanam Jalur* (Selective Cutting with Line Planting)
UNFCCC	The United Nations Framework Convention on Climate Change
UTM	Universal Transverse Mercator
WGS	World Geodetic System

Chapter 1

General Introduction

1.1. Research Background

Deforestation and forest degradation in tropics contribute to the rapid loss of tropical rainforest (Kim et al., 2015; Vidal et al., 2014). Both of the forest changes are the significant component of global environmental change (Bolliger and Kienast, 2010; Congalton et al., 2014; Kim et al., 2014) with substantial negative effects for ecosystem function (Aerts and Honnay, 2011; Aronson and Alexander, 2013; Müller et al., 2010) and biodiversity conservation (Cardinale et al., 2012; Scriven et al., 2015). Moreover, deforestation is responsible for the annual anthropogenic emissions of carbon dioxide (CO_2) to the atmosphere and is regarded as one of the significant sources of greenhouse gas (GHG) emissions (Budiharta et al., 2014; Houghton et al., 2012; Leblois et al., 2017; Pearson et al., 2014; Slik et al., 2010).

In Indonesia, tropical deforestation remains high, both regarding the area and rate. The Food and Agriculture Organization of the United Nations (FAO) reported that annual net loss of forest in Indonesia was 1.8 million ha/yr for 2000–2005 (FAO, 2006), 500 thousand ha/yr for 2000–2010 (FAO, 2010), and 700 thousand ha/yr for 2010–2015 (FAO, 2015). Indonesian forestry statistics stated that the deforestation rate was 800 thousand ha/yr for 2009–2010 (MoF, 2012); 400 thousand ha/yr for 2010–2012 (MoF, 2013); 600 thousand ha/yr for 2011–2012 (MoF, 2014a) and 700 thousand ha/yr for 2012–2013 (MoEF, 2015a). Deforestation and degradation in Indonesia are driven by many factors, including population growth, forest logging concessions, oil palm expansion, cultivation practices, settlement, road construction, international commodity demand, decentralization policy, forest fires, and global environmental factors (FWI/GFW, 2002; Hansen et al., 2009; Holmes, 2002; Tsujino et al., 2016).

The leading strategy for mitigating climate change in the forest-rich developing countries, including Indonesia, focused on reducing emissions from deforestation and forest degradation (REDD+) plus enhancing carbon stock in the forest areas and conserving high biodiversity (Arima et al., 2014; Gullison et al., 2007). As the third largest extent of tropical forest in the world, Indonesia has been extensively involved in REDD+ (Enrici and Hubacek, 2016). At the G-20 meeting in Pittsburg and the 15th Conference of the Parties (COP 15) of the United Nations Framework Convention on Climate Change (UNFCCC) on 2009 in Copenhagen, the Government of Indonesia voluntarily assured to reduce emissions by 26% on its efforts and up to 41% with international support by 2020. This commitment was submitted to the UNFCCC in January 2010 (Indonesia, 2013). Beyond 2020, Indonesia envisions an even braver reassurance to reduce emissions in 2030 by 29% below its BAU (business as usual) unconditionally and up to 41% conditionally. The commitment based on the nationally determined contribution (NDC) was submitted to the UNFCCC on 24 September 2015 (Indonesia, 2016).

To support the target, mapping land cover and analyzing land cover changes over time (Butt et al., 2015; Congalton et al., 2014; Rujoiu-Mare and Mihai, 2016) for monitoring its effect on tropical deforestation (Hirschmugl et al., 2014; Joshi et al., 2015; Leckie et al., 2015) and carbon emissions (Harris et al., 2012; Herold et al., 2011; Le Quéré et al., 2015) have been generally recognized as the significant scientific goal. The technology of remote sensing and Geographical Information Systems (GIS) has been widely used for obtaining spatial data and mapping land cover for environmental studies (Hereher et al., 2012; Lillesand et al., 2014; Purkis and Klemas, 2011; Rawat and Kumar, 2015). Satellite-based observations of forest change provide an alternative to estimate tropical deforestation rates consistently across space and time (Kuenzer et al., 2014; Zhuravleva et al., 2013). Forest cover change maps are increasingly generated from various satellite data sources (Disperati and Virdis, 2015; C. Li et al., 2017; Mas and González, 2015; Roy et al., 2014; Wan et al., 2015; Xin et al., 2013) at continental to global scales.

Satellite imageries from the Landsat series are one of the most significant data sources for studying different kinds of land cover changes due to the extended (since 1972), continuous observation records and free availability. As the most current progress, Landsat imageries have been used to determine deforestation rates (Broich et al., 2011; Estavillo et al., 2013; Hansen et al., 2013; JRC and FAO, 2011; Kim et al., 2014; Lehmann et al., 2012; Potapov et al., 2014, 2012). Moreover, previous study of forest changes have been integrated with the forest biomass information to quantify changes in forest carbon stocks (Achard et al., 2014; Baccini et al., 2012; Harris et al., 2012; Tyukavina et al., 2015), but they might report various result because of using different mapping and analyzing approaches.

East Kalimantan is the third largest province in Indonesia located on Borneo island which is one of the target provinces for implementing Indonesia's commitment and has developed the local action plan for reducing GHG emission (East Kalimantan, 2013) and the provincial REDD+ strategy (East Kalimantan, 2012). East Kalimantan has been selected as the leading member for the Forest Carbon Partnership Facility (FCPF) as the universal partnerships of governments, businesses, civil societies, and indigenous peoples (FCPF, 2017). East Kalimantan is also getting close support from the private sectors, who joined with the government to launch the Green Growth Compact (TNC, 2016). East Kalimantan is hosting some REDD+ projects managed by the non-governmental organizations (NGO's) and donors. However, the further work is required to integrate all actions at the provincial level within the official government climate mitigation measures (East Kalimantan, 2011a).

1.2. Statement of Research Challenges

Accurate, up-to-date, and long-term information on land cover is increasingly required for global environmental studies, appropriate decision of land management, proper improvement program, land change observing, carbon emission valuations, and many other requests (Belward and Skøien, 2015; Chen et al., 2015; Congalton et al., 2014; Gómez et al., 2016; Huang et al., 2017; Jin et al., 2017; Xing et al., 2017). Remote sensing technologies and Landsat imagery are commonly combined for obtaining spatial landscape data, deriving timely land cover information, and monitoring its changes over time (Brown et al., 2000; Hereher et al., 2012; Mashagbah et al., 2012; Purkis and Klemas, 2011; Reyes et al., 2017; Zanella et al., 2012). However, monitoring land cover change in tropical landscapes, particularly in Indonesia, is complicated by problematic remote sensing circumstances, which frequently leads to a crucial lack of accurate land cover information. Cloud cover is a major limitation to the use of optical imagery over Indonesia. The existence of clouds, shadows and illumination in Landsat images cause severe problems for approaching remote sensing technology, including satellite image mosaic (Roy et al., 2010), atmospheric correction (Nazeer et al., 2014), classification (Hereher et al., 2012), and change analysis (Mas and González, 2015) using digital image classification.

Other complicating issues include the lack of opportunity for acquiring the high-resolution satellite images annually due to the financial problems, particularly those in developing countries. Additionally, generating remote sensing products still require qualified operators and specified software that might be expensive (Jacobson et al., 2015). Some mistake in selecting, collecting, processing, and analyzing spatial datasets might also result in incorrect recommendations and conclusions (Watson et al., 2015). Misunderstanding of remote sensing analysis might affect inappropriate policy making (Arima et al., 2014; Nishioka, 2016) and impact to lose opportunities or squander resources (Wilson et al., 2005), particularly for landscape ecology and conservation applications (Jones et al., 2016; Robinson and Carson, 2013).

Various studies in the world have used different sources of satellite images data (Campbell et al., 2012; Deutscher et al., 2013; Hansen et al., 2014; Wan et al., 2015) and various methodological (Hussain et al., 2013; Mohd Hasmadi et al., 2009; Puig et al., 2002; Yu et al., 2016) to analyze land cover change and its effect on environment. However, the consistency of data sources and approaches (Purkis and Klemas, 2011) is required to avoid misunderstanding (Zanella et al., 2012) when interpreting land cover classes (Lillesand et al., 2014). Moreover, different mapping methods based on satellite imagery can affect the measurement of landscape metrics that may motivate flawed conservation actions.

In Indonesia, Ministry of Environment and Forestry (MoEF) produced the land cover maps in Indonesia, including East Kalimantan, published on the National Forest Monitoring System (http://nfms.dephut.go.id), but only for several years and lack in other years. From 2000 to 2009, land cover monitoring in Indonesia was conducted at three-year intervals due to the limitation of cloud-free satellite imagery availability, time-consuming work for completing the entire areas of Indonesia even for one-year coverage, and financial problems for obtaining the high-resolution satellite imagery. Since 2011, land cover monitoring in Indonesia has been conducted annually (Krisnawati et al., 2015). According to the Indonesia National Standard (SNI), these land cover maps have been produced using Landsat images source and by visual interpretation approach (BSN, 2014) and divided into 23 land cover classes (BSN, 2010). Visual image interpretation approach can be used to classify complex and heterogeneous landscapes with image pattern characteristics efficiently (Zanella et al., 2012), deliver better spatial detail (Puig et al., 2002), and enhance quality from medium-resolution satellite information (Ghorbani and Pakravan, 2013).

1.3. Research Objectives and Framework

This research aimed to formulate landscape strategies for restoring degraded forest landscapes and promoting sustainable forest management using time-series land cover maps and spatial datasets in the context on assisting the Government of East Kalimantan for applying REDD+ at the provincial level. To address the main objective, this research developed six specific objectives:

1. to complete spatial dataset of yearly land cover maps and analyze annual land cover changes in East Kalimantan Province from 2000 to 2016 using the existing land cover maps produced by the Government of Indonesia in combination with the visual interpretation of Landsat imageries and ancillary datasets,
2. to analyze forest cover changes over time, monitor annual deforestation and forest degradation, and assess forest cover transitions over time to detect the causes of deforestation and forest degradation,

3. to evaluate the percentage of REDD+ implementation in East Kalimantan Province by estimating annual GHG emissions, developing baselines of GHG emissions for historical baseline (2000–2010), REDD+ progress baseline (2010–2016), and also predicting and comparing the future trajectories of both baselines for 2030,
4. to investigate the potential forests by interpreting land cover within and outside the forest areas designated by the government,
5. to formulate landscape strategies for the degraded forest restoration classified by restoration activities and priority levels, and
6. to formulate silvicultural systems for sustainable forest management combined by timber harvesting practices and forest regeneration approaches.

Considering the challenges with the focus on reaching the research objectives, this study was begun by using the government datasets from both the national and provincial as the primary data and then completed by analyzing the ancillary datasets. Figure 1.1 shows the research framework that started with the formulation of research background, objectives, literature reviews, and an overview of the study area before doing the leading research. The first step of the research was the completion of the yearly land cover maps from 2000 to 2016 in East Kalimantan using the existing land cover maps produced by the Indonesia Government in combination with the visual interpretation of Landsat imageries. These datasets were used for the further steps: analyzing annual land cover changes, monitoring deforestation and forest degradation, assessing forest cover transitions, investigating the potential forests by interpreting land cover within and outside the forest areas, and estimating GHG emissions. This study also formulated landscape strategies for restoring degraded forest landscapes and managing sustainable forests using silvicultural systems.

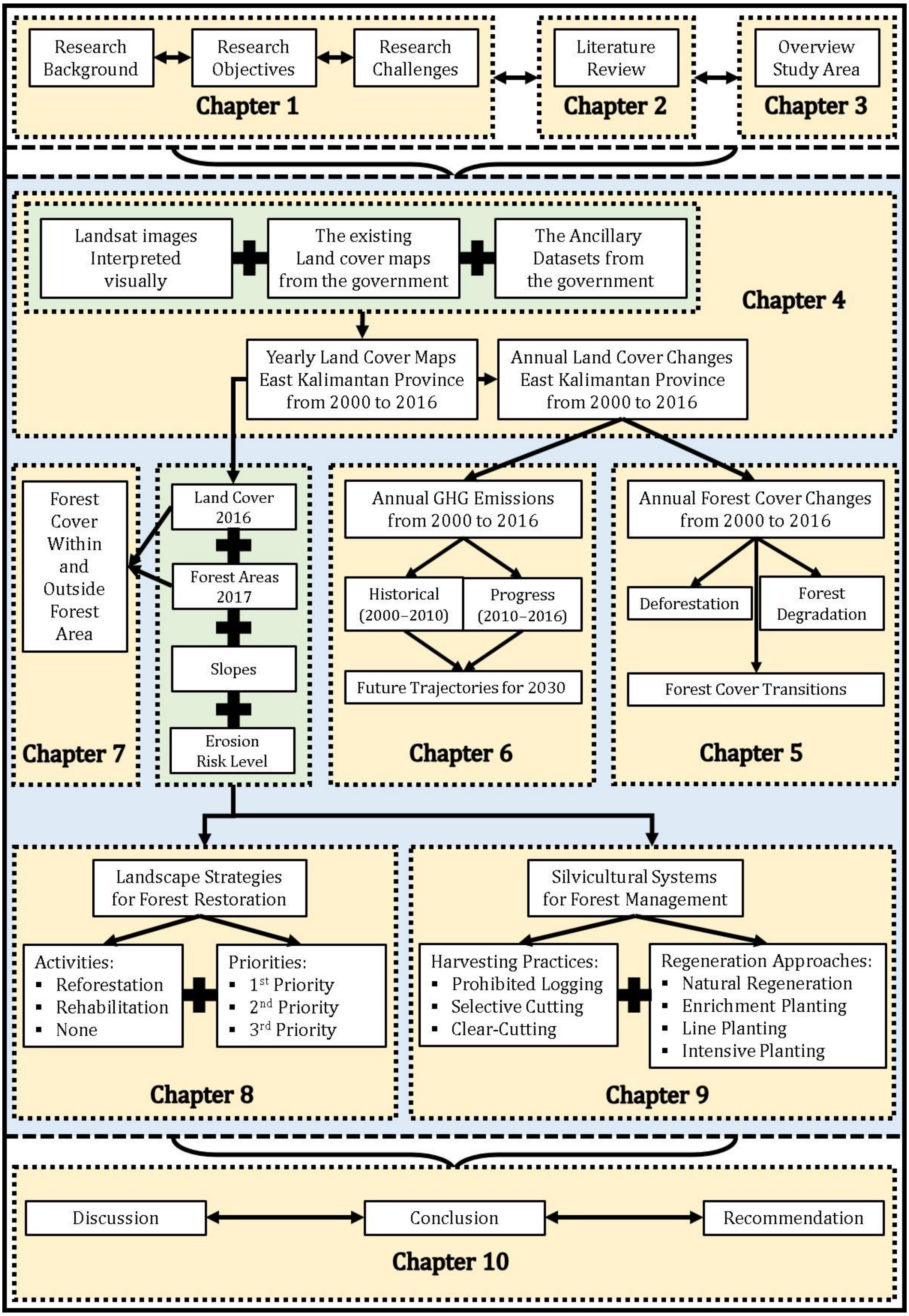

Figure 1.1. Research framework.

1.4. Scientific Contributions

Regarding the scientific responsibility for the better implementation of REDD+ in East Kalimantan Province, there are some contributions of this doctoral research that published in a journal and presented at the international conferences:

1. Kiswanto and Tsuyuki, S. 2016. Forest Cover Classification of East Kalimantan in 2015 Using Landsat Satellite Imageries. Oral presentation at the 127th Japanese Forest Society Annual Meeting held in the Nihon University, Tokyo (Japan) on March 27–30, 2016 ***(a part of Chapter 4)***.
2. Kiswanto, Tsuyuki S., Mardiany, Sumaryono. 2018. Completing Yearly Land Cover Maps for Accurately Describing Annual Changes of Tropical Landscapes. Original Research Article published on Global Ecology and Conservation, Volume 13, January 2018. https://doi.org/10.1016/j.gecco.2018.e00384 ***(Chapter 4)***.
3. Kiswanto and Tsuyuki S. 2018. Deforestation Trends and Forest Cover Transitions in Tropical Landscapes. Oral presentation at the World Conference on Ecology held in Berlin (Germany) on March 19–20, 2018 ***(Chapter 5)***.
4. Kiswanto and Tsuyuki S. 2018. Deforestation and GHG Emission Trends in Tropical Rainforest. Oral presentation at the European Conference of Tropical Ecology and Annual Meeting of the Society for Tropical Ecology held in Paris (France) on March 26–29, 2018 ***(Chapter 5 and Chapter 6)***.
5. Kiswanto and Tsuyuki S. 2018. Land Cover Change Effect on Deforestation and GHG Emissions in East Kalimantan, Indonesia. Oral presentation at Junior Researchers Workshop of Graduate School of Agricultural and Life Sciences of the University of Tokyo (Japan) in collaboration with Developing Research Center of Bonn University (Germany) held in Tokyo (Japan) on March 16, 2018 ***(modified from all chapters)***.

1.5. Thesis Structure

This thesis is separated into ten chapters with six main chapters which have the specific goals and fulfilling a portion of the great story with connectivity outlined in every section. The first chapter provides general information on research background, statement of research challenges, objectives and framework, and thesis structure. Chapter 2 consists of theoretical background from several kinds of literature related to study on land cover and land cover changes using remote sensing, forest monitoring system, deforestation and forest degradation, reducing emissions from deforestation and forest degradation, restoration of degraded forest landscapes, sustainable forest management, and landscape strategies for restoring and managing forests. Chapter 3 comprehends an overview of East Kalimantan Province as the study area and the REDD+ program.

Chapter 4 emphasizes on completing spatial dataset of yearly land cover maps in East Kalimantan from 2000 to 2016 using the existing land cover maps produced by the Government of Indonesia in combination with the visual interpretation of Landsat imagery and ancillary datasets. These datasets can be used to analyze the change trends of land cover in the province since 2000. The consistency of the interpretation approaches was tested in this study to ensure the similar sources and methods used for producing datasets. The mapping method used in this research effectively provides spatial information on land cover changes in tropical forests, which can support the global environmental monitoring and the government development programs.

Chapter 5 highlights on monitoring forest cover change for estimating annual deforestation and forest degradation. The yearly land cover maps in East Kalimantan from 2000 to 2016 resulted from the previous chapter were used to influence the research outcomes. Furthermore, the forest cover transitions over time were assessed for accurately identifying the causes of deforestation and forest degradation in East Kalimantan Province.

Chapter 6 focuses on estimating annual GHG emissions from deforestation and forest degradation in East Kalimantan based on land cover changes from 2000 to 2016. In this chapter, the percentage of REDD+ progress in East Kalimantan Province was estimated by comparing the future trajectories of GHG emissions for 2030 which was projected from both historical baseline (2000–2010) and the REDD+ progress baseline (2010–2016). The period of 2010 was selected as the base year due to the commitment of Indonesia was submitted to the UNFCCC in January 2010 (Indonesia, 2013).

Chapter 7 contains the spatial information of land cover within and outside the forest areas. This study overlaid the land cover map for 2016 produced in the previous chapter with the forest areas map designated by the Government of Indonesia through the MoEF Decree No. 278 of 2017 (MoEF, 2017). This study reported the condition of land cover within the forest areas and the coverage of forests outside the forest areas.

Chapter 8 involves the landscape strategies for restoring the deforested and degraded forests. Forest restoration activities were categorized as forest rehabilitation for recovering the degraded forest areas and reforestation for regaining forest cover within the deforested areas. Three levels of restoration priorities were also formulated by considering the forest vulnerability presented by slopes and soil erosion risk.

Chapter 9 focuses on formulating silvicultural systems for sustainable forest management based on landscape information. In this chapter, the forest management objectives as the essential aspect for formulating silvicultural systems were developed by considering the forest functions of the state forests and the combination of land cover, slopes, and soil erosion risk for formulating forest function of the private forests. The silvicultural systems for forest management were formulated by combining timber harvesting practices (prohibited logging, selective logging, clear-cutting) and forest regeneration approaches (natural regeneration, enrichment planting, line planting, intensive planting).

Finally, Chapter 10 comprehends the general discussion of research findings from the previous main sections and essential summaries to be shared as the general conclusions. In this chapter, some recommendations based on the research findings were also proposed to the Government of East Kalimantan which would be useful for designing the further action plans to realize the emissions reduction target for 2020 and 2030 more effectively.

Chapter 2

Theoretical Background

2.1. Study on Land Cover Change using Remote Sensing

Land cover refers to the physical characteristics of earth's surface (Rawat and Kumar, 2015), captured in the distribution of vegetation, inland water, bare soil and other physical features of the land, including human infrastructure (Gómez et al., 2016). Historical land cover information is important to understand the impact of land conversion on the temporal dynamics of environmental and ecological factors (Fuchs et al., 2015). During the last few decades, land cover changes on global environment have become a main international issue for the policy-makers and scientific community because they have primarily affected the global warming process through emissions of CO_2 (Muñoz-Rojas et al., 2015).

Changes in land cover represent the complex ecological, socioeconomic, and technological problems (Baldi and Paruelo, 2008). Land cover change has substantial impacts on the climate (Mahmood et al., 2014), surface temperature (Luyssaert et al., 2014), carbon stocks (Muñoz-Rojas et al., 2015), soil (Mohawesh et al., 2015), hydrology (Mango et al., 2011), evapotranspiration and streamflow (Dias et al., 2015), water resources (Rogger et al., 2017), biota (Scriven et al., 2015), and many other impacts. The effect of the land cover change on the supply of ecosystem services derives not only from a reduction in the area of the original cover but also from a transformation of the landscape structure (Baldi and Paruelo, 2008). Analyzing the effect of land cover changes require long-term historical reconstructions and future projections at regional to global scales (Lambin et al., 2003).

Study on land cover change is necessary for describing the land management approach that is currently used and also provides a starting point for future planning (Ayele et al., 2018). The common understanding of the causes of land cover change is dominated by interpretations which encourage various approaches to environment development (Lambin et al., 2001). Identifying the patterns of land cover change and their main proximate causes and underlying driving forces in tropical rainforests is an urgent mission for designing adequate land management and conservation policies (Quezada et al., 2014). The consistent, up-to-date, and accurate spatiotemporal data and information on land cover change is required for assessing the environmental changes (Giri et al., 2005) and formulating systematic methods, tools, and techniques (Rawat and Kumar, 2015).

The technique of remote sensing and Geographical Information System (GIS) have been commonly used for obtaining spatial data and mapping land cover for environmental studies (Hereher et al., 2012; Lillesand et al., 2014; Purkis and Klemas, 2011; Rawat and Kumar, 2015). Remote sensing has the capability for capturing land cover, extracting the information of land cover change (Roy et al., 2002), and analyzing satellite data required by software without any physical contact to the object, area, or phenomenon during the investigation (Lillesand et al., 2014). Land cover change detection by satellite imagery has been one of the goals of the advancement of remote sensing approaches (Martínez and Mollicone, 2012). The remote sensing role in monitoring land cover change and assessing its structural and functional attributes has been well documented (Reimer et al., 2015). Successful use of remote sensing for land cover change detection depends on an adequate understanding of landscape features, imaging systems, and information extraction method (Yang and Lo, 2002).

Time-series land cover maps can be derived from satellite remote sensing data (Balthazar et al., 2015) that are increasingly generated from various sources, such as Landsat (C. Li et al., 2017; Roy et al., 2014), Satellite Pour l'Observation de la Terre or SPOT (Disperati and Virdis, 2015; Mas and González, 2015), and Moderate Resolution Imaging Spectroradiometer or MODIS on Terra/Aqua (Wan et al., 2015; Xin et al., 2013), and many other satellites. However, satellite images from the Landsat series are one of the most significant sources for continuously detecting land cover change (Wulder et al., 2016) due to the long-term collecting images since 1972, continuous measurement and free availability for the public. International researchers have made some widespread efforts using the combination of Landsat images and remote sensing for land cover classification (Guo et al., 2015), continuous land cover change detection (Zhu and Woodcock, 2014a), large-scale forest cover assessment (Borrelli et al., 2013), forest aboveground biomass estimation (Zhu and Liu, 2015), deforestation detection (Reiche et al., 2015), and many other studies.

One of the ways to extract spatial information of land cover from remote sensing dataset is through visual interpretation (Rozenstein and Karnieli, 2011). Visual interpretation approach is the great measure of research in landscape ecology because it is a flexible approach to extract spatial information from satellite imageries (Zanella et al., 2012). Visual interpretation offers an efficient technique to classify complex and heterogeneous landscapes and spatial units with image pattern characteristics (Antrop and van Eetvelde, 2000). This method is efficient for interpreting spatial information (Panigrahy et al., 2010) from satellite images with low resolution (Puig et al., 2002) and medium resolution (Ghorbani and Pakravan, 2013) to overcome the risk factors in digital techniques because it delivers better mechanism to detect land cover change based on knowledge of interpreter (Lu et al., 2004). Because of the different results provided by different kinds of classification technique (Lillesand et al., 2014), it is essential to consider the consistency of methodological approach and spatial data source when performing landscape ecology studies (Zanella et al., 2012) to avoid misinterpretations on satellite imageries that may motivate flawed conservation action strategies.

2.2. Forest Monitoring System

Concerns over land cover changes have become more serious in the past few decades because of mounting forest loss, especially in tropical and subtropical regions (Caldas et al., 2013). The leading topic of study on land cover is the identification of forest cover as the most significant natural resources (Brandon, 2014) which should be conserved on a priority basis for sustainable management (Clark and Kozar, 2011). Forests conserve biodiversity, maintain the hydrological cycle, regulate climate change and reduce erosion (Kukkonen and Käyhkö, 2014). Forests perform a significant role in climate system by absorbing approximately one-fourth of anthropogenic emissions (Le Quéré et al., 2015), storing large carbon pools in tree biomass and soils (Carvalhais et al., 2014), and controlling the land-atmosphere net flux by conservating biological diversity and protecting the watershed (Zhao and Jackson, 2014). Forest ecosystem roles are threatened by what appears to be an unstoppable process of forest destruction (Caldas et al., 2013). Ongoing processes of forest destruction within tropical forest landscape pose the main pressure to the stock of biological diversity (Leblois et al., 2017), the stability of global climate (Tyukavina et al., 2015), hydrological and biogeochemical cycles (Bax and Francesconi, 2018).

Forest cover monitoring provides required spatial information on land cover and land use for supporting policies to conserve, protect and sustainably manage forests (Romijn et al., 2015). Forest change can be monitored either through national forest inventories using GIS and remote sensing (Y. Li et al., 2017) even though it has been challenging to implement in developing countries due to the lack of adequate technical and functional support (Romero-Sanchez and Ponce-Hernandez, 2017). Monitoring changes in tropical forest cover depend predominantly on optical satellite sensors because of their relative ease of processing and interpretation (Reiche et al., 2016). National forest monitoring system employs forest inventory data, growth analysis, and land cover change to estimate carbon stocks and formulate management actions (Kurz and Apps, 2006).

The national forest monitoring systems (Romijn et al., 2015), especially in the tropics where forests are declining at a rapid rate are capable for observing forest cover (Margono et al., 2014), evaluating forest change (Pransiska et al., 2016), estimating emissions (Baccini et al., 2012), and formulating forest rehabilitation (Zhao and Jackson, 2014) to preserve forest ecosystem balance (Wang et al., 2015). Improved monitoring of forest cover itself is unlikely to produce any change in behavior unless it is linked to research, forest policy and management and assessment (Fuller, 2006). Forest cover change trends can be quite effectively calculated using GIS and remote sensing data over following decades combined with forest cover change trajectory approaches (Kukkonen and Käyhkö, 2014). Because of many tropical countries had limited capacity to implement the monitoring system, the efforts of capacity building are now ongoing to strengthen the technical skill necessary to achieve national forest monitoring at institutional levels (Romijn et al., 2015).

Countries participating in the climate change mitigation mechanism are needed to establish national forest monitoring systems. The national forest monitoring system includes the provision of transparent, consistent and accurate estimates of emissions and removals from forests (Pelletier and Goetz, 2015), while also taking into national circumstances and capabilities . The system requires a combination of remote sensing and ground-based forest carbon inventory approaches (UNFCCC, 2014) and following the guidance (IPCC, 2003) and guidelines (IPCC, 2006) for estimating carbon fluxes from forests (Angelsen et al., 2009). The preparation of developing countries for measuring and reporting emissions based on forest cover change (activity data) and carbon density (emission factors) is rapidly advancing (Pelletier and Goetz, 2015). However, only 4 of 99 developing countries were effectively approaching the national forest monitoring (Romijn et al., 2015).

For measuring activity data (forest cover change), satellite remote sensing is the most practical way to establish baseline deforestation rates against which future rates of change can be monitored (Achard et al., 2014). Many developing countries lack the assets and capability to use remote sensing (Karan et al., 2016) to evaluate forest extent and change (Pelletier and Goetz, 2015), and some countries do not have the national land cover map (Romijn et al., 2015), so widespread technical capacity building efforts are required. Some developing countries have land cover maps for several years, but they fail to capture deforestation events annually and associated land cover dynamics (Hosonuma et al., 2012). Moreover, the approaches used to create such maps often lack technical details necessary for adequately assessing map accuracy (Pelletier and Goetz, 2015), which caused to the variability of the carbon emissions estimation (Olofsson et al., 2013).

2.3. Deforestation and Forest Degradation

Deforestation and forest degradation are definitely different processes (Sasaki and Putz, 2009), but there are no globally agreed definitions of deforestation and forest degradation within the UNFCCC (Lund, 2009). In the climate change, it is critically important to know the context of forest disturbance, whether the clearing of a high-biomass natural forest, managed natural forests, or a short-cycle plantation (Margono et al., 2014). Deforestation is defined as the permanent conversion processes of forests to other non-forest uses as a consequence of human activities, while forest degradation means the deterioration of quality, capacity, and carbon stock in the forest area during a specified period as a result of human activities (FAO, 2011; ITTO, 2002; Margono et al., 2016; MoF, 2009a; Sasaki and Putz, 2009).

Deforestation and forest degradation, both kind of forest cover changes, contribute to the rapid loss of forests (Kim et al., 2015; Vidal et al., 2014), global environmental change (Bolliger and Kienast, 2010; Congalton et al., 2014; Kim et al., 2014), ecosystem function (Aerts and Honnay, 2011; Aronson and Alexander, 2013; Müller et al., 2010), and biodiversity conservation (Cardinale et al., 2012; Scriven et al., 2015). Deforestation in Southeast Asia is one of the leading causes of carbon emissions and reductions of biodiversity (Brun et al., 2015). Deforestation in the tropics is responsible for 17–25% of the annual anthropogenic emissions of carbon dioxide (CO_2) from the atmosphere (Le Quéré et al., 2015) and is regarded as the most significant sources of GHG emissions (Harris et al., 2012; Houghton, 2003; Rudel et al., 2005; Tyukavina et al., 2015; van der Werf et al., 2004; Zarin, 2012; Zarin et al., 2016). When forests are cleared, carbon stored above and below ground in leaves, branches, stems, and roots, as well as carbon in soil, is released to the atmosphere (Baccini et al., 2012).

Early discussions of the climate change caused by deforestation demonstrated the polarity of positions between the developed countries and the developing countries (Bulkeley and Newell, 2010). Forest-rich developing countries, including Indonesia (Pirard et al., 2015; van Noordwijk et al., 2014; Yusuf, 2010), are highlighted by countries in the world because of high deforestation rates while tropical ecosystem protection is an essential action for mitigating climate change, preventing biodiversity loss, and providing ecosystem services (Pirard et al., 2015). The forest-rich developing countries should decide upon the specific scenario of policies and measures to achieve national emission reduction target (Busch et al., 2012). On another side, the sufficient funding from developed countries should support the tropical forested country to enforce the environmental regulation, economic alternatives, and build institutional capacity in the remote area (Santilli et al., 2005).

Understanding drivers of deforestation and forest degradation (Khuc et al., 2018) are fundamental for the development of policies and measures that aim to alter existing trends in forest activities concerning a more climate and biodiversity-friendly outcome (Hosonuma et al., 2012). Proximate drivers and underlying causes (Adhikari et al., 2017; Carodenuto et al., 2015; Miyamoto et al., 2014; Quezada et al., 2014) usually relate to anthropogenic systems and environmental factors (Bax and Francesconi, 2018) that are recognized to play a significant role in the process of forest cover change. The direct drivers of tropical deforestation and forest degradation are mainly caused by human activities (Kissinger et al., 2012) which are the combination of agricultural expansion, timber plantation, population growth, and infrastructure development (Geist and Lambin, 2001). Underlying or indirect drivers are complex interactions of social, economic, political, cultural and technological processes that might affect the proximate drivers to cause deforestation or forest degradation (Kissinger et al., 2012). Tropical deforestation is also indirectly caused by multiple factors, with more than one-third of the cases being driven by the full interaction of economic, institutional, technological, cultural, and demographic variables (Geist and Lambin, 2001).

Forest monitoring can assist in identifying proximate drivers and underlying causes of deforestation and forest degradation by distinguishing anthropogenic from non-anthropogenic forest loss (Potapov et al., 2014), attributing forest loss to particular land uses or land owners (Goetz et al., 2015), attributing forest loss based on remote sensing (Heino et al., 2015), and assessing the relative contribution of multiple causes of deforestation (Ferretti-Gallon and Busch, 2014). Spatially-explicit information on forest cover change at large scales must be derived from satellites to achieve increased monitoring accuracy and transparency (Olander et al., 2008). Assessing the transition of forest cover change (Mather, 2005) over time using remote sensing technology can be useful to accurately identify types (Bax and Francesconi, 2018), characteristics (Yoshikura et al., 2016), human-induced changes (Watson et al., 2015), and various drivers of deforestation and forest degradation (Hosonuma et al., 2012) at the national scale. The forest cover transitions represent a subset of land use transitions (Rudel et al., 2010) that are mostly influenced by national contexts, global economic forces and government policies (Angelsen, 2009).

2.4. Reducing Emissions from Deforestation and Forest Degradation

The topic of climate change, mainly reducing greenhouse gas (GHG) emissions from deforestation and forest degradation (de Andrade et al., 2017), is one of the most pressing scientific and political efforts (Bulkeley and Newell, 2010). The international mechanism for reducing emission (Figure 2.1) negotiated under the United Nations Framework Convention on Climate Change (UNFCCC) has developed rapidly (Pistorius, 2012). The possibility of compensating developing countries for reduced emissions was proposed by the governments of Papua New Guinea and Costa Rica (Sasaki and Putz, 2009) at the eleventh conference of parties (COP 11) Montreal in 2005 that was known as the reducing emission from deforestation (RED) in developing countries by economic and financial incentives (Agrawal et al., 2011). Currently, this mechanism is continued for fighting global climate change and encourage the forest-rich developing countries to reduce deforestation, and forest degradation (Angelsen, 2009) called reducing emissions from deforestation and forest degradation (REDD+). The plus sign on the REDD+ mechanism indicates the enhancement of carbon stock in the forested areas, rehabilitation, zero degradation, negative emissions, carbon sequestration and forest carbon pools.

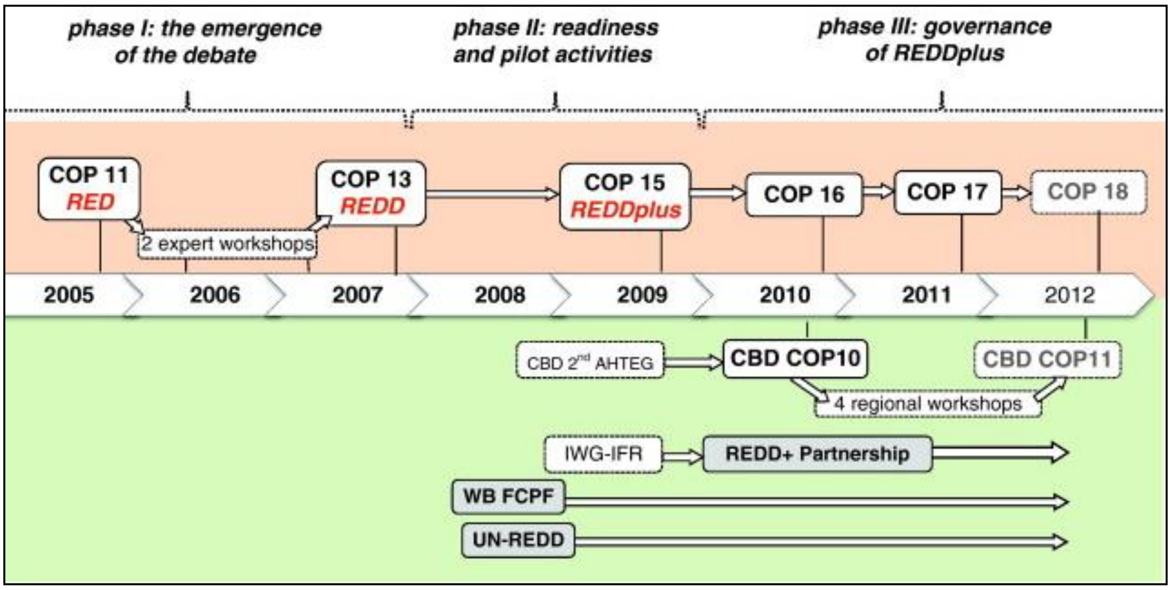

Figure 2.1. The phase of the REDD+ mechanism (Pistorius, 2012).

The REDD+ mechanism remains the fundamental strategy for mitigating climate change that is constructed on the principles of additionality against reference emission level (REL), with no emissions displacement to neighboring areas (Reimer et al., 2015). The REDD+ development focuses on establishing and supporting the methodological and technological foundations for analyzing forest cover and changes in carbon stocks (Corbera and Schroeder, 2011). Understanding the ecological, economic and social context (Hein and van der Meer, 2012) are required for implementing REDD+. On the other hand, issues related to the implementation of the REDD+ scheme are numerous (Hein and van der Meer, 2012; Herold et al., 2011; UN-REDD, 2015), including how to enhance its effectiveness in addressing the drivers of deforestation and forest degradation (Murray et al., 2015; Venter and Koh, 2012; Yoshikura et al., 2016). Several globally funded demonstration projects (GCF, 2014; TNC, 2016) are now in progress to develop robust methods for monitoring and reporting REDD+ and assessing their impacts on forest management and ecosystems (Miles and Kapos, 2008).

In the context of REDD+, the developing countries have to develop a kind of approach to constructing reference levels (Reimer et al., 2015), incorporating better data (Reiche et al., 2016), improved methodologies (Baccini et al., 2012), and additional pools that should periodically be updated (Jin et al., 2017), taking new knowledge into account (Haugo et al., 2015). For effective REDD+ implementation with multiple readiness activities, agents and drivers of deforestation and forest degradation need to be identified appropriately (Yoshikura et al., 2016). REDD+ activities should be coordinated by governments (Bulkeley and Newell, 2010), promoted by private or public actors (Pistorius, 2012), supported by REDD+ incentives mechanism (Busch et al., 2012), and reported with accountability, transparency, accuracy, completeness, and consistency (Fuller, 2006; Wollenberg et al., 2009). At the national level, developing country governments will need to decide where to allocate often scarce organizational and financial efforts to achieve emission reductions with the potentially highest success rate at the minimum cost, with subsequent environmental, social and political ramifications (Corbera and Schroeder, 2011).

Accurate, consistent and globally comparable data on GHG emissions is important for the global community to take the most relevant action to mitigate climate change (Hairiah et al., 2011). Monitoring forest cover changes and measuring forest carbon stock changes are more challenging due to the availability of historical data (Herold et al., 2011), capacities and resources (Romijn et al., 2015), and the potentials and limitations of many measurement and monitoring approaches (Goetz et al., 2015). Many studies of forest cover change have also been integrated with satellite-based forest biomass information to quantify changes in forest carbon stocks (Achard et al., 2014; Baccini et al., 2012; Harris et al., 2012; Tyukavina et al., 2015), but they might show a diverse result because of using different procedures for mapping and analyzing. For reasons of transparency and consistency (UNFCCC, 2014), countries should use the same sources, approaches, and data for reporting forestry emissions in national GHG inventories and REDD+ reports (GFOI, 2016).

2.5. Restoration of Forest Landscapes

Massive areas of tropical deforestation and forest degradation (Vidal et al., 2014), combined with increasing awareness in mitigating climate change (da Fonseca et al., 2007) and conserving biodiversity (Wilson et al., 2010), revealed the potential value of restoring forest landscape (Wheeler et al., 2016). Efforts to value and protect ecosystem services (Aronson and Alexander, 2013) over the previous decade have been promoted for restoring ecological landscape (Walther et al., 2002), particularly for the forested area. Forest restoration (van Oosten et al., 2014) appears to be one of the most promising approaches (McRae et al., 2012) for renewing ecosystem integrity and functionality (Balaguer et al., 2014). Ecological restoration of forest landscapes has advanced significantly intentional activity (Young et al., 2005) as the scientific and practical approaches for landscape management (Robinson and Carson, 2013) and ecosystem services (Daily and Matson, 2008) by benefiting both biodiversity (Newton et al., 2012) and human well-being (Daily et al., 2009).

Tropical forest restoration should be integrated into extensive disaster threat reduction programs, adaptation strategies, and landscape management plans (Higgs et al., 2014; Locatelli et al., 2015; Perring et al., 2015). The outlining feature of forest restoration is its focus on sustainability of multi-scale processes (Stanturf et al., 2014), including hydrologic cycles (Carvalhais et al., 2014) and ecosystem productivity (Seidl et al., 2012), rather than tree compositions and forest structures (Haugo et al., 2015). Commonly, the most efficient forest restoration strategies (Aerts and Honnay, 2011), regarding cost and effectiveness, facilitate natural successional processes (Corbin and Holl, 2012). The approaches of forest reforestation are now emerging (Lamb et al., 2005), that might offer the additional ways of dealing with degraded forest landscapes (Stanturf et al., 2014). Notably, restoration of forest landscape is designed to ensure that present and future generations have vital ecosystem services and capably deal with the uncertainties of climatic, economic and social change (Laestadius et al., 2011).

International and national leaders have committed to restore deforested and degraded land, especially forest area, to be productive, functional and biodiversity-friendly landscapes (Chazdon et al., 2017). The common problem in the integration of ecological purposes with forest planning is the lack of practical approaches when assessing the environmental benefits of alternative forest treatment (Kangas and Leskinen, 2005). At the landscape level, the goal of forest and landscape restoration is to regain ecological functionality and enhance human well-being across degraded landscapes (Stanturf et al., 2012). Even though many principles of forest restoration are derived from insights of historical change (Balaguer et al., 2014), the proposed forest restoration should be distinguished from the natural forest succession (Chazdon, 2013).

Forest restoration is usually applied under two main conditions: the occurrence of a degraded forest which should be rehabilitated or the presence of a cleared area that should be reforested (Orsi et al., 2011). Reforestation is the practice of regaining forest cover in the selected area where it was previously deforested (Chazdon, 2008), while forest rehabilitation is defined as the recovery acceleration of forest area that has been degraded (Stanturf et al., 2014). Although diverse stakeholders have different goals in reforestation (Chazdon, 2013), many of these objectives are compatible with landscape-scale reforestation (Robinson and Carson, 2013) that generates the compulsory prospects for collaboration (Schultz et al., 2012), local empowerment (Newton et al., 2012), and long-term support for reforestation.

2.6. Sustainable Forest Management

The quantitative understanding of the functional changes in the ecosystems in comparison with natural forests is needed due to an increasing requirement of the forests being intensively managed for wood, fiber and ecosystem services (Noormets et al., 2015). The concept of sustainable forest management is increasingly required for mitigating and adapting climate change (Baskent et al., 2008). Adopting the principles and practices of forest management can provide a sound basis for challenging climate change (Keenan, 2015). The sustainability of forest management is rooted in the two premises: (1) ecosystems have the perspective to renew themselves, and (2) socio-economic perceptions showed as the human-environment interactions can be adapted to ensure the long-term ecosystem productivity and health (MacDicken et al., 2015). Currently, a subtle shift from multiple-use management to ecosystems management is being experimented and the new ecological perspective of forest management is based on the principles of ecosystem diversity, stability, and elasticity (Kangas et al., 2008).

Even though the forest management concern on mitigation and adaptation is relatively new (D'Amato et al., 2011), many approaches appear for enhancing carbon stock and stand density (Moore et al., 2012; Sierra et al., 2012). The modification of traditional forest management strategies is needed (Lindner, 2000) for mitigating climate change conditions by adopting the landscape strategies (Boutin and Hebert, 2002). The requirement for scale-up management activities demands that the patch based approach consider processes at the broader landscape and regional scales (Perring et al., 2015). The scale of forest changes requires the adoption of a landscape perspective, for instance where there has been the regional hydrological changes or large-scale deforestation or tree mortality (Allen et al., 2015).

The decision of forest management is principally based on economic analyses (Muzika, 2017) and forest management objectives (Li et al., 2011), which may also change over time for a specified region where different jurisdictions exist (Bettinger et al., 2009). Numerous stakeholders have different objectives concerning the use of forests or other environment resources (Kangas et al., 2008) that may increase the complexity of the decision (Ananda and Herath, 2009).

2.7. Silviculture and Landscape Strategies for Restoring and Managing Forests

Forest restoration activities are similar to forest management in that both rely on silviculture although sometimes forest restoration involves extraordinary measures (Stanturf et al., 2014). Forest management approaches and silvicultural practices must be viewed within the context of synchronous ecology, economic, societal, and cultural developments (Puettmann et al., 2009). The practice of both forest restoration and management use the conventional techniques of silviculture (Ferez et al., 2015) with landscape perspective (Stanturf et al., 2014) with no apparent boundaries with the conventional forest approaches. Indeed, silviculture encourages forest landscapes from historical circumstances (Hummel and Cunningham, 2006) through forest restoration and management activities (Dumroese et al., 2015) for reaching various objectives (Hummel et al., 2015) and desired outcomes (Chazdon, 2008).

Silviculture is defined as the practice, science, and art of tending forests to reap goods and services, including timber and non-timber forest products (Nyland, 2016) that also focuses on the stand values for reaching forest functions through more considerable attention to sustainable forest management (Guldin and Graham, 2007). Because the goals of silviculture are defined by ownership objectives, resilience in managed forests is best defined operationally as the ability to efficiently provide desired ecosystem goods and services (Puettmann, 2011). Silviculture integrates ecology and management at the landscape scales (Selman, 2009) where the choices are applied to the uncertainties of climate change (Janowiak et al., 2011).

At the landscape level, the first fundamental challenge of silviculture approach for restoring and managing tropical forest landscape is how to decide the optimal function of the forest (Bolliger and Kienast, 2010) among many different land purposes (de Groot et al., 2010). In this stage, detail landscape information on forest area designated by the government in combination with spatial datasets of forest cover, slope, and erosion risk level would be useful for considering the optimum forest function. According to the Indonesian Law No. 41 of 1999 on Forestry (Indonesia, 1999), forest area has three broad categories based on its function: protection forest, conservation forest, and production forest. The land that was not designated as a forest area was entitled non-forest area (other purposes). Protection forest is a forest area with a primary function for protecting life support systems to manage water, preventing flooding and seawater intrusion, controlling erosion, and maintaining soil fertility. Conservation forest is a forest area with a particular characteristic which has a principal function for preserving the biodiversity and ecosystem. Production forest is a state forest area with a principal function for producing forest products, mainly commercial timber.

Another stage for restoring forest landscape is the identification of location that should be accorded priority for intervention (Orsi and Geneletti, 2010). The selection of restoration location priorities at the landscape scale massively depends on the objectives of the reforestation action (Orsi et al., 2011) that can be seen as a multi-purpose planning problem (Kangas and Leskinen, 2005) in which nature conservation (Pimm and Brooks, 2013) and other issues. The process of scenery restoration goals, conditioned by the scale and level of restoration preferred, translates ambiguous aims into achievable, measurable targets and ultimately activities on the ground (Orsi and Geneletti, 2010).

On the forest management, the silvicultural system is known as the combination of silvicultural techniques planned for the forest areas over its entire rotation using regeneration approaches and timber harvesting practices (Muzika, 2017) based on management purposes (Hummel et al., 2015). In Indonesia, the government customs several kinds of silvicultural systems, i.e., *Tebang Pilih Tanam Indonesia* (selective cutting with enrichment planting), *Tebang Pilih Tanam Jalur* (selective cutting with line planting), and *Tebang Habis Permudaan Buatan* (clear-cutting with intensive planting) (MoF, 2009b). A single forest management unit can apply more than one system, known as multi-systems of silviculture (MoF, 2014b).

Chapter 3

Overview of Study Area and REDD+ Program

3.1. Overview of East Kalimantan Province

This research focuses on East Kalimantan Province in Indonesia as the study area. East Kalimantan was established as the provincial administrative area under Indonesian Law No. 25 of 1956 on the establishment of autonomous regions of West Kalimantan, South Kalimantan and East Kalimantan (Indonesia, 1956). In the further development, the area surrounding the province since 2012 was divided into two provinces: East Kalimantan and North Kalimantan. Four districts (Bulungan, Nunukan, Malinau and Tana Tidung) and one city (Tarakan) located in the northern part were clustered as North Kalimantan Province (Indonesia, 2012a). East Kalimantan consists of seven districts (Berau, Kutai Kartanegara, Kutai Timur, Kutai Barat, Paser, Mahakam Ulu, Penajam Paser Utara) and three cities (Samarinda, Balikpapan, Bontang).

East Kalimantan is located on Borneo island with coordinate between 2°33' N and 2°25' S and between 113°44' E and 119°00' E (Figure 3.1). As the third largest province in Indonesia with the total area of 12,733,250 ha (6.66% of Indonesia), East Kalimantan has a land area of 12,620,448 ha and inland water of 112,802 ha (BPS, 2017). The province is bounded by Sarawak (Malaysia) to the northwest, the Celebes Sea to the northeast and Makassar Strait to the southeast, North Kalimantan to the north, South Kalimantan to the south, Central Kalimantan to the southwest, and West Kalimantan to the west. Its position is strategic as one of the Indonesian Archipelagic Sea Lane for an international sea transport route, that invites many investors (East Kalimantan, 2012).

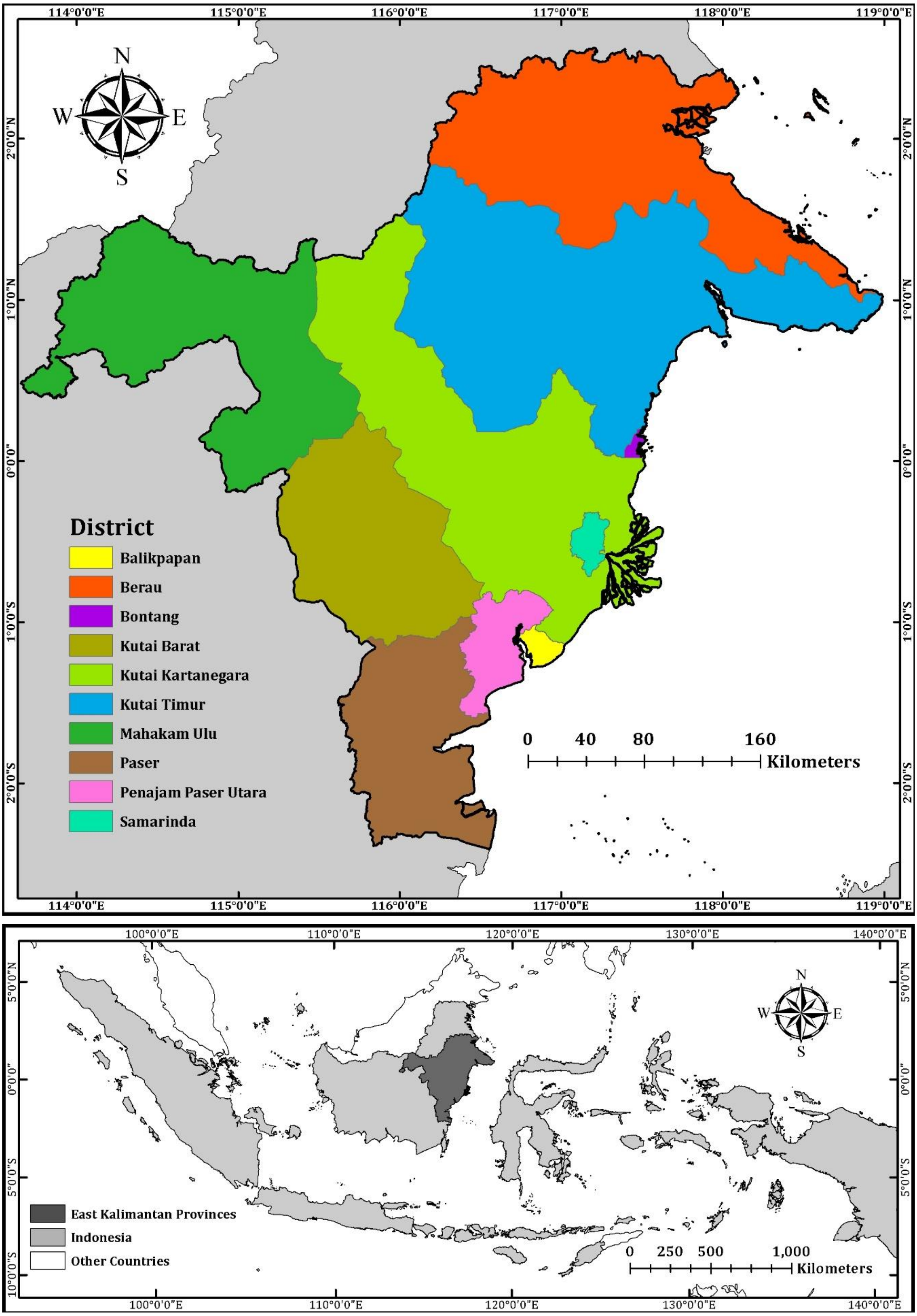

Figure 3.1. The East Kalimantan Province of Indonesia as the study area.

Similar to other Indonesian provinces, East Kalimantan has a tropical climate with a dry season from May to October and a rainy season from November to April. However, the season situations have more recently been unpredictable due to climate change effects. With the tropical climate and extensive forest habitats, East Kalimantan has relatively high humidity, with the average record from 79 to 87% (BPS, 2017). Based on the geophysical information, topography in East Kalimantan is generally dominated by wavy, from flat to steeply, with altitude ranging from 0-1,500 meters above sea level. The province generally has a slope class ranging from 0-60%, of which more than half is a slope class of more than 40% (East Kalimantan, 2013). Lowland areas are commonly found along rivers and beaches with a length of 10-1,900 km. The hills and mountains have an average height of more than 1,000 meters above sea level with a distance of 47-2,467 meters and a slope of 30 percent, located in the Northwest that borders directly with Malaysia (East Kalimantan, 2012). Most of the mountainous areas spread in the western part of Kutai Kartanegara, Kutai Timur, Kutai Barat and Mahakam Ulu to the Malaysian border. Coastal regions, tidal swamps, alluvial plains, sedimentary pathways, and rivers are on the east coast, while alluvial plains and valleys mostly follow the direction of river flows (BPS, 2017). This conditions significantly affect the cultivation opportunities, water supply, hydrological system, and erosion susceptibility.

East Kalimantan lies in the Sundaland biogeographic (Myers et al., 2000) as one of the wealthiest provinces for both ecological and economic aspects. The province is also a worldwide principal for both carbon storage and biodiversity in Southeast Asia, due to its extremely high species richness (Budiharta et al., 2014; de Bruyn et al., 2014; Slik et al., 2010). Tropical forests in this province are well known for their high biodiversity (Casson et al., 2015) and it ranges from lowland forest to montane forest, swamp forest, and mangrove forest (Wilson et al., 2010). The forest of East Kalimantan also contains almost 15 million hectares of forests (FCPF, 2017) and more than 800 tree species are listed as threatened species by the International Union for the Conservation of Nature (IUCN) as well as several endangered animal species such as orangutans, proboscis monkeys, sun bears and gibbons (TNC, 2016). Despite their vital role in the global carbon cycle and biodiversity conservation (Wilson et al., 2010), the combination of logging (Pearson et al., 2014), oil palm plantation development (Carlson et al., 2013), mineral extraction (Abood et al., 2015), and forest fires (van Nieuwstadt and Sheil, 2005) have threatened the biodiversity and have produced carbon emissions (Harris et al., 2012; Hiratsuka et al., 2014) of the region.

3.2. Tropical Deforestation and GHG Emissions

According to the Forest Resource Assessment (FAO, 2015, 2010, 2006), Indonesia experiences the second highest rate of tropical deforestation. Deforestation pressures and their underlying drivers in Indonesia have been in flux regularly over the past 60 years (Tsujino et al., 2016). The deforestation rate in Indonesia is accelerating that lost about 17% of the forest area (1.6 million hectares) between 1985 and 1997 (FWI/GFW, 2002). Since 1996, tropical deforestation in Indonesia appears to have accelerated again to approximately 2 million ha per year (Holmes, 2002). High rates of deforestation and forest degradation in tropical forests have mainly resulted from inappropriate practice for reaching forest management goals (Harris et al., 2008). The main drivers causing the rapid forest destruction in Indonesia are frequent conversion to timber plantation, oil palm plantation, and mining which are triggered by illegal logging, droughts, forest fires, and political decisions from the national to district level (FWI/GFW, 2002; Holmes, 2002; Margono et al., 2014, 2012; Nguyen et al., 2016; Tsujino et al., 2016; van Nieuwstadt and Sheil, 2005; Yoshikura et al., 2016).

Indonesia has long promoted the extraction of natural resources to stimulate economic development (Casson et al., 2015). Deforestation became a concern in the early 1970s when Indonesia began to use forest resources to its economic benefit that triggered to the establishment of large-scale logging concessions and the rapid growth of timber production (Kartawinata et al., 2001). Oil palm plantations expansion has exerted pressure on the natural forests from at least the mid-1980s (Koh and Wilcove, 2008). The transmigration program in 1980s has encouraged people to move from Java to the outer islands to relieve population pressure and poverty that affected on the starting of tropical deforestation in the outer Java island, including Kalimantan (FWI/GFW, 2002). Failure of the Million Hectare Rice Project in the early 1990s to establish rice cultivation in Kalimantan's peat swamp forest led to large logged forests lying idle (Tsujino et al., 2016).

In 1998, the government of Indonesia began decentralization by transferring authorities to districts that brought confusion in forest management and affected to illegal logging and forest clearance during the decentralization transition (Pransiska et al., 2016). The condition became severe due to drought, failed rice harvest, and the largest forest fires that burned forests in Kalimantan and Sumatra attributed to the El Niño Southern Oscillation (ENSO) event (Slik et al., 2002; van Nieuwstadt and Sheil, 2005). Natural resource extraction for large-scale oil palm plantation, timber plantations, and agriculture expansion was highlighted in the Master Plan 2011–2025 to accelerate Indonesia economic development (Casson et al., 2015).

In East Kalimantan, most lowland areas in the early 1970s were covered with primary dipterocarp forest (Slik et al., 2002). However, most of the dipterocarp forests have been selectively logged, burnt, or converted into cropland and agriculture, with only a few small intact forests remaining. The large-scale tropical deforestation in East Kalimantan started in the 1980s when people came from Java through Transmigration Program (Tsujino et al., 2016). The transmigrants influx supplied labor forces to East Kalimantan which also affected forestry expansion and crop production (FWI/GFW, 2002). The timber extraction based on forest concession (Curran et al., 2004) and oil palm plantation expansion (Carlson et al., 2013) have also resulted in highly deforested and degraded forests in East Kalimantan. Droughts and forest fires were also increasingly documented as the drivers of tropical deforestation dynamics in East Kalimantan (van Nieuwstadt and Sheil, 2005).

High rates of tropical deforestation have led to an unprecedented biodiversity loss in the humid dipterocarp forest (Barlow et al., 2007). Many studies have attempted to address the carbon emissions from deforestation and forest degradation in tropical landscapes (Harris et al., 2012; Hiratsuka et al., 2014; Kotowska et al., 2015; Miller et al., 2011; Nguyen et al., 2016; Pransiska et al., 2016; Ramdani and Hino, 2013; van Noordwijk et al., 2014; Zarin et al., 2016). Land use, land use change, and forestry (LULUCF) activities, mainly as a result of deforestation and forest degradation, are currently net sources of carbon dioxide (CO_2) emissions (Harris et al., 2008). In Indonesia, the emissions from LULUCF was estimated to be 78% of total national emissions in 2005 and is expected to be 68% of total emissions in 2020 (Casson et al., 2015). Oil palm plantation expansion in Kalimantan contributes 18–22% of CO_2 emissions in Indonesia for 2020 (Carlson et al., 2013). The highest logging intensity in

East Kalimantan emitted 15% of total forest carbon stock (Pearson et al., 2014), but adoption of reduced-impact logging (RIL) could reduce emissions by 30–50% across at least 20% of tropical forests (Griscom et al., 2014). Nevertheless, the land allocation for logging concessions, oil palm plantation, and mining also needs to be evaluated to ensure that rational and suitable lands are allocated (Casson et al., 2015).

3.3. Green Growth Initiatives and REDD+ Program

International concerns on reducing emissions from deforestation and forest degradation (REDD+) are continuing under the United Nations Framework Convention on Climate Change (UNFCCC). REDD+ implementation in Indonesia (Indonesia, 2012b) has five principles: effectiveness, efficiency, fairness, transparency, and accountability. A number of REDD+ demonstration projects have been implemented in Indonesia. In 2013, approximately 52 REDD+ demonstration projects had been established (Casson et al., 2015), mostly in Kalimantan (21 projects) and Sumatra (6 projects), with only a few each on Java, Lombok and Nusa Tenggara (4 projects), Sulawesi (5 projects) and Papua (6 projects). In September 2013, the president of Indonesia signed a decree to establish the REDD+ Task Force (Indonesia, 2012b). the task force will be responsible for developing a national strategy, formulating policies, managing funds, developing standards, increasing capacity, and coordinating law enforcement.

In East Kalimantan, the Governor also committed and has been active in encouraging the implementation of REDD+ commitment. Since 2008, East Kalimantan has taken steps for implementing the green growth concept that focused on sustainable development and forest-friendly model (Figure 3.2). In 2008, the Government of East Kalimantan created the working group of REDD and began supporting a range of initiatives at district and project levels (TNC, 2016). In 2010, the Governor declared the Green East Kalimantan (East Kalimantan, 2011b) program for reducing carbon emission in combination with the economic development. The program has four goals: (1) improving the quality of life with harmonizing economic, social, cultural, and ecological aspects; (2) reducing the threat of climate change; (3) reducing ecosystems degradation; and (4) increasing awareness of conservation and wise use of renewable natural resources.

Figure 3.2. The concept of Green Growth in East Kalimantan (East Kalimantan, 2013).

Since launch of the program, a number of steps at the provincial level have been taken to follow the green growth initiatives, including establishment of the Regional Council on Climate Change (DDPI) in January 2011 (East Kalimantan, 2011c), and the creation of policy documents, including the local action plan (East Kalimantan, 2013) and the provincial strategy (East Kalimantan, 2012) for reducing greenhouse gas emissions. The action plans of REDD+ are categorized and structured into three main group sectors comprising of policymakers from departments in the respective sector. The working groups are expected to coordinate the further design and implementation of specific action in respective sectors that consist of the land-based sector, integrated energy, and mixed waste. East Kalimantan seeks to reduce emissions by 22.38% from the landbased sector by 2020 that has been formulated in the local action plan (East Kalimantan, 2013) formalized by Governor Regulation No. 39 of 2014 (East Kalimantan, 2014). According to the provincial REDD+ strategy (East Kalimantan, 2012), emissions should be reduced by a ban on burning; reduced-impact logging; using degraded lands for plantation expansion; reducing composition of peatland, and reforestation.

As one of the target provinces for reducing carbon emissions, East Kalimantan is a leading member of the GCF (Governors Climate and Forests Task Force) and has been selected as the focal province for Indonesia's efforts to reduce deforestation through the Forest Carbon Partnership Facility's (FCPF) Carbon Fund. FCPF is the global partnership of governments, businesses, civil societies, and indigenous peoples (IP), focused on reducing emissions from deforestation and forest degradation, forest carbon stock conservation, the sustainable forest management, and the enhancement of forest carbon stocks in developing countries (FCPF, 2017). East Kalimantan is also working through close support from civil societies and private sectors, which have joined with the government to launch a Green Growth Compact by the end of 2017 (TNC, 2016). Green Growth Compact is centered around two interrelated targets to reduce tropical deforestation by at least 80% by 2025, and to increase economic growth by 8% by 2030.

Along with a sub-national partnership of 26 states and provinces, the provincial government signed the Rio Branco Declaration in 2014 that committed to reducing deforestation by 80% by 2020 (GCF, 2014). In 2017, the provincial government has organized the GCF meeting and announced the Balikpapan Challenge that was designed for the provisional partnerships to attack tropical deforestation (EII, 2017). The province is also hosting several REDD+ demonstration projects managed by international NGO's and donors. However, further work is required to integrate within official government climate mitigation measures (East Kalimantan, 2011a).

Chapter 4 (Abridged Version)

Completing Yearly Land Cover Maps for Accurately Describing Annual Changes

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Any inquiry or further question, please send an email to

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Chapter 5 (Abridged Version)

Assessing Forest Cover Transitions for Detecting The Causes of Deforestation

This chapter is scheduled to be published in the form of a paper in a scholarly journal in the near future. Any inquiry or further question, please send an email to kiswantosardji@gmail.com

Chapter 6 (Abridged Version)

Estimating Historical Baselines and Future Trajectories of GHG Emissions

This chapter is scheduled to be published in the form of a paper in a scholarly journal in the near future. Any inquiry or further question, please send an email to kiswantosardji@gmail.com

Chapter 7 (Abridged Version)

Monitoring Forest Cover within and outside Forest Area

This chapter is scheduled to be published in the form of a paper in a scholarly journal in the near future. Any inquiry or further question, please send an email to kiswantosardji@gmail.com

Chapter 8 (Abridged Version)

Landscape Strategies for Forest Restoration

8.1. Introduction

8.2. Materials and Methods

8.2.1. Spatial Datasets

8.2.2. Formulating Forest Restoration

8.3. Results

8.3.1. Forest Restoration Based on Activities

8.3.2. Forest Restoration Based on Priorities

8.4. Discussion

8.5. Conclusions

This chapter is scheduled to be published in the form of a paper in a scholarly journal in the near future. Any inquiry or further question, please send an email to kiswantosardji@gmail.com

Chapter 9 (Abridged Version)

Silvicultural Systems for Managing Forests Based on Landscapes Information

This chapter is scheduled to be published in the form of a paper in a scholarly journal in the near future. Any inquiry or further question, please send an email to kiswantosardji@gmail.com

Chapter 10 (Abridged Version)

General Discussion and Conclusion

This chapter is general discussion combined with previous main chapters (from Chapter 4 to Chapter 9) which are scheduled to be published in the form of a paper in a scholarly journal in the near future.

Any inquiry or further question, please send an email to

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