Doctoral Dissertation

Sustainable Peatland Management in Riau Province, in terms of Fire Risk, Biodiversity and Land Management

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Table of Contents

List of figures

List of tables

Abbreviations and acronyms

AMO	:	Atlantic Multidecadal Oscillation
ANOVA	:	Analysis of Variance
ASEAN	:	Association of Southeast Asian Nations
BA	:	Basal Area
C	:	Carbon
CSV	:	Comma Separated Values
CIFOR	:	Center for International Forestry Research
DBH	:	Diameter at Breast Height
DOS	:	Dark-Object Subtraction
ENSO	:	El Nino Southern Oscillation
FIV	:	Family Importance Value
FDRS	:	Fire Danger Rating System
FIRMS	:	Fire Information for Resource Management System
FMU	:	Forest Management Unit
GCP	:	Ground Control Point
GLOVIS	:	Global Visualization Viewer
GPS	:	Global Positioning System
Gt	:	Gigaton
IODM	:	Indian Ocean Dipole Mode
IVI	:	Important Value Index
KLG	:	Peatland hydrological unit

LIDAR	:	Light Detection and Ranging
MJO	:	Madden-Julian Oscillation
MODIS	:	Moderate Resolution Imaging Spectroradiometer
MoEF	:	Ministry of Environment and Forestry
MRP	:	Mega Rice Project
NASA	:	National Aeronautics and Space Administration
NDVI	:	Normalized Difference Vegetation Index
ONI	:	Oceanic Nino Index
OLI	:	Operational Land Imager
PA	:	Protected area
RSPO	:	Roundtable on Sustainable Palm Oil
RU	:	Record Unit
ROR	:	Relative Occurrence Rate
SST	:	Sea Surface Temperature
THPA	:	Transboundary Haze Pollution Act
TOA	:	Top of Atmosphere
UAV	:	Unmanned Aerial Vehicle
WWF	:	World Wildlife Fund

Abstract

Sustainable peatland management has become an international priority as the relationships among peatland management, fires, haze and air pollution, biodiversity, land subsidence, permanent inundation, and climate change have become better understood. A major catalyst has been the fire haze and air pollution in Southeast Asia, which have caused a negative impact on economies and human life across the region.

Sustainable peatland management is a challenge because peatlands have an important role in the economic growth of Indonesia due to their value for agricultural development (e.g., oil palm, acacia). However, tropical peatlands remain poorly understood. Tropical peatlands have experienced extensive fires and deforestation for timber and convertion to plantation and undeveloped land. This rapid land use and land cover change on contested land and complex drivers of peatland degradation and loss requires new research. Research to date has been about peatland characteristics and restoration and has not focused on practical knowledge such as best management practices. As a result, different approaches to tropical peatland management are currently being taken by various stakeholders. Therefore, research on monitoring of tropical peatland management is important.

This study focused on Riau Province (Sumatra), one of the most fire-prone provinces of Indonesia. Riau has the highest deforestation in Sumatra, more than half of forest lost during 1990 to 2010 (3 million ha). A large area of peatland has been converted into plantation area, with associated environmental and economic impacts. Fires in Riau have been associated with land mismanagement policy. To work toward sustainable peatland management, we need to assess peatland utilization by the various types of landholders.

This study was conducted with four objectives:

(1) Investigate the use of satellites to monitor no-deforestation commitments and no-burning compliance by industrial plantation companies.
(2) Assess the drivers of fire and the relationship among fire occurrence, land cover type, landholders, and accessibility.
(3) Examine fire occurrence in relation to climate and deforestation.
(4) Determine tree diversity in peat swamp forests.

Chapter 1 presents the study background study, statement of the research problem, aims and objectives, significance of the study, scientific contribution of the study, and structure of the dissertation.

Chapter 2 consists of the theoretical background and methodological approaches such as the theory of sustainable peatland management, theory of interactions between human and climate factors on fire activities, theory of biodiversity and land management, general description of peatland management in Indonesia, and methodological approaches.

Chapter 3 presents results of the investigation of the reliability of satellite remote sensing (web GIS) to monitor fire activities. Satellite images, a map of land concessions and a field investigation were used to analyze fire occurrence. We found: 1. Undeveloped peatlands were the target of fires and wildfires spread into plantation; 2. Farmers may have been responsible for fire inside and outside concessions; 3. Industrial actors (unregistered companies) were responsible for fire outside concessions; 4. There was a mismatch between land occupancy and legal concessions; 5. Burned area outside concessions was predominantly State Forest Land. 6. Draining of peatlands within concessions may promote fire in those peatland. Results suggest that fire was used to clear undeveloped land. Fires will occur in our study area regularly in the future, given the large amount of remaining idle lands. Effective satellite monitoring needs a resolution of overlapping land claims; land tenure inventories are needed to identify de facto ownership, potential claims, and disputes.

We assess the drivers of fires and the relationship among fire occurrence, land cover type, landholders, and accessibility in chapter 4. We investigated data on deforestation, landholder, concession map, State Forest Land, LANDSAT images, and MODIS hotspot data to analyze fire regime. Findings of this study suggest that: 1. People used fire to clear agricultural land and forest land. 2. The drivers of fire were land type, landholder, period of deforestation, and district boundary. 3. Shrublands were the most fire-prone land cover type. 4. Landholder affects fire occurrences in the forest area. 5. Companies had more fires than smallholders due to plantation management differences among landholders. 6. Roads and canal increased fire occurrences in the forest. The results indicate that good land use governance policies such as spatial planning, law enforcement, and best management practices are important to mitigate peatland fire.

In chapter 5, we examine the role of climate and deforestation on fire activity using rainfall data, MODIS hotspot, LANDSAT images from 2000 to 2013, and the land cover map from Ministry of Environment and Forestry. The results concluded that: 1. Climate is a pre-condition that encourages fire activity 2. More frequent fires in the future are likely as continuing deforestation, higher temperatures, and reduced rainfall all contribute to increased fire risk. 3. Fire was concentrated in peatlands; 4. Riau experienced rapid deforestation to plantation and shrubland; 5. Conservation forest and protection forest had low fire activity. These results highlight the important influence of climate anomalies, deforestation, and land management on fire activity in Sumatra.

Finally, this study addresses tree diversity in peat swamp forests in chapter 6. We recorded 59 tree species belonging to 31 families in 9 sample plots (9 ha). *Syzygium acutifolium* and *Shorea uliginosa* were the dominant species. Stand density varied from 78 to 186 stems ha^{-1} while the basal area was 7.41 to 12.34 m^2 ha^{-1}. Species richness and tree density declined with increasing of tree diameter class. The pattern of tree density indicates good succession. The forests have good tree diversity. This indicated by Shannon–Weiner Index and Simpson Index varied from 1.91 to 2.88 and 0.08 to 0.24 respectively. Priorities for management of peat swamp forest should be conservation, enrichment planting, and prevent degradation of the forests.

The main contribution of this study is that it was successful in assessing the role climate, deforestation, landholders and peatland management on fire activity and tree diversity in peat swamp forest in Riau Province. We suggest the government should prioritize the management of unmanaged peatland and the remaining peat swamp forest. We highlight the importance of peat swamp forest, land tenure, and best management practices to minimize fire activities.

Chapter 1. Introduction

1.1 Background

Peatlands are extensive areas dominated by peat soils, which are organic soils formed from the slow decomposition of vegetation in waterlogged ecosystems. The accumulation of organic material forms layers more than 30 cm thick over thousands of years. Peatlands can be found in almost all countries, from polar through subtropical and tropical climates. Most peatlands are located in the northern hemisphere (89%), particularly in Russia, North America and Europe, with low temperature and precipitation (Page et al., 2011). Although peatlands comprise only 3% of the total land area, peat contains 329-525 gigatons (Gt) of carbon (C), which is approximately 35% of the total world carbon stock. Of which, tropical peatlands contain a substantial amount of carbon, around 80–90 Gt C (Page and Hooijer, 2016).

Forests naturally occur on tropical peatlands under the appropriate temperature and precipitation regimes. The tropical peatlands have an area around 441,025 km² (11% of global peatlands). Southeast Asia has the most significant tropical peatlands, about 56% of the total (or 12% of its land), followed by South America at 24% of total, Central Africa at 13%, Central America and Caribbean at 5%, and Asia (mainland) at 1%. Most of the peatlands in Southeast Asia are or were located along the coasts of eastern Sumatra, the coast of Kalimantan, the coast of southern Papua and Sarawak. Indonesia and Malaysia have the most significant area 206,950 km² and 25,889 km², respectively (Page et al., 2006).

Indonesia has a long history of peatland utilization in. Local people in Kalimantan and Sumatra initiated peatland utilization for agriculture. The success of local people inspired the colonial government to utilize peatlands at the beginning of the twentieth century. The first project was in the coastal peatland of Kalimantan (Sabiham et al., 2016). Peatland utilization for rice production was in line with the transmigration program. After Indonesian independence, peatlands in Sumatra and Kalimantan were utilized for agricultural, settlement, and forestry purposes. By 1989, around 1.3 million hectares (ha) of peatlands had been developed, of which 0.5 million ha were logging concessions in coastal peatlands (Tsujino et al., 2016).

However, large-scale peatland utilization started in the 1990s for agricultural purposes (rice and plantation). In 1995, the government announced a one million ha rice project in Central Kalimantan (Hoscilo et al., 2011). A large area of Indonesian peat swamp forest has been converted to plantations of oil palm and acacia within the last two decades (Miettinen et al., 2012b). For example, 25 % and 41% of peat swamp forest in Kalimantan and Sumatra was lost from 2000 to 2010, respectively.

The large scale of peatland utilization has had a positive impact on economic growth (Uda et al., 2017). However, peatland utilization also has had a negative impact on the economy, society, and the environment. Wildfires in Indonesia have increased in frequency, area and intensity since the last 1990s. These fires have been associated with land mismanagement policy (Murdiyarso and Adiningsih, 2007). Peatland fire contributes significantly to air pollution that affects human health and economic activity (Hayasaka et al., 2014). Other significant impacts include flooding, land subsidence due to peatland drainage, and the loss of valuable biodiversity in peat swamp forests (Turetsky et al., 2015).

The rapid conversion of tropical peatlands (Page et al., 2011) in contested land and complex drivers need new research. Peatland research is still primarily focused on temperate and boreal areas. Moreover, most research has been about peatland characteristics and restoration (Worrall et al., 2007) and not focused on practical knowledge such as alternative for peatland best management practices. Therefore, there is a substantial gap between research and practical work. Previous studies highlighted the need for monitoring tropical peatlands management, such as agricultural uses and water levels (Wösten et al., 2006).

To work toward sustainable peatland management, we need applied research which integrates aspects of economic, social, and environmental sciences such as impact assessment caused by peatland utilization (Sumarga et al., 2016). The international community with global concerns also supports these efforts. We need to assess peatland utilization by the various landholders. Our priority is information on peatland utilization in fire-prone regions of Indonesia to mitigate environmental and human health disasters.

1.2 Statement of Research Problem

The lack of understanding of tropical peatlands hampers planning processes toward sustainable management. Stakeholders have different opinions on sustainable peatland management due to their different interests. Thus, stakeholders take different approaches to managing peatlands in Indonesia (protection vs cultivation) or (conversion to oil palm and acacia vs forest conservation). Conflicts over how peatlands should be managed threaten the importance of collaboration among stakeholders. Therefore, better knowledge of peatlands will facilitate collaboration among stakeholders.

To improve peatland management in Indonesia, this study will address the issues of wildfire, deforestation, land management, and biodiversity. Until now in Indonesia, studies on peatland management can be divided into a "cultivation group" and a "protection group." The cultivation group argues that sustainability of drainage-based agriculture can be achieved through the best management practices. Conversely, the protection group argues that conserving all peatlands is the only sustainable form of peatland management.

Unfortunately, there have been no studies that bridge the gap between these two groups, especially in Riau Province. Riau is representative of Sumatran peatlands that have experienced rapid rates of deforestation. Moreover, Riau is located next to Malaysia and Singapore, and these countries have been affected regularly by air pollution from wildfires in Riau during the "burning season" months. Thus, this study is an important contribution to balancing economic and environmental interests in peatland utilization.

1.3 Aim and objective of the study

To help solve the research problem, this study aims to assess stakeholder commitment toward sustainability of peatland management in Riau Province, Sumatra, Indonesia. Specific objectives are to:

1. Investigate the capability of satellites to monitor no-deforestation commitments and no-burning compliance by industrial plantation companies.
2. Assess the drivers of fire and the relationship among fire occurrence, land cover type, landholders, and accessibility.
3. Examine fire occurrence in relation to climate and deforestation.
4. Determine tree diversity in peat swamp forests.

1.4 The significance of the study

1. Peatlands are vital for the ecosystem services as they provide carbon storage, water regulation (e.g., flood reduction), biodiversity, unique ecosystem features, and refuge for fauna from non-peatland areas. Particularly important is the carbon storage capacity of peatlands. Because of its extensive peatlands, Indonesia has a significant function in reducing global carbon emission, mitigating climate change, and maintaining biodiversity.

2. Peatland management is important in the context of sustainable development. Their role has attracted international interest because peatland link with persistent fires, loss of biodiversity, and increased carbon emissions that contribute to climate change.
3. Numerous studies have focused in part on the connection between fire and land cover change, biodiversity, and peatland management. However, these studies lack a comprehensive understanding of various aspects of peatland monitoring in the context of sustainable management, specifically the role of various agricultural practices (e.g., oil palm, acacia) among stakeholders.
4. To date, research on peatland management in Indonesia and its impacts on the environment is still limited. A better understanding of the processes and implication of peatland management is vital for collaboration among stakeholders.
5. Collaboration is essential because peatland management is a complex issue involving environmental, social, and governance problems. Therefore, this scientific information produced through this study will be valuable for all stakeholders and sectors in Indonesia to mitigate the negatives impact of certain types of peatland management.

1.5 Scientific contribution of the study

Regarding the scientific contributions of this study, four scientific papers form the backbone of the dissertation as follows.

1. David L.A. Gaveau, Romain Pirard, Mohammad A. Salim, Prayoto, Husna Yaen, SeanA.Park, and Rachel Carmenta, 2017. Overlapping land claims limit the use of satellites to monitor no-deforestation commitments and no-burning compliance. Conservation Letters, Vol.10, No. 2, pp.257-264. (Chapter 3).

2. Prayoto, Masae Iwamoto Ishihara, Rachmad Firdaus, and Nobukazu Nakagoshi, 2017. Peatland fires in Riau, Indonesia, in relation to land cover type, land management, landholder, and spatial management. Journal of Environmental Protection, Vol.8, No. 11, pp.1312-1332. (Chapter 4).
3. Prayoto, Rachmad Firdaus, and Nobukazu Nakagoshi, 2018. Woodland fires in Sumatra, Indonesia in relation to climate and deforestation (Chapter 5).
4. Prayoto, Rachmad Firdaus, and Nobukazu Nakagoshi, 2018. Tree diversity and structural composition of tropical peat swamp forest: a study in Riau, Indonesia (Chapter 6).

1.6 Dissertation structure

The dissertation consists of seven chapters showing in Figure 1.1. Chapter 1 presents the background and aims of the study. Chapter 2 provides the theoretical background, methodology, and description of the study area in Riau Province, Sumatra, Indonesia. Chapter 3 discusses the capability of satellites to monitor zero burning and zero deforestation policies by the companies. Chapter 4 presents the drivers of fire and the relationship between fire occurrence, land cover type, land management, landholders, and proximity to roads and canals. Chapter 5 examines factors that affect fire activity such as human-ignition, land cover, and climate. Chapter 6 presents, diversity and structural composition of tropical peat swamp forest in Riau and the last chapter (Chapter 7) present a general discussion and conclusion of this dissertation.

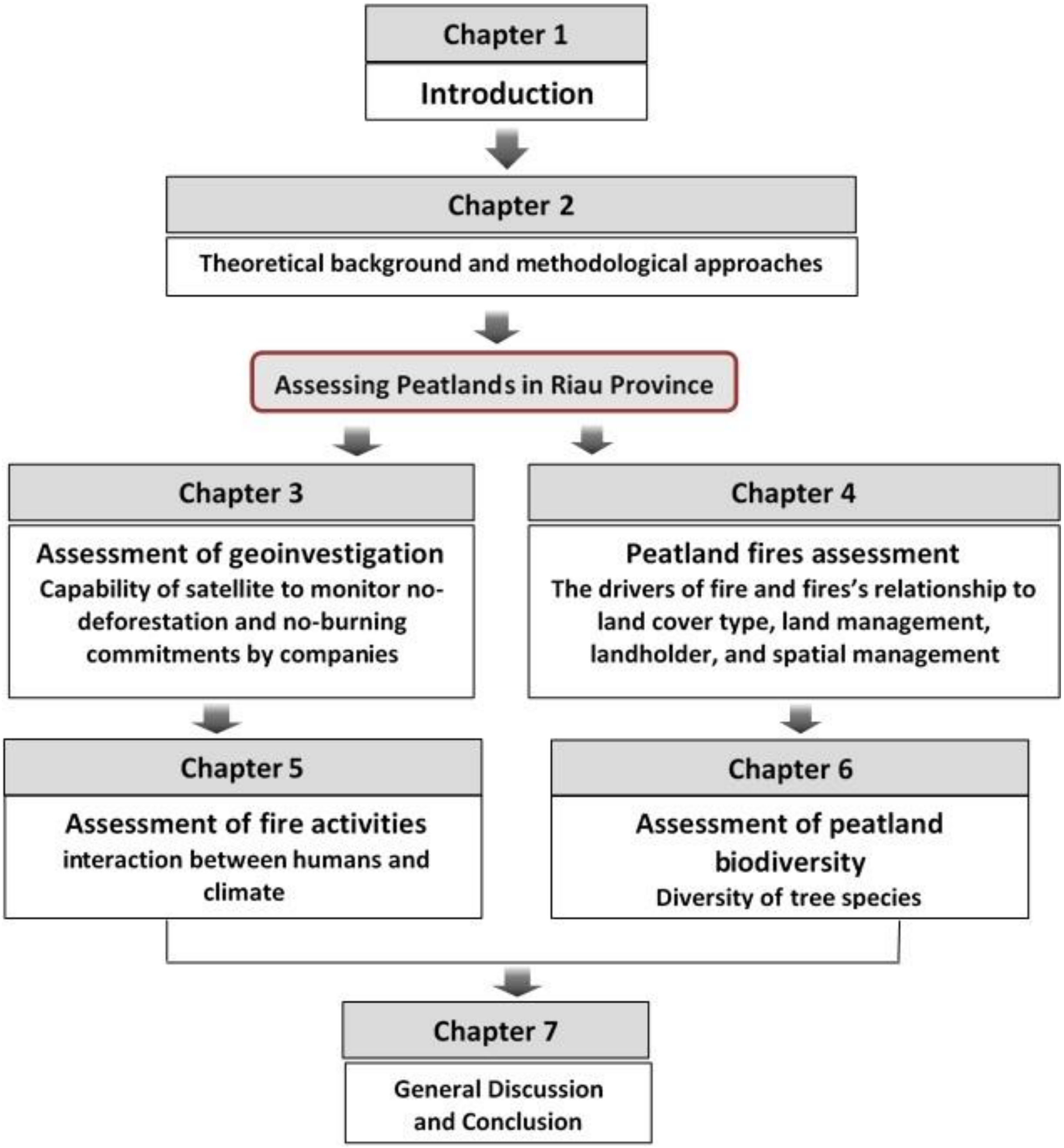


Figure 1.1 Dissertation structure

Chapter 2. Theoretical background and methodological approaches

2.1 Theoretical background

2.1.1 Theoretical framework of sustainable peatland management

2.1.1.1 Defining sustainable management

Sustainable management is defined as a form of management that provides the needs of the current generation and future generations with minimum impact on the environment (Gupta and Vegelin, 2016). Most researchers define sustainability as an integrated approach to improve the quality of the environment and human beings that can be sustained over the long term. Interactions among the environment, society, and the economy have an impact on each (Glavic and Lukman, 2007). Based on these three foundations in Figure 2.1, sustainable management aims to balance environmental protection, social well-being, and economic growth.

In Southeast Asia, public awareness of environmental sustainability, especially in peatland management, has increased as a result of severe disasters such as wildfires, air pollution, climate change, and biodiversity loss. These disasters have caused a significant economic loss and contributed to human health problems for over a million people throughout the region (Glauber and Gunawan, 2015). Therefore, sustainable peatland management is vital in balancing agricultural demands and environmental protection to mitigate anthropogenic disasters (Hansmann et al., 2012).

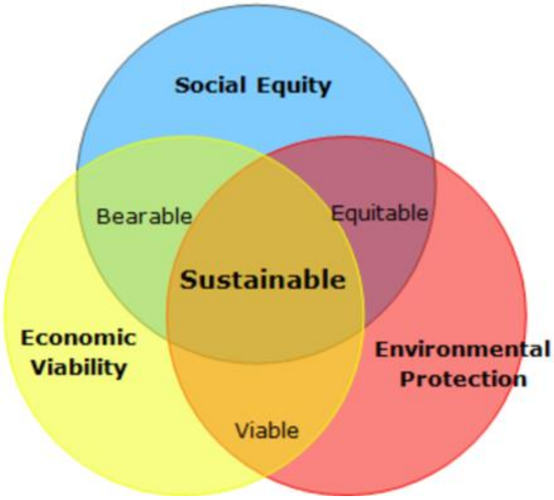


Figure 2.1 The three sustainable pillars

2.1.1.2 Peatland management: issues and approaches

Sustainable peatland management is a significant challenge because peatland utilization is vital for economic growth (Susanti and Maryudi, 2016) in Sumatra and Kalimantan (Riau, South Sumatra, Jambi, Aceh, Central Kalimantan, and West Kalimantan). For over 30 years, peatland utilization was not implemented using sustainable principles (Dohong et al., 2017), resulting in problems: 1. degraded and unproductive peatlands; 2. forest and biodiversity loss; 3. deterioration of the quality of environment due to peatland fires, floods, and subsidence; and 4. loss of local people's livelihood.

As a consequence of these problems, the Indonesian Government is looking to implement sustainable peatland management based on scientific studies because peatlands are an important source of the plantation products (palm oil and paper). Recently, the Indonesian Government has developed a system of peatland hydrological units (KHG) to manage peatlands (Ministry of Environment and Forestry, 2017). A KHG is a management unit comprised of a peatland ecosystem located between two rivers, or rivers and the sea. Indonesia has 673 KHGs (26,477,720 ha) of which Sumatra has 210 KHGs (9,646,460 ha). The government manages these peatlands with three tools: 1. spatial arrangement of protected areas and plantations/agriculture; 2. water management (zoning, networks of canals, and water level control); and 3. commodity selection such as coconut, and sago palm.

Sustainable peatland management requires a landscape approach in which the condition of the hydrology and biology are the most important considerations (Evers et al., 2017). Therefore, factors that degrade hydrological and biological processes should be minimized and land intensification should be implemented. The four important approaches:

a. Prevent deforestation

Deforested peatland should be the primary target of new agricultural (plantation) areas. Conversion of deforested peatland for agricultural areas will reduce the pressure on the remaining forest.

b. Limit water table lowering to no more than 40 cm below ground surface

The water table should be as close as possible to the soil surface, but at a level that is still optimum for crop productivity. A competitive paludiculture system is needed to generate benefit for undrained agricultural systems.

c. Fire management

A fire prevention system should be developed through early warning, fire control, forest fire brigade, and community awareness.

d. Regulation and incentive

Forest plantations are profitable businesses that have a high opportunity cost relative to peatland protection. For smallholders of less than five hectares, there is a little possibility to conserve peat swamp forest because income loss will be too high. Therefore, the government should give an incentive to companies with larger land holdings to conserve peat swamp forests, because they can afford to do so. Another option is a land swap, where allocation for a plantation area can be moved from the peat swamp forest to nonforest areas to obtain carbon credit.

2.1.2 Theoretical frameworks of fire risk

2.1.2.1 Defining fire risk

Fire occurrence requires three elements: fuel, oxygen, and ignition. Fire is a chemical reaction that releases energy in the form of heat and light (Cochrane, 2003a). That reaction converts fuels into charcoal, ash, and aerosol. Satellite sensors can detect the released energy from fire, quantify burned areas, and determine the distribution of haze. We need fire risk information to prevent and mitigate land fires. Indonesia uses the Fire Danger Rating System (FDRS) to determine the level of fire risk (Murdiyarso and Lebel, 2006). FDRS is measured based on weather parameters such as temperature (T), air humidity (RH), wind (W), rainfall (R), and air pressure (P).

2.1.2.2 Interaction between factor of human and climate on fire activities

Despite its critical role, human action is rarely involved in fire models. The predominant effect of increasing human population is to reduce fire frequency, except for extremely sparsely populated areas, where the effect is only slightly positive (Sumarga, 2017). Also, (Hantson et al., 2015) state “both human and natural factors determine the global pattern, with the human factors explaining the larger part of the variance.” Furthermore, a global fire model is being developed to explore the role of anthropogenic and climate drivers (Sloan et al., 2017).

Human decisions on land management can not only increase fire severity but also may inhibit fire ignition and propagation. National parks, national forests, and indigenous lands are good examples of where land management policies have inhibited fire (Nepstad et al., 2006). The role of human in reducing forest fire is important. Nelson and Chomitz (2011) found that Protected Areas (PA) can significantly reduce fire occurrence in Asia and Latin America, additionally, multi-use PAs were even more useful in mitigate fire.

Major sources of fire ignition in Indonesia are: land clearing and preparation, escaped fires; and overlapping land claim (Dennis et al., 2005). Commodity price such as oil palm and acacia may encourage the use of fire for plantation development. Another ignition sources is fire for resource extraction such as fishing areas (Chokkalingam et al., 2005). The arrival migrants onto community land intensify the fire probability (Galudra et al., 2014).

Several factors drive forest change in Sumatera and these have evolved over time. In the early period (1950-1970) forest clearing was needed to expand rice cultivation, small-scale rubber and coffee plantation, and traditional shifting cultivation practice. Next, in 1970-1990, large-scale commercial logging concessions started to take place. Later in 1990-2000, oil palm estates and industrial forest plantations begin to be established. Finally, during 2000-2010, large companies' land holdings were expanded (Margono et al., 2014). The pattern of what has happened on Sumatra has also occurred at the provincial level. For example, the tropical rainforest in Riau decreased from 65% in the 1990s to 37% in 2000s and only 22% was remaining in 2012. As the largest oil palm producing region in Indonesia, the land cover change in Riau has been closely related to the expansion of commodity plantations (oil palm and acacia). Between 1990 and 2000s, the primary land used for oil palm plantations was intact forest on the western part of Riau. Later, palm oil plantations expanded to the eastern part of the province, distributed across mineral soil of intact and logged forest (28%), peatlands (70%), and mangroves (2%) (Ramdani and Hino, 2013).

The vulnerability of wood and peat fuels to ignition and burning increases as they dry, which is usually caused by peatland drainage, higher air temperature, and lower precipitation. The weather in some regions is correlated with Sea Surface Temperature (SST) in another area through a sequence of physical processes. To study this phenomena, several metrological indexes have been developed such as: Atlantic Multidecadal Oscillation / AMO (Schlesinger and Ramankutty, 1994); el-Nino Modoki (Ashok et al., 2007); El Nino Southern Oscillation / ENSO (Wolter and Timlin, 1998); Oceanic Nino Index / ONI; Indian Ocean Dipole / IOD (Saji et al., 1999); Madden-Julian Oscillation / MJO (Wheeler and Hendon, 2004).

Reid et al. (2012) analyzed the relationships of burning and smoke transport to the above climate indices in the Maritime Continent (10^{o}S to 10^{o}N latitude, 90-150^{o} W) during the 2003-2009 period. They found that ENSO is indeed the most significant factor. However, burning is also enhanced by periods of El Nino. On the other hand, IOD influences are unclear. This type of relationship is also observed in the Amazon Basin, where ONI was connected with interannual fire activity in the eastern part, but the AMO was more closely connected with fires in the southern and southwestern region (Chen et al., 2011). In another example, Spessa et al., (2015) found that fire activity and rainfall is negatively correlated and is positively connected with deforestation in Indonesia. Similarly, Wooster et al. (2012) found that El Niño is a climatic factor that induces fire activities resulting in numerous land cover changes and agricultural preparation practices.

2.1.2.3 Fire data

Fire activity can be detected using satellites through two methods: burned area mapping and hotspot detection. Burned area mapping usually depends on changes in reflectance caused by burning, whereas hotspot detection relies on the recognition of thermal infrared radiation produced by fires (Miettinen et al., 2013a).

Automated burned area mapping in Southeast Asia is challenging due to the high variability of vegetation reflectance (before and after fire) and fire regimes (Miettinen et al., 2007). However, burned area mapping can be done via visual or semi-automated inspection of satellite imagery such as example LANDSAT (Gaveau et al. 2014) and Rapid Eye (Konecny et al., 2016) but visual mapping method is time-consuming.

The most widely used sensor for active fire detection is the MODIS (Hantson et al., 2013). MODIS sensor has some advantages such as fire detection sensors saturates at higher temperatures and four daily observations in the equator (Terra at 10:30 am and 10:30 pm and Aqua at 1:30 am and 1:30 pm).

The MODIS sensors have coarse spatial resolution (1 km^2) but the sensors can detect even smaller fires until 100 m^2 (Giglio et al., 2003). Automated burned area mapping and hotspot detections suffer from error (commission and omission). Omissions errors for hotspot detections are cloud cover, dense canopy, haze, missed detection because of short-burning, and smouldering fires in peatland under low temperature (Tansey et al., 2008). Therefore, the most accurate sources of fire data are high-resolution satellite imagery.

2.1.3 Theoretical frameworks of biodiversity

2.1.3.1 Defining biodiversity

Biological diversity is defined as the variability among organisms from all of ecosystem such as inter alia, terrestrial, marine and other aquatic. The ecological complexes of biological diversity are diversity within species, between species and ecosystems (Gregorius et al., 2003). Peatlands have many characteristics of both terrestrial and freshwater ecosystems; these characteristics contribute to making peatlands habitat for unique biodiversity. Indonesia's tropical peatlands have a variety of endemic flora and fauna (Wilcove et al., 2013). Indonesia's peatland ecosystems have 13-15% (35,000-40,000) of the 258,650 species of tall trees recorded in the world (Rahajoe et al., 2016). From 30 to 122 tree species with diameter 10 centimetres or higher occur in one ha of peat swamp forest in Indonesia (Posa et al., 2011).

2.1.3.2 Threats to peatland biodiversity and approach

The majority of Indonesia's peatlands are now suffering from significant damage as a result of peatland utilization. Peatlands have been burned for agricultural land, plantations, and settlements, logged both legally and illegally, subjected to ditching for drainage and irrigation canals, and subjected to other impacts. These activities have led to the loss of biodiversity and natural resources (Yule, 2010), particularly the loss of unique peat swamp forests.

Because of the important roles and functions of peatlands, peatland conservation and monitoring activities are vitally necessary. There has been a government-issued moratorium on new concessions in peatland since 2011 (Busch et al., 2015).

2.1.4 The theoretical framework of land management

The Earth System is the appropriate interaction among factor of chemical, physical, and biological global-scale (commonly called as biogeochemical cycles) and energy flow which provide the conditions necessary for life on the planet (Steffen et al., 2005). The Earth System directly influences the Land System through its interaction with social and ecological systems. Simultaneously, human decisions about land use and management practices will change ecosystem services. For example, the Earth is substantially altered by land transformation and discharging of carbon dioxide and nitrogen which are caused by human actions in agriculture, industry, international trade and recreation (Vitousek et al., 2008). Human have the important role on global ecosystem change, mostly by the way how to use and manage land resources. The illustration can be seen in Figure 2.2 (Ojima et al., 2007).

A well-known example of land transformation is forest loss. This ecological disturbance covered 2.3 million square kilometres globally between 2000 and 2012, including forest and industrial forest plantation (Hansen et al., 2013). In Indonesian primary forest, 6.02 million ha of loss occurred within intact or degraded forests during that same period. That deforestation locate in lowland forest (3.04 million ha) and peat swamp forest (2.60 million ha) (Margono et al., 2014).

Furthermore, land management change may affect environmental elements such as air quality. Land degradation contributed approximately 80% of emission in Sumatra during 2005-2009, and it is predicted that 37-48% of future carbon dioxide emission on this island will come from fuel-rich peat swamps (Marlier et al., 2015).

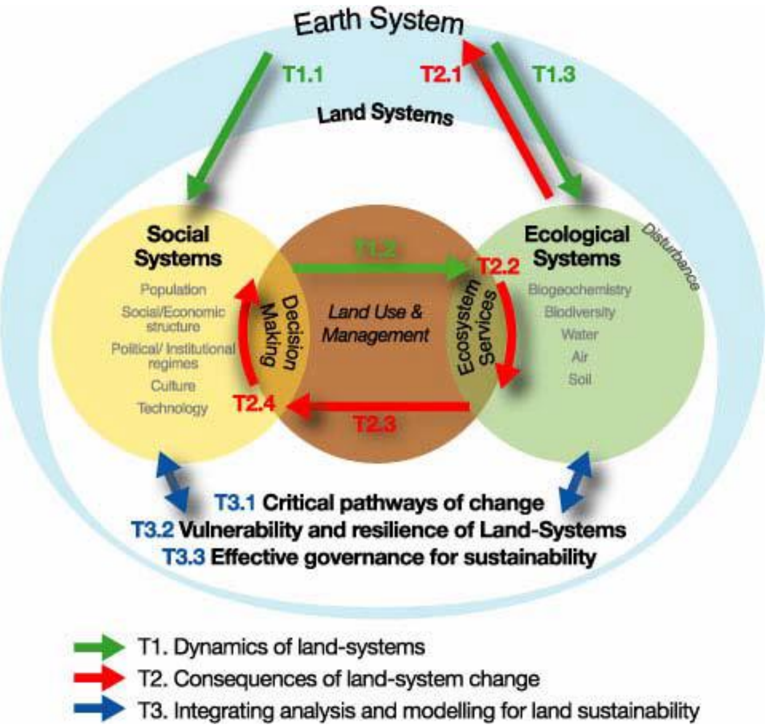


Figure 2.2 Land use and management structure
Humans have important role on global ecosystem change

2.2 General description of peatland management in Indonesia

2.2.1 Legal history of peatland management in Indonesia

Formally, the Indonesian government started to manage peatlands based on Act No. 5/1967 on Forestry as summarized in Figure 2.3. This law was issued for forest timber exploitation. Subsequently, the government regulated forest concessions through government regulation No. 21/1970 on logging concessions rights. For sustainability purposes, forest logging has been regulated through the Indonesian Selective Logging Silviculture system. Timber logging is carried out using a rail system to maintain natural condition. However, the amount of forest timber was greatly reduced in the 1990s due to overlogging. Afterwards, the government replaced logging concessions with oil palm plantations and industrial forest plantations to maintain land productivity (Kusmana, 2011).

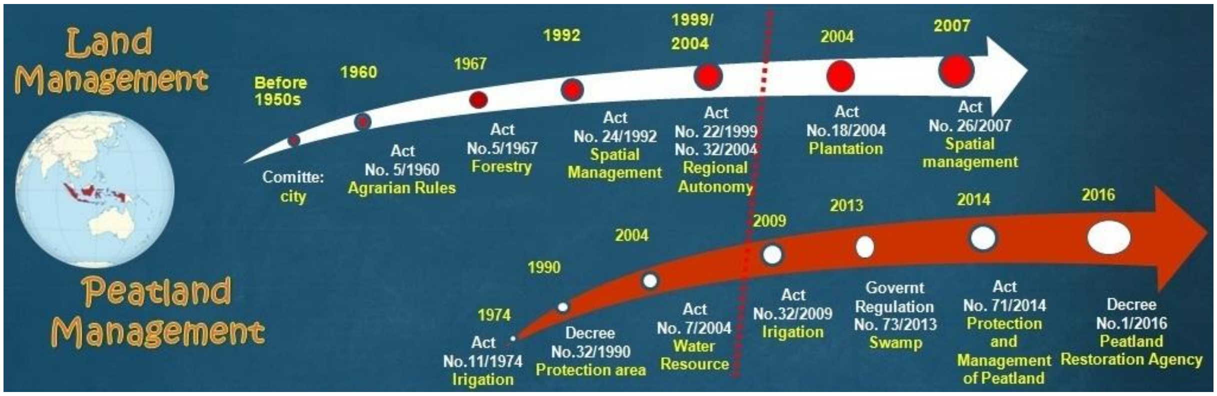


Figure 2.3 History of regulation for land management and peatland management

Recently in 2016, Government established peatland restoration agency to restore deforested peatland

To anticipate the negative impact of large-scale plantation development, the government allocated protected areas through Presidential Decree No. 32/1990 on protected areas. This decree declares that peatlands where peat depth is more than 3 meters are set aside as protected areas. Peatland protection was strengthened through Act No. 24/1992 on Spatial Planning. Furthermore in cultivation areas, the government regulated the criteria of peatland damage when the water level was more than 25 cm through the government regulation No. 150/2000. In the era of regional autonomy, peatland protection was regulated through Act No. 24/2007 on spatial planning (Dohong et al., 2017).

Unfortunately, Indonesia’s policy of peatland protection is ineffective because of some problems such as data availability and coordination between Ministries. The Ministry of Forestry uses forestry law to regulate peatlands, in which the forestry law does not regulate peatland. At the same time, the Ministry of Environment and Ministry of Public Works use the spatial planning law. Due to peatland destruction in many areas, the government issued a moratorium on new concessions in peatlands in 2011.

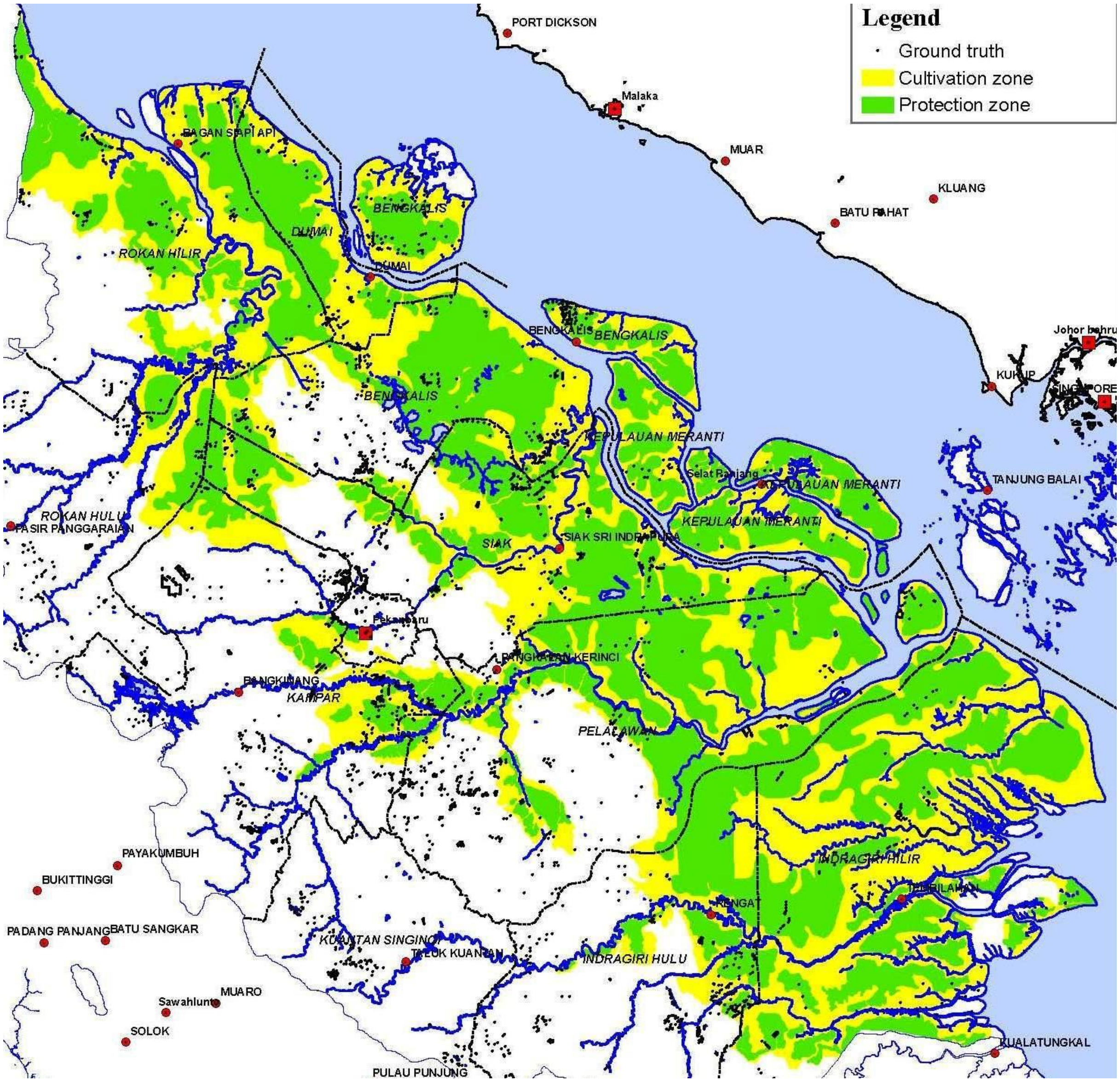


Figure 2.4 Zonation of peatland (cultivation and protection) in Riau and ground truth point

The government strengthens the moratorium policy through government regulation No. 71/2014 on protection and management of peatland ecosystems. This regulation determines that 30% of peatlands must be protected areas and also protects peatland more than 3m deep (Varkkey, 2013). In 2017, the government has established designations of protection area and cultivation area in peatlands. The policy is that planted areas within protection areas will be restored to a natural condition. The utilization of peatland in the cultivation area is done with a maximum water level 40 cm below ground surface.

2.2.2 General descriptions of peatland in Riau

Riau has the largest area of peatlands in Indonesia shown in Figure 2.4 depicts Riau peatlands and their designation as protection or cultivation zones. Most of the peatlands are located in the eastern part of Riau, which is dominated by peatland more than 4 meters depth (Sizer et al., 2014). The local people started peatlands utilization in Riau during the colonial era. People developed coconut, sago palm, and rubber plantations in shallow drained peatland conditions. Trade in sago palm started hundreds of years ago, after this palm was introduced by Bugis traders and Chinese traders (Darnley, 2018).

Before the 1990s, peatland deforestation usually occurred in shallow peatlands (peat layer less than 0.6 m thick) for agricultural purposes. Shallow peatland can be converted into productive cropland after shallow drainage. People dig canals into peatlands to lower the water level (water table) and then the soils can be planted for rice or other crops. Peatland productivity decreases with the increasing of peat depth (Notohadiprawiro, 1997).

Starting from 1990, the government encouraged the development of large-scale plantation (oil palm and acacia plantation) in deep peat soils as part of Indonesia’s agricultural policy. As a consequence, Riau’s peatland experienced rapid deforestation and fires became more frequent in this region. Peat swamp forest loss in Riau was 692,000 ha from 2007 to 2015 (Miettinen et al., 2016). The problem of peatland utilization became more complex because the conflict among different land uses, policies, land grabbing, and land encroachment.

Finally, the theoritical background of this study is represented in Figure 2.5.

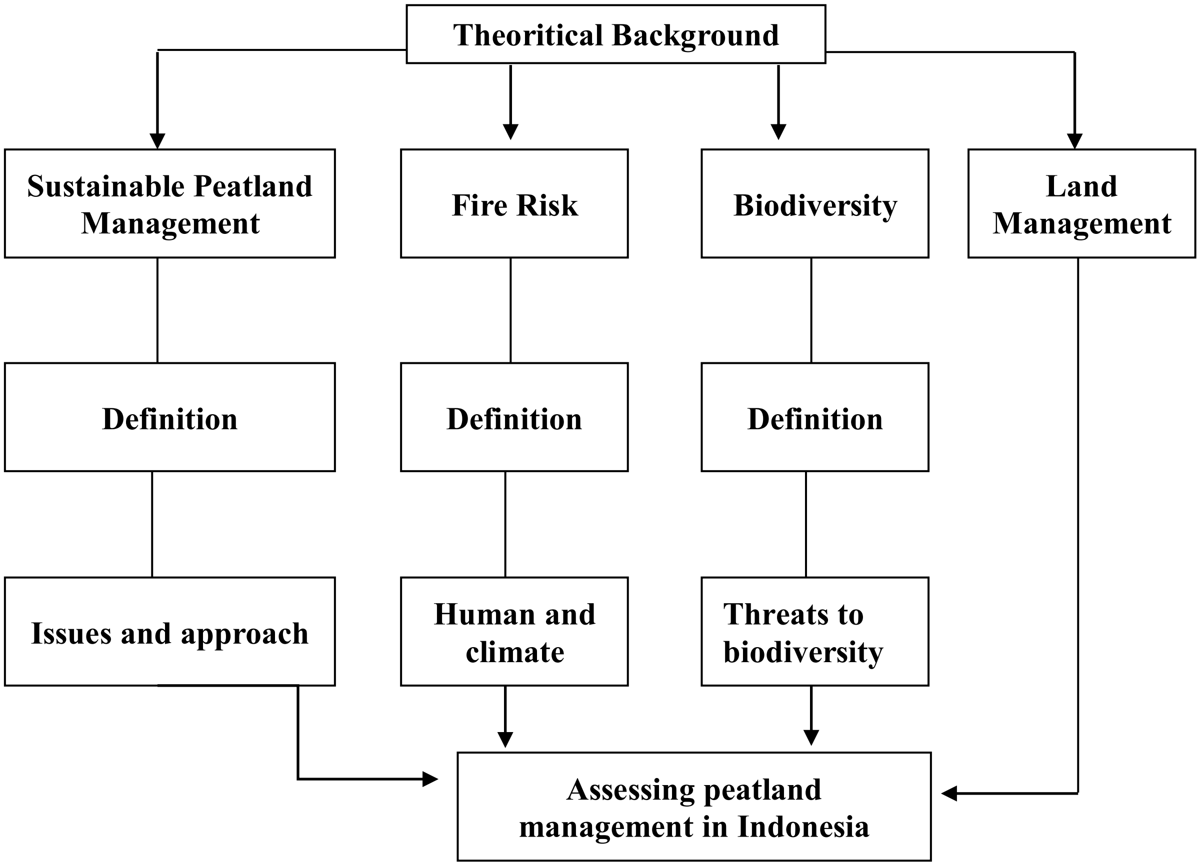


Figure 2.5 Summary of theoretical background

2.3 Methodological approach

2.3.1 Method for land cover classification

a. Pre-processing of the satellite data

The purpose of image pre-processing is to enhance geographical data into a more meaningful display for users and provide quantitative information about an object. Pre-processing of the satellite image consists of atmospheric correction and geometric correction (Jensen, 2004). Atmospheric correction eliminates the atmospheric effect by adjusting the value of radians or reflections close to the true value. The raw information derived from the spectral band is mixed with the elements and molecules in the atmosphere, thus affecting the accuracy of the information in a particular spectral band such as blue, green, red and near-infrared. The most influencing elements are aerosols and water vapour. The result of atmospheric correction is the surface reflectance product.

Top atmospheric (TOA) reflectance in this study used the dark object subtraction (DOS). TOA method supposes that there are at least few pixels within an image will be zero or black reflectance. To calculated TOA reflectance of LANDSAT image we used Quantum GIS 2.14.2.

Geometric correction is an effort to improve image quality from the influence of earth curvature and earth movement by adjusting the satellite image with the earth coordinates (latitude and longitude). Several methods are available for geometric correction including triangulation, polynomial, ortho-rectification. We used Ground Control Point (GCP) and map projection for geometric correction.

b. Method for land cover classification

Humans need tools to analyze and interpret a high variety of spectral values in the pixel (especially if done only manually). Therefore, we need a technique to simplify the process of recognizing patterns of spatial elements. Land cover classification is needed to classify the digital images based on their fundamental elements (Martínez and Mollicone, 2012).

The classification of satellite imagery into a land cover map is the most common method used in remote sensing applications. Land cover classification is a process of interpretation and labelling land cover classes according to the pixels in satellite imagery. Each pixel in a class is assumed to have a homogeneous characteristic. The purpose of this process is to extract the spectral patterns (especially the dominant ones) associated with specific land cover types. The result of the classification process is the land cover map, which depicts the spatial distribution of land cover categories in a unit area (Jia et al., 2014).

For this study, land cover classes from Indonesian National Standard No. 7645-1:2014 specified by the National Standard Agency of Indonesia were modified as described in Table 2.1. Composite and pan-sharpened image were made to increase accuracy of land classification. We use visual assessment for the training area and visual inspection in post-classification.

Table 2.1 Description of land covers classes used in this study

Land cover classes	Definition
Oil palm	Homogeneous plantation of oil palm with regular pattern
Acacia	Homogeneous plantation of acacia with regular pattern
Peat swamp forest	Wetland ecosystem more than 0.5 hectares in size, tree canopy more than five meters and canopy area more than ten percent
Shrubland	The area of vegetation with average height less than 2 meters including shrub, fern, and grass
Settlement	Land used as a residential
Sago palm	Homogeneous plantation planted with sago palm
Rubber	Homogeneous plantation planted with rubber
Coconut	Homogeneous plantation planted with coconut
Mangrove	Natural forests with more than thirty percent of canopy cover, composed of species of mangrove trees, located along coastal area which is affected by saltwater
Burned area	The area experienced fire event either by natural processes or human activity or with no or scarce vegetation. Usually, fire occurred one year or less before imagery taken
Paddy field	Homogeneous plantation planted with paddy which requires inundation

c. Ground truth

The results of image classification need to be checked against field observation data in a representative sample of areas of each land cover type (ground truthing) as shown in Figure 2.6. The goal of ground truthing is to check the quality of image classification. The geographical location of the field observations is determined by using a Global Positioning System (GPS). Field data consisting of observation of land cover in the sample plot area is checked against the land cover classification to determine accuracy. The location of these field observation should be easy to access and represent all existing land cover classes, so that information of land cover can be identified and monitored easily (Lubis and Nakagoshi, 2011).

d. Method for image classification

Supervised classification with maximum likelihood is commonly used in land cover classification. We need user's knowledge on land cover information in the study area in Supervised classification. In this method, the user controls most of the classification process. Each land cover class need training area that selected by the user (Firdaus and Nakagoshi, 2013).

e. Post-classification enhancement

Post-classification enhancement was conducted to improve the quality of image classification and classify the unknown pixel. The general steps to clean up the classified image were filtering, smoothing class boundaries, and removing small isolated regions. These steps will produce a good visual image.

f. Accuracy assessment

Accuracy assessment is the comparison between image classification and ground truth data. The user should check several samples in the field as a comparison. Calculation of accuracy performed by visual inspection and confusion matrix. The result of image classification checked with pan-sharped, NDVI, and high-resolution image such as Google Earth.

Confusion matrices arrange classification data and ground truth data in a percentage in a comparison table. The most common method to calculate accuracy is kappa accuracy. The formula of Kappa accuracy is:

$$Kappa\ (k) = \frac{N\ \sum_i^r X_{ii} - \sum_i^r X_{i+}X_{+i}}{N^2 - \sum_i^r X_{i+}X_{+i}}\ x\ 100\%$$

Where r represents the rows number, xi represent the observations number in row i and column i, Xi+ and X+i represent the marginal totals of row and column, and N represent the total number of observed pixels. A value higher than 0.80 represents good classification; a value between 0.40 and 0.80 is moderate classification and a value less than 0.40 is poor classification (Jensen, 2004).

g. Normalized Difference Vegetation Index (NDVI)

The vegetation index is the greenish vegetation value of the brightness data of several satellite sensor data canal. Vegetation monitoring use value of the comparison of red and near-infrared canal. Index value is -1 to 1 and green vegetation value is 0.2–0.8 (Sulma et al., 2016).

We use vegetation index to measure vegetation density or biomass using digital brightness value. A Vegetation index is a combination of several spectral values by adding, divided, or multiplied to produce a single value indicating the amount or strength of pixel vegetation (Sholihah et al., 2016).

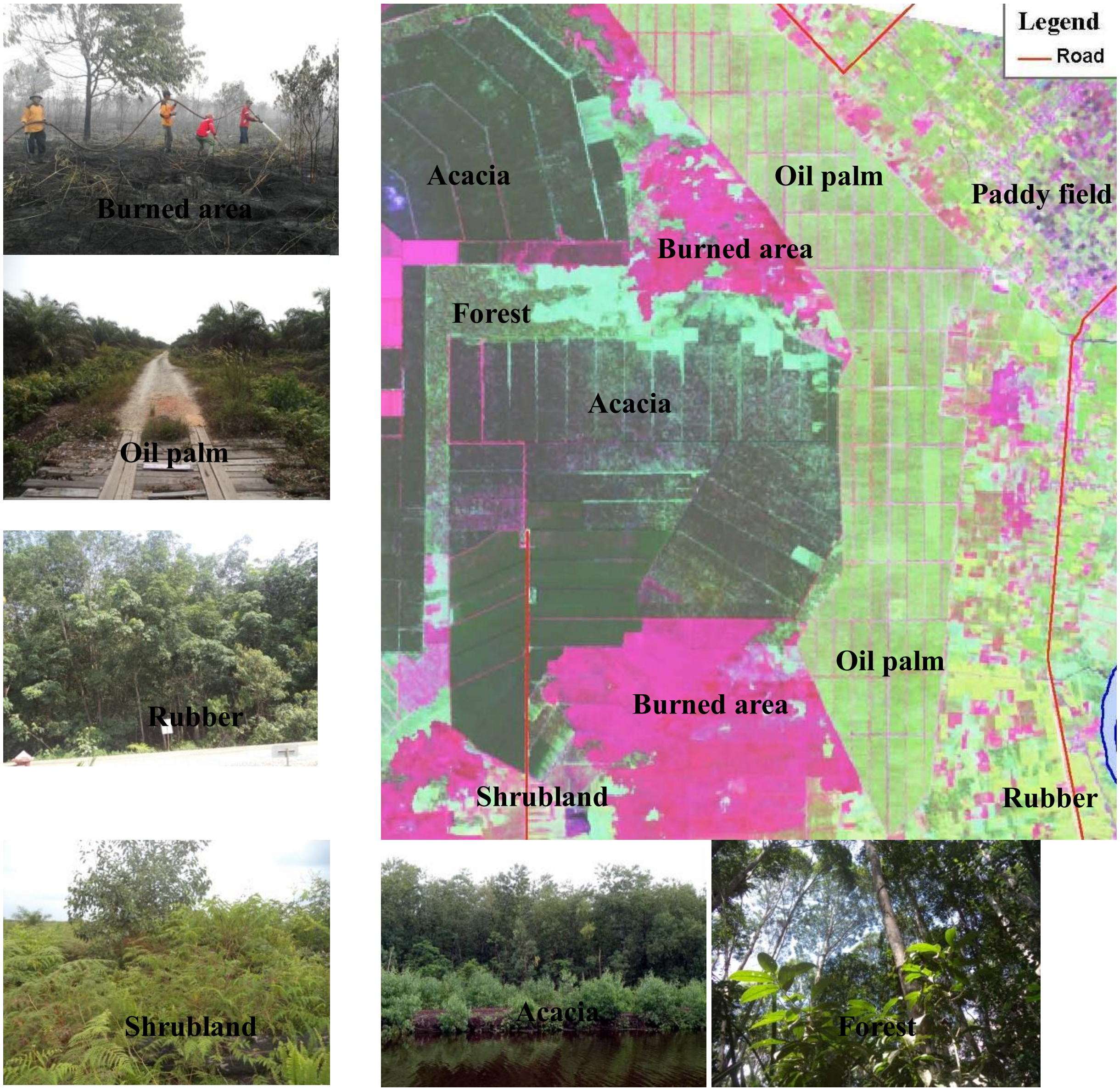


Figure 2.6 Some examples of satellite imagery showing typical land cover types in Riau

2.3.2 Method for identification of land management and landholder

We used concession maps from Indonesia's Ministry of Forestry. These maps show two types of concessions: oil palm plantation and industrial forest plantation. The Indonesian government previously allocated concession area to various companies to develop industrial plantation. Concessions were divided into: (i) areas managed by companies; (ii) areas occupied by small landholder; and (iii) undeveloped lands. This category could be identified by using land pattern on the pre-fire LANDSAT imagery (Gaveau et al., 2014). Networks of canals and roads visible in the LANDSAT imagery are company plantations in the peatlands. The boundary of land parcels was used to assign them to either oil palm or acacia plantation. We use visual interpretation and concession maps to determine the landholder. Category of registered company was the regular pattern inside the concession and covered by acacia, oil palm, coconut, or sago palm. While category of unregistered company was the regular pattern of oil palms outside the concession. Land parcels of irregular shape, varying size and direction, and covered by oil palm, coconut, and sago palms were categorized as smallholder plantations.

2.3.3 Method for mapping fire progression

Daily fire data was used to identify the location of fires ignited and spread into surrounding areas. Fire progression was estimated using the (Parks, 2014) methods. We used MODIS data (MCD14ML product, Collection 5) for interpolation. MODIS fire data show the coordinate and date of MODIS burned pixels, and even though the image resolution is low (1 km^2). We map daily fire progression via interpolation of the daily temporal resolution. This method was used to map fire progression because local government did not map fire progression and interpolation of MODIS fire data offer good estimation.

2.3.4 Method for burned area estimation and hotspot density

Burned areas were estimated based on a grid analysis of hotspot data (1 km^2). Grids without hotspots were assumed to be unburned while grids with at least one hotspot were assumed to be burned 70 ha (Ballhorn et al., 2009). The Riau boundary was used to make a grid of 1 km^2. Hotspot density was used to examine fires activity in a land cover type. Hotspot density was calculated by dividing number of hotspots in a land cover type and its area.

2.3.5 Assessing drivers of fire with Maxent model

Some modelling techniques have been used to model fire-distribution such as statistical methods (regression) and machine-learning methods. Machine-learning methods have to be specified in advance to automatically identify interactions between variables and fit response functions (Merow et al., 2013).

Maxent is a machine-learning method based on the maximum entropy approach, which estimates the probability distribution of a target by finding the probability distribution that is closest to uniform and subject to known constraints. It commonly utilised for species distribution modelling. Maxent has been found to work well in data-poor situations such as high omission rates (Phillips and Dudík, 2008) because Maxent treats non-presence areas as background.

The inputs to Maxent are a list of hotspot data (samples) and thematic map (environmental layers) or predictors that are divided into grid cells. Maxent analyze only the presence of the target (binary) rather than the count. A certain number of samples are also taken at random from across the study area to form the background locations. Maxent finds the most uniform distribution of the target with the constraint that the average value for each explanatory variable (also known as covariate or predictor) should equal (or at least be very close to) the average value of the explanatory variable at the presence sites (Phillips et al., 2006). The explanatory variables may also be transformed via features to fit the target's response to the explanatory variable, in which considered the average value of each element. Maxent have six feature classes i.e. linear, quadratic, product, threshold, hinge, and auto.

Maxent's raw output can be interpreted as relative occurrence rate (ROR), and is the core of the Maxent model output, giving understanding into what features are important and approximating the relative suitability of one place vs. another. Two other types of Maxent output are available: cumulative and logistics. Three output categories are connected monotonically and identical based on rank-based metrics (AUC). Nevertheless, the different scaling of output types give different interpretations and predictive maps (Merow et al., 2013).

The logistic output is a transformation of the raw output between 0 and 1. Logistic output is valuable for comparison between models with dissimilar spatial scales because the raw output is scaled differently based on the number of background points, spatial resolution and extent (Elith et al., 2011). Nonetheless, the analysis should be limited to qualitative, rank-based comparisons. Quantitative analysis, such as references to relative occurrence probability in different environmental conditions, should still be based on raw output (Yackulic et al., 2013).

2.3.6 Method for biodiversity index

A diversity index is used to determine species diversity, with a high index value meaning the community is more diverse and not dominated by a single species. The diversity index used in this study were Simpson's richness index, Shannon-Wiener Index, Shannon Evenness Index, and Importance Value Index (IVI). In the forest ecosystem, the diversity index and IVI can be calculated by counting the number of tree species, measuring the diameter, and tree height (Magurran, 1988). The entire analysis process is presented in flowchart form in Figure 2.7.

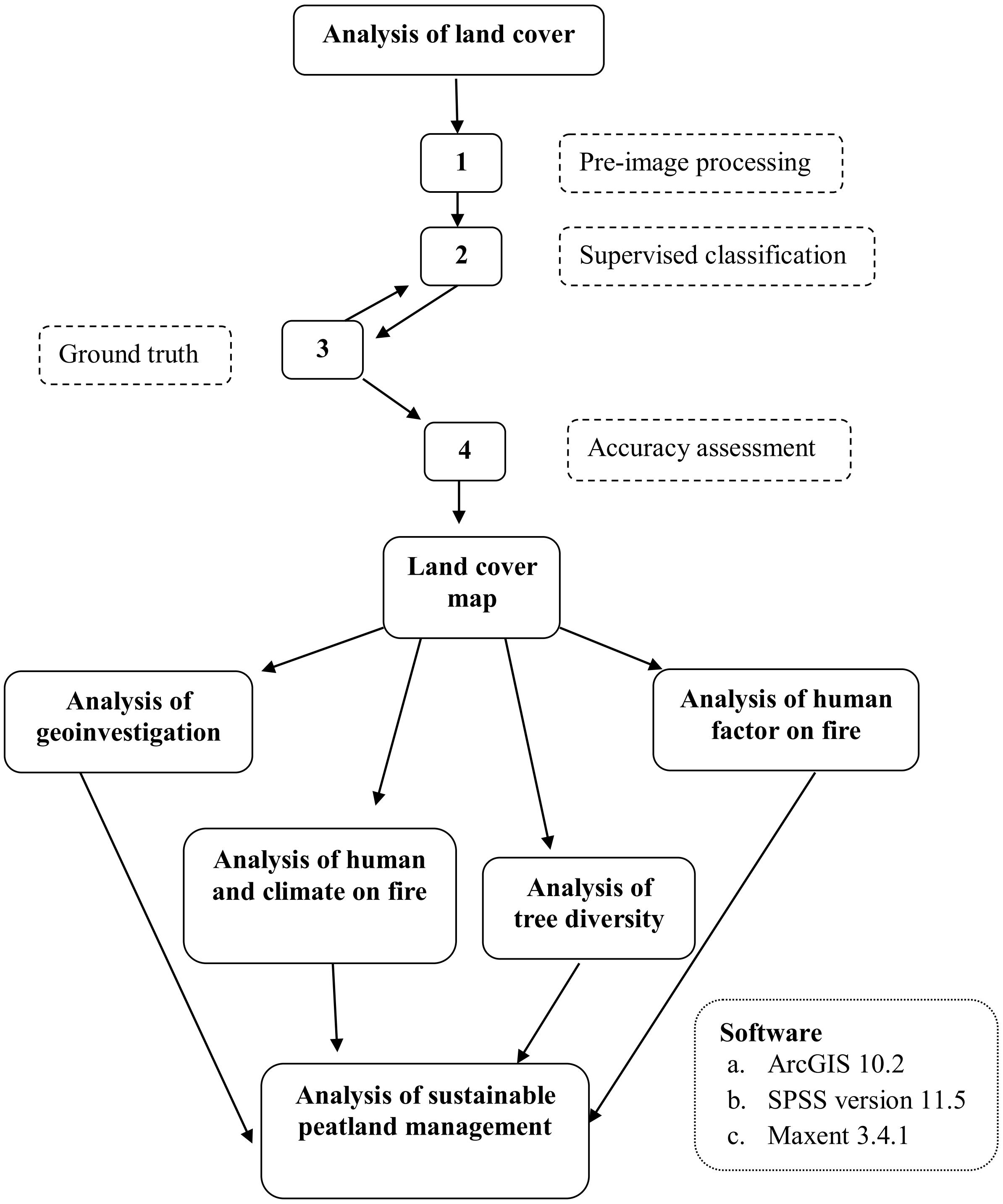


Figure 2.7 Summary of methodological approaches

Chapter 3. Limitation of the use of satellites to identify who might be responsible for haze in Southeast Asia

3.1 Introduction

Peatlands fire in Indonesia have negative impacts on human health, with high environmental and economic costs to Sumatra, Kalimantan, and nearby countries. In 2015, several assessments of the economic impact of fires were published by some agencies, of which the government estimated a total economic loss of 16 billion US dollars (Glauber and Gunawan, 2015).

A major area of debate concerning Indonesia's fires is responsibility. The debate over the root cause of persistent fires and the haze problem is between deforestation by industrial plantations and fire as a tool for land clearing by small farmers (Suyanto et al., 2004). In the bad haze year of 2015, the public, NGOs, media, and the international community accused industrial plantation companies, which in the past used fire to open large-scale plantations (Dennis et al., 2005).

In concept, all stakeholders and even the public can identify who is responsible for fire in Indonesia by Geoinvestigation—comparing fire data from the satellite with concession maps that show plantation area managed by companies. In ASEAN countries, maps are essential to the implement policies, such as the Trans-boundary Haze Pollution Act (THPA) (Lee et al., 2016). Now, everyone can access concession maps (sometimes not out of date), deforestation maps and hotspots online via several web-portals such as Global Forest Watch and Greenpeace (Marlier et al., 2015).

In this study, we investigate the capability of geoinvestigation as a tool for monitoring company commitments on zero deforestation and zero burning. We focus on peatland fires because they are a primary environmental problem in Southeast Asian countries (Lee et al. 2016). According to Indonesian law, concessions should be responsible for any fire or deforestation in their area because the company legally manages the land. Similarly, independent farmers ignite fires outside concessions. In some areas, overlapping land claims, different land-use practices and/or illegal activities make it difficult to assign responsibility to either companies or independent farmers.

In regard to company practices, there are five considerations. First, some companies may not plant all the land within their concession for a number of reasons such as ownership claims by independent small and medium-sized farmers, lack of resources, and government regulation. Some studies have noticed the discrepancy between official licenses and existing on-the-ground conditions by a variety of land users (Levang et al., 2012). Second, companies may be faced with difficulties in controlling fires around their concessions, leading to wildfire spreading in concessions. Independent farmers may be responsible for fires detected in concessions. Third, environmental investigations report that some oil palm companies operate illegally without a license from the government (Varkkey, 2012). The majority of these are medium-and large-holders plantations of greater than 25 ha (Indonesian law requires the formation of a company for land areas greater than 25 ha) or small-holders plantation of less than 25 ha, which burn land in preparation for planting. Fourth, acacia and oil palm companies drain peat swamps with deep canals for their plantation. This practice dries the upper layers of peat, thereby increasing the flammability of peatlands in and around concession areas (Konecny et al., 2016). Finally, fire ignition outside concession area could be caused by various industries, whether registered or not, whether directly or indirectly.

I begin the analysis by testing the general assumption that fires mainly burn unproductive lands; i.e., forest and 'idle' non-forested lands rather than plantations areas. Concerning the complicated situation on the ground, we address some questions that inform assigning responsibility for fires and determining the reliability of maps. (i) How much burning occurs inside and outside concessions? (ii) What percentage of concession area is occupied by independent farmers? (iii) Is there evidence for fires starting on land in concessions occupied by independent farmers? (iv) Is there evidence for fire starting outside, and spreading into concessions? (v) Is there evidence of fire caused by companies outside concessions?

I address these questions by analyzing maps of the burned area in and around 163 government-registered concessions (67 Acacia and 96 Oil-Palm concessions) totalling 1.8 million hectares (Mha) in a 4.1 Mha region in Riau province, Sumatra. This region was the epicentre of severe fires in 2013 and 2014 in Indonesia (Gaveau et al. 2014) and has experienced rapid deforestation and transformation of cutover lands into plantations. Two multinational companies monopolize acacia plantation in peatland (Thorburn and Kull, 2015). First, i mapped burned areas, vegetation burned, fire progression, and land occupancy in concessions using medium and high-resolution satellite imagery. Second, we estimated the respective shares of burned forest, 'idle' non-forested land, Oil-Palm, and Acacia plantations. Third, we disaggregated concessions into: (i) areas planted (or under development) by companies; (ii) areas occupied by independent farmers; and (iii) undeveloped forest areas.

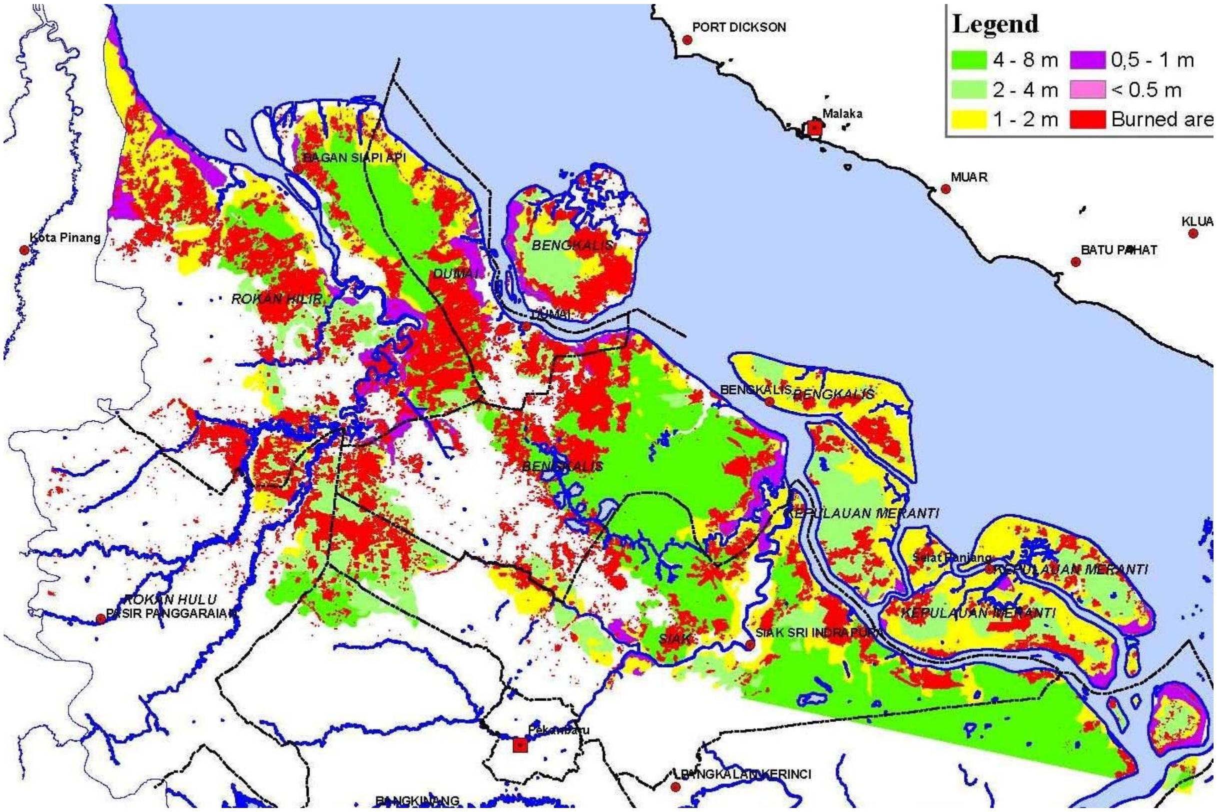


Figure 3.1 Peatland depth and area that burned in 2013 and 2014 in the study area
Most of burned area were located in peatland

3.2 Materials and methods

3.2.1 Study area

The 4.1 Mha study area is located in northern part of Riau province (2˚34'N - 0˚18'N, 100˚3'E - 103˚19'E) is presented in Figure 3.1. The study area consists of 7 regencies: Rokan Hilir, Rokan Hulu, Bengkalis, Kepulauan Meranti, Siak, and Dumai. Riau has a tropical climate with annual mean temperature of 26˚C. Riau has a bi-modal rainfall pattern with peaks in September to January and April to May (Aldrian and Susanto, 2003). Annual mean rainfall and monthly mean rainfall was 2,782 mm and 234 mm, respectively during 2001 to 2016.

3.2.2 Data collection

The details of data sets are described in Table 3.1. Secondary data were collected from government agencies, while LANDSAT and MODIS hotspot were downloaded via website.

Table 3.1 Data collection, its description, and source

Data	Description	Source
LANDSAT 8 OLI	Path 127 Row 59 and Path 126 Row 59 April 2013 to November 2014	http://glovis.usgs.gov/
High-resolution image	August 2013 2014	Unmanned Aerial Vehicle (UAV) 1301 ha Digital globe via Google earth
MODIS hotspot	June 2013 to March 2014	https://firms.modaps.eosdis.nasa.gov/download/
Rainfall	2013 to 2014	Meteorology, Climatology, and Geophysical Agency
Administrative	Riau Province	- Geospatial Information Agency of Indonesia - Planning Agency of Riau
Forest boundary	Riau Province	Ministry of environment and forestry
Concession boundary	Riau Province	Ministry of environment and forestry
Cultivation right	Riau Province	National land agency
Wetland map	Riau Province	Ministry of agriculture

3.2.3 Mapping burned areas and prior vegetation in the study area

For accurate analysis, LANDSAT images were pre-processed using georeferencing and geometric correction (Jensen, 2004). WGS datum 1984 was used as the coordinate system. We mapped burned areas using LANDSAT satellite imagery acquired shortly before and after fire (supervised classification). Multiple images were employed to reduce areas covered by clouds and haze. We used RGB colour (Short-wave infrared: band 6; Near-infrared: band 5; Red: band 4) to display LANDSAT imagery in false colour. There are three primary colours namely green (unburned vegetation)**,** pink (opened area), and dark red (burned area). Generally, the darkest was the most severely burned area. We use visual interpretation for burned areas underneath haze or clouds after employing local contrast enhancement.

A confusion matrix between UAV imagery (0.1 m) and LANDSAT imagery was used to assess the accuracy of land cover map. We observed a classification accuracy of 85%. We use peatland map from Indonesia's Ministry of Agriculture to estimate the area burned on peatland (Haryono et al., 2011).

We conducted a two-step process to characterize the types of burned vegetation. First, we mapped the area of natural forest, nonforest, and plantation before fire using the pre-fire LANDSAT imagery. These three vegetation classes can be mapped with high accuracy using LANDSAT (Gaveau et al. 2014). Forest was defined as natural forest that has remained in sufficiently good condition to be seen as intact or nearly intact – this includes old-growth forest (Dipterocarps and Kerangas, on dry mineral soils, and on fresh-water and peat swamps as well as mangrove forests), selectively logged forest, and possibly some forest mildly impacted by ground fires. Second, we refined the nonforest classification by analyzing high-resolution images (≤ 1 m). We determined the proportion of unplanted nonforest (idle) lands and planted lands by analyzing a sample of 682 high-resolution (10-cm) images (144,960 ha in area), collected with an Unmanned Aerial Vehicle (UAV) or ‘‘drone’’ (Skywalker Aero model with a camera Canon S100) between 28 July and 02 August 2013 as well Digital Globe satellite imagery for 2014 (60-cm) available on Google Earth. We quantified the proportion of burned idle and planted lands by analyzing a subset from our image blocks where fire had occurred (n = 440; mean block size: 107 ha; total area: 47,018 ha). The error bar is calculated as ± 1 SD).

3.2.4 Mapping fire progression

We identified where fires ignited and where they spread in the two largest burned areas by retrospectively mapped daily fire progressions. We used the Parks methods, where day-of-burning for each 30 x 30 m pixel, and hence fire progression, was estimated by spatially interpolating MODIS fire detection data (NASA MCD14ML product, Collection 5, Version 1) (Parks, 2014). MODIS fire detection data depict the date and location (i.e., pixel centroid) of actively burning MODIS pixels, and although the spatial resolution is relatively coarse (pixel size = 1 km^2), the fine temporal resolution (there are two MODIS sensors, each passing two times per day) allows day-of-burning to be mapped at finer spatial resolution via interpolation. We used this approach to map fire progression because agency-generated fire progression maps were not available and interpolated MODIS data provide reasonable estimates (Parks, 2014).

3.2.5 Landholder in the study area

We acquired concession maps from Ministry of Environment and Forestry. As previously mentioned, the Indonesian government allocated the concessions to companies for industrial plantations (oil palm or acacia). Concessions (36% of our study area, or 1.8 Mha) were divided into: (i) areas occupied by plantation companies; (ii) areas occupied by small and medium-sized farmers; and (iii) forest (undeveloped lands). This partitioning could be achieved by delineating the spatial arrangement of land parcels on the pre-fire LANDSAT imagery. Independent farmer plantations exhibit clusters of irregular shape, varying size, and direction. Medium-sized plantations exhibit more orderly clusters. Large plantations exhibit regular, grid-like planting patterns. The grid-like network of roads and canals on the pre-fire LANDSAT imagery is company-owned plantations in peatland. We delimited the boundary of those grids (and, in some cases, concentric patterns) by visual interpretation and assigned them to either Oil-Palm or Acacia occupied by the company, using the concession maps. Areas in concessions that did not show grid-like patterns, but exhibited clusters of rectangular land parcels of varying shape, size, and direction were characterized as lands occupied by independent farmers. Areas in concessions without clusters were characterized as idle undeveloped lands (these were mainly forest remnants). I afterwards determined the proportion of idle and planted lands in nonforest areas inside and outside concessions by our UAV image blocks.

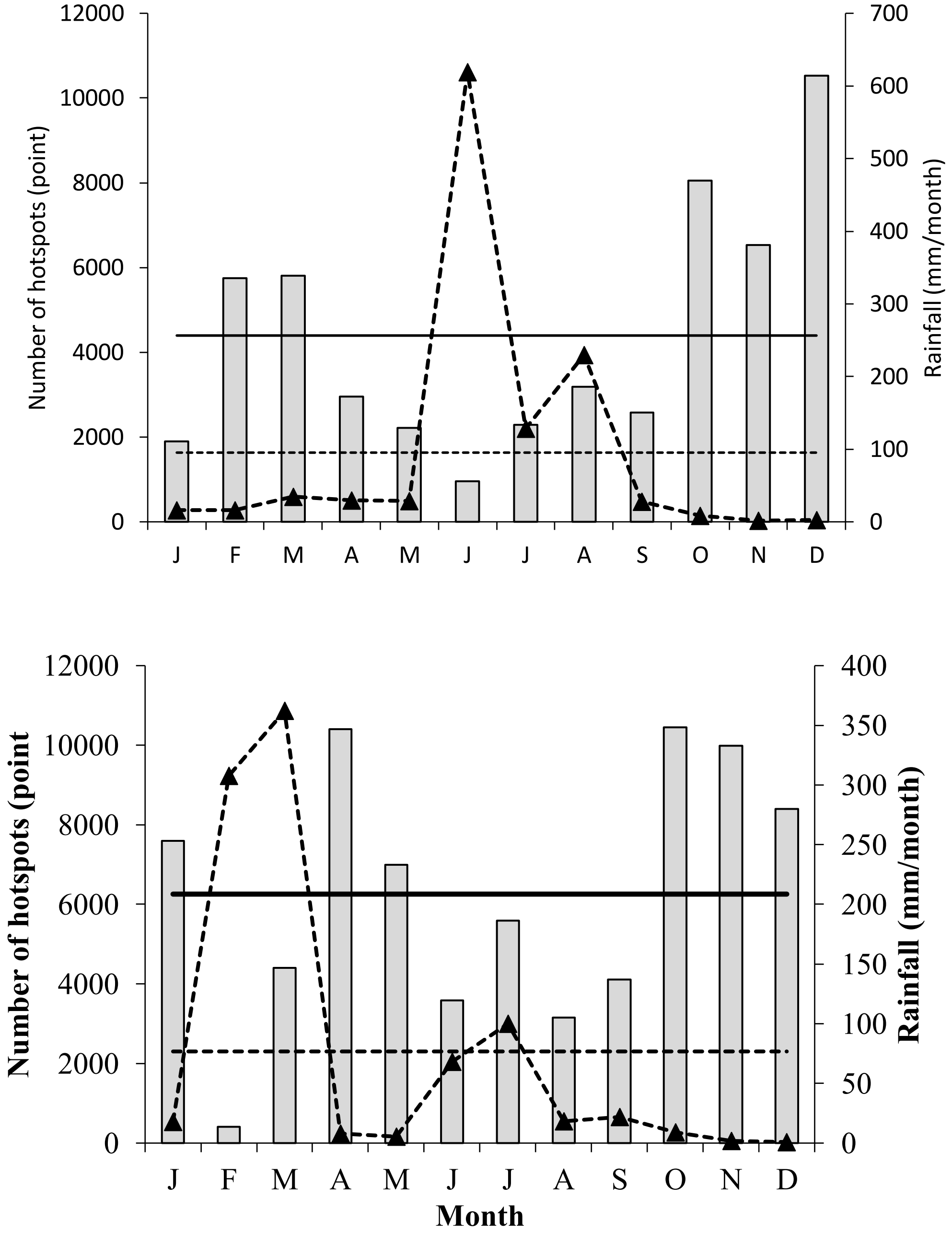


Figure 3.2 Hotspot and rainfall

Monthly hotspots (triangle with dashed line), monthly rainfall (hollow bar) in 2013 (top) and 2014 (bottom), annual mean monthly hotspot (dashed line) and annual mean monthly rainfall (solid line). Major fire events occurred in short dry period

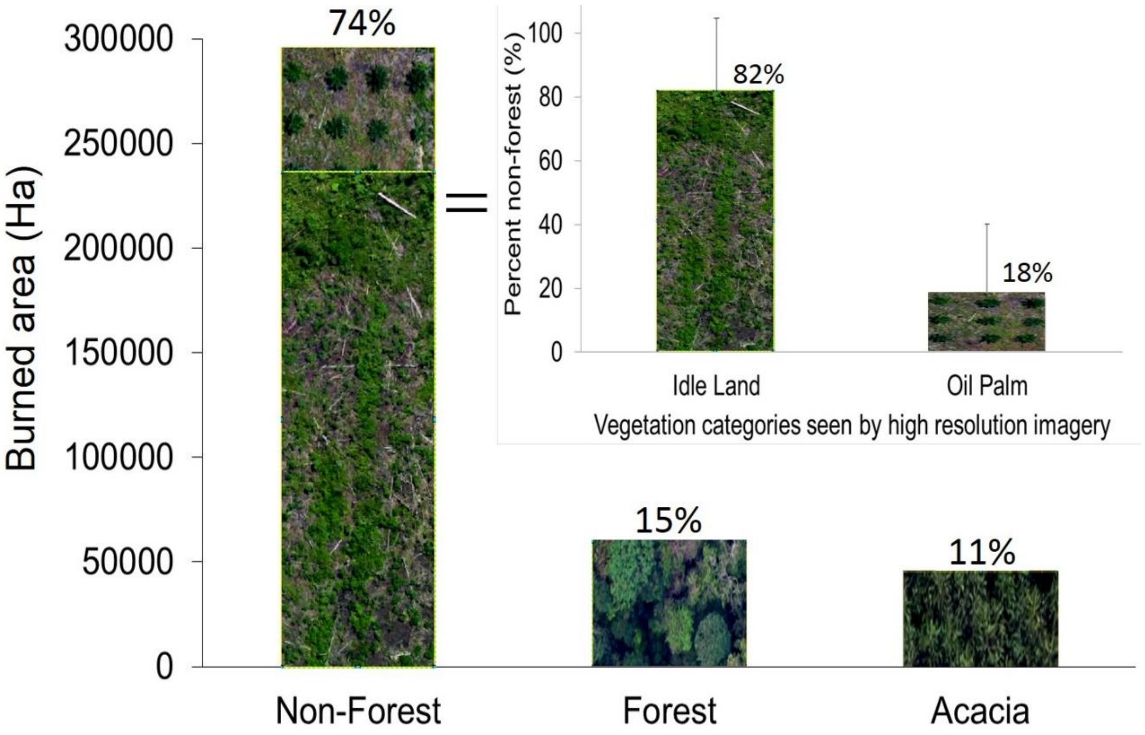


Figure 3.3 Vegetation type of burned area before the fire the 2013–2014 fires. Fire targeted nonforest land

3.3 Results and discussion

3.3.1 Relationship between rainfall and fire

The number of hotspots was inversely related to the rainfall pattern. The highest number of hotspots occurred when monthly rainfall was less than 100 mm and monthly rainy days fewer than eight days in 2013 and 2014 shown in Figure 3.2. This dry period occurred in February to March or June to August. Nevertheless, the major fires in 2013 were an anomaly, as they occurred in wet years. The correlation between hotspots and rainfall was strong, R Square was -0.49 in 2013 and -0.54 with a p-value less than 0.05. Riau’s hotspots in 2013 numbered 19,596 points while hotspot in 2014 numbered 27,634 points showing in Figure 3.2.

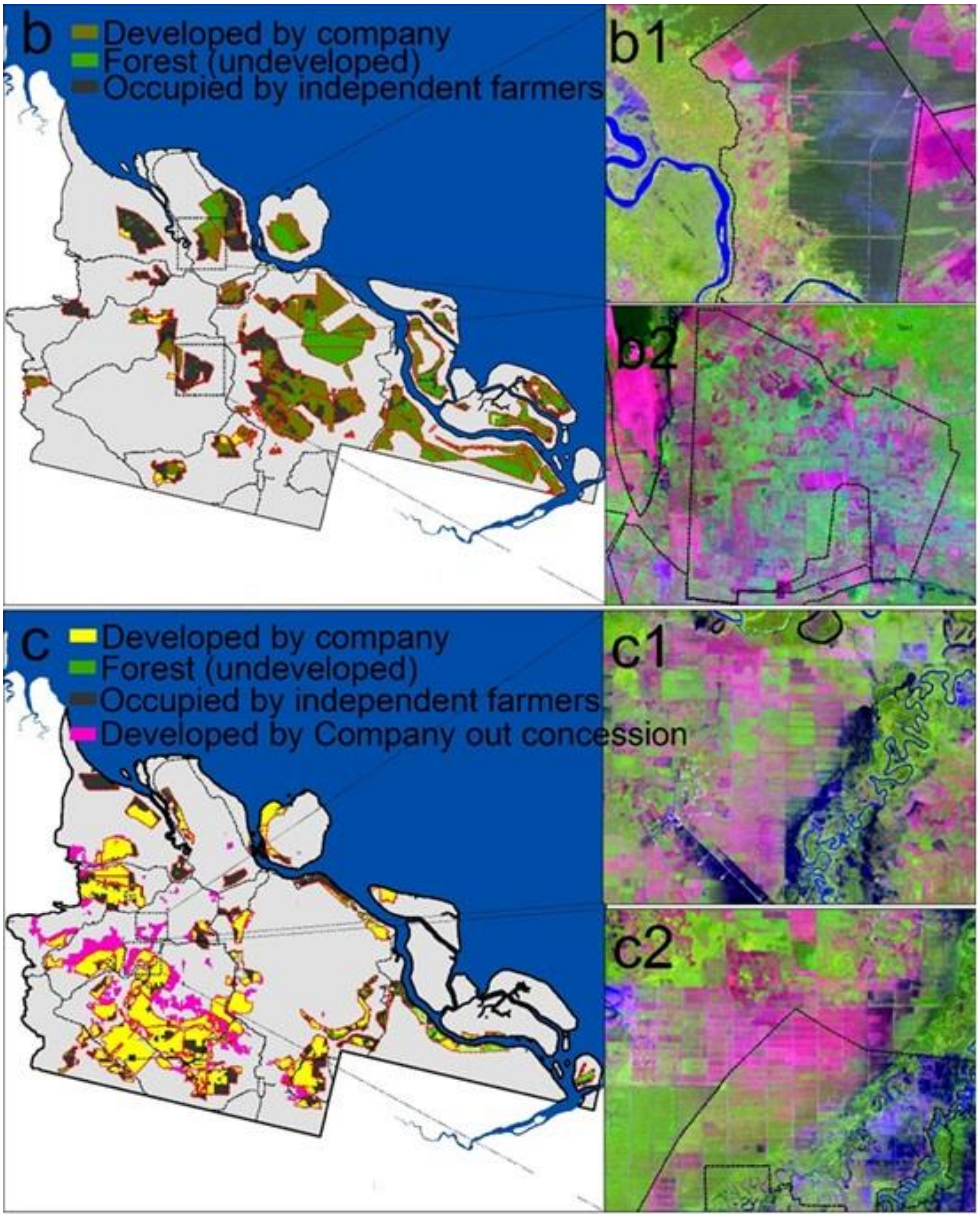


Figure 3.4 Land occupancy in acacia (b) and oil-palm concessions (c)
There is a discrepancy between land occupancy and legal concession

3.3.2 Undeveloped peatlands are the target of fires and the fires spread into plantation

We find that 0.40 Mha burned in our study region in 2013–2014, including 0.33 Mha (84%) on peat shown in Figure 3.3 and Table 3.2. Seventy-five percent (0.30 Mha) of areas burned occurred on previously nonforest land, 82% of these burned nonforests were idle lands, that is, unplanted peatlands covered with shrubs and wood debris. Therefore, the assumption that fire was used to clear unused land before planting appears to be confirmed. In comparison, only 15% (61,078 ha) of burned areas were peat-swamp forests that had been degraded by selective logging before fire.

Planted lands were also affected by fire. Ten percent (38,451 ha) of all burned areas were mature acacia tree stands before fire, and 18% (54,870 ha) of burned nonforests were oil-palm stands. Plantations in proximity to idle land are at risk of fire escape, especially on drained peat, where fires can easily propagate uncontrolled well beyond their targeted areas and also where fires may be the result of grievances over land rights (Galudra et al., 2014). Therefore, escaped land-clearing fires on peat can cause direct and substantial financial losses for investors in plantations (loss of assets and agricultural production) both inside and outside concessions. Fires will likely re-occur in our study region, given a large amount of remaining idle lands showing in Figure 3.3, unless the Indonesian government and the private sector can enforce No-Burning regulations, or successfully improved management on peatlands.

3.3.3 Role of independent farmers inside concessions

There is a mismatch between land occupancy (de-facto) and the legal occupancy (de jure) in concessions. Although independent farmers cannot legally occupy land in concessions, we detected their presence in 160 of the 163 concessions shown in Figure 3.4. An estimated 33% (607,369 ha) of the total concession area (1,848,689 ha) is occupied by independent farmers showing in Table 3.2.

Nearly half (48%; 191,221 ha) of the total burned area (404,713 ha) was in concessions, and half of the burned area in concessions (95,835 ha, or 24% of total burned area) was occupied by independent farmers before fire showing in Figure 3.4. Fires in concessions occupied by independent farmers targeted idle land (82%), but also burned planted oil-palm (18%). Independent farmers are also present along concession borders likely employed fire near boundaries, which led to some fire escape into concessions. Our fire propagation maps show for the two largest burned areas in three acacia concessions (18,028 ha and 22,700 ha) that fire had started immediately outside shown in Figure 3.5, which resulted in the destruction of 11,211 ha of planted acacia.

Independent farmers may be responsible for a substantial amount of fires inside concessions and around concessions. We still know too little concerning these specific fire events, but these findings imply that analyses of deforestation and fire data in concessions is not sufficient to prescribe attribution of fire event to concession owners without detailed field investigations.

3.3.4 Role of companies outside concessions

There is a mismatch between land occupancy (de facto) and legal allocation (de jure) outside concessions as well. Although companies cannot legally operate outside their concessions, we detect their presence in these areas. Over 28% (195,665 ha) of industrial oil palm plantations by registered company (695,695 ha) were found immediately outside of the legal boundary of the concession shown in Figure 3.1 and Table 3.2. This estimate is conservative because it does not count medium and large plantations (>25 ha) owned by unregistered companies without formal company status; these are often owned by well-connected entrepreneurs from cities who rely on local informal networks to secure their lucrative investments in oil palm (Purnomo et al., 2017).

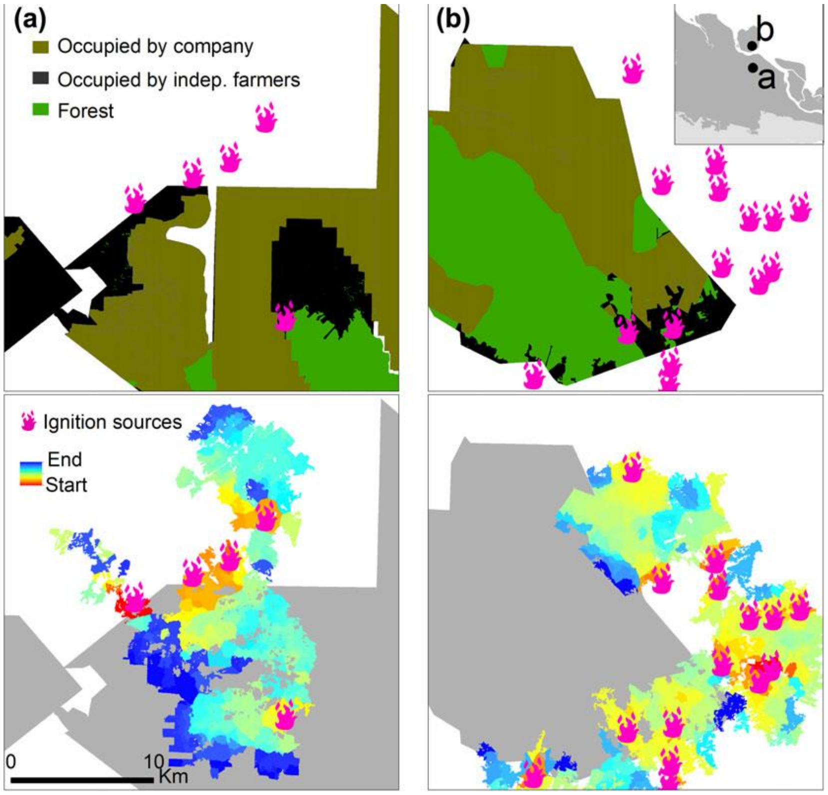


Figure 3.5 Propagation of fire in the two largest burned areas in acacia concessions.

Fire ignited immediately outside concessions or inside on land occupied by independent farmers (disputed land) and spread well into the interior of the concessions where fire eventually ended

Table 3.2 Statistic of land occupancy and burned area inside and outside concessions

	Inside concessions					Outside concessions			
	Study area	Company	Farmer	Forest	All inside	Company	Farmer	Forest	All outside
Area (ha)	4,107,077	899,642	591,061	304,726	1,821,774	181,178	1,626,053	478,072	2,285,304
Burned area (ha)	404,713	60,461	95,835	29,274	194,719	7,956	168,827	33,210	209,994

Company refers to land occupied by companies. Independent farmers are mainly local and migrant communities. Forest refers to unoccupied forested land

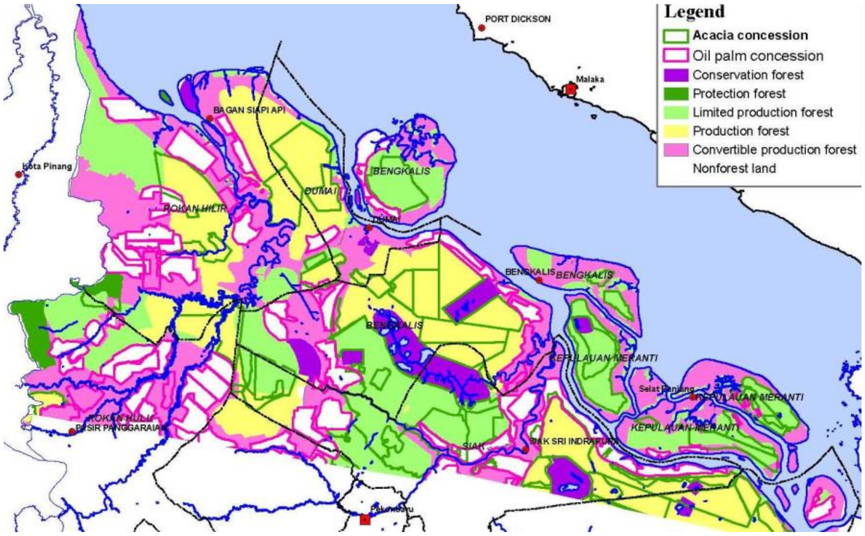


Figure 3.6 State forest land and concessions
The majority of burned area outside concessions were on state forest land

Over half (52%; 209,994 ha) of the total burned area detected was outside concessions is represented in Figure 3.1 and Table 3.2. The majority of these (73%) were on State Forest Land (9,700 ha in protected areas), for which there is no Land Registry for agricultural land because the development of agriculture is illegal on State Forest Land shown in Figure 3.6. Eighty-two percent (55 of 67) of the studied acacia concessions are located on peat domes, which is surprising given that plantations on deep peat (> 3 meters) is forbidden (Varkkey, 2012). Over 59% (123,343 ha) of total burned areas outside concessions occurred within a five-kilometre buffer bordering acacia concessions showing in Figure 3.6 indicating that there may be a relationship. Modelling the exact impact of draining in concessions on fires immediately outside would require using advanced terrain and hydrology models.

In conclusion, a substantial number of fires ignited outside concessions by industrial actors, whether duly registered or not, whether directly or indirectly, is extremely likely, but hard to quantify precisely. Scrutiny of activities within concessions alone is therefore insufficient to attribute causation, and demonstrates a valid need to investigate fire origin and spreading within a landscape, and with field assessment.

3.4 Conclusion

Lack of rain is a pre-condition that contributes to more fires in Riau Province. Indonesian peatlands are now the primary target for agricultural expansion, while categorized as marginal land. Now, peatlands are typified by a diversity of actors intent on land use conversion to Oil-Palm and Acacia plantations, resulting in fire every year during the dry season. These actors are large registered companies, or small migrant farmers searching for land in frontier areas to improve their economic condition, or well-connected medium or large entrepreneurs from cities who rely on local informal networks to secure their lucrative investments and operate without formal company status. Registered companies are in the spotlight because fires regularly occur on their land (concessions). Our results suggest caution is needed in assigning responsibility for fires in concessions to companies because other actors may share responsibility. Therefore, focusing on concessions alone, which the Indonesian government and also non-government organizations seem to do, is not going to reduce the problem. Companies may share responsibility for fires outside concessions. Scrutiny of company activities needs to be extended beyond concession boundaries. This study highlights the urgent need to develop a detailed Land Registry in rural Indonesia, showing de-facto land ownership of land parcels inside and outside concessions to unravel the complex land use on the ground. This can be achieved by combining high-resolution satellite imagery with detailed field investigations under Indonesia's One Map Initiative. The reliable monitoring of various corporate sustainability commitment initiatives and attribution of responsibilities for fires and deforestation events will only be possible in such circumstances.

Monitoring of these commitments must be accurate. Such accuracy cannot be attained under current circumstances in Indonesia with simple and superficial techniques based on satellite imagery. These have to be advanced to a higher level, for example using "smart-mapping," namely the combination of techniques relying on additional sources of information for concession boundaries, fire propagation maps to infer whether the fire started outside or inside concessions, and comprehensive procedures for ground-truth. In addition, the reliable monitoring of corporate sustainability commitments requires a resolution of overlapping land claims.

Chapter 4. The driving force of fires and the recent peatland fires regimes in Riau

4.1 Introduction

A peatland is a wetland ecosystem in which the production of organic matter from dead plants is higher than its decomposition, resulting in accumulation of peat. Several factors influence peatland formation, including climate, humidity, topography, and geology (Page et al., 2006). The majority of peatlands are located in temperate and boreal zones under low-temperature conditions. However, regional environmental and topographic conditions have resulted in the formation of tropical peat swamp forests in Southeast Asia, Southern Africa, South America, and Central America (Page et al., 2011).

Peatlands provide a variety of ecosystem services. Despite covering only 3% of the Earth's surface, peatlands store 500-700 Gigatons (G ton) of carbon (Page and Hooijer, 2016). The majority of this carbon is stored in temperate and boreal peatlands, but tropical peat swamp forests also store a significant amount of carbon at around 80-90 G tons, 69 G tons of which is stored in Southeast Asia. Furthermore, peat swamp forests in Southeast Asia provide other ecosystem services such as climate regulation, water supply, flood control, and high biodiversity (Miettinen et al., 2016).

When tropical peatlands start to burn they release a significant amount of carbon into the atmosphere, around 243 ton per ha (van der Meer and Verwer, 2011). Peatland fires have changed peatland function in Southeast Asia from a carbon sink to a carbon source (Page et al., 2009). Moreover, in recent years, persistent peatland fires have been identified as a hazard with serious effects on human health and society. The total economic, social, and ecological damages and losses due to fires in Indonesia were estimated to be at least 16.1 billion USD in

2015 (Glauber and Gunawan, 2015). The effect of fires on peatland ecosystems may persist for a long time (Mabuhay et al., 2004), particularly if the peat layer is extensively burned.

Peatland fires have a long history, and are not a new phenomenon in Southeast Asia. Major fire events occurred in Kalimantan in 1846, 1902, 1915, and 1972, all of which were El Niño Southern Oscillation (ENSO) years (Aiken, 2004). El Niño reduced precipitation drastically (Putra et al., 2008), which makes peatlands more susceptible to fire due to lowered water table (Wösten et al., 2006) and associated peat drying. Local communities in East Kalimantan and South Sumatra have traditionally conducted slashing and burning in peat swamp forests along the river bank and forest edges to convert the forest to agricultural land (Chokkalingam et al. 2005; 2007).

However, fire has become a more frequent and severe problem in Southeast Asia since the late 1990s (Goldammer, 1999). Visibility records from the airports in Sumatra and Kalimantan since the 1960s indicate higher fire frequency after industrial plantations or the Mega Rice Project in Kalimantan began (Field et al., 2009). Twenty percent of peat swamp forests in Peninsular Malaysia, Sumatra, and Kalimantan were transformed to industrial plantations by 2010 (Miettinen et al., 2012a). Fire was a tool for land preparation after logging to create plantations by palm oil and industrial forest companies (Suyanto et al., 2004). Furthermore, the water table was lowered by the creation of canals to grow oil palms or acacia plantations and to create large-scale rice paddy fields, which increased fire risk (Hooijer et al., 2012) because of peat drying. Industrial plantation concessions contributed to fire at a level ten times higher than selective logging concessions (Marlier et al., 2015).

Fires can be minimized by sustainable management practices (Mabuhay et al., 2003). Fire occurrences in Southeast Asian peatlands are related to land cover (Miettinen et al., 2012b). Many studies have reported that fires occurred more frequently in deforested areas than in forests or oil palm and acacia plantations. For example, fires originated and spread from deforested areas more often than oil palm plantations and settlements in Central Kalimantan (Cattau et al., 2016a). The sources of fires in this region have shifted from peat swamp forests due to slash and burn to deforested areas since 2002, due to the Mega Rice Project (Hoscilo et al., 2011). In Riau, most of the burned area was deforested area that was enlarged by a previous fire or created due to the failure of industrial plantation development (Gaveau et al., 2014). To prevent recurrent peatland fires, factors that affect fire occurrences in addition to climate should be elucidated.

Although deforested areas consist of various land cover types, such as shrubland regenerated after a fire (Haryati and Nakagoshi, 2013), rice paddy fields, coconut and rubber cultivation, young oil palm plantations, and bare soil, most previous studies have not classified these land cover types because they used moderate-resolution satellite images to cover large regions and these images were not capable of distinguishing among these land cover types. These deforested land cover types may contribute to fire occurrence differently. In Jambi Province, Stolle et al. (2003) demonstrated that few fires occurred in rice paddy fields, coconut, plantations, grassland, and rubber cultivation. In contrast, recurrent fires occurred in shrubland, and ferns dominated vegetation that grew after fire (Page et al., 2013). Young oil palm and acacia plantations in South Sumatra were susceptible to fires (Page et al., 2013). Understanding which types of deforested land cover are more prone to fire is necessary for sustainable development of peatland.

Although all land within concessions belongs to the Indonesian government, land is used by different landholders. Concession holders may not control all the land within their management area because migrants and local communities may claim land tenure in the concession area and forests (Galudra et al., 2014). Land discrepancies among existing conditions, concession holders, and land management are major problems in peatland management. Owing to land discrepancies, the government has difficulties identifying the responsible parties for peatland fire.

Even if the land cover type are the same, land management may influence fire occurrence. In Kalimantan, fewer fires occurred in protected forest areas than in forests subjected to selective logging or conversion to a plantation (Langner and Siegert, 2009).

Fire occurrence may also be affected by landholder type. Land utilized by smallholders has generally been managed intensively and been more protected against fires than concession areas (Stolle and Lambin, 2003), because smallholders clear their land at smaller scales than concession companies. Oil palms are planted by either a registered large-scale concession company, an unregistered company, or smallholders in Indonesia (WWF Indonesia, 2013). The registered companies implemented a zero-burning policy to obtain a sustainable management certification. This certificate is mandatory for all palm oil companies in Indonesia. In contrast, unregistered companies do not follow the policy and one company has used fire to develop plantations in an Indonesian national park (Ekadinata et al., 2013).

The proximity to a road or canal could be another important factor affecting fire occurrence. Road density affects spatial fire distribution (Raharjo and Nakagoshi, 2014). In Jambi, forests within 1-5 km of the road suffered fires almost five times more than forests over 20 km away from the road (Stolle et al., 2003). Similarly, in Kalimantan, most forest fires occurred within 5 km from the forest edge (Langner and Siegert, 2009), and many fires occurred near canals (Hoscilo et al., 2011). Roads and canals are the main methods of access to plantations. Additionally, canals may also lower the level of the water table by drainage, thus creating a more fire-prone environment.

This study aims to analyze the drivers of fire and relationships between fire occurrence and land cover type, land management, landholders, and proximity to roads and canals. We focus on Riau Province on Sumatra Island, Indonesia, because Riau has extensive peatlands, frequent fires, and has experienced rapid deforestation. We analyze data from 2001 to 2014 and choose 2014 to know the fire regime due to the severe impacts of fire showing in Figure 4.1 on the economy, social, and ecological aspects in Riau that year, where damage and loss totalled an estimated 935 million USD (The World Bank, 2014). We focus on four questions:

1) What are the drivers of fire in Riau?
2) To what extent landholder and deforestation affect fire in Riau?
3) Are fire occurrences more frequent in shrubland than other land cover types?
4) Do fires occur more frequently in peat swamp forests allowed that have been converted to a plantation or other uses than protected peat swamp forests?
5) Is smallholder cultivation better for fire prevention than registered and unregistered companies?
6) Does closer proximity to road and canal result in more frequent fires?

4.2 Materials and methods

4.2.1 Study area and data collection

Riau Province is located on the eastern coast of Sumatra island, stretching from the Barisan Hills in the west downwards to the Malacca Strait in the east (2˚35'N - 0˚58'S, 100˚13'E - 103˚50'E). Riau has a tropical climate, with annual mean precipitation and temperature of 2400 mm and 26˚C, respectively, between 2012 and 2014 (Statistics of Riau Province, 2015).

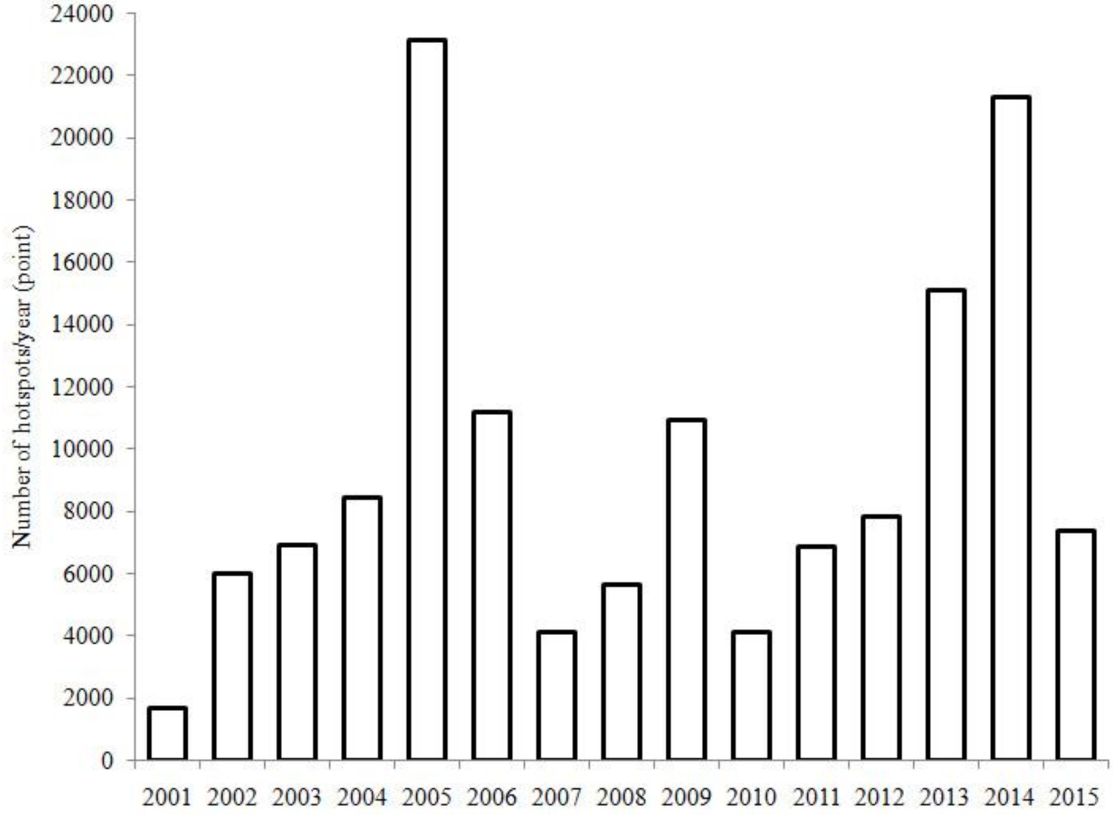


Figure 4.1 Number of MODIS fire hotspots from 2001 to 2015 on peatland. The highest hotspot occurred in 2005 and 2014

The details of data sets utilized in the analyses are described in Table 4.1. The secondary data were collected from government agencies while deforestation, land ownership, LANDSAT and MODIS hotspot data were downloaded via website.

4.2.2 Mapping deforestation, landholder, and hotspot

A deforestation map produced by Centre for International Forestry Research (CIFOR) was used (Gaveau et al., 2014). The deforestation map was made with supervised and visual classification of LANDSAT images. The deforestation map categorized to deforestation before 1990, deforestation from 1990 to 2000, and yearly deforestation from 2000 to 2013.

A landholder map from CIFOR were used (Gaveau et al., 2014). This map was generated from LANDSAT and concession map. The landholder was disaggregated into areas developed by plantation companies, areas occupied by small-scale agriculturalists, and idle undeveloped lands.

Hotspot data (2001 to 2014) were downloaded from the National Aeronautics and Space Administration via the Fire Information for Resource Management System (FIRMS) data portal. MODIS fire hotspot data show the coordinates of the center of 1 km^2 pixel where persistent fire was detected from a MODIS image using an algorithm (Cattau et al. 2016; Giglio et al. 2003).

Table 4.1 Data collection, its description, and source

Data	Description	Source
Deforestation	1990 to 2013	https://data.cifor.org/dataset.xhtml?persistentId=doi:10.17528/CIFOR/DATA.00079
Land ownership	2013	https://data.cifor.org/dataset.xhtml?persistentId=doi:10.17528/CIFOR/DATA.00081
Reppprot	1990	https://databasin.org/datasets/eb74fe29b6fb49d0a6831498b0121c99
Slope	1990	Geospatial information agency
MODIS hotspot	2001 to 2014	https://firms.modaps.eosdis.nasa.gov/download/
Landsat 8 OLI	April 2013 to November 2014	http://glovis.usgs.gov/ Path and Row: 128_58, 128_59, 127_59, 127_60, 126_60, 125_60, 125_61
High-resolution image	2013 to 2014	Digital Globe via Google Earth
Administrative	Riau Province	- Geospatial Information Agency of Indonesia - Planning Agency of Riau
Forest boundary	Riau Province	Ministry of Environment and Forestry
Concession boundary	Riau Province	Ministry of Environment and Forestry
Peatland map	Riau Province	Wetlands International
Ground truth	2013 to 2015	Field survey

4.2.3 Assessing the drivers of fire with Maxent model

Drivers of fire were computed in Maxent 3.4.1, a free software (https://biodiversityinformatics.amnh.org/open_source/maxent/). Maxent requires data points in format of comma-separated values (CSV) with three columns: code, longitude, and latitude. The data points (hotspot) were converted to WGS 1984 projection. X, Y coordinates in the attribute tables were updated with the Calculate Geometry tool. The updated attribute tables (DBF format) were converted CSV format with Microsoft Excel for use in Maxent software.

Maxent need all environmental variables in ASCII raster format with the same projection system, geographic reference, geographic extent, and grid cell size. First, environmental variables in shapefile format were clipped to extent of land ownership map by using Geoprocessing in ArcMap 10.2. This clipped process set the geographic reference, projection system, and geographic extent for each environmental variable were set exactly the same. Second with conversion tool, the clipped files were converted to raster with processing extent and raster analysis used land ownership raster file. All environmental variables used WGS 1984 projection and 1 km^2 grid cell size. Third using DIVA-GIS 7.5.0, the modified environmental variables were converted to ASCII files with and stored in a folder. Fourth run Maxent model, the directory of ASCII file was uploaded into the "Environmental Layers" and hotspot data (CSV) was uploaded into the "Sample". We used categorical parameter in environmental layers, logistic output format, respond curves, and jackknife to measure variable importance.

Maxent output maps (ASCII) were converted to a floating-point raster grid using conversion tool. Logistic outputs from Maxent software indicated 1 is the best conditions for fire occurrence and 0 is inappropriate conditions.

4.2.2 Mapping Riau's peatland post-fire land cover map in 2014

A map of land cover after a severe fire between January and March 2014 was created using post-fire Landsat 8 images, acquired from April to November 2014. Landsat 8 has a spatial resolution of 15 × 15 m (Roy et al., 2014). Satellite images from time periods with less than 50% cloud cover were used (Margono et al., 2012). Satellite images were downloaded from the US Geological Survey National Center for Earth Resources Observation and Science via the Global Visualization Viewer (GLOVIS) data portal (http://glovis.usgs.gov/). This study was conducted with LANDSAT 8 pre-processing (atmospheric correction), land cover classification, and an accuracy check of land cover classification (Jia et al., 2014).

Atmospheric correction was conducted to reduce atmospheric distortion. To enhance image information, Quantum GIS 2.14.2 Essen was used by transforming radiance at the sensor into surface reflectance values (Chavez, 1996). Physics-based derivation of surface and atmospheric properties of hyperspectral and multispectral data were presented by image enhancement process. This is based on atmospheric radiative transfer, input of atmospheric parameters, and calibration of the instrument accuracy. Spectral differences were enhanced with the algorithm that divided spectral band (numerator) by another band (denominator) (Roy et al., 2014).

A supervised classification through a maximum likelihood algorithm method in ArcGIS 10.2 software was used to classify land cover into 11 types are represented in Table 2.1. Training areas were used to define the spectral reflectance patterns of each land cover type in supervised classification. The classifier used the pattern of the training area to group pixels of a certain category with the same spectral patterns (Yacouba et al., 2009). Pixels of an unknown category had a certain probability of belonging to a particular category in the maximum likelihood algorithm classifier. All categories had equal probabilities following the Gaussian (normal) distribution function.

For the training areas, ground truth data were used. Geographical coordinates and land cover types were recorded in the field for 1301 sampling points during 2013-2015. To avoid pseudoreplication, stratified random sampling was conducted by the Sampling Design Tool (Buja and Menza, 2013) in ArcGIS 10.2. Ten percent of sampling points that were at least 5 km apart from each other were randomly sampled for each land cover type. The sampling points were not sufficient for some land cover types (shrubland, settlement, mangrove, and water body), so points were added using Google Earth images acquired from 2013 to 2015.

A training area was created for each sampling point with the assistance of visual inspection of LANDSAT images through displaying RGB combination (bands 654) and the image from Google Earth. The training area was checked against the 2013 land cover map (unpublished data).

Accuracy assessment is an important step because land cover maps derived from remote sensing commonly contain errors that result from the method used by the satellite to capture data or the classification procedure (Powell et al., 2004). The accuracy assessment usually uses an error matrix that represents the number of sample units (i.e. pixels, clusters of pixels, or polygons) in a set of numbers of rows and columns assigned to a particular type, relative to the actual type in verification data. For verification data, stratified random sampling was conducted for the remaining ground truth data that was not used for creating the training area. The Sampling Design Tool (Buja and Menza, 2013) was used to sample 50% of the points that were more than 5 km apart from each other for each land cover type. Google Earth was used to add additional data for the categories with few sampling points. User accuracy was calculated by dividing the number of correctly identified ground truth points by the total number of verification points.

4.2.3 Identification of pre-fire land cover and hotspot in 2014

To elucidate the relationship between fire occurrence and land cover type, pre-fire land cover was identified for areas burned by the fire from January to March 2014. The burned area in the post-fire land cover map can be classified into two types: 1) areas burned by the fire in January to March 2014; and 2) areas burned before January 2014 or after March 2014. The January-March burned area was identified by the presence of MODIS fire hotspots during January 29th to March 28th. For the areas burned by the fire in January to March 2014, the pre-fire land cover was determined through visual interpretation of LANDSAT 8 images acquired from September to December 2013, with Google Earth data as supportive data.

4.2.4 Identification of land management system

According to Indonesian forestry laws, the peatland in Riau Province has been divided into conservation forest, protection forest, production forest (limited production forest, regular production forest, and convertible production forest), and non-forestland. Conservation forest was designated in order to maintain biodiversity and ecosystems, and can be utilized for research purposes. Protection forest was designated for protecting water systems, preventing flooding, soil erosion, seawater intrusion, and maintaining soil fertility, and can only be utilized for research purposes and non-timber forest products. Limited production forest was designated for selective logging. Regular production forest was designated for producing wood through the clear-cutting system, planting, and harvesting industrial forests. Convertible production forest was designated for wood production or conversion to non-forestland. Non-forestland was designated for non-forestry activities, such as agriculture (Margono et al., 2012). A land management map for 2011 was obtained from the Ministry of Forestry.

4.2.5 Landholders in 2014

Based on land management, the government has granted forestry concession and non-forestry concession. Industrial forest plantation concessions were granted for logging and development of acacia plantations in regular and limited production forests. Non-forestry concessions (cultivation right and forest release area) were granted for development of oil palm plantations on convertible production forest and non-forestland.

We categorized landholders into registered companies, unregistered companies, smallholders, cooperation between a company and smallholders, and unidentified landowners (Hoscilo et al., 2011). We identified the landholder of the area that was burned by fire in January to March 2014 using pre-fire land cover information, concession boundary data in 2013 that were issued by the Ministry of Forestry and National Land Agency, and images from LANDSAT 8 and Google Earth that were captured in 2013. Registered and unregistered company plantations exhibit more orderly clusters, with regular canals, roads, and palm oil mills. If the regular pattern was located inside the concession and covered by acacia, oil palm, coconut, or sago palm, it was categorized as a registered company. If the regular pattern was located outside the concession, it was categorized as an unregistered company. Smallholder plantations were categorized by land parcels of irregular shape, varying size and direction, and covered by oil palm, coconut, and sago palms. The boundaries of those areas were drawn by visual interpretation. These patterns are visible on the LANDSAT 8 and Google Earth images. Usually, acacia plantations were developed inside the concession area; however, occasionally the companies cooperate with the local community to plant acacia outside their concession area (Indonesian Working Group on Forest Finance, 2010). If an acacia plantation was found outside the concession, these were categorized as cooperation between a company and smallholders. For shrubland, we could not identify landholders by our method as migrants may encroach the shrubland under concession.

4.2.6 Map analysis and proximity analysis

To elucidate the relationship between fire occurrence and land cover type, land management, landholders, and accessibility, geospatial analysis was conducted using ArcGIS 10.2. The burned area map was overlaid onto the land cover map, land management map, and the map of landholder. We conducted buffer analysis for the roads and canals to test whether proximity affects fire occurrence. The probability of a burned area was compared between areas with different proximity to roads and canals. A buffer area was created every 1 km up to 5 km for the canal and every 1 km up to 10 km for the road.

4.2.7 Statistical Analysis

Data of forest patch sizes were analyzed with R statistical software. Analysis of variance (ANOVA) was used to determine significant differences between forest group at confidence level of $p < 0.05$.

4.3 Results and discussion

4.3.1 Relationship between deforestation, landholder, and fire

Riau experienced rapid deforestation from 1990 to 2013 is given in Table 4.2. Over the past 23 years, forest area declined rapidly from 2,080,000 ha in 1990 to 360,263 ha in 2013. More four-fifth (1.7 million ha) of forests was lost from 1990 to 2013. The highest deforestation occurred in the last five years during 2008 to 2013 (0.5 million ha).

Human uses fire to clear deforested land and forest. One-third of Riau's hotspots from 2001 to 2014 (32.9%) were located in non-forest area in 2000. Deforested land from 1990 to 2000 showed high hotspots after deforestation (62.5% in 2001) and reduced gradually to 14% in 2014 shown in Figure 4.2.

Most of hotspot from 2001 to 2014 occurred in area developed for oil palm by independent farmer (73.7 %) is presented in Table 4.3. On contrary, area developed by company (acacia, rubber, and oil palm) has less hotspot. However, the forest has the least hotspot density (0.9 km^2) than other landholders type. The condition of hotspot occurrence is almost simillar every year from 2001 to 2014.

Table 4.2 Period of deforestation and hotspots number

Period of deforestation	Hotspots number	% Hotspot	Area (ha)	% area	Hotspot density
1990-2000	21,905	23.0	868,228	27.1	2.5
2000-2001	810	0.8	13,794	0.4	5.9
2001-2002	3,021	3.2	23,017	0.7	13.1
2002-2003	2,417	2.5	18,168	0.6	13.3
2003-2004	6,199	6.5	58,282	1.8	10.6
2004-2005	8,389	8.8	81,872	2.6	10.2
2005-2006	6,213	6.5	72,509	2.3	8.6
2006-2007	2,064	2.2	38,910	1.2	5.3
2007-2008	3,031	3.2	41,905	1.3	7.2
2008-2009	7,439	7.8	86,832	2.7	8.6
2009-2010	4,794	5.0	82,573	2.6	5.8
2010-2011	3,323	3.5	50,166	1.6	6.6
2011-2012	6,522	6.8	90,726	2.8	7.2
2012-2013	6,453	6.8	192,755	6.0	3.3
Forest 2013	3,313	3.5	360,263	11.3	0.9
Non-forest in 1990	9,478	9.9	1,122,219	35.0	0.8
Total	95,371		3,202,219		

Fire is not directly connected with deforestation and fire was used to clear deforested land

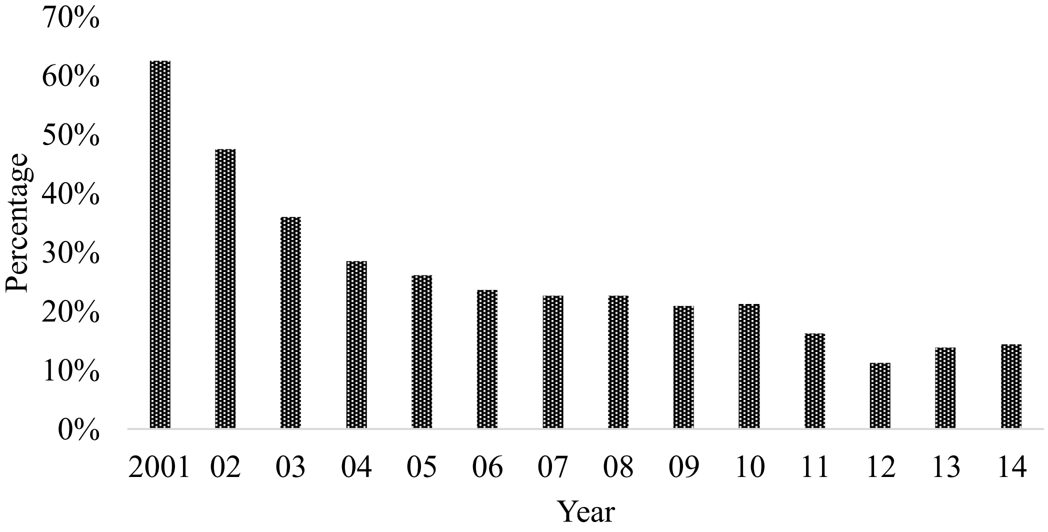


Figure 4.2 Trend of hotspot in area that deforested in 1990 to 2000 period
Fire occurrence will reduce after plantation was developed

Fire has been strongly associated with peatland deforestation. Instead, there are two types of deforestation in Sumatra: (1) Unmanaged land that lead to persistent fire and (2) managed land for industrial plantation (Miettinen et al., 2012c). Our study give new perspective that fire target unmanaged land with unclear land tenure. Most of fires are connected with human activities because natural ignitions are very limited. Thus, fuel condition such as soil moisture is the important factor to reduce fire. In addition, human affect fuel condition (amounts, composition, and configuration) through land use and land management (Butsic et al., 2015). Therefore, effective fire management should target independent farmers group in unmanaged land.

Table 4.3 Type of landholders in 2013 and hotspots number (2001 to 2014)

Type of landholders	Hotspot numbers	% Hotspot	Area (ha)	% area	Density
Developed by communities for oil palm	70,329	73.7	1,771,322	55.3	4.0
Developed by communities for rubber	121	0.1	20,181	0.6	0.6
Developed by company for acacia	9,380	9.8	276,746	8.6	3.4
Developed by company for oil palm	12,033	12.6	769,371	24.0	1.6
Developed by company for rubber	22	0.0	4,336	0.1	0.5
Forest	3,486	3.7	360,263	11.3	1.0
Total	95,371		3,202,219		

Independent farmers use fire to develop plantation

Table 4.4 Analysis of variable contributions

Variable	% of contribution	Permutation importance
District boundary	34	19.3
Type of lands	25.2	23
Slope	15.2	6.5
Landholder	11.4	22.1
Period of deforestation	10.8	21.3
Status of forest area	3.5	7.9

Table 4.5 Type of lands and hotspots number

Type of lands	Hotspot numbers	% Hotspot	Area (ha)	% area	Density
Plain	9,876	10.4	1,087,737	34.5	0.9
Aluvial plain	2,109	2.2	177,562	5.6	1.2
Meander	1,045	1.1	91,602	2.9	1.1
Aluvial valey	363	0.4	23,365	0.7	1.6
Mountains	49	0.1	35,729	1.1	0.1
Hilly	1,021	1.1	41,839	1.3	2.4
Tidal swamp	157	0.2	51,284	1.6	0.3
Peat swamp	74,086	77.7	1,259,729	40.0	5.9
Terrace	6,665	7.0	433,373	13.7	1.5
Total	95,371		3,202,219		

Peat swamp was the source of fire

4.3.2 The drivers of fire

The land type was the most important driver of fire with permutation importance was 23 is presented in Table 4.4. This is because most of hotspot located in peat swamp (77.7%) with hotspot density was 5.9 shown in Table 4.5. The second highest hotspot density was hilly (2.4) followed by alluvial valley (1.6). Peat swamp was the largest land system type in our study area (39.2%) followed by plain and terrace.

Landholder and deforestation were the next important driver of fire that contribute by independent farmer and time of deforestation. District boundary was also the important factor. On the contrary, slope and forest area status showed the marginal driver of fire.

Recently, fires occurred mostly in unmanaged peatlands. This is because small land size in unmanaged area is highly vulnerable to fire escape from surrounding properties (Cattau et al., 2016a). Fire management should prioritize unmanaged peatland and control the fire usage by all land operators during dry periods. We suggest protection of remaining peatland swamp forest and peatland restoration to mitigate haze disaster. We predict the future severe haze disaster unless strong law enforcement is taken in peatlands showing in Figure 4.3.

4.3.3 Accuracy assessment for land cover classification in 2014

The user’s accuracy of each land cover was 65% - 100% is presented in Table 4.6 and the producer’s accuracy was 75% - 100%. The overall accuracy and the Kappa coefficient was 83% and 0.81, respectively. It indicated that image classification was good (Jensen, 2004).

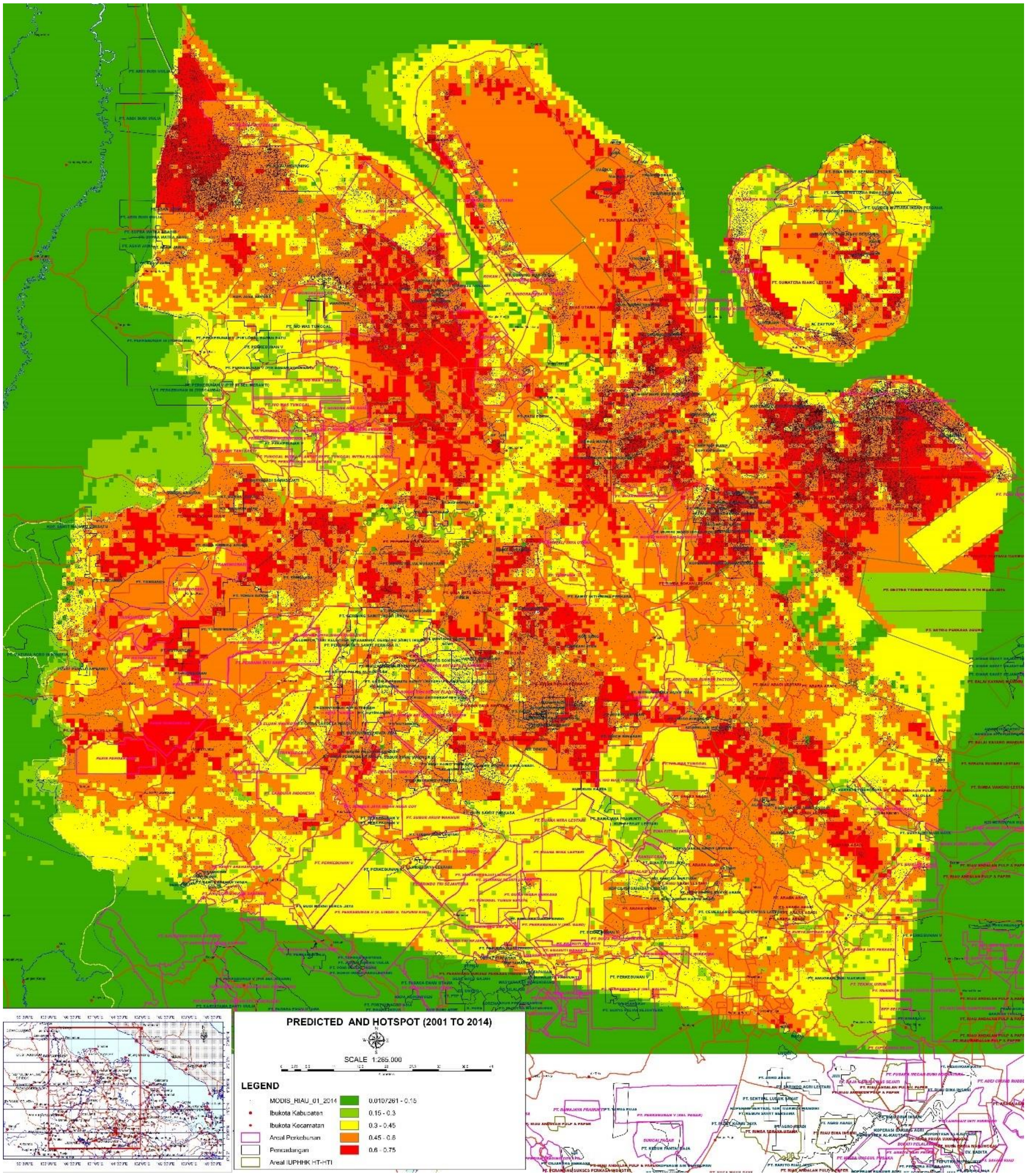


Figure 4.3 Long-term fire probability map hotspot between 2001 and 2014.

Old red colour indicate areas with high fire probability while green colours suggest lower fire probability

4.3.4 Land cover types and land management in 2014

Plantations and agricultural land covered 47% of peatland showing in Table 4.7 and Figure 4.4. Oil palm plantations were the most dominant type (17%), followed by coconut (13.9%), and acacia (13.5%). Peat swamp forests covered only 29.2% of peatland.

Peatlands in Riau are categorized into conservation forest (5.7%), protected forest (0.3%), production forest (77.5%), and non-forestland (16.5%) shown in Table 4.8. Half of the peatland has been granted concessions, namely cultivation rights (10.2% of peatland), industrial forest plantation (30.4%), and release of forest area (8.5%).

Table 4.6 Accuracy assessment for land cover classification

Land cover classification	Reference data											Total	User's accuracy (%)
	Ac	Ba	Cc	Mg	Op	Ps	Rb	Sp	St	Sh	Wb		
Acacia (Ac)	17	2	0	0	2	2	0	0	0	1	0	24	71
Burned area (Ba)	4	43	1	0	6	3	2	1	0	6	0	66	65
Coconut (Cc)	0	0	18	1	1	0	0	1	0	0	0	20	90
Mangrove (Mg)	0	0	0	24	0	0	0	1	2	0	0	27	89
Oil palm (Op)	1	2	0	2	43	0	0	0	1	4	0	53	81
Peat swamp forest (Ps)	1	0	0	0	1	24	0	1	0	0	0	27	89
Rubber (Rb)	0	0	0	0	0	0	18	0	0	0	0	18	100
Sago palm (Sp)	0	0	0	0	0	0	0	33	0	1	0	34	97
Settlement (St)	0	0	0	0	0	0	0	0	22	0	0	22	100
Shrub land (Sh)	0	0	0	0	0	3	0	0	1	33	0	40	83
Water body (Wb)	0	0	1	0	0	1	0	0	2	0	24	28	86
Total	23	47	20	27	55	33	20	37	28	45	24	359	Overall accuracy
Producer's accuracy (%)	74	91	90	89	78	73	90	89	79	73	100		83.3%

Table 4.7 Area burned by fire between January-March 2014 and post-fire, by land cover type.

Land cover	(A) Area after the fire (ha)	Proportion of A to the total area (%)	(B) Burned Area (ha)	Proportion of B to the total burned area (%)	(B/(B+A)) Percentage of burned area (%)
Shrubland	378,110	9.4	157,794	36.8	29.4
Sago palm	61,653	1.5	14,735	3.4	19.3
Burned area	463,925	11.5	43,099	10.0	9.3
Peat swamp forest	1,177,034	29.2	118,923	27.7	9.2
Acacia	544,740	13.5	39,633	9.2	6.8
Water body	14,210	0.4	906	0.2	6.0
Oil palm	686,280	17.0	29,554	6.9	4.1
Coconut	560,413	13.9	21,463	5.0	3.7
Rubber	61,215	1.5	1,884	0.4	3.0
Mangrove	66,759	1.7	1,134	0.3	1.7
Settlement	14,952	0.4	31	0.0	0.2
Total	4,029,292	100	429,155	100	10.7

Shrubland was the most prone land cover type

Table 4.8 Fire occurrence in 2014 in different concession and land management.

	(A) area (ha)	Proportion of A to the total area (%)	(B) Burned area (ha)	(B/(A) Percentage of burned area (%)
Concession types				
Cultivation right	411,285	10.2	47,351	11.5
Release of forest area	341,932	8.5	42,349	9.9
Industrial forest plantation	1,225,027	30.4	136,037	11.1
Outside concession	2,051,048	50.9	203,419	12.4
Total	4,029,292		429,155	
Land management types				
Non-forestland	666,046	16.5	81,213	12.2
Convertible production forest	1,132,257	28.1	108,332	9.6
Limited production forest	629,537	15.6	120,313	19.1
Protection forest	10,964	0.3	279	2.5
Regular production forest	1,362,289	33.8	111,539	8.2
Conservation forest	228,043	5.7	7,480	3.3
Total	4,029,292		429,155	

Conservation forest and protection were the least fire-prone

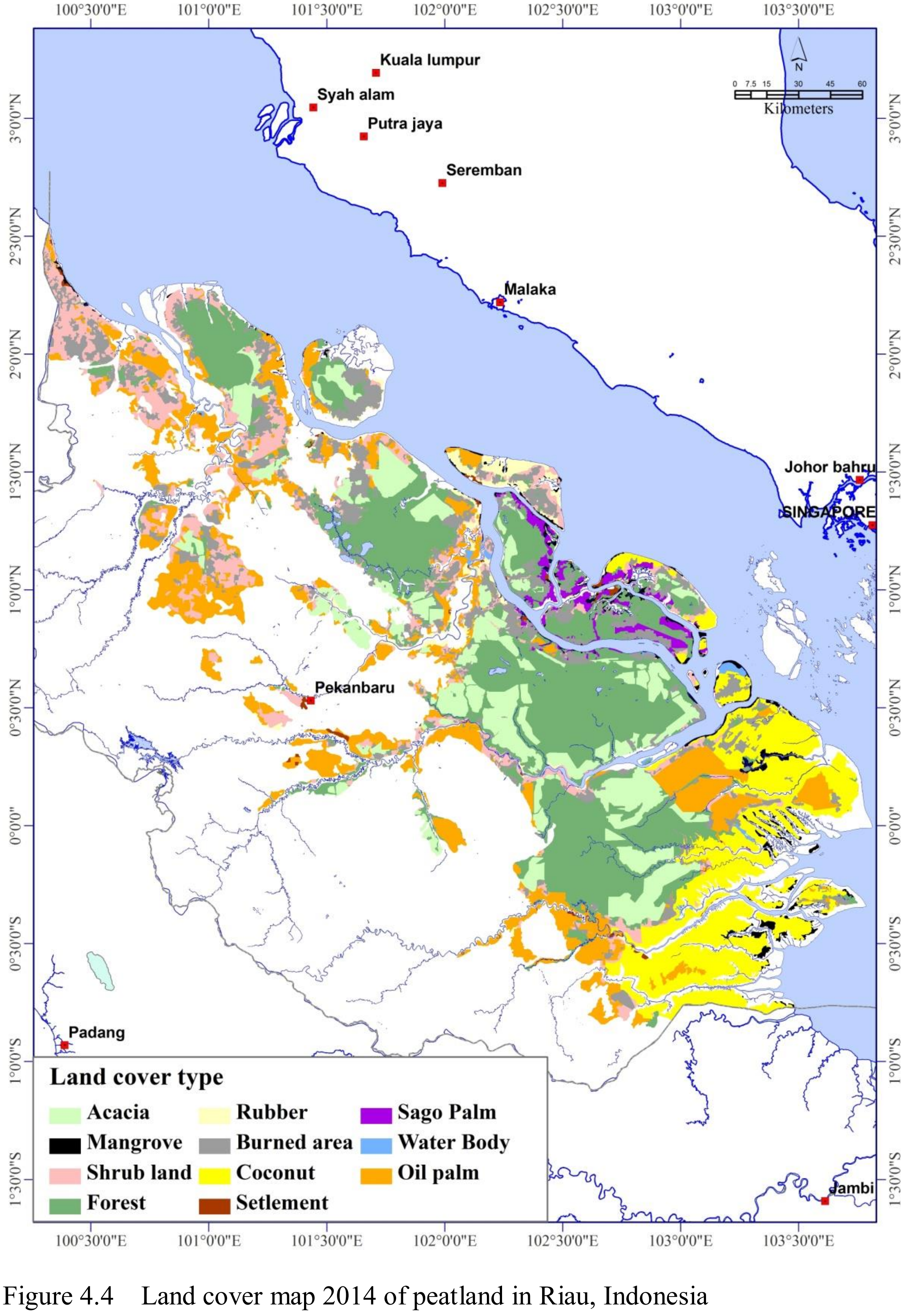


Figure 4.4 Land cover map 2014 of peatland in Riau, Indonesia

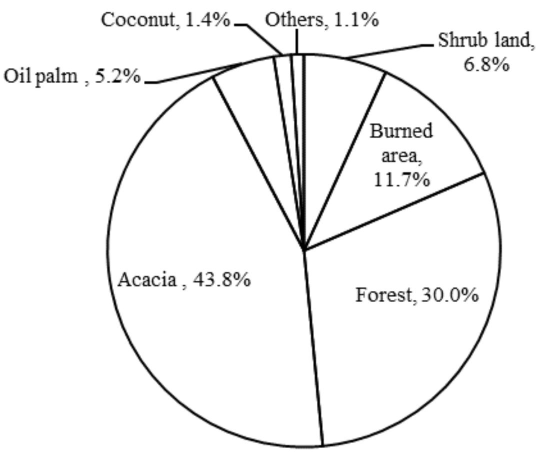


Figure 4.5 Percentage of the land cover map in industrial forest concession.

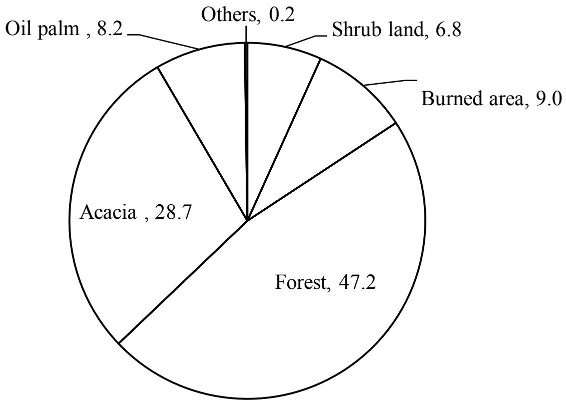


Figure 4.6 Percentage of the land cover map in regular production forest.

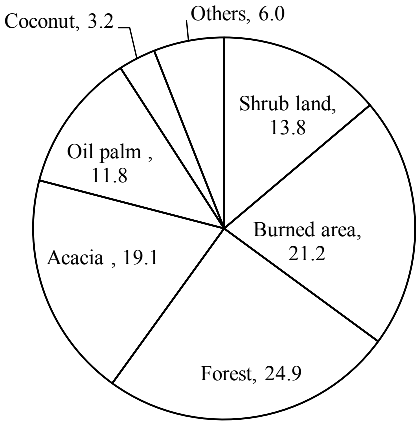


Figure 4.7 Percentage of the land cover map in limited production forest.

Peatland utilization is expected to be determined by the type of land management and concessions. However, there was a discrepancy between actual peatland utilization and the types of land management and concessions. For instance, we detected 5.2% of oil palm plantations inside industrial forest plantation concessions where acacia should be planted shown in Figure 4.5, 8.2% of oil palm plantations inside regular production forest where only acacia was permitted to be planted shown in Figure 4.6, and 11.8% of oil palm plantations inside limited production forest where selective logging was permitted showing in Figure 4.7.

4.3.5 Land cover types and fire occurrences in 2014

Eleven percent of peatland was burned by the fires between January and March 2014 shown in Table 4.7. Most of the burned areas were shrublands (36.8%) and peat swamp forests (27.7%). Conversely, burning was lower in plantation areas, with 9.2% of burned area occurring in acacia plantations, 6.9% in oil palms and 5% in coconut plantations. Different land cover types faced different occurrences of fire. The more fire-prone land cover types were shrublands, where 29.4% of it burned, followed by sago palm plantations (19.3%), areas that were burned in 2013 (9.3%), and peat swamp forests (9.2%). Rubber and mangroves were the least fire-prone land cover types.

More than one-third of burned areas were located in shrubland, which was the most fire prone land cover type showing in Table 4.7, as we predicted. This result supports previous studies which found that deforested and unmanaged areas were the main source of burned area (Gaveau et al. 2014; Miettinen et al. 2011). Shrubland is dominated by fire-prone ferns and grass species (Miettinen et al., 2013b), and contains recovering vegetation that appears after fires or when oil palm plantations are not well managed (Clough et al., 2016). Migrants and local communities use fire for clearing land in shrubland to develop oil palm plantation

(Purnomo et al., 2017). The combination of fire-prone vegetation and social factors make shrubland the most burned land cover type.

Peat swamp forests were less susceptible to fire than shrubland showing in Table 4.7. Intact peat swamp forests are resistant to fire because the ecosystem is moist throughout the year (Page and Hooijer, 2016). Soil moisture in peat swamp forests is high because of the tree canopy, while in shrubland, sunlight directly reaches the ground's surface (Cochrane, 2003a). In our results, 9% of peat swamp forests were burned, while 6% and 0.1% of intact peat swamp forests were burned in Kalimantan in 2002 and 2005, respectively (Langner et al., 2007), and 3.8% of logged-over forests and 0.7% of intact forests were burned in Jambi in 1993 (Stolle et al., 2003). The differences between our results and those of previous studies could be because we did not differentiate between intact, secondary, and degraded forests. Degraded forests were reported to be more susceptible to fire than intact forests. In 1997-2005, after the Mega Rice Project, degraded forests were a main cause of fire (Hoscilo et al., 2011).

Our results, and all recent results, suggest that shrubland is the most important land cover type for focusing on fire prevention. Mechanisms to financially and technically support the restoration of shrubland into peat swamp forests or the conversion of shrubland to other land cover types without causing largescale fires are required.

4.3.6 Land cover and fire under different land management in 2014

Shrubland was prone to burning regardless of the type of land management or concession. In contrast, in peat swamp forests, fire occurrence was influenced by the type of land management and concession shown in Table 4.9. The percentage of burned forest was three times larger on lands under cultivation right (33.1%) than those under industrial forest plantations (8.9%). Conservation and regular production forests rarely faced fires, with only 1.3% and 3.2% burned, respectively.

Land management types affected fire occurrence in peat swamp forests. Conservation and regular production forests were less fire-prone than those under other land management types showing in Table 4.9, similar results were found in Kalimantan (Langner and Siegert, 2009). This was not due to differences in forest patch sizes because there were no differences in forest patches between different land management types (p = 0.22, ANOVA after log-transforming the area to meet normality of errors). This result is probably due to differences in law enforcement because the government prioritizes law enforcement in conservation and protected forests than other types of land management (Gaveau et al., 2009).

Table 4.9 Fire occurrence in peat swamp forests under different concession and land management

	(A) Non-burned area (ha)	(B) Burned area (ha)	The proportion of B to the total burned area (%)	(B/(A+B)) Percentage of burned area (%)
Concession types				
Cultivation right	27,539	13,655	11.5	33.1
Release of forest area	26,656	8,409	7.1	24.0
Industrial forest plantation	367,116	35,933	30.2	8.9
Outside concession	755,723	60,926	51.2	7.5
Land management types				
Non-forestland	43,426	18,839	16.2	30.3
Convertible production forest	113,606	35,163	30.3	23.6
Limited production forest	156,663	40,585	34.9	20.6
Protection forest	2,158	253	0.2	10.5
Regular production forest	642,364	21,291	18.3	3.2
Conservation forest	218,818	2,791	2.4	1.3

Land management and concession types affected fire occurrence in peat swamp forests

Concession types also affected fire occurrence in forests. Forests under cultivation rights were three times more prone to fire than forests under industrial forest plantations showing in Table 4.9. This difference may be due to the activities allowed under each concession type. Industrial forest plantations have a zero-burning policy (Pasaribu and Supena, 2008). Wood is a raw material for paper production, and the company will harvest wood from peat swamp forests and convert the forest to an acacia plantation. In contrast, in cultivation right areas, palm oil companies are not interested in wood harvesting, because obtaining permission for logging involves complex and costly procedures (Ekawati, 2013). Hence, forest burning is a simple and cheaper option for land clearing. Another difference between concession types may be the spatial arrangement of land cover types. Industrial forest plantations allocate peat swamp forests on one large landscape surrounded by acacia plantations (Gunawan et al., 2012). Consequently, access to these forests by smallholders may be prohibited. Conversely, forests under cultivation rights are more easily accessible by smallholders because the forest is adjacent to their cultivation area. These results suggest that governmental policies through law enforcement, spatial arrangement of land cover types, and various management schemes for land under different concession types are important factors related to peatland fires.

4.3.7 Landholders and fires in 2014

Even in areas with the same commodities (e.g., acacia and oil palm), the occurrence of burned areas differed among the types of landholders. Coconut plantations by companies were four times more prone to fire (8.4%) than coconut cultivation by smallholders (1.8%) shown in Table 4.10. Similarly, sago palm plantations by companies were four times more prone to fire (41.3%) than sago palm cultivation by smallholders (10.7%) shown in Table 4.11. Oil palm plantations by unregistered companies were more prone to fire (8.5%) than those by registered companies (3.3%) or smallholders (2.1%) showing in Table 4.12. Acacia plantations under cooperation between companies and smallholders were three times more prone to fire (21.8%) shown in Table 4.13 than acacia plantations controlled by a company (6.6%).

Table 4.10 Fire occurrence in coconut plantations by landholder type.

Landholder types	(A) Non-burned area (ha)	(B) Burned area (ha)	Proportion of B to the total burned area (%)	(B/(A+B)) Percentage of burned area (%)
Company	151,433	13,847.1	64.5	8.4
Smallholder	408,981	7,616	35.5	1.8

Table 4.11 Fire occurrence in sago palm plantations by landholder type.

Landholder types	(A) Non-burned area (ha)	(B) Burned area (ha)	Proportion of B to the total burned area (%)	(B/(A+B)) Percentage of burned area (%)
Company	12,569	8,858.0	60.1	41.3
Smallholder	49,084	5,877	39.9	10.7

Table 4.12 Fire occurrence in oil palm plantations by landholder type.

Landholder types	(A) Non-burned area (ha)	(B) Burned area (ha)	Proportion of B to the total burned area (%)	(B/(A+B)) Percentage of burned area (%)
Unregistered Company	155,592	14,396	57.6	8.5
Registered Company	315,107	10,605	42.4	3.3
Smallholder	215,581	4,553	31.6	2.1

Table 4.13 Fire occurrence in acacia plantations by landholder type.

Landholder types	(A) Non-burned area (ha)	(B) Burned area (ha)	Proportion of B to the total burned area (%)	(B/(A+B)) Percentage of burned area (%)
Cooperation company and smallholder	7,620	1,660	4.2	21.8
Company	537,120	37,973	95.8	6.6

Although previous studies focused on land cover types and neglected or only partly focused on landholders (Cattau et al. 2016; Gaveau et al. 2014), our results clearly demonstrated that, even with the same commodities, fire occurrence differs depending on landholders showing in Tables 4.10~4.13. In the case of acacia, plantations operated by cooperation between a company and smallholders were three times more prone to fire than those solely operated by the company shown in Table 4.13. Management by cooperation may be less intensive than management by company. In the cooperation area, land clearing and planting activities were carried out by the company, but after one year, acacia grows without treatment (Indonesian Working Group on Forest Finance, 2010). The company will only return when they harvest the acacia, therefore, the water table in the cooperation area might not be well maintained and fire risk increases.

In the case of oil palm, plantations operated by unregistered companies were more susceptible to fire compare to those by registered companies or smallholders shown in Table 4.12. The Indonesian government has a zero-burning policy; however, this policy is only effective on registered palm oil companies. It is difficult to implement the policy on unregistered palm oil companies. Oil palm plantations operated by companies that are not members of the Roundtable on Sustainable Palm Oil (RSPO) were more fire-prone than RSPO companies in Sumatra and Kalimantan (Cattau et al., 2016b). Unregistered oil palm companies use fire to reduce the cost of land clearing (Purnomo et al., 2017). Under El Niño conditions, fire originally intended for land preparation will become difficult to control and spread into the plantation (Murdiyarso and Adiningsih, 2007). Smallholders do not follow the zero-burning policy, but they usually manage their oil palm cultivation intensively (Stolle and Lambin, 2003).

Coconut and Sago cultivations by smallholders were less susceptible to fire than company plantations, as we predicted shown in Tables 4.10 and 4.11. Coconut cultivation by smallholders in Riau uses a shallow canal to dry peatland and uses tides to maintain soil moisture and provide nutrients to coconut palms (Notohadiprawiro, 1997). In contrast, industrial coconut plantations operated by a company use a deep canal to develop the plantation and do not use tides to maintain soil moisture. As a result, peatland may become drier, especially in a dry year. Similarly, sago cultivation by smallholders maintains wet conditions (Indonesia Climate Change Center, 2014). Rubber cultivation is planted by smallholders, and it was one of least-fire-prone land cover types showing in Table 4.7. Before the government developed industrial plantations in Riau, the local community developed coconut, sago palms, and rubber cultivation systems in peatland. These traditional cultivation systems could reduce peatland fires as well as providing economic benefits to the local community.

The extent of law enforcement and management schemes, especially the method landholders use to maintain soil water content, appear to be the factors that affect fire occurrences most, even considering the same commodities.

We could not identify landholders in shrublands through the use of remote sensing images and concession maps. Landholder mapping by a combination of remote sensing and ground surveying is necessary to effectively enforce zero-burning policies on landholders such as encroaching migrants and locals, unregistered companies, and acacia cooperatives. Furthermore, comparative sociological, economic, and ecological studies of management schemes by different landholders cultivating the same commodity are required for creating sustainable and fire-resistant production systems.

4.3.8 Proximity to roads and canals and fires in 2014

In shrubland, the percentage of burned areas gradually increased from 1 km to 10 km from the road showing in Figure 4.8, while it gradually decreased in the forest. Shrublands were prone to fire up to 4 km from the canal shown in Figure 4.9. Forest areas closer to the canal were more prone to fire.

Roads affected fire occurrence, but the pattern differed between peat swamp forests and shrubland showing in Figure 4.8. Forests near to roads were susceptible to fire. Road development makes forests more easily accessible by the community and migrants, and local communities claim land ownership by clearing forest with fire. Commonly, forest clearing was conducted adjacent to the roads because this makes transportation of agricultural products easier (Akbar, 2008). For shrubland, fires were used to exhibit land ownership, and as a result, fire occurrences were high for all distances from the road up to 10 km.

Canals can drain water and lower the water table within a distance of up to several kilometres, and thus vegetation becomes more susceptible to fire (Wösten et al., 2008). Even peat swamp forests became more susceptible to fire showing in Figure 4.9, which could be because drainage reduces forest soil moisture. Based on these findings, landscape planning considering proximity to roads and canals is needed.

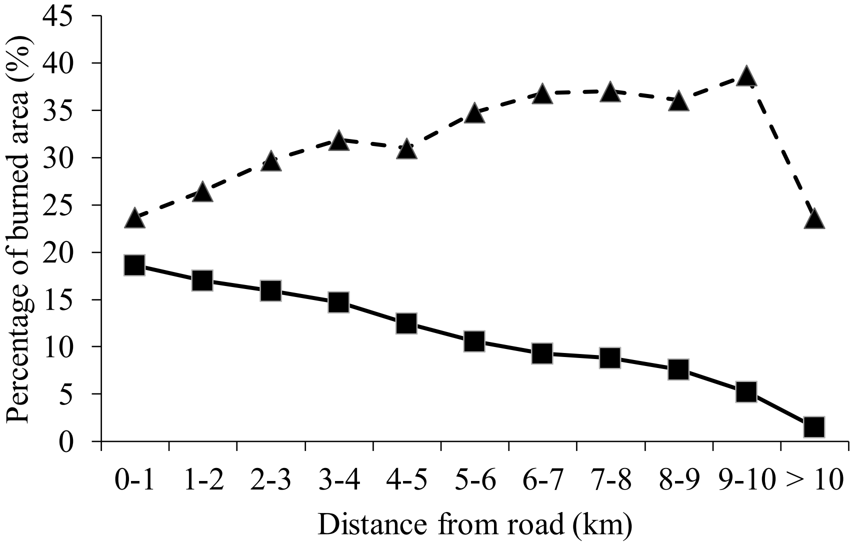


Figure 4.8 Burned area in relation to distance from roads in shrubland (triangle with dotted line) and in peat swamp forests (square with solid line)

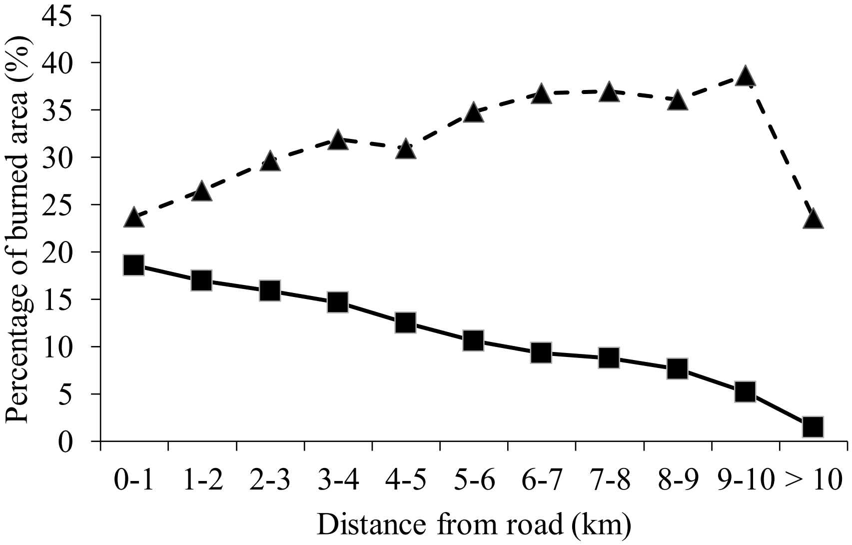


Figure 4.9 Burned area in relation to distance from canals in shrubland (triangle with dotted line) and in peat swamp forests (square with solid line)

4.4 Conclusion

Besides predisposing factors, such as climate and hydrology, peatland fires are affected by interactions between land type, land cover, land management systems, landholders, and proximity to roads and canals. Land type was the main factor that affected fire occurrence. In addition, land cover, land management systems, landholders, and proximity to roads and canals also affected fire occurrence. These results indicated the importance of peat swamp forest, sustainable plantation development, and land tenure to mitigate haze disaster. The fire distribution modelling can develop fire risk maps that can help government focus on high-risk areas. To fully understand the direct and indirect causes of peatland fires and develop integrated peatland management practices, further sociological, economic, and ecological studies on law and land management systems, management schemes by different landholders, and spatial arrangements of land cover, roads, and canals are needed.

Chapter 5. Woodland fires in Sumatra, in relation to climate and deforestation

5.1 Introduction

Historical records showed that tropical forest fires were prevalent in Indonesia, primarily due to traditional slash-and-burn agricultural practices in the last thousand years (Cochrane, 2003b). Fires have occurred in Kalimantan area since the 18th Century specially during drought periods (Aiken, 2004). However since the 1980s, the frequency of fires in Indonesia has increased in size and intensity. These fires were associated with the Indonesian Government's poor land development policy (Murdiyarso and Adiningsih, 2007). The most severe fire occurred in 1997–1998 and burned around 11.7 million hectares (Tacconi et al., 2007), majority of areas were lowland forests (31%), agricultural land (30%), and peat swamp forests (18%). The second most severe fire occurred in 2015 and burned around 2.6 million hectares, of which one-third of the area was peatland (Glauber and Gunawan, 2015). Among these crucial periods, there were other annual fires occurred at different intensities in Indonesia.

The destructive consequences of Indonesian fires were also observed in other Southeast Asian countries. These consequences include the negative impacts on environment and climate in which fires affected air quality and human health, caused deforestation, loss of biodiversity and global warming. In terms of economic consequences, fires had direct and indirect losses to agriculture, plantation, healthcare, transportation, trade, tourism, and education. Researchers have stated that the 1997-1998 fire loss was approximately US$ 20 billion (Varma, 2003), whereas the 2015 fire loss was approximately US$16 billion (Glauber and Gunawan, 2015). The last consequence of fires relates to diplomacy. Fires generate diplomatic crisis and weaken the integrity of the Indonesian government by frequently creating an image of lack of ability in dealing with catastrophic fires.

The causes of fires in Indonesia are quite complex (Dennis et al., 2005). Fires occur due to a combination of predisposing conditions and human ignition factors. Some of the predisposing conditions are low rainfall, deforestation, type of land cover, land management and peatland degradation. Human-induced fires can be intentional or unintentional fires. Some of the careless activities which cause fires include the poor disposal of cigarettes, uncontrolled campfires and other out of control fire activities.

The lack of rain is also a factor that increases the frequency and intensity of fires. This is caused by the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole Mode (IODM). This decrease in rainfall in Indonesia leads to severe droughts (Murdiyarso and Adiningsih, 2007). Two of the most severe fires were correlated with El Niño periods. Fire vulnerability increased in Kalimantan when rainfall do not occur for a period of just two weeks (Putra et al., 2008). Further, there is a significant negative correlation between the number of hotspots and lack of rainfall in Kalimantan (Yulianti and Hayasaka, 2013).

Among tropical countries, Indonesia has the highest prevalence of deforestation (Hansen et al., 2009). Some of the negative impacts include an increase of temperatures and reduction of soil moisture and rainfall. This enhances drought conditions and affects the regional climate (Feddema et al., 2005). Moreover, the peatland deforestation results in unstable water level conditions. This causes floods during the rainy season and fires during the dry season (Sumarga et al., 2016). Further, subsidence, carbon emissions, and peat oxidation (Hooijer et al., 2012) also occur. For example, Sumatra experienced rapid deforestation with a forest loss of around 3.4 million ha (24% of deforested area) from 2000 to 2010 (Miettinen et al., 2011b).

The type of land cover (e.g. plantation or forests) also affects fire intensity. Fires occurred most of the time in Riau's deforested areas, when compared to natural forests or industrial plantations (Gaveau et al., 2014). The sources of fire have altered from peat swamp forests to non-forest because of peatland drainage in Mega Rice Project (Hoscilo et al., 2011). Furthermore, fire also disturbed ecological succession in Riau, which result in creating large shrublands in post-fire sites (Haryati and Nakagoshi, 2013).

The cause of fire ignition is generally associated with land mismanagement which is partially regulated by land tenure (Suyanto, 2007). Small landholders are more secured against fire than those who are large landholders. This is because small landholders area is usually more intensively managed than large landholders area. Small landholder plantations mostly consist of mixed forest plantation, and may also include rubber, coconut, sago palm, and paddy fields. Large landholders plantations consist of monoculture crops of oil palm, acacia, and sago palm (Stolle et al., 2003). Small landholders and large landholders are responsible for fires in Riau. Furthermore, accessibility to peatland increased fire occurrences (Raharjo and Nakagoshi, 2014).

The utilization of fire to clear the land should be minimized, particularly during the drought period. This requires an understanding of a fire's location, predisposing conditions and possible causes. Although it is essential to highlight the main trends on a regional scale, generalization will lead to inconsistent, uncertain, and confusing results. This refers to the fire regime which is specific in various regions. For example, Northern Sumatra was more sensitive to short-lived fires when compared to Southern Sumatra and Southern Kalimantan

(Fanin and Werf, 2017). In Riau, major fire events are no longer restricted to drought years, which is different to other areas in Indonesia (Gaveau et al., 2014).

This study aimed to determine when, where, and why fires occur in Riau, Sumatra. This includes examining the climate and deforestation processes that affect the intensity and sizes of fires. Riau has the largest peatland area making it one of the most fire-prone provinces in Indonesia. Due to its location, Riau contributes significantly to haze pollution in Malaysia and Singapore. As a result, this study focuses on four key questions: (1) Is there any correlation between rainfall and fire occurrences? (2) When and for how long do severe fires occur? (3) Is industrial plantation a driving force of deforestation? and (4) Are land cover and land management types affecting fire activity?

5.2 Materials and methods

5.2.1 Study area

The Riau province is located in the center of Sumatra (2˚35'N - 0˚58'S, 100˚13'E - 103˚50'E). It has 8.9 million ha area with a total population of about 5.5 million and population density was 62 people per km^2 in 2010 (Statistics of Riau Province, 2015). This province has a diverse farmers (new and old settlers), land cover and land management practices.

Riau has experienced rapid deforestation in the last two decades (Margono et al., 2012). Before the industrial plantation period, Riau was covered by various types of natural forests. At present, Riau is the center for large-scale plantations of rubber, coconut, palm oil and acacia in Indonesia (Koizumi, 2016), and the remaining natural forests can be found mainly in remote areas.

5.2.2 Analyzing data of rainfall and hotspot

The data of Pekanbaru's rainfall was obtained from Meteorology, Climatology, and Geophysical Agency. The data on hotspots and rainfall from 2001 to 2016 were used to examine rainfall patterns and correlations between hotspots and rainfall. These data were analyzed using Person's correlation in SPSS Software. Based on this data, wet months are indicated when rainfall is more than 200 mm/month, while dry months are indicated by rainfall less than 100 mm/month (Fanin and Werf, 2017).

5.2.3 Processing hotspot data to estimate burned area and hotspot density

Burned areas were estimated based on a grid analysis of hotspot data 1 km^2. Grids without hotspots were assumed to be unburned while grids with at least one hotspot were assumed to have burned area of 70 ha (Ballhorn et al., 2009). The Riau boundary was used to make a grid of 1 km^2. We use MODIS hotspot data from 2001 to 2016, this data were downloaded via Fire Information for Resource Management System (FIRMS) (https://firms.modaps.eosdis.nasa.gov/download/create.php).

The hotspot density was used to examine fire activity in a land cover type. The hotspot density was calculated by dividing the number of hotspots in a land cover type and the area.

5.2.4 Classifying land cover of peatland

The peatland map from Wetland International and land cover map from Ministry of Environment and Forestry in 1990, 2000, 2004 and 2013 were overlaid to determine the land cover types of peatland. The polygons of land cover types were digitized on-screen by visual interpretation of moderate and high-resolution satellite imagery such as SPOT-5, IKONOS, and Qucikbird. This classification technique depend on image information such as color, size, shape, pattern, texture, association site, and tone. The Ministry of Environment and Forestry performed field observations to improve the classification accuracy up to 90% (Margono et al., 2012).

For the purpose of this study, 23 classes of the land cover maps from the Ministry of Environment and Forestry was reclassified into 11 classes. All forests in the peatland were considered as peat swamp forest. Non-forest areas, except plantation, paddy fields, and settlement, were categorized as shrubland. Plantation areas were divided into oil palm, acacia, coconut, sago palm, and rubber. The reclassification of land cover map used multiple LANDSAT images to reduce the area contaminated by clouds. The false Red, Green, and Blue (RGB) color to display LANDSAT image for visual interpretation were used.

To examine the rate of deforestation, the forest covers in 1990, 2000, 2004 and 2013 were compared. The forest cover in 2000 was used as a baseline data to compare the relationship between the land cover change, land management and fire. This is because there was no severe fires report in Riau before 2000 (Schultz et al., 2008).

5.2.5 Land management and concession

The concession and forest area maps were obtained from the Ministry of Environment and Forestry. According to Indonesian law, Riau is divided into protection forest (HL), conservation forest (HK), production forest, and non-forestland (APL). Three types of Production forest were limited production forest (HPT), regular production forest (HP), and convertible production forest (HPK).

The Indonesian government allocated concession areas based on the status of particular forest area. The non-forested land and convertible production forest were designed for agriculture (oil palm). Companies are able to develop plantation on HPK designated land, only after the HPK status has been changed to forest release area (KBN). Forest land (HP and HPT) was allocated for industrial forest plantation such as acacia.

5.2.6 Analyzing characteristic of Riau's population

The data of Riau's population was collected from statistics of Riau Province. The population data from 1990 to 2013 were used to predict the relationship between migration and hotspots occurrence. We classify migration as the movement of people with the purpose of settling in a new site through administrative boundaries (Statistics of Riau Province, 2015).

5.2.8 Map analysis and proximity analysis

ArcGIS 10.2 was used to determine the relationship among land cover change, fires, and land management. Buffer analysis in ArcGIS 10.2 was used to examine the effect of proximity from forest to number of hotspots. The buffer area was created every 1 km up to 5 km.

5.3 Results and discussion

5.3.1 Relationship between rainfall and hotspot

Riau's number of hotspots has fluctuated from 2001 to 2016 following the trend in monthly rainfall. The high amount of rainfall reduced the number of hotspots. Riau has a bi-modal rainfall pattern with peaks in September to January and in April to May showing in Figure 5.1. This rainfall pattern is less sensitive to sea surface temperature anomalies than other fire-prone provinces (Aldrian and Susanto, 2003). The annual mean rainfall and monthly mean rainfall was 2,782 mm and 234 mm, shown in Figures 5.1 and 5.2 respectively.

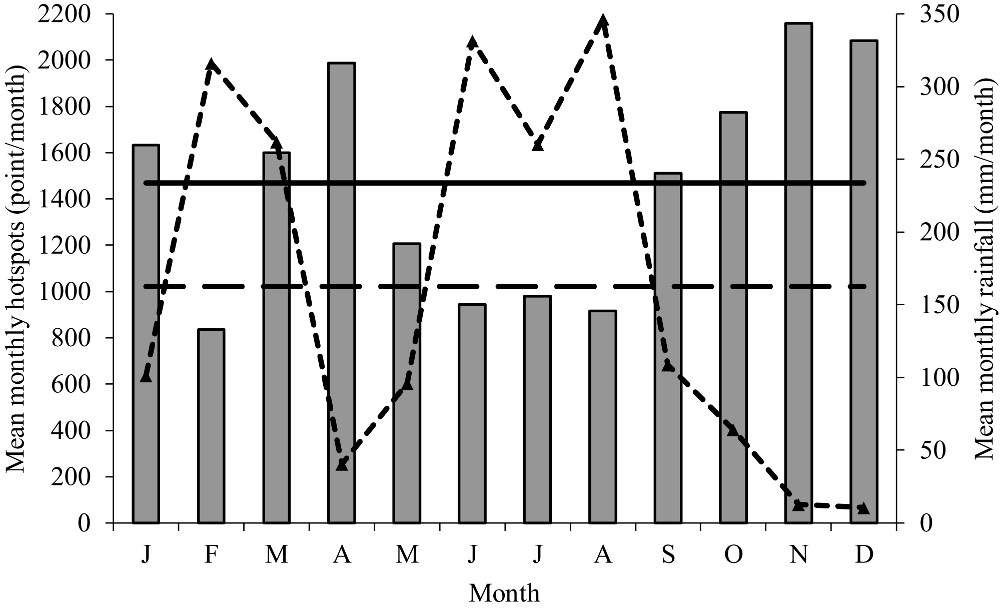


Figure 5.1 Monthly mean hotspot (triangle with dashed line), monthly mean rainfall (black bar), annual mean monthly hotspot (dashed line) and annual mean monthly rainfall (solid line) from 2001 to 2016

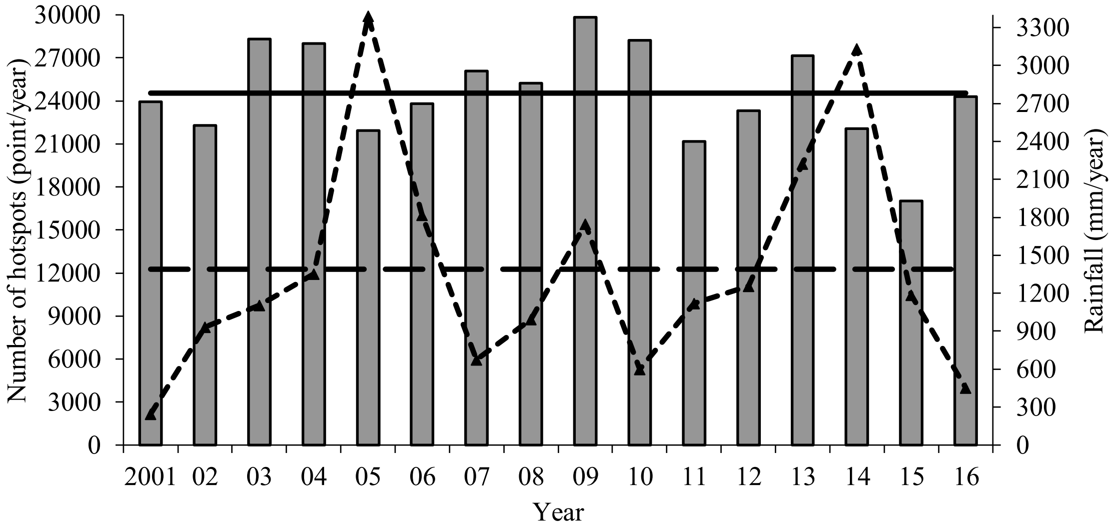


Figure 5.2 Annual hotspot (triangle with dashed line), annual rainfall (black bar), annual mean hotspot (dashed line), and annual mean rainfall (solid line) from 2001 to 2016

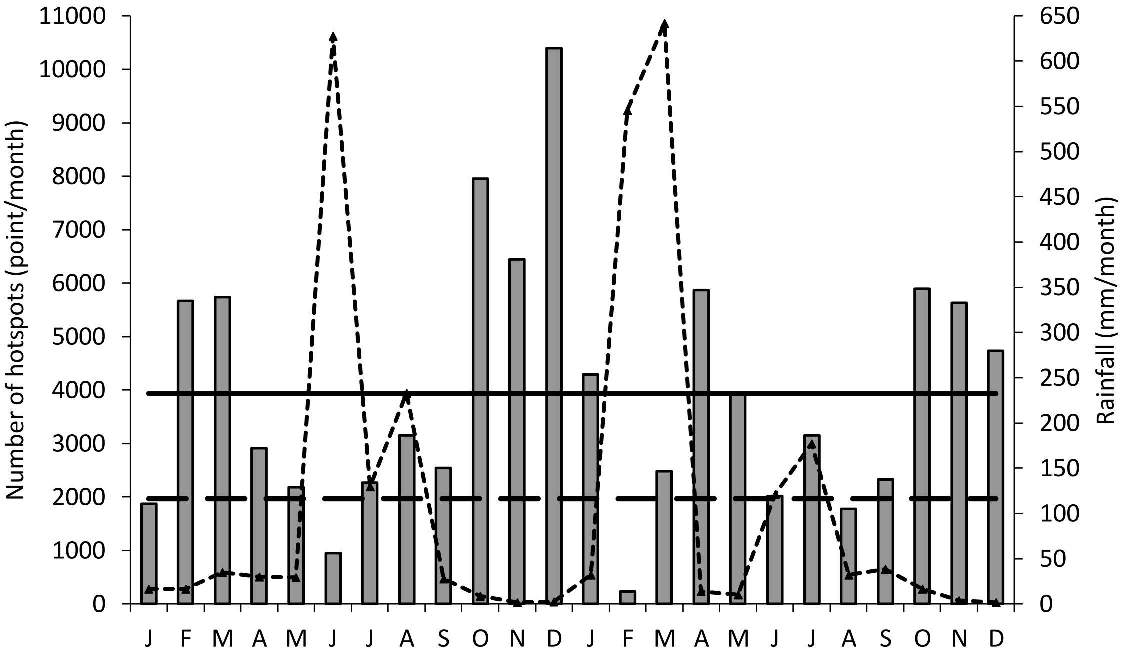


Figure 5.3 Monthly hotspot (triangle with dashed line), monthly rainfall (black bar), mean monthly hotspot (dashed line) and mean monthly rainfall (solid line) in 2013 and 2014

The major fires that occurred in Riau in 2005, 2006, 2009, 2013 and 2014 shown in Figures 5.2 and 5.3 happened during brief dry spells. This dry spell occurred for less than two months between February to March or June to August is given in Figure 5.1. High fire activities occurred when rainfall was less than 160 mm/month and rainy days were less than 15 days/month showing in Table 5.1. Nevertheless, major fires in 2009 and 2013 were an anomaly as they occurred in years of above annual mean rainfall showing in Figure 5.2. The correlation between hotspots and rainfall was strong, with r^2 = -0.45 to -0.77 shown in Table 5.1 and p-value less than 0.05. Riau has an annual mean of 12,263 hotspots and a monthly mean hotspot 1.022 points showing in Figures 5.1 and 5.2.

There is a negative correlation between rainfall and hotspot in Riau from 2001 to 2016. Major fires events occurred in brief dry spells. It was expected that more frequent fires events in the future (Gaveau et al., 2014) will continue as deforestation, high temperature (Fernandes et al., 2017), and reduction of rainfall also continue in Sumatra (Iskandar et al., 2011). The instance of brief drought (Yulianti and Hayasaka, 2013) posed a challenge to predict major fire occurrences in the future.

As this study relied on MODIS hotspot data, the fire condition before MODIS era cannot be compared. Moreover, the detection of small fires requires the use of high-resolution satellite technology, which is difficult to detect by MODIS satellite.

Table 5.1 Maximum monthly hotspot (B), monthly rainfall (C), and monthly rainy days (D) from 2001 to 2016

YEAR	(A) Month	(B) Hotspot (point)	(C) Rainfall (mm)	(D) Day	Correlation B to C	Correlation B to D	R^2
2001	7	1,076	88	7	-0.44	-0.69	0.49
2002	2	2,096	24	4	-0.70	-0.72	0.53
2003	6	4,207	106	7	-0.64	-0.78	0.61
2004	6	4,187	151	5	-0.55	-0.81	0.75
2005	2	8,986	39	6	-0.72	-0.81	0.66
2006	8	4,719	63	6	-0.68	-0.86	0.75
2007	2	1,066	151	10	-0.43	-0.62	0.42
2008	8	3,175	155	11	-0.57	-0.65	0.43
2009	7	3,527	75	8	-0.73	-0.74	0.56
2010	10	1,965	82	8	-0.60	-0.70	0.50
2011	7	2,616	26	6	-0.62	-0.88	0.77
2012	8	3,317	97	12	-0.52	-0.73	0.53
2013	6	10,621	56	7	-0.48	-0.67	0.49
2014	3	10,860	147	6	-0.61	-0.73	0.54
2015	7	3,106	14	3	-0.53	-0.76	0.60
2016	8	1,428	44	7	-0.54	-0.67	0.45

Pearson's correlation was calculated with $p < 0.05$. Source: Rainfall and MODIS hotspot

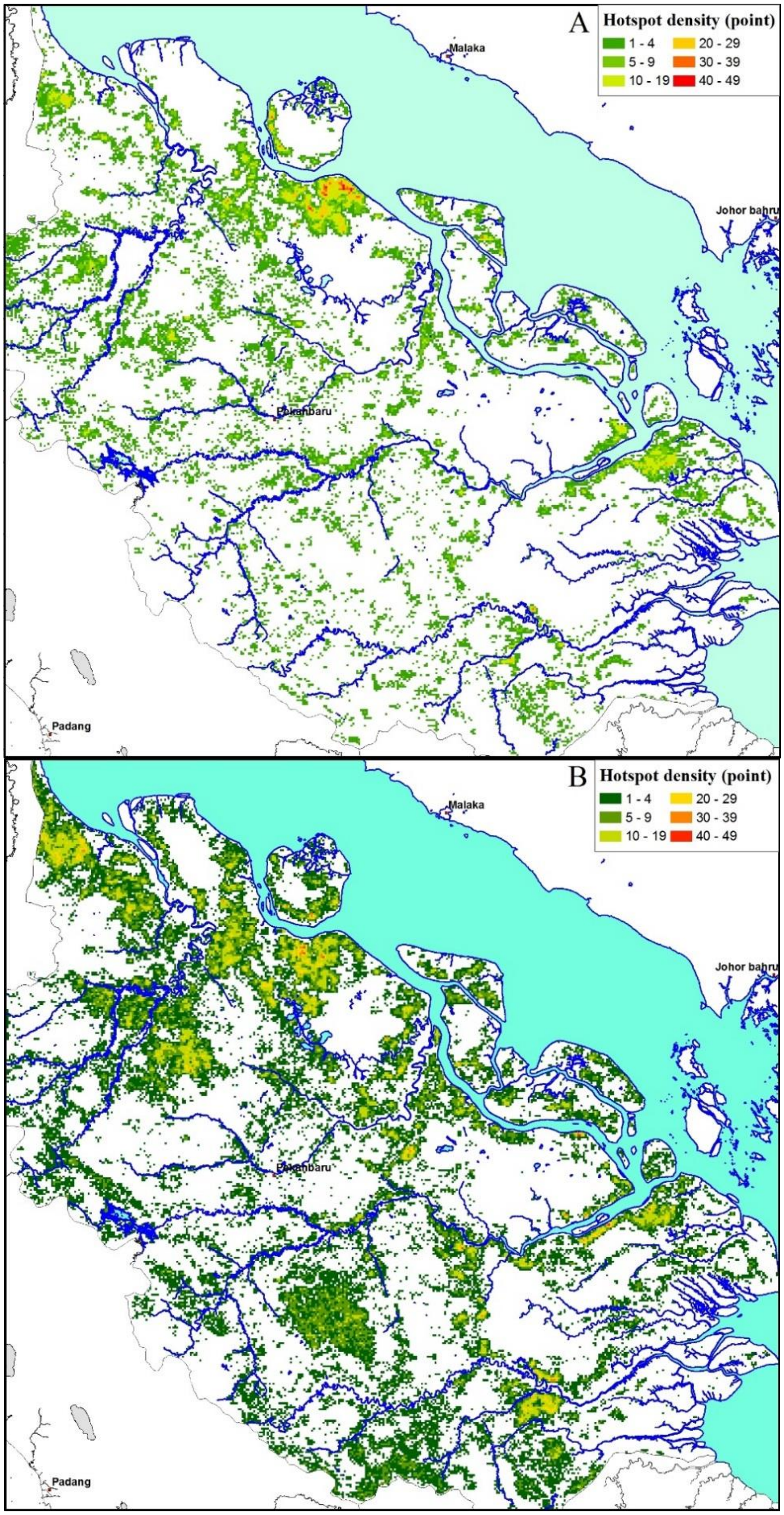


Figure 5.4 Number of hotspot per 1 km^2 in 2001 to 2005 (A) and in 2006 to 2014 (B)

5.3.2 Burned area and fires density

The total burned area in Riau increased almost two times from 1.1 million ha in 2001 to 2005 to 2 million ha in 2006 to 2014 shown in Table 5.2 and Figure 5.4. Half of the burned area in 2001 to 2005 was burned again in 2006 to 2014, so it can be assumed that the areas may not have been well managed. Fire density in the same location was low as the majority of grid cells have less than five hotspots through 2001 to 2014.

Riau has a high number of peatland fires (68%), which have occurred from 2001 to 2016 showing in Figure 5.5. The proportion of fires were high in 2005 (76%), 2013 (71%), 2014 (88%), and 2016 (77%). Therefore, the relationship between deforestation of peatland and fire in these areas was given focus.

Table 5.2 Number of hotspot per 1 km^2 grid from 2001 to 2014

Hotspot number in grid	Number of grid	
(point)	(A) 2001 to 2005	(B) 2006 to 2014
1 – 4	13,334	21,457
5 – 9	1,766	5,394
10 – 19	811	2,588
20 – 29	184	394
30 – 39	33	35
40 – 49	10	8
Total	16,138	29,876
Area	1,123,438	2,081,029
Overlap between A and B (Ha)		617,666

Source: MODIS hotspot and 1 km^2 grid map

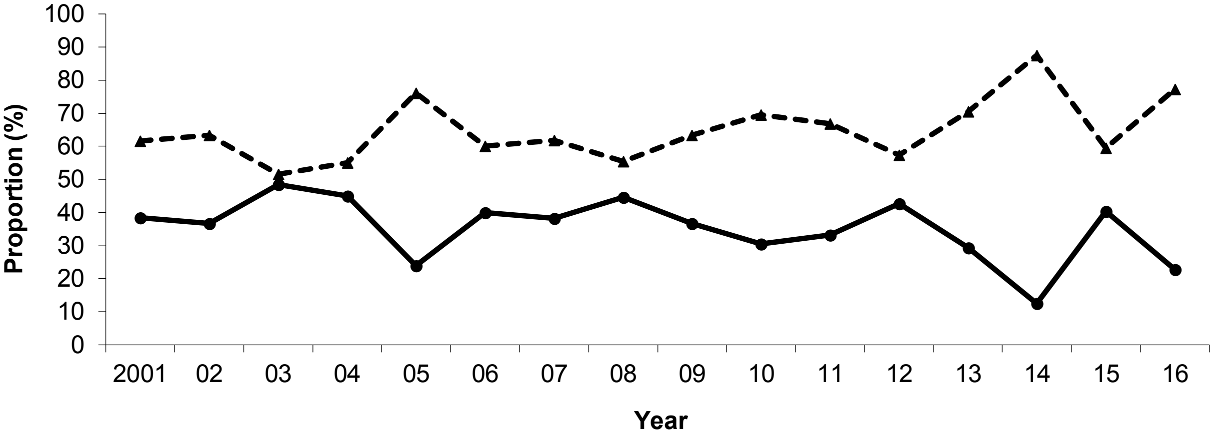


Figure 5.5 Proportion of fire in peatland from 2001 to 2016.
Peatland (triangle with dashed line) and mineral land (circle with solid line)

Fires typically occurred in peatland areas. Shrublands were observed to be more prone to fires and this land cover type increases rapidly. Land burning has become a source of profit for local elites (Purnomo et al., 2017). This is due to high demand for land by small farmers from North Sumatra (Koizumi, 2016). This condition leads to ineffective zero burning policy in Riau as the small landholders continue to use fire for land clearing. Hence, there is a need for total ban on the use of fires for all landholders.

Fire is concentrated in peatland because the low water level during drought spell induces fire in peatland. Fires start when the water table is more than 20 cm below ground surface (Putra et al., 2008), which usually start after 11 days without rain. Results of this study suggest that fire management should focus more on monitoring the climate and fire occurrences in drought period to develop an early warning system.

5.3.3 Peatland deforestation and concession area

Riau experienced rapid deforestation from 1990 to 2013. Before the deforestation, logging concession companies managed most of the peatland areas (78% of 4 Mha) in 1990. Over the past 23 years, the percentage of peat swamp forest declined rapidly from 81% in

1990 to 28% in 2013 shown in Table 5.3. More than two-thirds (2.1 million ha) of peat swamp forests was lost from 1990 to 2013. The annual deforestation rate has increased to almost double from 2.4% in 1990's to 4.2% in 2000 to 2013. At the same time, concession areas of industrial plantations have increased significantly from 1% in 1990 to nearly half of peatlands in 2013.

The land cover change of peat swamp forest from 2000 to 2013 was investigated shown in Figure 5.6. Most of the peat swamp forests (1,345,732 ha) were converted into acacia plantation (491,175 ha), shrubland (533,082 ha), and oil palm plantation (287,222 ha) showing in Table 5.4. A land cover change matrix was used to analyze the rate and direction of land cover change. The deforested areas (366,757 ha) from 2000 to 2004 were converted to acacia plantations (189,302 ha), shrubland (125,151 ha), and oil palm plantations (34,598 ha). From 2004 to 2013, the deforested areas (978,975 ha) were converted to shrubland (462,608 ha), acacia plantations (291,261 ha), and oil palm plantations (207,334 ha). On the contrary, we detect only 54,304 ha of the shrubland in 2004 was converted to industrial plantation while the remaining area (70,474 ha) remained as shrubland until 2013.

Table 5.3 Forest cover and concession area in peatland from 1990 to 2013

Year	Area (ha)	Percentage (%)	Change
Forest			(2,135,344)
1990	3,281,944	81	-
2000	2,492,331	62	(789,613)
2004	2,125,574	53	(366,757)
2013	1,146,599	28	(978,975)
Concession			1,886,108
1990	59,644	1	-
2000	1,061,595	26	1,001,951
2004	1,288,333	32	226,738
2013	1,945,752	48	657,418

Numbers in parentheses represent losses.

Source: Concession boundary and LANDSAT imagery from 1990 to 2013

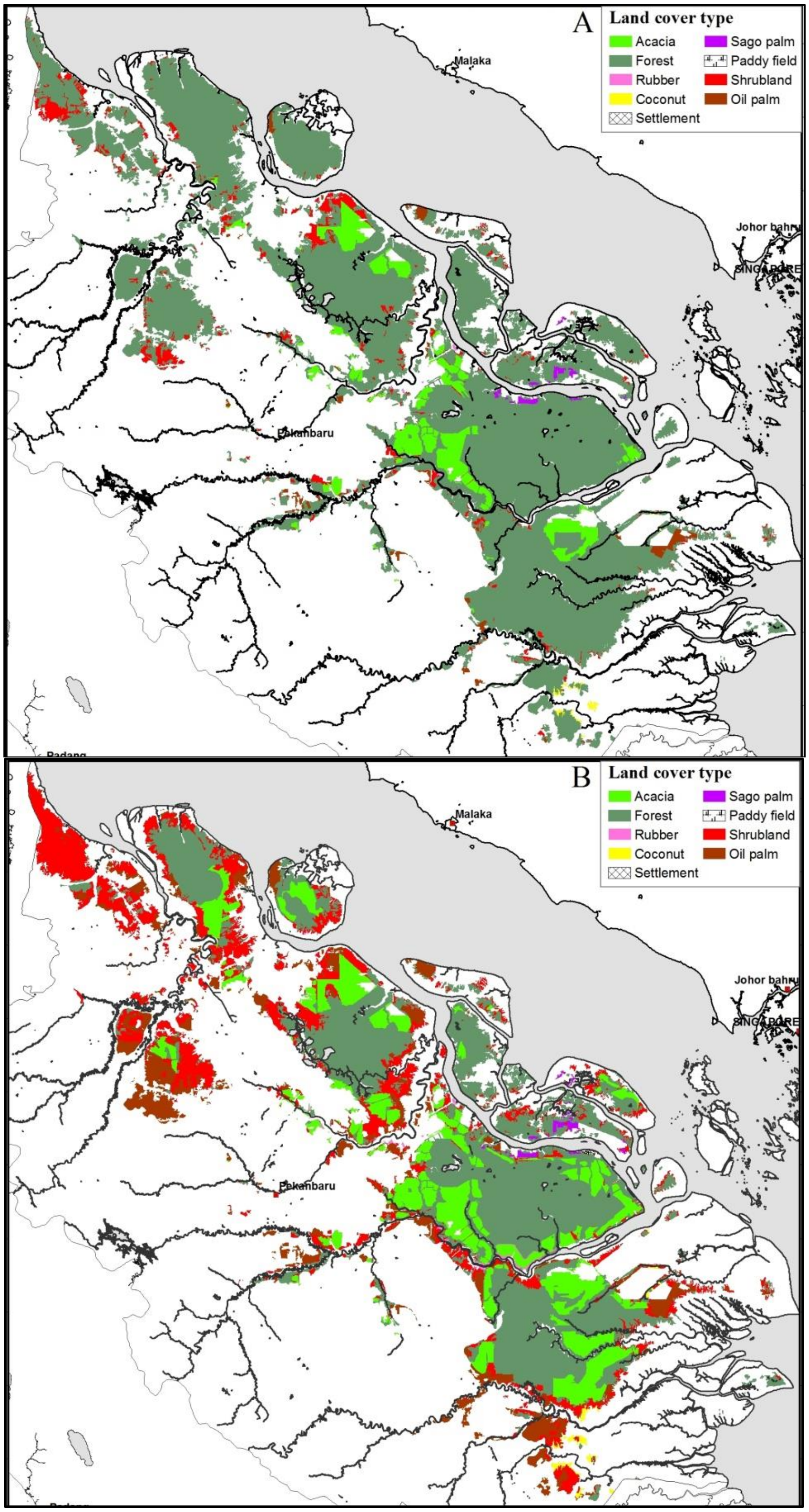


Figure 5.6 Deforestation of peat swamp forest in 2004 (A) and in 2013 (B). Peat swamp forest in 2000 was used as a starting point

It is assumed that deforestation is always connected to concession companies. To examine this assumption, the land cover change in concession area was observed. The percentage of forests reduced sharply in concession area from 2004 to 2013 showing in Table 5.5, while the percentage of plantations increased in the concession area. The percentage of acacia plantations in industrial forest plantation concession increased from 33% in 2004 to 45% in 2013. Similarly, the percentage of oil palm plantation in forest release area concession also increased from 7% in 2004 to 41% in 2013. However, release of forest area has the percentage of shrubland three times higher (39%) than shrubland under industrial forest plantation (13%).

Table 5.4 Land cover change matrix from 2004 to 2013

Land cover 2004	Land cover 2013									
	Ac	Fr	Rb	Cc	St	Sp	Pf	Op	Sh	Total
Acacia (Ac)	189,302	0	0	0	0	0	0	0	0	189,302
Forest (Fr)	291,261	1,146,599	6,545	6,451	39	3,842	885	207,344	462,608	2,125,574
Rubber (Rb)	0	0	1,932	0	0	0	0	0	0	1,932
Coconut (Cc)	0	0	0	4,795	0	0	0	547	0	5,342
Settlement (St)	0	0	0	0	0	0	0	0	0	0
Sago palm (Sp)	71	0	0	0	0	9,391	0	971	0	10,433
Paddy field (Pf)	0	0	0	0	0	0	0	0	0	0
Oil palm (Op)	91	0	0	0	0	0	0	34,507	0	34,598
Shrubland (Sh)	10,450	0	0	373	0	0	0	43,854	70,474	125,151
Total	491,175	1,146,599	8,478	11,619	39	13,233	885	287,222	533,082	2,492,331
Change 04-13	301,874	(978,975)	6,545	6,277	39	2,799	885	252,625	407,931	
Change (%)	17.7	-5.1	37.6	13.1		3.0	0.0	81.1	36.2	

Most of land cover change located in the forest. Peat swamp forest in 2000 (2,492,331 ha) was used as a starting point. Source: LANDSAT imagery from 2004 to 2013

Although the Indonesian Government has regulated plantation areas according to land management, the land discrepancy between land occupancy and land management is still a common problem in Indonesia. One-third of oil palm plantations were found to be located outside the designated area, 33% in 2004 and 37% in 2013 shown in Figure 5.7.

Table 5.5 Change of forest cover in concession area from 2004 to 2013

Concession type	2004 (ha)	Percentage (%)	2013 (ha)	Percentage (%)
Industrial forest plantation				
Acacia	183,066	33.5	484,470	45.1
Forest	338,045	61.9	401,451	37.3
Rubber	40	0	4,619	0.4
Coconut	0	0	2,043	0.2
Settlement	0	0	0	0
Sago palm	3,607	0.7	5,256	0.5
Paddy field	0	0	47	0
Oil palm	3,863	0.7	34,962	3.3
Shrubland	17,221	3.2	142,275	13.2
Total	545,842		1,075,123	
Release of forest area				
Acacia	752	0.3	1,988	0.7
Forest	174,982	75.8	40,798	15
Rubber	1,287	0.6	1,958	0.7
Coconut	2,057	0.9	4,907	1.8
Settlement	0	0	28	0
Sago palm	897	0.4	4,077	1.5
Paddy field	0	0	130	0
Oil palm	16,412	7.1	111,276	40.9
Shrubland	34,404	14.9	107,024	39.3
Total	230,791		272,185	

Riau has experienced rapid deforestation due to conversion to industrial plantation and shrubland. The industrial plantation is usually criticized as reason for deforestation (Wilcove et al., 2013). Nonetheless, based on land cover change data, less than half of the concession area was planted. In recent years, the percentage of shrubland in deforestation areas increased faster than the percentage of industrial plantation. This data was in line with the previous study where only 34% of deforested areas during 1990's were converted to plantations by 2008, while more than 40% remained unmanaged and dominated by shrubland (Miettinen et al., 2012c) . In addition, oil palm was also planted outside designated areas (Galudra et al., 2014). For effectiveness of land management policy, the government should focus on shrublands management and conservation of peat swamp forest.

The sustainability of peatland development for plantation areas must be considered. The peatland functions will disappear due to the reduction of water level for crop productivity. Moreover, the majority of peatlands are located in lowland areas near the sea level where soils are highly acidic. It is unclear how long would the industrial plantation activity can sustain the peatland to prevent flooding due to land subsidence (Hooijer et al., 2012). The responsible plantation techniques and adaptive plant under wet conditions are needed to overcome the long-term issues such as carbon emission, fires and land subsidence.

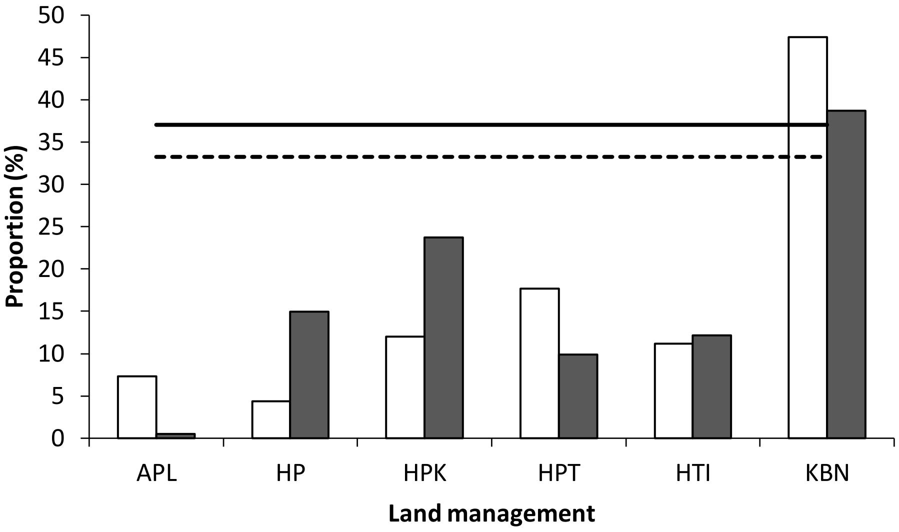


Figure 5.7 Oil palm plantation base on land management in 2004 (hollow bar) and 2013 (black bar).

Percentage of oil palm plantation outside designated area in 2004 (dashed line), and outside designated area in 2013 (solid line). APL: non-forestland; HL: protection forests; HP: regular production forest; HPK: convertible production forests; HPT: limited production forests; HTI: industrial forest plantation; HK: conservation forests; and KBN: release of forest area

5.3.4 The relationship between land cover, land management, and fires activities

The land cover and land management policies affect fire activity. Most of hotspots were detected in shrublands, forests, acacia plantations and oil palm plantations showing in Tables 5.6 and 5.7. The percentage of hotspots in shrublands and oil palm plantations was higher in the 2006 to 2014 period than in 2001 to 2005. On the contrary, the percentage of hotspots in acacia plantations and forests occurred less frequently in 2006-2014 when compared to those that occurred during 2001 to 2005. The hotspot density in shrublands was high, while the hotspot density in the forests was low.

The protected areas (conservation forest and protection forest) had the least number of hotspots density compared to other areas with different land management types shown in

Tables 5.6 and 5.7, while the highest hotspot densities were found in concession areas (e.g., industrial forest plantation and release of forest area) from 2001 to 2005 showing in Table 5.6. Recently, fire activity tends to be high in nonconcession areas which are unprotected. As a result, limited production forest and convertible production forest had higher hotspot density than other land management types in 2006 to 2014 showing in Table 5.7.

Table 5.6 Land cover, land management, hotspot number, hotspot density, and burned area from 2001 to 2005

Type	Hotspot number (point)	(%)	Area (Ha)	Density / km²	Burned area (Ha)	(%)	% of burned area
Land cover							
Acacia	4,141	21.1	189,302	2.2	46,409	16.9	24.5
Forest	6,015	30.7	2,125,574	0.3	147,676	53.9	6.9
Rubber	29	0.1	1,932	1.5	626	0.2	32.4
Coconut	99	0.5	5,342	1.9	1,734	0.6	32.5
Sago palm	47	0.2	10,433	0.5	1,330	0.5	12.7
Oil palm	1000	5.1	34,598	2.9	12,804	4.7	37
Shrubland	8,255	42.1	125,151	6.6	63,439	23.2	50.7
Total	19,586				274,018		
Land management							
APL	491	2.5	43,800	1.1	6,603	2.4	15.1
HL	1	0.0	2,485	0.0	103	0.0	4.1
HP	3,450	17.6	794,304	0.4	41,880	15.3	5.3
HPK	1,819	9.3	270,793	0.7	40,733	14.9	15.0
HPT	2,605	13.3	394,750	0.7	42,841	15.6	10.9
HTI	7,029	35.9	545,842	1.3	90,820	33.1	16.6
HK	93	0.5	209,566	0.0	2,387	0.9	1.1
KBN	4,098	20.9	230,791	1.8	48,650	17.8	21.1
Total	19,586				274,018		

APL: non-forestland; HL: protection forests; HP: regular production forest; HPK: convertible production forests; HPT: limited production forests; HTI: industrial forest plantation; HK: conservation forests; and KBN: release of forest area. Source: Concession boundary, MODIS hotspot, and LANDSAT imagery from 2001 to 2005

In Riau, fire intensity has increased, and fires have moved from peat swamp forests to shrublands. During the study period, the total burned area increased almost three times, from 274,018 Ha in 2001 to 2005 showing in Table 5.6 to 747,743 Ha in 2006 to 2014 shown in Table 5.7. In the first period, peat swamp forests have the largest percentage of burned area (53.9%) shown in Table 5.6. However, in the next period after the forest was lost, the shrublands became the largest burned area (43.4%) showing in Table 5.7. Majority of these fires occurred within 5 km away from the forest edge shown in Table 5.8. In 2006 to 2014, Rokan Hilir, Rokan Hulu, and Dumai have the highest hotspot densities showing in Table 5.9.

Table 5.7 Land management, land management, hotspot, density, and burned area from 2006 to 2014.

Type	Hotspot number (point)	(%)	Area (Ha)	Density / km^2	Burned area (Ha)	(%)	% of burned area (ha)
Land cover							
Acacia	6,885	11.0	491,175	1.4	138,051	18.5	28.1
Forest	5,439	8.7	1,146,599	0.5	125,180	16.7	10.9
Rubber	88	0.1	8,478	1.0	2,247	0.3	26.5
Coconut	255	0.4	11,619	2.2	5,324	0.7	45.8
Settlement	0	0.0	39	1082.8	0	0.0	1.2
Sago palm	421	0.7	13,233	1.6	5,681	0.8	42.9
Paddy field	214	0.3	885	253.0	616	0.1	69.7
Oil palm	12,473	19.8	287,222	3.6		19.5	50.8
Shrubland	37,099	59.0	533,082	7.0	324,722	43.4	60.9
Total	62,874				747,743		
Land management							
APL	56	0.1	1,772	3.2	960	0.1	54.2
HL	23	0.0	1,630	1.4	492	0.1	30.2
HP	9,587	15.2	468,397	2.0	97,964	13.1	20.9
HPK	10,252	16.3	247,099	4.1	108,128	14.5	43.8
HPT	10,100	16.0	219,153	4.6	96,769	12.9	44.2
HTI	21,538	34.2	1,075,123	2.0	293,653	39.3	27.3
HK	874	1.4	206,973	0.4	13,887	1.9	6.7
KBN	10,444	16.7	272,185	3.9	135,889	18.2	49.9
Total	62,874				747,743		

APL: non-forestland; HL: protection forests; HP: regular production forest; HPK: convertible production forests; HPT: limited production forests; HTI: industrial forest plantation; HK: conservation forests; and KBN: release of forest area

Source: Concession boundary, MODIS hotspot, and LANDSAT imagery from 2006 to 2014

Table 5.8 Hotspot number within 5 km from forest edge

Distance (Km)	2001 - 2005 (point)	(%)	2006 - 2014 (point)	(%)
1	7,158	36.5	13892	22.1
2	3,247	16.6	9737	15.5
3	1,803	9.2	6269	10.0
4	953	4.9	4931	7.8
5	271	1.4	4146	6.6
Outside 5 km	6,154	31.4	23899	38.0
Total	19,586		62,874	

Source: MODIS hotspot and 1 km^2 grid map

Table 5.9 Hotspot density per regency from 2001 to 2014

Regency	Hotspot (point)	Area (Ha)	Density in 2001-2005 (Km^2)	Density in 2006-2014 (Km^2)
Bengkalis	8,111	401,569	2.0	3.2
Dumai	2,584	118,200	2.2	4.0
Indragiri Hilir	498	314,307	0.2	1.3
Indragiri Hulu	527	199,920	0.3	1.8
Kampar	890	44,468	2.0	1.8
Meranti	587	182,250	0.3	1.3
Pekanbaru	3	296	1.0	1.4
Pelalawan	2,003	567,013	0.4	1.1
Rokan Hilir	3,016	297,267	1.0	5.6
Rokan Hulu	86	45,122	0.2	4.8
Siak	1,281	321,918	0.4	2.9
Total	19,586	2,492,331		

Source: MODIS hotspot and regency boundary

Shrublands were the most fire-prone land cover type while forest was the least fire-prone land cover type. This result supports previous studies that have focused on Southeast Asia (Miettinen et al., 2017). In particular, those studies have also highlighted the relationship between the type of land cover and fire. For example, severely burned deforested peatland areas in 2015 in Central Kalimantan and South Sumatra were shrubland (Miettinen et al., 2017). Shrublands are dominated by fire-prone species and recovered vegetation after fire or land clearing. The combination of the use of fire for land preparation and fire-prone vegetation causes shrublands to become the most frequently burned land cover type.

It seems that the zero burning policy was more effective on acacia plantations than oil palm plantation. This effectiveness was indicated by decreasing the hotspot density on acacia plantation while hotspot density on oil palm plantations increased. In Jambi, 20% of burned areas were converted to industrial forest plantations and 27% of burned areas were converted to oil palm plantations (Prasetyo et al., 2016). It might be because the acacia plantation is only managed by a registered company (Obidzinski and Dermawan, 2012), while some parts of the oil palm plantations are managed by unregistered company (Fitzherbert et al., 2008). The unregistered companies use fire for land clearing in Riau in 2006 (Miettinen and Liew, 2009). Furthermore, another study stated that registered companies that have Roundtable on Sustainable Palm Oil (RSPO) certificate has a low hotspot occurrence in Sumatra and Kalimantan (Cattau et al., 2016b).

The protected areas (conservation forest and protection forest) have the lowest hotspot density than other land management types (Langner and Siegert, 2009). It is possibly due to law enforcement by the government (Gaveau et al., 2009). Sources of fire moved from peat swamp forest to deforested area (Miettinen et al., 2017), and most of the fires occurred within

5 km away from the forest edge in Kalimantan (Langner et al., 2007). This pattern of fires indicated the expansion of oil palm plantation towards the forest area.

Intact peat swamp forests are poorly drained and waterlogged throughout the year. Moreover, forest canopy prevents sunlight directly reaching the soil surface. As a consequence, it is difficult to burn. Only a few burned intact forests are present in Kalimantan, 6% and 0.1% in 2002 and 2005, respectively (Langner et al. 2007). Similar in Sumatra, only 0.7% of burned intact forests and 3.8% of burned logged-over forests in Jambi in 1993 (Stolle et al. 2003). However, fire in peat swamp forest can increase due to the peatland drainage (Hoscilo et al., 2011).

All recent results recommend that the Indonesian Government should focus on shrublands and unregistered company to prevent fire. Technical and financial support is strongly required for the restoration of shrublands into forest or other vegetation with minimum fire risk.

Table 5.10 Land cover after fire

Land cover	Land cover 2013									
2004	Ac	Fr	Rb	Cc	St	Sp	Pf	Op	Sh	Total
Acacia (Ac)	46,409	0	0	0	0	0	0	0	0	46,409
Forest (Fr)	14,826	33,867	236	976	27	925	545	29,706	66,568	147,676
Rubber (Rb)	626	0	0	0	0	0	0	0	0	626
Coconut (Cc)	0	0	0	1,556	0	0	0	178	0	1,734
Settlement (St)	0	0	0	0	0	0	0	0	0	0
Sago palm (Sp)	0	0	0	0	0	978	0	352	0	1,330
Paddy field (Pf)	0	0	0	0	0	0	0	0	0	0
Oil palm (Op)	37	0	0	0	0	0	0	12,767	0	12,804
Shrubland (Sh)	6,138	0	0	39	0	0	0	22,830	34,433	63,439
Total	68,036	33,867	236	2,570	27	1,903	545	65,833	101,001	274,018
Change04-13	21,627	(113,809)	(390)	837	27	573	545	53,029	37,561	
Change (%)	5.2	(8.6)	(6.9)	5.4	0	4.8	0	46.0	6.6	

The land cover change after fire depended on the land cover types.

Source: MODIS hotspot, 1 km^2 grid map, and LANDSAT imagery from 2004 to 2013

5.3.5 Vegetation after fire

The land cover change after fire depended on the land cover types. It seems that fire results in land cover change in unmanaged land (forest and shrubland). On the other hand, fire did not result in land cover change in managed land (acacia plantations and oil palm plantations). After the fires that occurred in 2004, burned forest areas were changed to acacia and oil palm plantations with 10% and 20% change, respectively and the remaining area (45%) became shrubland until 2013. Burned shrublands were also cultivated and now contains oil palm and acacia (46%). On the other hand, no land cover changed in plantations after fire showing in Table 5.10.

5.3.6 Characteristic of Riau's population

Within the three decades, Riau's population has increased sharply from 1.7 million in 1980 to 5.5 million in 2010. The population growth was 56% between 1980 and 1990, 44% between 1990 and 2000, and 42% between 2000 and 2010. This rapid increase is a result of natural population growth and migration from other provinces. Based on population census in 2010, 41% of the population was categorized as migrants.

Agriculture is an important livelihood for Riau people as majority of the population in Riau live in rural areas (61%). Based on the agricultural census in 2013, 44% of Riau's households were farmers (581,517 of 1,328,461). Oil palm was the major crop cultivated by the farmers (70%). The number of household farmers increased by 7% (from 541,050 to 581,517) from 2003 to 2013. Most of the increases were in the regency of Rokan Hulu, Rokan Hilir, and Bengkalis. These increases may result in high hotspot density in those regencies shown in Table 5.9.

Many migrant farmers looking for land may have affected the high hotspot density in certain regencies in Riau. The coming of migrant farmers appear to increase in the land fire occurrences (Ekadinata et al., 2013). For example, the area that was developed by farmers were the major sources of fire in Riau. Furthermore, migrant farmer groups obtained enormous advantage from land fires (Purnomo et al., 2017). Law enforcement and land policy should consider these migrant farmer groups to successfully reduce fire at ground level.

5.4 Conclusion

These results highlight the important effect of climate anomalies, rapid deforestation, migrant farmer, and land management on fire activities in Indonesia. Drought is a pre-condition that promotes fire in Riau. Based on average data, the fires were short-lived and typically occur between February to March and June to August. The frequency and area of fires in this area are increasing due to continuing deforestation, migration, and land burning. Afterwards, land cover type and land management type further affect fire activity. Shrubland was the target of land burning and the fires spread into surrounding areas. The cause of fire is complex because the deforested area is predominantly shrubland. To achieve effective fire management, landscape management involving all stakeholders will be required as peatland fire is a multi-dimensional issue. Future studies should focus on adaptive crops under wet conditions, land clearing without fire, land tenure, community engagement, and alternative livelihoods for community members.

Chapter 6. Tree diversity and structural composition of tropical peat swamp forest: a study in Riau, Indonesia

6.1 Introduction

Tropical peat swamp forests have global importance for biodiversity conservation at genetic, species and ecosystem levels, as they contain habitat of endemic plant species found only in tropical peatlands. These endemic species are adapted to special conditions such as acidic and nutrient-poor soil which is inundated with water (Posa et al., 2011). Peatlands are fragile to human interventions that may lead to loss of biodiversity and ecosystem services.

Ombrogenous peatland is a type of tropical peatland that has specific vegetation characteristics. A landscape of natural ombrogenous peatland consists of several types of forests with no clear boundaries namely riverine forest, riverine peat swamp forest, mixed swamp forest, and mixed swamp-low pole forest (Page et al., 1999). These types of peatland are commonly found in Sumatra, Kalimantan, and Papua, and has peat depths up to 20 meters or more.

The Kampar Peninsula showing in Figure 6.1 is the largest contiguous peat swamp forest in Indonesia that has high biodiversity value; for example this has an essential bird habitat (Yupi et al., 2016). This landscape is the focus of biodiversity preservation which is currently experiencing a continuous decline due to deforestation (Miettinen et al., 2016). To reduce deforestation and improve forest management in Kampar Peninsula, the Indonesian Government established a Forest Management Unit (FMU) in Tasik Besar Serkap (TBS), which manages an area of 513,276 hectares (Suwarno et al., 2014). The FMU of TBS is a government institution that aims to strengthen state forest land and manage the forest in the field level. Moreover, the FMU is expected to develop non-timber forest products and environmental services through partnerships with private companies and communities.

The area of FMU of TBS is divided into five blocks (Suwarno et al., 2014). These blocks include plantation forest, natural forest, community empowerment, and specific area. The block of specific area (27,238 ha) is the remaining area without a forest concession. The FMU of TBS can manage this block directly for the utilization of environmental services and non-timber forest products.

To date, there have been no ecological studies in the block of specific area. This block is logged peat swamp forest. Furthermore, the study of peat swamp forest structure and composition in Riau is still limited. Earlier studies were conducted in Naga Sakti Lake (Sribudiani, 2009), Giam Siak Kecil Wildlife Reserve (Haryati and Nakagoshi 2013; Gunawan et al. 2012), PT. National Sago Prima (Rosalina et al., 2013), and Senepis (Mawazin and Subiakto, 2013).

The diversity and structural composition of tree species are important parameters in forest management (Oldfield, 2018), because we can use them to estimate tree productivity and conserve rare species (Bohn and Huth, 2017). Quantitative studies here have focused on tree species, because they form the main function and structure of peat swamp forest ecosystems (Wilcove et al., 2013).

As a first step to manage the forest in block of specific area, a study on biodiversity in FMU of TBS is needed. Also, biodiversity data are crucial to provide a baseline to measure sustainable forest management. Thus, this study aimed to determine the diversity and structural composition of tree species of the peat swamp forest in FMU of TBS.

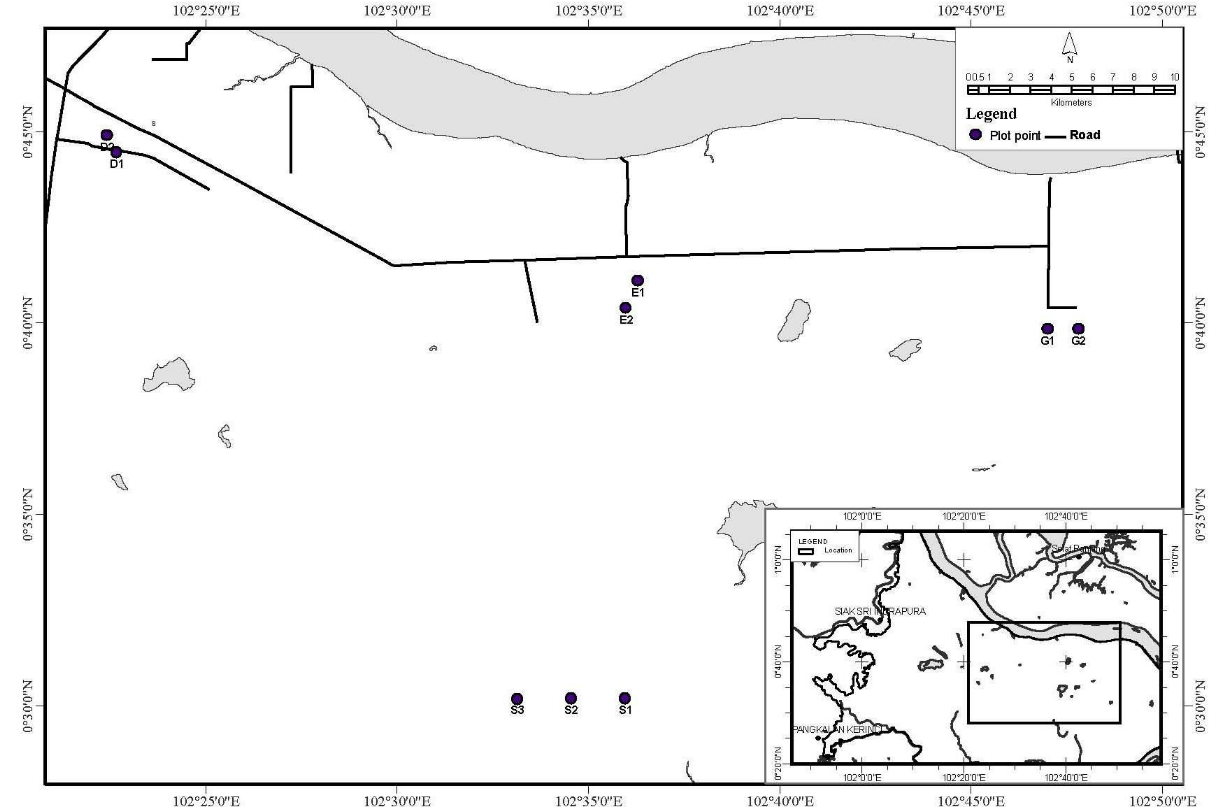
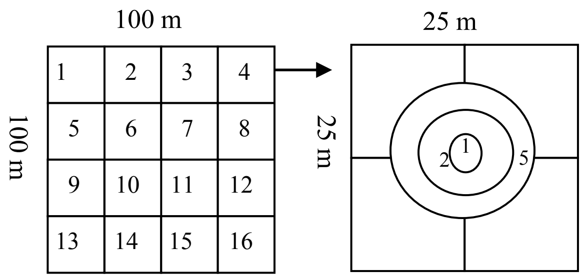


Figure 6.1 The location of sampling plots in forest management unit of TBS, Indonesia

6.2 Material and methods

6.2.1 Study area

FMU of TBS is located in Sumatra between Siak River and Kampar River (0°10’N–1°514’S, 101°50’–103°07’E) shown in Figure 6.1. It has a tropical climate with annual mean rainfall and temperature about 2500 mm and 26.5°C, respectively (Statistics of Riau Province, 2015). The area has several peat domes and four Wildlife Reserve namely Tasik Serkap, Tasik Belat, Danau Pulau Besar, and Tasik Metas showing in Figure 6.1.



- Sub RU Ø 1 m for seedlings (height 30 cm–150 cm)
- Sub RU Ø 2 m for saplings (height ≥ 150 cm, Ø < 5 cm)
- Sub RU Ø 5 m for poles (Ø 5–20 cm)
- Sub RU 25 m x 25 m for trees (Ø >20 cm)

Figure 6.2 Design of sampling plots for vegetation measurement.

Each plot (100 m x 100 m) divided into 16 Record Unit RU with size 25 m x 25 m. Each RU consisted of several sub-Rus based on growth stage

The land cover of the FMU of TBS is comprised of peat swamp forest, sago palm plantation, shrubland, industrial forest plantations, oil palm plantations and settlement area. This area has a long history of timber extraction from selective logging activity since 1969 to industrial forest plantation since 1997 (Yupi et al., 2016).

6.2.2 Vegetation measurement

The plots were purposively selected as sampling areas. The coordinates of each plot can be seen in Table 6.1 Each plot measured 100 m × 100 m and divided into 16 Record Units (RU) with 25 m × 25 m size shown in Figure 6.2. Each RU consists of several sub-RUs depending on growth stages of trees.

Table 6.1 Coordinates of sampling plots in forest management unit of Tasik Besar Serkap

Plot	E	N	Plot	E	N
G1	102.7834	0.6637	E2	102.5997	0.6728
G2	102.7969	0.6635	S1	102.5996	0.5027
D1	102.3780	0.7406	S2	102.5761	0.5027
D2	102.3739	0.7479	S3	102.5525	0.5026
E1	102.6050	0.6847			

The vegetation measurement was conducted from July 2014 to September 2014. Species were identified by a local villager and technical staff from Forestry Service of Riau Province where the local names were translated into scientific names. Tree diameter was measured at 130 centimetres above ground using a phi band meter and the first branch height was stated as the tree height. The limit of tree diameter measurement was ≥ 20 cm. A Hagameter was used to measure tree height using trigonometry algorithm. The accuracy of height measurement of individual trees ranged from 3% to 20% difference between field data and LIDAR data (Hunter et al., 2013).

6.2.3 Data analysis

A diversity index is a mathematical quantification of species diversity in an ecosystem and can be measured in various ways. The two main way are richness and evenness. Richness is the number of species in an ecosystem, while evenness compares the number of individuals of the species in an ecosystem. To know the diversity and structural composition of tree species, the following formulas were used:

a. *Shannon-Weaver index (H')*

The Shannon-Weaver index calculates the abundance and evenness of the species present in a sample (Shannon and Weaver, 1963). The formula is:

$$H' = -\sum_{i=1}^{s} Pi \times Ln(Pi)$$

Where

H' = Shannon-Weaver Index
Pi = number of individuals of i species to the totals (pi=ni/N)

N = Total number of individuals
ni = Number of individuals of each species in the sample

b. Simpson's index (D)

The Simpson index is used to know the dominance of certain species over another species (Simpson, 1949). The bigger the value of Simpson index, the lower the diversity. A value of 0 indicates high diversity (i.e., multiple species present with no species totally dominant) and a value 1 indicates no diversity (i.e., dominance by one species). The diversity increases as species richness and evenness increase. Simpson's Index measures both richness and evenness. The formula is:

$$D = -\sum_{i=1}^{s} (ni / N)^2$$

c. Shannon Evenness Index (E')

The Shannon Evenness Index is used to know the relative abundance of the different species making up the richness of an ecosystem (Pielou, 1975). For the classification categories, less than 0.3 is low evenness, 0.3 to 0.6 is moderate, and more than 0.6 is high. The formula is:

$$E' = {}^{H'}/_{lnS} \times 100\%$$

Where S' = species richness (Magurran, 1988)

d. Important Value Index (IVI)

The IVI is used to analyze floristic composition (Curtis and McIntosh, 1951). The IVI represents dominance of a species over other species in the community, with a maximum value of 300. The family importance value (FIV) is a summation of IVI species belonging to a botanical family. The formula is as follows:

IVI = relative density (Rdt) + relative dominance (Rdc) + relative frequency (Rf)

Where:

$$Rdt = \frac{\text{Number of individuals of a species}}{\text{total number of individuals of all species}}$$

$$Rdc = \frac{\text{total basal area of a species}}{\text{total basal area of all species}}$$

$$Rf = \frac{\text{Number of the sampling plots in which a species occurs}}{\text{total number of the sampling plots}}$$

e. *Basal area (BA) and tree volume*

Basal area ($m^2\ ha^{-1}$) of trees calculated as follows:

$$BA = 0.7854\left(\frac{D}{100}\right)^2$$ (Priatna et al., 2004).

While tree volume calculated as follows:

V = BA × height × 0.7

f. *Sorensen Index (SI')*

The Sorensen index compares the similarity between two samples (Chao et al., 2005). The formula is:

$$SI' = {}^{2C}/_{(A+B)}$$

Where,

C = number of species present in both plots

B = number of species in the second plot

A = number of species in the first plot

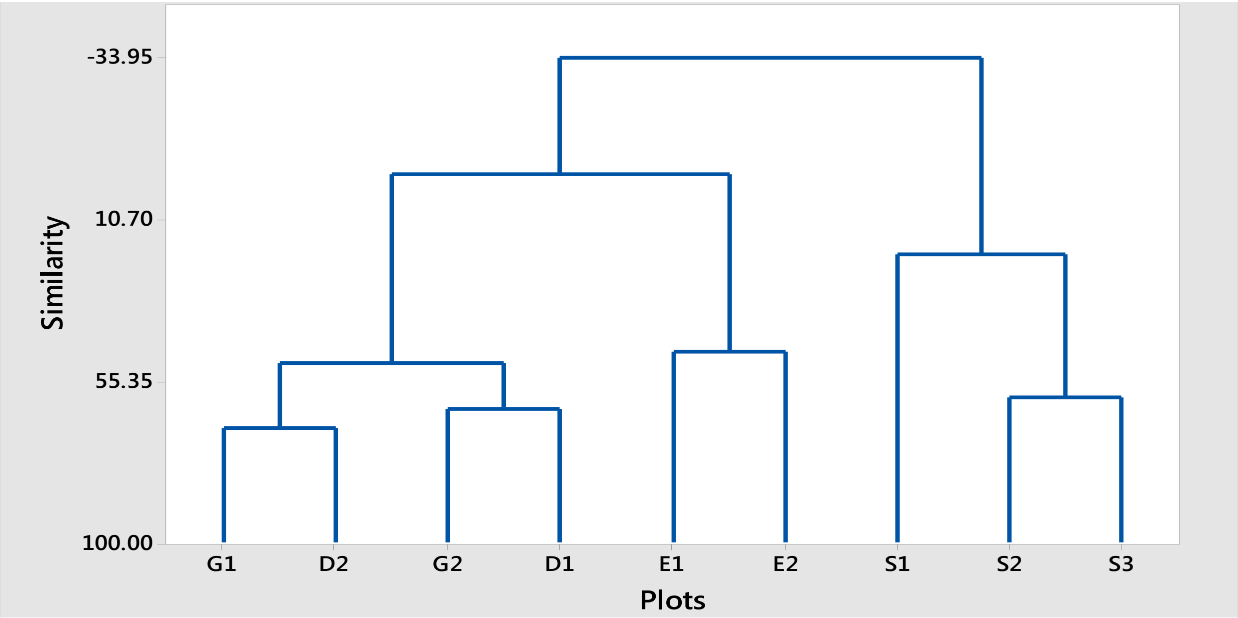


Figure 6.3 Dendrogram of similarity of tree species among the sampling plots

6.3 Results and discussion

6.3.1 Species richness and diversity

There were 59 tree species belonging to 31 families showing in Table 6.3 found in the nine plots of the block of specific area (9 ha). Plot E2 and plot D1 have a maximum of 28 species followed by plot S3 (23 species) and plot D2 (22 species). There was a correlation between tree species richness and stand density. The high-density plot has high species richness. R Square were -0.65 with p-value less than 0.05. It was observed that the highest species richness (28 species) and highest stand density (186 trees ha^{-1}) were in plot E2 followed by plot D1 and plot S3. Plot S1 has the lowest species richness (12 species) and lowest stand density (78 trees ha^{-1}).

The Sorensen Index revealed the average of similarity among all plots was 0.52 in terms of tree species showing in Table 6.2. Plots G1 and D2 had a maximum similarity of followed by plot G2 and plot D1 (0.71) shown in Table 6.2 and Figure 6.3. On the contrary, the least similarity (0.26) was shown to be between plots E1 and S1.

The highest Shannon-Weaver and Simpson's indices were 2.88 and 0.08 respectively for all plots are presented in Table 6.3. The values of the two diversity indices varied among all plots. The maximum Shannon-Weaver Index was 2.88 in plot E2, and the minimum was 1.91 in plot S1. The Simpson's index ranged from 0.08 in plot S3 to 0.24 in plot S1. Similarly, the Shannon Evenness Index varied between of 0.77 in plot S1 and 0.88 in plot S3.

Table 6.2 The similarity of tree species among the sampling plots

Plot	G1	G2	D1	D2	E1	E2	S1	S2	S3
G1	1.00	0.67	0.64	0.74	0.57	0.50	0.36	0.49	0.56
G2	0.67	1.00	0.71	0.67	0.56	0.42	0.38	0.49	0.56
D1	0.64	0.71	1.00	0.68	0.51	0.50	0.45	0.57	0.51
D2	0.74	0.67	0.68	1.00	0.54	0.48	0.29	0.51	0.58
E1	0.57	0.56	0.51	0.54	1.00	0.60	0.26	0.50	0.48
E2	0.50	0.42	0.50	0.48	0.60	1.00	0.35	0.33	0.39
S1	0.36	0.45	0.29	0.29	0.26	0.35	1.00	0.48	0.57
S2	0.49	0.57	0.57	0.51	0.50	0.33	0.48	1.00	0.68
S3	0.56	0.56	0.51	0.58	0.48	0.39	0.57	0.68	1.00

Plot G2 and D2 was the highest similarity while plot E1 and S2 was the least similarity

Table 6.3 Tree diversity indices of the sampling plots

No	Plot	Number of species	Number of individuals	Number of families	Basal area (m^2)	Simpson Index	Shannon-Weiner Index	Evenness index	Volume (m^3)
1	G1	16	126	15	11.33	0.15	2.16	0.78	138.84
2	G2	20	104	16	10.67	0.11	2.49	0.83	117.55
3	D1	28	165	19	12.05	0.09	2.77	0.83	131.11
4	D2	22	101	19	8.26	0.13	2.48	0.80	89.32
5	E1	19	127	14	8.45	0.11	2.51	0.85	99.04
6	E2	28	186	18	12.34	0.08	2.88	0.87	252.19
7	S1	12	78	10	7.41	0.24	1.91	0.77	81.49
8	S2	21	101	14	11.96	0.09	2.66	0.87	144.28
9	S3	23	134	19	12.28	0.08	2.75	0.88	141.01
Total		59	1222	30	94.74	0.12	2.51	0.83	1,1945

The species richness, abundance, density, and distribution of individual species are quantifiable parameters of forest diversity (Kessler et al., 2005). The tree species richness of peat swamp forest varied in Sumatra and Kalimantan. Studies conducted in a one-hectare forest at Tebing Tinggi, Riau, recorded the presence of 50 species (Rosalina et al., 2013), 82 species in 3 ha sampling plots at Bukit Batu wild reserve, Riau (Gunawan et al., 2012), and 72 species were documented in 9 ha sample plots at the former Mega Rice Project in Central Kalimantan (Blackham et al., 2014). The occurrence of 59 tree species over the 9 hectares sampled in this study reveals a moderate level of species richness.

The adaptation of species on environmental conditions and the stability of community affect the species diversity. The Shannon Weiner index is usually high for peat swamp forest in Sumatra and Kalimantan, ranging from 2.07 to 3.6 (Gunawan et al. 2012; Brearley and Kidd 2004). In the present study, the Shannon Weiner Index varied from 1.91 to 2.88. The forest composition and forest types often used the most abundant species as an indicator (Slik et al., 2009)(Slik et al., 2009). Two dominant species, the *Syzygium acutifolium* and *Shorea uliginosa*, contributed to 49.7% (558 individuals) of the total tree population in our sampling plots.

6.3.2 Species abundance

The abundance of tree species in the nine plots varied from one individual for *Alstonia pneumatophora* and *Aporusaa aurita* to 196 individuals of *Syzygium acutifolium* are given in Table 6.4. Tree species were grouped into four categories based on abundance: very rare (1–2 individuals), rare (3–20 individuals), common (21–100 individuals), and dominant (101–500 individuals) in our sampling plots (Pragasan and Parthasarathy, 2010). Fifteen (15) species were categorized as very rare, 30 species as rare, 12 species as common, and 2 species as dominant shown in Table 6.4. The common and dominant species contributed to 47.06% (528 individuals) and 28.70% (322 individuals), respectively, of forest composition in the study area.

The dominant species *Syzygium acutifolium* and *Shorea uliginosa* have broad distribution across the Kampar Peninsula. Of the counted tree species, *Litsea firma, Palaquium leiocarpum, Tetramerista glabra, Ganua motleyana, Aglaia ignea, Garcinia parvifolia, Blumeodendron tokbrai, Stemonurus secundiflorus, Mangifera griffithii, Campnosperma coriaceum, Combretocarpus rotundatus,* and *Pimelodendron griffthianum* were categorized as common showing in Table 6.4.

6.3.3 Family composition

The Family Important Value (FIV) from the highest to lower were Myrtaceae (39.37), Sapotaceae (37.98), Dipterocarpaceae (36.98), Lauraceae (20.15), and Tetrameristaceae (16.71) are listed Table 6.5. Moraceae (4 species) had low FIV because of the low density and small basal area. Regarding species richness, Sapotaceae had the maximum number of species (7) followed by Euphorbiaceae (5 species), Annonaceae (4 species), Moraceae (4 species), and Myrtaceae (4 species). Sixteen families have single species. However, based on stem density and basal area, Myrtaceae dominated the peat swamp forests in all plots (214 individuals).

The most species abundance family at Bukit Batu wild reserve were Myrtaceae, followed by Sapotaceae, and Dipterocarpaceae (Gunawan et al., 2012). Likewise in Tebing Tinggi, Myrtaceae was the richest followed by Euphorbiaceae and Sapotaceae (Rosalina et al., 2013). In our study area, Myrtaceae, Sapotaceae, Dipterocarpaceae, and Lauraceae were the most species abundance. Furthermore, the majority of the three families in our study grown in peat swamp forests in Sumatra and Kalimantan, such as Anacardiaceae, Annonaceae, Burseraceae, Dipterocarpaceae, Euphorbiaceae, Lauraceae, Myristicaceae, and Myrtaceae (Brearley and Kidd, 2004).

Table 6.4 Phytosociological attributes of tree species at the sampling plots

No	Species	Family	Abundance	Basal area (m^2)	Relative Density	Relative Dominance	Relative Frequency	IVI
1	*Syzygium acutifolium*	Myrtaceae	196	13.04	17.47	13.05	4.76	35.28
2	*Shorea uliginosa*	Dipterocarpaceae	126	17.86	11.23	17.88	4.23	33.34
3	*Palaquium leiocarpum*	Sapotaceae	87	11.67	7.75	11.68	4.76	24.20
4	*Litsea firma*	Lauraceae	94	6.40	8.38	6.40	4.23	19.02
5	*Tetramerista glabra*	Moraceae	55	6.44	4.90	6.44	4.23	15.58
6	*Aglaia ignea*	Meliaceae	45	5.49	4.01	5.50	3.70	13.21
7	*Ganua montleyana*	Sapotaceae	45	2.77	4.01	2.77	2.12	8.90
8	*Stemonurus secundiflorus*	Icacinaceae	32	1.77	2.85	1.77	4.23	8.86
9	*Bleumeodendron tokbrai*	Euphorbiaceae	35	1.64	3.12	1.64	3.17	7.93
10	*Campnosperma coriaceum*	Anacardiaceae	25	2.38	2.23	2.38	3.17	7.78
11	*Garcinia parfifolia*	Guttiferae	36	1.90	3.21	1.90	2.65	7.76
12	*Mangifera griffithii*	Anacardiaceae	29	1.90	2.58	1.90	3.17	7.66
13	*Xylopia altisima*	Annonaceae	14	1.63	1.25	1.63	3.70	6.58
14	*Gonystylus bancanus*	Tymelaceae	14	1.89	1.25	1.89	3.17	6.31
15	*Knema conferta*	Myristicaceae	15	0.88	1.34	0.88	3.17	5.39
16	*Palaquium sumatranum*	Sapotaceae	11	1.73	0.98	1.73	2.65	5.36
17	*Polyaltia hypoleuca*	Annonaceae	16	1.20	1.43	1.20	2.65	5.27
18	*Diospyros maingayi*	Ebenaceae	16	1.00	1.43	1.00	2.65	5.07
19	*Combretocarpus rotundatus*	Anisophylleaceae	24	1.05	2.14	1.05	1.06	4.24
20	*Pimelodendron griffthianum*	Euphorbiaceae	21	1.09	1.87	1.09	1.06	4.02
21	*Calophyllum pulcherrimum*	Clusiaceae	8	0.44	0.71	0.44	2.65	3.80
22	*Koompassia malaccensis*	Fabaceae	10	2.24	0.89	2.24	0.53	3.66
23	*Paratocarpus triandus*	Moraceae	7	0.62	0.62	0.62	2.12	3.36
24	*Cratoxylum arborescens*	Hypericaceae	7	0.72	0.62	0.72	1.59	2.93
25	*Quassia borneensis*	Simaroubaceae	6	0.28	0.53	0.28	2.12	2.93
26	*Artocarpus kemando*	Moraceae	5	0.90	0.45	0.90	1.59	2.93
27	*Durio carinatus*	Bombacaceae	8	1.11	0.71	1.11	1.06	2.88
28	*Timonius flavescens*	Rubiaceae	8	0.49	0.71	0.49	1.59	2.79
29	*Palaquium obovatum*	Sapotaceae	6	0.64	0.53	0.64	1.59	2.76
30	*Myristica lowiana*	Myristicaceae	12	0.56	1.07	0.56	1.06	2.69
	Total1 - 30 species		1,013	91.70	90.29	91.80	80.42	262.51
	All of 59 species		1,122	99.89	100	100	100	300

IVI is important value index

6.3.4 Important value index, stand density, and basal area

Syzygium acutifolium and *Shorea uliginosa* have the highest IVI of 35.28 and 33.34 respectively are presented in Table 6.4 followed by *Palaquium leiocarpum* (24.20); *Litsea firma* (19.02); *Tetramerista glabra* (15.58), and *Aglaia ignea* (13.21). The IVI of dominant species and common species contributed to 22.88% and 41.22% of total IVI values in the study area respectively. The *Syzygium acutifolium* and *Shorea uliginosa* had the highest IVI in all plots, with the exception in plots S1 and S2, where *Litsea firma* and *Aglaia ignea* had the maximum IVI.

A total of 1,122 individual trees were found in all plots shown in Table 6.3 and the mean tree density was 125 stems ha^{-1}. The total basal area was 99.89 m^2 ha^{-1} and the mean value was 11.10 m^2 ha^{-1}. Plot E2 (17.49 m^2 ha^{-1}) has the highest the total basal area followed by plot S3 (12.28 m^2 ha^{-1}) and plot D1 (12.05 m^2 ha^{-1}). Plot S1 has the lowest basal area (7.41 m^2 ha^{-1}).

The family of Dipterocarpaceae showing in Table 6.5, with two species, had the maximum total basal area (18.88 m^2) followed by Sapotaceae (17.66 m^2), Myrtaceae (14.24 m^2), Tetrameristaceae (6.44 m^2), and Lauraceae (6.40 m^2). The Dipterocarpaceae, Myrtaceae, and Sapotaceae dominate tree families in the FMU of TBS.

The IVI indicates the overall dominance of one species over another species. The high IVI species utilize the environment more efficiently than other species. The high IVI of dominant and common species showed the higher relative frequency, density, and dominance of these species compared to other species. (Gunawan et al., 2012) found the dominant species were unique to peat soil condition. It was found that the highest IVI species in our study area was *Syzygium acutifolium* followed by *Shorea uliginosa*, *Palaquium leiocarpum, Litsea firma,* and *Tetramerista glabra*.

The mean stand density of trees in peat swamp forests of Sumatra and Kalimantan varies from 134 stems ha^{-1} at Barito Ulu with Diameter at Breast Height (DBH) ≥ 30 cm to 550 stems per ha^{-1} at Tebing Tinggi with of DBH ≥ 10 cm. The average tree density in this present study with DBH ≥ 20 cm was 125 stems ha^{-1}.

Table 6.5 Family composition of tree species at the sampling plots

No	Family	Number of species	Number of individuals	Volume m^3	Basal area (m^2)	Relative basal area	Relative diversity	Relative Density	FIV
1	Myrtaceae	4	214	146.53	14.24	14.26	6.04	19.07	39.37
2	Sapotaceae	7	160	229.55	17.66	17.67	6.04	14.26	37.98
3	Dipterocarpaceae	2	135	254.81	18.88	18.90	6.04	12.03	36.98
4	Lauraceae	1	94	63.28	6.40	6.40	5.37	8.38	20.15
5	Tetrameristaceae	1	55	71.79	6.44	6.44	5.37	4.90	16.71
6	Anacardiaceae	3	59	49.13	4.49	4.49	5.37	5.26	15.12
7	Euphorbiaceae	5	67	34.57	3.34	3.34	5.37	5.97	14.68
8	Meliaceae	1	45	64.91	5.49	5.50	4.70	4.01	14.21
9	Annonaceae	4	32	37.51	2.98	2.98	5.37	2.85	11.20
10	Icacinaceae	2	33	19.44	1.90	1.90	5.37	2.94	10.21
11	Guttiferae	2	38	19.04	1.98	1.98	4.03	3.39	9.40
12	Myristicaceae	2	27	15.40	1.44	1.44	5.37	2.41	9.21
13	Moraceae	4	17	24.86	1.90	1.90	4.70	1.52	8.12
14	Tymelaceae	1	14	29.27	1.89	1.89	4.03	1.25	7.16
15	Ebenaceae	1	16	10.81	1.00	1.00	3.36	1.43	5.78
16	Fabaceae	2	17	44.56	2.83	2.83	1.34	1.52	5.69
17	Anisophylleaceae	1	24	11.71	1.05	1.05	1.34	2.14	4.53
18	Clusiaceae	1	8	4.67	0.44	0.44	3.36	0.71	4.51
19	Simaroubaceae	1	6	2.67	0.28	0.28	2.68	0.53	3.50
20	Hypericaceae	1	7	7.23	0.72	0.72	2.01	0.62	3.36
21	Rubiaceae	1	8	4.12	0.49	0.49	2.01	0.71	3.22
22	Malvaceae	1	8	13.77	1.11	1.11	1.34	0.71	3.16
23	Apocynaceae	2	6	3.05	0.31	0.31	2.01	0.53	2.86
24	Dilleniaceae	1	4	12.01	0.82	0.82	1.34	0.36	2.52
25	Phyllanthaceae	2	3	1.57	0.16	0.16	2.01	0.27	2.44
26	Ixonanthaceae	1	10	9.16	0.86	0.86	0.67	0.89	2.43
27	Burseraceae	1	8	4.94	0.40	0.40	0.67	0.71	1.78
28	Chrysobalanaceae	1	3	1.66	0.17	0.17	0.67	0.27	1.11
29	Rutaceae	1	2	1.14	0.11	0.11	0.67	0.18	0.96
30	Convovulaseae	1	1	1.27	0.09	0.09	0.67	0.09	0.85
31	Aquifoliaceae	1	1	0.39	0.04	0.04	0.67	0.09	0.80
	Total		1122	1195	99.89	100	100	100	300

FIV is family important value

The basal area is an important characteristic of forest quality and productivity (Bohn and Huth, 2017). The average basal area of our sampling plots was 11.10 m^2 ha^{-1} and varied between 7.41 m^2 ha^{-1} to 17.49 m^2 ha^{-1}. The calculated basal area of forest vegetation in Tebing Tinggi was 18.32 m^2 ha^{-1}. In Barito Ulu (Brearley and Kidd, 2004), the observed mean basal area was 6.43 m^2 ha^{-1}. The mean basal area described in the present inventory range similar with those previous studies.

6.3.5 Distribution of diameter class, height, and volume

The species richness, tree density, and basal area decreased with the increasing diameter of tree in the study area shown in Table 6.6. The DBH class (20–29 cm) had the maximum number of species (53 species). The DBH class 20–29 cm represented 89.83% of all tree species recorded from the sampling plots. Similarly, the DBH class 20–29 cm also dominated the tree density (649 stems) and basal area (30.08 m^2).

The tree volume from the all sampling plots was 1,195 m^3 are given in Tables 6.3 and 6.5 and the mean tree volume was 133 m^3 ha^{-1}. Plot E2 (252 m^3 ha^{-1}) had the highest total volume and the plot S1 the lowest total volume (81m^3 ha^{-1}).

Table 6.6 Phytosociological attributes of DBH class at the sampling plots

DBH class (cm)	Species richness	Number of stem ha^{-1}	% to density	Basal area	% to BA
20-29	53	72	57.84	3.34	30.12
30-39	44	30	24.15	2.64	23.75
40-49	22	10	8.20	1.55	14.01
50-59	16	7	5.88	1.65	14.89
60-69	12	3	2.23	0.85	7.70
> 70	6	2	1.69	1.06	9.54

The species richness, tree density, and basal area decreased with the increasing diameter

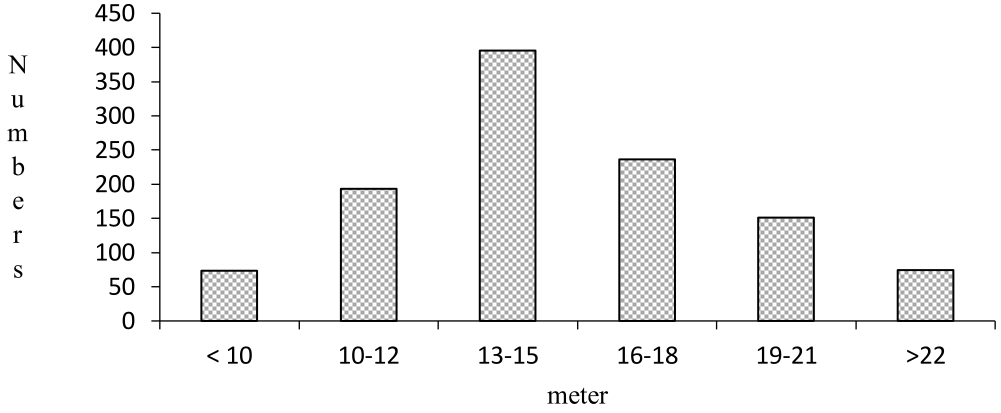


Figure 6.4 Classes of tree height in the sampling plots.
Tree height class 13–15 m has maximum the number of individuals

The number of individuals of the tree height class 13–15m was the greatest (35.2%), followed by the 16–18m and 10–12m showing in Figure 6.4. The species with the highest stand and volume were *Shorea uliginosa, Palaquium leiocarpum* and *Syzygium acutifolium* shown in Table 6.4. These species have high canopy and naturally straight.

The distribution of the diameters of tree reveals the level of disturbance in the forests and the developments of regeneration (Lussetti et al., 2016). In the present study, the DBH 20 – 29 cm category contributed to 57.84% of the tree density and 30.12% of basal area. On the contrary, the high DBH class (≥ 50) cm represents only 32.12% of the tree density. A reversed J pattern of tree density and tree diameter indicates a good process of natural succession in term of trees which are proportionally distributed (Brearley and Kidd, 2004).

Secondary forests have lower tree height. The average tree height in our study area was 15.32 m. This is similar to the secondary forest in Barito Ulu where average tree height of 19 m while the average tree height in the primary forest was 22.10 m (Brearley and Kidd, 2004).

The tree volume of DBH ≥ 10 cm in peat swamp forest varied from 110.00 m^3 ha^{-1} at Barito Hulu (Brearley and Kidd, 2004) to 195.16 m^3 ha^{-1} at Sungai Kumpeh, Jambi (Mawazin, 2013). The tree volume at our study area was comparable with this range (133.76 m^3 ha^{-1}).

6.3.6 Regeneration

The best tree regeneration rate was in plot E2 with 27,852 seedlings ha^{-1} are listed in Table 6.7 while the lowest tree regeneration rate was found in plot S1 with 7,759 seedlings ha^{-1}. The species with highest regeneration (i.e., highest number of seedlings) were *Syzygium acutifolium* followed by *Stemonurus secundiflorus, Mangifera grafitii, Litsea firma, and Shore uglinosa* showing in Table 6.8. On the other hand, the regeneration of *Macaranga semiglobasa, Mezzetti parviflora, Syzygium inophylla, Ilex cymosa* and *Alstonia pneumatophora* was low in the study area.

The distribution of growth stage followed a reversed J-shape pattern. The density of trees was lower than seedlings and saplings in all of the sampling plots. For instance, for *S. acutifolium,* tree density was 196 trees ha^{-1}, whereas for its seedlings was 33,030 ha^{-1} and saplings was 11,887 ha^{-1} shown in Table 6.8.

Regeneration is an essential factor in forest management because regeneration preserves the diversity and species composition after natural or human disturbances (Okuda et al., 2003). Environmental conditions such as peat subsidence, peat depth, and flooding influence the natural regeneration of the peat swamp forest (Page et al., 1999). Dominant species in sampling plots of this study have good regeneration status, while rare species have lower regeneration rate. Thus, human intervention such as enrichment planting is needed to enhanced biodiversity (Okuda et al., 2003).

According to the International Union for the Conservation of Nature (IUCN) Red List, three species were endangered species namely *Shorea uliginosa, Gonystylus bancanus* and *Combretocarpus rotundatus*. Hence, there should be greater attention toward these species since they are commercially important species being utilized as timber and at risk of illegal logging.

6.4 Conclusion

This study gives information on diversity and structural composition of tree species of the FMU of TBS. The main concern of the forest management are a few numbers of the individual tree species of higher diameter class, abundance of trees in the lower diameter class of 20–29 cm, and poor regeneration rate of many tree species. Thus, the management of peat swamp forest should prioritize conservation, enrichment planting, and fire prevention. This is because logging activity, peatland drainage, recurring fires are the main factors for forest degradation in FMU of TBS.

Table 6.7 Trees regeneration of sample plots

Plot	Seedlings	Saplings	Poles	Trees
G1	1,636	508	72	126
G2	376	525	165	104
D1	221	663	126	165
D2	906	437	43	101
E1	442	409	73	127
E2	177	519	71	186
S1	332	249	77	78
S2	1,901	475	111	101
S3	133	437	110	134
Total	6,123	4,222	848	1,122

Table 6.8 Regeneration of top 15 of tree species of sample plots

Tree species	Trees ha^{-1}	Poles ha^{-1}	Saplings ha^{-1}	Seedlings ha^{-1}
Syzygium acutifolium	196	149	1,321	3,559
Shorea uliginosa	126	41	94	376
Palaquium leiocarpum	87	37	50	221
Litsea firma	94	50	177	906
Tetramerista glabra	55	7	11	442
Aglaia ignea	45	8	61	177
Ganua montleyana	45	38	88	332
Stemonurus secundiflorus	32	93	287	1,901
Bleumeodendron tokbrai	35	25	94	133
Campnosperma coriaceum	25	11	22	44
Garcinia parfifolia	36	10	17	155
Mangifera griffithii	29	25	99	928
Xylopia altisima	14	2	99	332
Gonystylus bancanus	14	9	11	22
Knema conferta	15	32	83	133

Seedlings have the highest number of individuals

Chapter 7. General discussion and conclusion

This chapter discusses major findings, limitations of the study, recommendations, and future research to support sustainable peatland management. This thesis has addressed research questions to improve understanding of fire regimes, biodiversity, and land management in peatlands in Riau Province, Indonesia. We discussed the results in the previous chapters

7.1 General discussion

7.1.1 Summary of findings

1. The susceptibility of peatlands to large-scale fires is directly related to periods less or no rain. In Riau, we observed fire activity increases when rainfall is less than 100 mm/month and rainy days are fewer than eight per month. Some drought mitigation can be accomplished through integration of drought prediction, improvement of existing drought indices, rewetting of peatland, and water management (Taufik et al., 2015).
2. Two-thirds of the peat swamp forest in Riau was lost from 1990 to 2013. The forest was converted predominantly to plantations of acacia and oil palm and shrublands. Consequently, the highly fire-resistant peat swamp forest landscape was transformed to a more fire-prone landscape because of the expansion of fire-susceptible shrublands and forest fragmentation.
3. The most important driver of fire was the soil type (peatland or mineral land), followed by landholder and year of deforestation. In contrast, slope and legal land status were shown to be marginal drivers of fire. Therefore, the government should prioritize conservation of peat swamp forest and the “one map” policy to prevent fire.

4. Peat drainage and roads are indirect contributors to increased fire activity. Preventing construction of new forms of access, specifically roads and canals, will likely reduce the occurrence of fires.
5. Human ignition of fires is associated with unsustainable plantation development and unclear land tenure in idle peatlands/shrublands. Thus, sustainable plantation development should prioritize the new actor e.g., local, mid-level entrepreneurs as well as small and large-landholder.
6. Peat swamp forests were shown to have lower fire risk because of the high humidity of their canopy and high soil moisture. On state forest land, forests under conservation and regular production forest have low fire activity. This result shows the importance of protecting peat swamp forests and avoiding their degradation.
7. Land management and concession type affected fire occurrences in the peat swamp forest. The spatial arrangement of industrial forest plantations and law enforcement in the forest can prevent fires.
8. Land concession type affected fire ocurrences in plantations, even with the same commodity (e.g., acacia, oil palm). Company plantations had more fires than smallholder plantations. High water levels in smallholder plantations can reduce fire activity.
9. The use of geoinvestigation/web GIS to monitor fire has been challenged because of discrepancies between legal concession boundaries and actual land occupancy. Farmers start fires inside or along concessions boundaries and these fires often spread into plantations. Thus, to be successful, geoinvestigation needs to be based on resolution of overlapping land claims.
10. Peat swamp forests have a good succession. Thus, proper management of peat swamp forest should be prioritized with effort on conservation and enrichment planting.

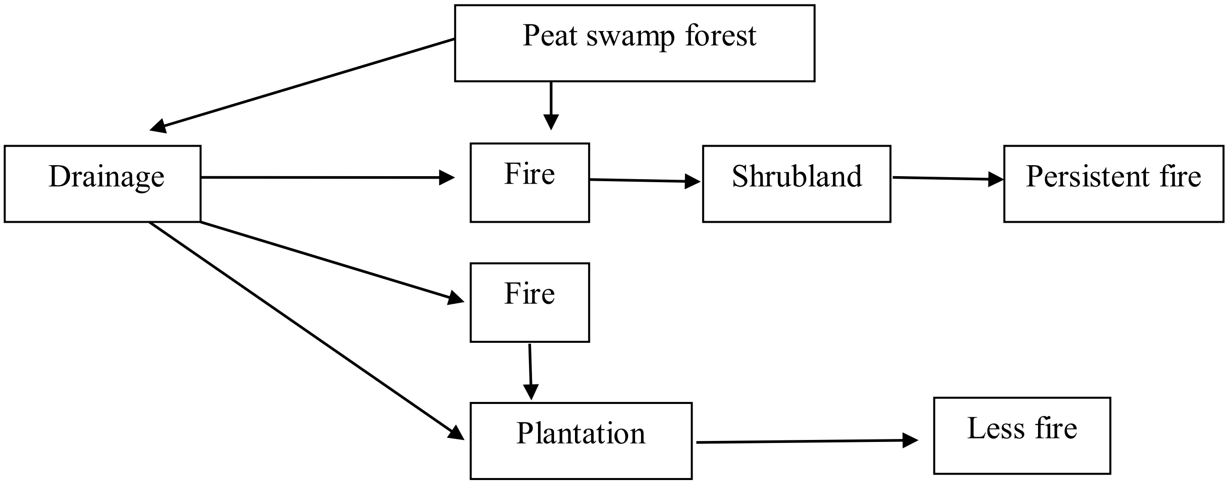


Figure 7.1 Peat swamp forest degradation and fire.

7.1.2 Scientific contribution

This study gives new insight into the important contribution of the role of land use governance in mitigating fire disasters in Riau. The simplistic view that industrial plantation companies are the main driving force of fire is not consistent with reality and requires detailed investigation. This study found that independent farmers are a main source of fire inside and outside concessions. These farmers target idle peatland to develop plantation and fires they start in these areas spread into plantation areas. We have shown that fire activity has expanded along with deforestation. However, smallholder plantation has fewer fires than company plantation. We highlight the importance of peat swamp forest in prevent fire. The process of peat swamp forest degradation and fire is shown in Figure 7.1. Thus, government policies should promote conservation, best management practices, and peatland restoration to overcome the fire problem in Sumatra. Previous research only explored land cover type or concession area without considering land occupancy. The recommendations for future research and collaboration present priority research to enhance our understanding of peatland fires in the future.

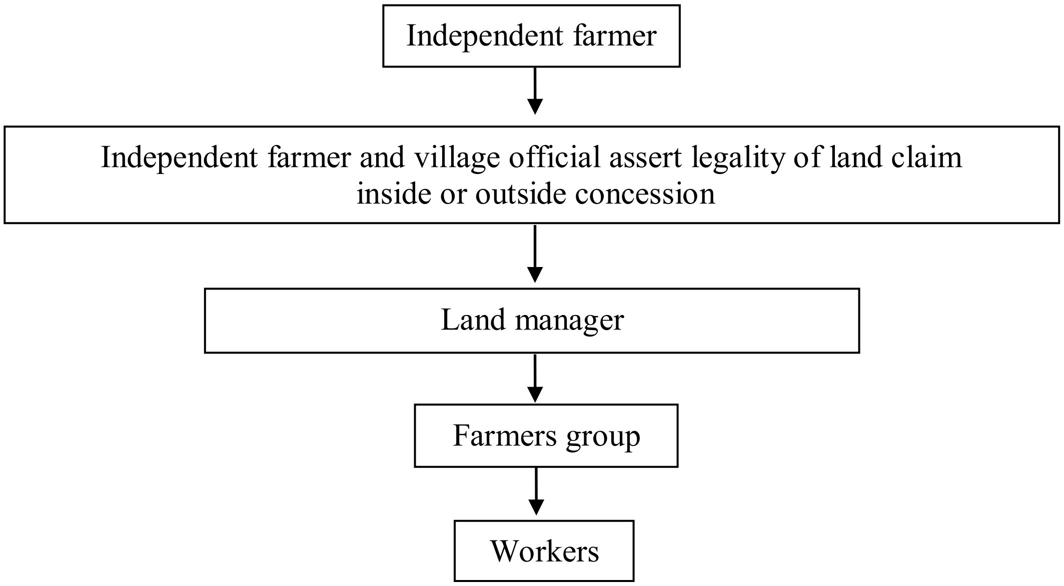


Figure 7.2 Process of land claim inside concession or outside concession
Independent farmer uses farmers group because Government limit individual land owner less than 25 ha

7.2 Limitation of the study

The reliability of the analyses depends on data accuracy and precision (i.e., sample size, resolution of spatial and temporal). Ideas need further refinement and new techniques, as follows:

1. Inadequate data on climate, hydrology, agricultural economy, historical fire, land cover and land management, and lack of high-resolution satellite imagery reduce the accuracy of the analysis of climate and anthropogenic factors as causes of fire.
2. As human migration has been identified as an important factor in land cover change, an analysis on population data and land cover will provide a more complete explanation of land cover change. The process of land claim by migrant is shown in Figure 7.2.

3. No holistic modeling of fire activity, climate, and anthropogenic factors was conducted in this study. This modeling can be used to predict future fire activity and improve our understanding of fire regimes in peatland.
4. Insufficient historical data on tree diversity, number, and distribution of tree sample plots affected the quality of the tree diversity analysis. The primary challenge to monitoring forest throughout Indonesia has been the number of sample plots in studies.

7.3 Recommendation

Conversion of peat swamp forest into industrial plantations causes negative impacts to the environment and is connected with severe fires. Recently, sustainability of plantations has become a main concern of the global community in order to mitigate the negative impact of industrial plantations. We propose some strategies to minimize fires in peatlands:

a. Conserve the remaining peat swamp forests and improve the condition of degraded peatland;
b. Define clear land use categories in peatlands as “protected zone” and “cultivated zone”;
c. Resolve overlapping land claims with “one map” policy;
d. Develop policy, regulation, institutional arrangement, and law enforcement to improve peatland management;
e. Develop peat ecosystem data such as topography, land cover, hydrology conditions, and carbon content to understand peatland condition in greater detail;
f. Conduct real time monitoring of water level in peatlands;
g. Develop and apply best plantation management practices;
h. Develop wetland-adapted livelihoods and viable agro-business options;
i. Process the litter or crop residues into finished products to reduce the potential fuel;

j. Develop economic policy (incentives and disincentives):
   1. Incentives for agriculture farming without burning, provide the equipment and good seeds;
   2. Fund assistance with interest subsidies for farmers who clear their land without burning;
   3. Reward for the fire-prone villages that do not experience a fire in a year;
   4. Increase the price of villager products in the market;
   5. Stop the financial credit to the burned concession;
   6. Revoke the permit of burned concession;

k. Promote community engagement through training and fire prevention assistance;

l. Implement one water management strategy in one landscape of peatland;

m. Promote fire prevention and early fire response:
   1. Develop meteorological monitoring system for prediction of drought and fire;
   2. Develop early warning system for forest and land fire; and
   3. Develop communication system for fire prevention and early response in the villages.

7.4 Future research and collaboration

Due to the importance of sustainable peatland management and limitations of this study, we suggest relevant future research as follows.

1. Investigate appropriate incentives for farmers to implement zero burning in drought periods; Currently, farmers do not have technical and financial assistance to clear their land without fire;

2. Conduct holistic modeling of climate, hydrology, and fire activity in various land cover and land management types. Recent remote sensing technology such as LIDAR can improve the accuracy of fire modeling in peatlands;
3. Study social and cultural influences on fire management by local community;
4. Study motives of the people to burn their land (e.g., competing land claims easier land clearing);
5. Investigate fire ignition and fire propagation within the landscape by the various types of landowner;
6. Study alternative plantation crops that have high economic value in wet condition in peatlands;
7. Assess ecosystem services to support sustainable peatland management.
8. Study biodiversity and carbon storage in peatland.

As sustainable peatland management is of global interest and requires multidisciplinary research, we will develop collaborative research which involves universities, international institutions, government, and other interested partners and stakeholders.

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