Spatial Analysis to Establish Agroforestry Areas as Buffer Zones in Tropical Peatland Forest of Indonesia

---

A Thesis presented to

the Faculty of the Graduate School

at the University of Missouri

In partial Fulfillment

Of the Requirement of the Degree

Master of Science

---

by

Haryo Ajie Dewanto

Dr. Hong S. He and Dr. Shibu Jose, Thesis Supervisors

July 2018

The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

Spatial Analysis to Establish Agroforestry Areas as Buffer Zone in Tropical Peatland Forest of Indonesia

presented by Haryo Ajie Dewanto,

a candidate for the degree of Master of Science, and hereby certify that, in their opinion, it is worthy of acceptance.

Professor Hong S He

Professor Shibu Jose

Assistant Professor Mary Hendrickson

Acknowledgments

This work funded through USAID-CIFOR Fellowship Program. We would like to express our thanks to Center for Agroforestry, School of Natural Resources, the University of Missouri for the support. We would like to express our thank to Dr. Sonya Dewi from the World Agroforestry Center, and PT. Rimba Raya Conservation. I also would like to deliver my sincere thanks to Dr. Hong He, Dr. Shibu Jose and Dr. Marry Hendrickson for their guidance for my data analysis. Thank you to everyone for the unwavering support.

Table of Contents

List of Figures

List of Table

Abstract

Indonesia, as a tropical country in South-East Asia, has a vast area of peatland forest threatened by deforestation and forest degradation. Peatland Forest in Kalimantan, Indonesia, has been heavily over-exploited for about five decades. Before it was the indigenous people, who utilized peatland forests as a resource to produce traditional food crops, fruits, and spices. Commercial exploitation, particularly for palm oil plantation, has become the primary reason in recent decades. In 2015, Indonesia Government applied a moratorium policy on peatlands to reduce the rate of peatlands degradation. Agroforestry practices have been proposed as an alternative livelihood to the rural communities that live near peatlands ecosystem in Kalimantan (Borneo) and as a buffer to protect the peatland ecosystems. A village spatial planning tool is used in determining the appropriate locations of the buffer zones. It considers the traditional land-use of the indigenous people as the base map. The objective of this study was to combine readily available ecological data and the base map data gathered from participatory approach to determine the most suitable locations for buffer zones in the Rimba Raya Biodiversity Reserve. Together through the participatory approach, the communities, government, and private sector conducted the planning, surveying and developing a suitability base map. The other variables considered in the making of a suitability map were ecologic factors (Peat soil depth, landcover, and NDVI) and disturbance factors (access and established traditional land use). The arc-map software was used to model the parameters. The southern area and some parts of the northern region of Rimba Raya Biodiversity Reserve were the most suitable locations to implement agroforestry.

Key Words: Agroforestry, Analytical Hierarchy Process, Buffer, Participatory Mapping, Peatland, Rural Community, Spatial Analysis

Chapter 1

Introduction

Tropical Peatland Forest and Their Conservation Challenges in Indonesia

Peatlands in Indonesia are estimated at 20.7 Mha of the total geographic area (47% of total tropical peatland), 1138 Gm^3 of volume (65% of the total tropical peatlands), and with average 5.5 m thick peat layer (Page et al., 2011). Peatland in Indonesia is spread out in three big islands. They are Sumatra 43% or 6.44 Mha, Kalimantan 32% or 4.78 Mha, and Papua 25% or 3.69 Mha, (Figure 1) (Osaki, 2016).

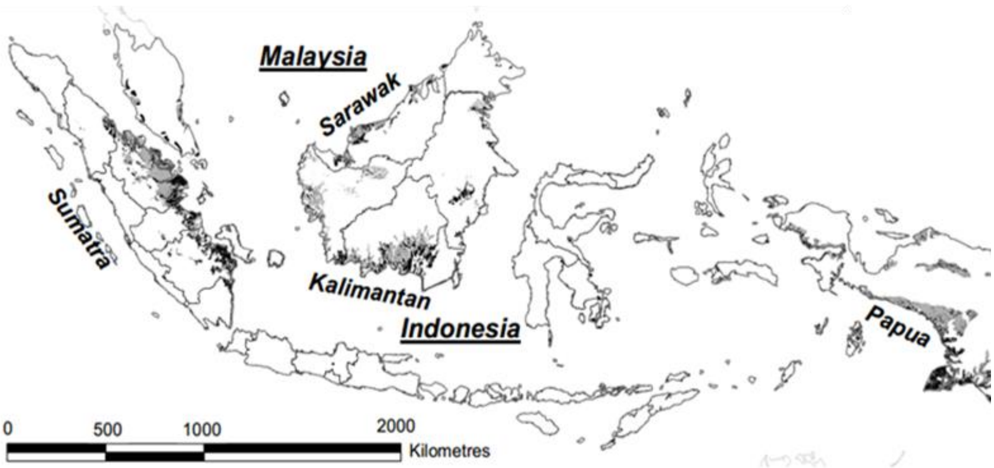


Figure 1 Peatland in Indonesia (Hooijer et al., 2010)

Peatland in Indonesia threatened by deforestation and forest degradation. Kalimantan (Borneo) is one of the areas of tropical peatland, which has been affected seriously by both human and climate change impact. In Kalimantan (Borneo), trees from *Dipterocarpaceae* family are dominated tropical peatland ecosystem. *Dipterocarpaceae* trees species are highly commercial, especially in Indonesia. Trees such as *Shorea balangeran*, *Shorea parvifolia*, *Calophyllum spp*, *Alstonia spp* are favorites among other species to build a house, boat, and furniture in Kalimantan.

Tropical peat swamp forest is crucial not only for its wealth of diverse bio-resources but also for its huge carbon pool (Tawarya et al. 2003). Peat soil is considered as organic soil (Histosols). The unique properties of Histosols are a very high content of organic matter in the upper 80 cm (32 in) of the soils and no permafrost. The amount of organic matter is at least 20 to 30 percent in more than half of this thickness, or the horizon that is rich in organic matter rests on rock or rock rubble (USDA, 1999). Peat soil can be found in transitional ecosystems between aquatic and terrestrial ecosystems.

Literature Review

Conservation Challenges for Indonesian Peatland

Peat soil is vulnerable if it is over exposed and cultivated without considering the conservation rules. Destruction of peat soil damages its physical, biological and chemical properties (Noor, 2010). Peat soil is hydrophilic which mean it can bind water. There are three categories of peat soil; first, fibric peat (raw) that can bind water as much as 850% from its dry weight, meanwhile in sapric peat (processed) that only bind water as much as 450% from its dry weight (Noor, 2010). If the physical, chemical and biological properties of hydrophilic soils are damaged, it will become hydrophobic, where the peat soil cannot bind water anymore.

Peatland utilization for agriculture is not a new thing in Indonesia, especially in Sumatera and Kalimantan. It was the indigenous people who looked and utilized peatland as a resource to produce traditional food crops, fruits, and spices. However, traditional peatland utilization changed when the mega rice project was initiated. The project was established in 1995 and discontinued in 2000 in the Central Kalimantan Province. It was a project proposed to open one-million-hectare of peatland as paddy fields to produce rice in support of food security in Indonesia. The opened peatland areas in Kalimantan for this project also known as the three largest GHG emission zones in the world (Noor, 2010).

In the 1990s, the local communities relied on the forest to make a living. They opened the land for ladang (farm), paddy fields, palm oil and rubber plantations by using the slash and burn method, but most of the land cultivations did not manage the fire well. The communities also logged timber inside the forest to get some cash income. After the 1990s, Indonesian Government introduced a *Manajemen Hutan Lestari* (Sustainable Forest Management) operation to regulate logging activity. This policy made logging activity became the least favored livelihood option for the local communities. However, these communities still harvest timber on a smaller scale. Besides the government policy, the decrease in the number of commercial timber species in these forests also led to the reduction in logging activities. Lately, most of the villagers earn their living from river fishing (Lemons et al., 2011).

Conservation Options

Agroforestry

Agroforestry systems can be defined as an agroecosystems approach to land use that incorporates trees and shrubs into farming practice, in which both trees and agricultural crops or livestock are combined on the same field (Reynolds et al. 2007; Quinkenstein et al. 2009; Cardinael et al. 2015). Agroforestry systems combine the potential to provide a variety of non-marketed ecosystems while maintaining a high agricultural production (Clough et al. 2011). Agroforestry can contribute to water quality improvement (Bergeron et al. 2011), biodiversity enhancement (Schroth et al. 2013), and soil conservation (Young 1989). Based on the structure, the interaction of agroforestry systems can be classified as windbreaks, silvopastoral systems, forest farming systems, integrated riparian forest systems, and tree-based intercropping system – also known as alley cropping (Reynolds et al. 2007).

Agroforestry systems can provide the security of a diversified source of products, usually by combining food crops, cash crops, timber, and various non-timber products and they are very resilient to the economic and ecological crisis (Feintrenie et al., 2010). As a strategy in reducing tropical forest destruction and degradation, agroforestry systems are becoming important in tropical areas (Perfecto & Vandermeer., 2008).

Agroforestry, based on Merwin (1997) should fulfill 4 I's criteria, they are:

1. Intentional, the combination of tree species, crops and/or livestock should be intentional.
2. Intensive, agroforestry practices have to handle the maintenance and management of the productive and protective function intensively.
3. Integrated, integration of multiple crops utilizes more of the productive capacity of the land and helps to balance the economic and conservation aspect.
4. Interactive, by manipulating and utilizing the biophysical interaction, agroforestry practices could provide numerous conservation and ecological benefits.

Agroforestry is considered as a viablealternative to provide income and protect peatlands in Indonesia by not only the government but by the local communities as well. Lemons et al., (2011) indicated that the goal of agroforestry implementation was to achieve restoration and reforestation through integrated natural forest re-growth with a community-based cash crop, multi-story mixed agroforestry and low-impact aquaculture programs that alleviate hunger, poverty, and pressures on the surrounding primary and secondary forests.

Lemons et al. (2011) also suggested executing agroforestry in cooperation and participation with the palm oil concessionaires (as Joint Venture partners) to address leakage. Leakage in this context consists of canal opening, illegal logging, peat burn and other ecological disturbance that threats the ecological balance of the peatlands. The idea is that the establishment of agroforestry practices would become the buffer zones of the conservation areas and protect the forest from future encroachment and deforestation.

Tools to Assist Conservation Efforts

GIS and remote sensing method are very useful tools to address problems in agriculture and forestry. Modeling by using GIS and remote sensing method is essential to create a clear border between the conservation area and utilization area. Modeling to make the zonation regarding the real world are simply possible if there are sufficient data model. In this case, both ecological and socio-economic data are needed for data model description and representation (Longeley et al., 2010). Using GIS is beneficial in this context because of its ability to perform spatial analysis. Here are some examples of spatial analysis functions (Prahasta, 2009):

1. *Query*, in the query database it is used for retrieving data or attribute table without altering or editing/updating the data.
2. *Measurement*, GIS is also capable of performing measurement functions on existing spatial data in the form of analysis of distance, area, circumference, centroid, etc.
3. *Proximity*, this function is used to determine the relationship or juxtaposition of a spatial element with other spatial elements
4. *Reclassify*, this function can be used to reclassify a spatial data (or attribute) into new spatial data by using specific criteria
5. *Overlay*, this function serves to generate new spatial data from at least two spatial data into new spatial layer.

Suitability index as one of GIS analysis output could be one of the best methods to determine the locations that perfectly compatible to do the agroforestry practice in degraded peatland ecosystem.

Analytical Hierarchy Process (AHP) developed by Saaty (1980). The fundamental principle of this method is to solve the problem and build the level of importance of the variable. The level of interest allows estimating the contribution of single criteria at a lower level to evaluate the criteria at its higher level.

Study Area

The study area was located in Seruyan district, Central Kalimantan Province, Indonesia. It is bounded by Tanjung Puting National Park to the west, Java Sea to the south, Seruyan River to the east and KUCC oil palm plantation to the north (Figure 2) (Lemons et al. 2011). Rimba Raya divided into three-unit management, Northern unit (10,978.53 Ha), Central Unit (25,022.13 Ha) and Southern unit (28,161.33 Ha)

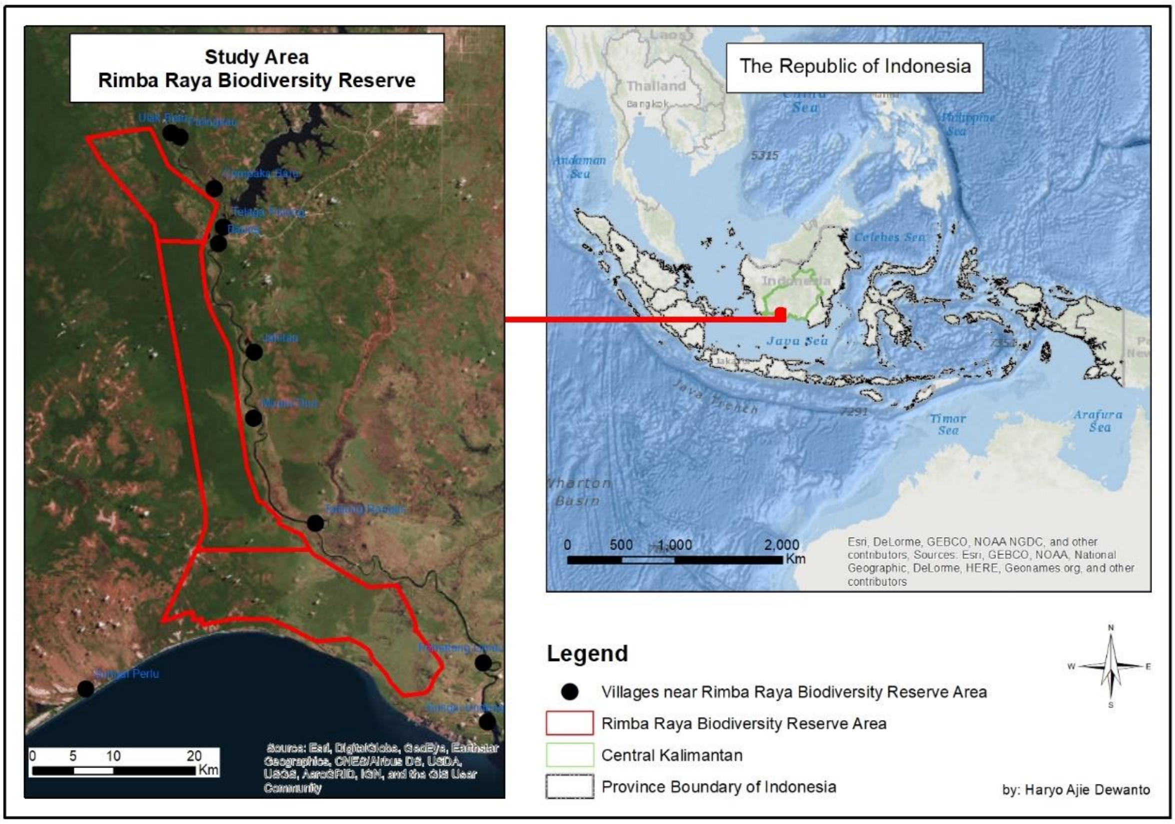


Figure 2 Study Area Location

Mean annual rainfall in the Project Zone is approximately 2500-2700 mm/year. Based on Oldeman classification, the Project Zone falls into B1 and C1 zone. Zone B1 has >200 mm/month of precipitation for long-term averages of 7 – 9 months per year and <100 mm/month for <2 months per year (Lemons et al. 2011). Furthermore, C1 has >200 mm of precipitation/month for 5 – 6 months and < 100 mm per month for < 2 months per year (Oldeman *et al.* 1980). The mean annual temperature is 20-32 ^{0}C with the average relative humidity is 75% (seruyankab.go.id).

Rimba Raya Biodiversity Reserve as a Case Study

Indonesia is one of the best places to implement the REDD+ project. One of the ecosystem restoration concessions (ERC) that held in Central Kalimantan to implement the REDD+ project in peat swamp forest is PT Rimba Raya Conservation. This concession has been carrying out a project named Rimba Raya Biodiversity Reserve Project that started at 2008 (Indriatmoko et al., 2014).

Rimba Raya Conservation is one of private sector companies in Indonesia that get the license from the Ministry of Forestry (Figure 3) to manage a restoration concession. Administratively, this region is located in Seruyan Regency, Central Kalimantan Province, Indonesia. PT Rimba Raya Conservation administers the project on peat swamp forest called Rimba Raya Biodiversity Reserve Project initiated by Infinite EARTH. The project was started in 2008 and has a crediting period for 30 years. The total areal of the project is 64.162 ha (Project Management Area) with 47.237 ha of it is for Carbon Accounting Area (Lemons et al., 2011).

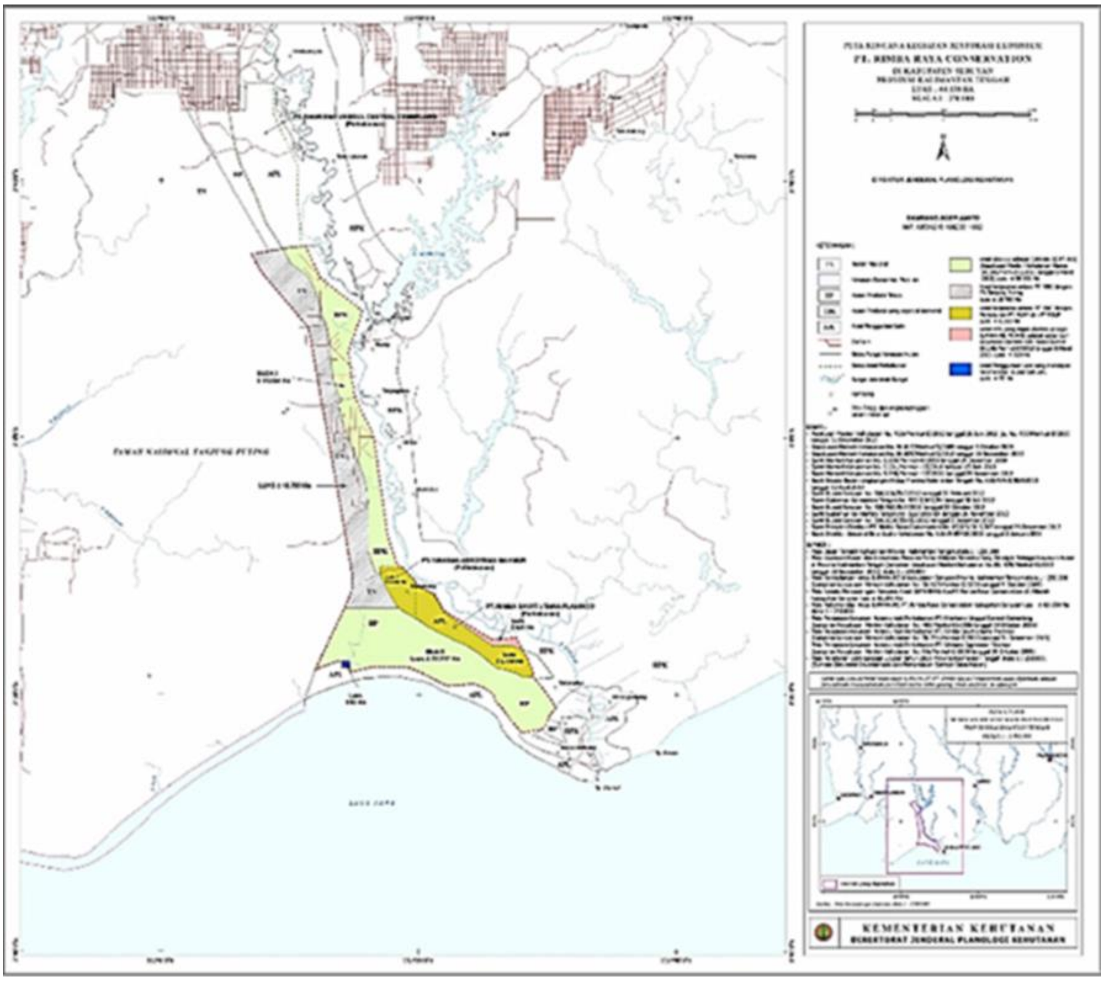


Figure 3 Concession Map of Rimba Raya Conservation (Ministry of Forestry, 2013)

The location was chosen because of its representativeness as restoration concession in peat swamp forests which experiencing forest degradation, deforestation, fires, illegal logging and other threats. Also, the location is critical to protecting the habitat of endangered species, especially Bornean orangutans. Moreover, this concession has received recognition from VCS (Verified Carbon Standard) and CCBA (Climate, Community, and Biodiversity) Alliance standards (www.rimba-raya.com). For this reason, the location is considered to be a good representative site to describe the condition of tropical peat swamp forest restoration.

The Rimba Raya project will eliminate many of the incentives driving illegal logging and the unnecessary conversion of forest to agricultural land. The project will also work to train project-zone community members and offer them priority employment in all the key project activities (Lemons et al., 2011).

Project Justification

This research is intended to map the potential areas that are suitable for agroforestry practices within the study area. The agroforestry systems are trying to combine much technique to gain optimum output both in social-economic and ecological factors. Some developing country like Indonesia, livelihood is a primary concern to keep local communities' sustenance. Therefore, agroforestry could provide alternative livelihood to the community and could protect the natural resource due to overexploitation.

Overall Goal and Objectives

The main goal of this research is to assist the establishment of agroforestry areas as buffer zone (adaptive management zone) in Rimba Raya Biodiversity Reserve.

To acomplished the main goal, the following objectives were constructed:

1. Determine suitable locations for agroforestry practices as buffer zones to the conservation area.
2. Determine whether agroforestry areas could reduce the pressure to natural forests from deforestation or forest conversion.

Chapter 2

Methods and Approach

Data

Data used for this research includedecologic factors including peat soil depth, landcover data and NDVI data (Normalized Difference Vegetation Index), and disturbance factors including fire hotspots data, access data and traditional land use data. All data sets were obtained from either direct measurements or from secondary data provided by Rimba Raya Biodiversity reserve.

Soil

A soil map for the Project Zone was produced using the Soil Resource Exploration Map (Pontianak MA49, Centre for Soil and Agroclimate Research, Bogor, Indonesia) at a scale of 1: 1,000,000 (Figure 4).

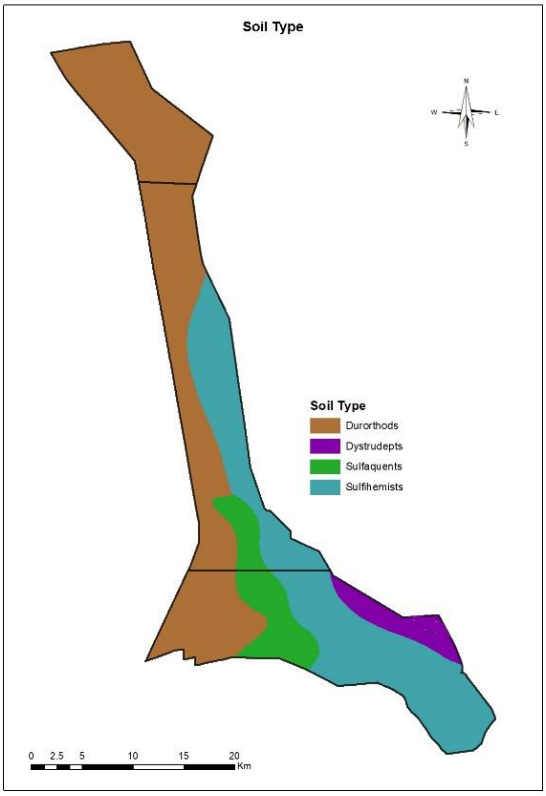


Figure 4 Soil Type Map

Associated soil types in each mapping unit are summarized in Table 1. The great groups and general descriptions are derived from Soil Taxonomy (Soil Survey, USDA

1999). Co-dominant soil types derived from peat (SMU 3) and riverine alluvium (SMU 20) under the Project Zone. Coarser-textured sediment-derived soils are also found in the north). The soil map shows general agreement with the geological map, and RePPProT land systems (Lemons et al., 2011)

Table 1. Soil type (Lemons et al., 2011)

Soil type	General description	Parent material	Sub-landform	Relief
Haplohemist Sulfi hemists	Moderately decomposed peat soils some of which are sulphic	Organic	Peat Dome	Flat
Endoaquepts Sulfaquents	Saturated Inceptisols and saturated sulphicentisols	Alluvium	Delta or estuary	Flat
Endoaquepts Dystrudepts	Saturated Inceptisols and acidic inceptisols	Alluvium	Alluvial Flood Plane	Flat
Quartzipsamments Durorthods	Quartzicentisols and Spodosols with a cemented Hardpan	Sediment	Terraces	Flat-rolling

Soil types and its description were derived from Soil Taxonomy (Soil Survey, USDA 1999).

Peat soil in Sumatera is more fertile than peat soil in Kalimantan depend on the basic material, mineral materials and soil depth. Based on the depth, peat soil classified as (Noor, 2010):

- Shallow peat (50 – 100 cm)
- Medium – shallow peat (101-200 cm)
- Deep peat (201-300 cm)
- and very deep peat (> 300 cm)

Rimba Raya Biodiversity Reserve conduct a massive works to map the peat depth inside their concession. According to referrals of Department of Agriculture (BB Litbang SDLP, 2008), the peatlands area that can be used for agriculture is in a shallow peatlands depth (<100 cm). The reason behind this referral is based on the characteristic of peatlands in a shallow area has a relatively higher fertility rate with lower environmental risk than peat in deeper area. Peatlands with 1.4 – 2 m depth is classified as best fit area for crops plantation. The major limiting factor are the lack of soil condition for rooting and the absence of nutrition that suitable for crops cultivation. Some examples of crops species that capable to adapt to this condition are rice, corn, soy, sweet potato, long bean, and other vegetables species. Peat soil with >3 meters depth is used to be conservation area. This condition is the concern for the peat soil as it's fragile if converted to farm land.

Rimba Raya Biodiversity Reserve has various peat depth from 0 – 720 cm (figure 5).

Figure 5 Peat Soil Depth

Landcover

Land cover map 2017 was produced from Landsat 8 OLI (figure 6). To classify the land cover type in Rimba Raya area, the unsupervised and supervised classification were assigned. Unsupervised method was done using object-based tool (Feature

Extraction) in ENVI 5.3 with the value of edge feature is 10 and merge level is 90. This method was used because there is a haze that covers the area. The haze will disrupt the pixel recognition if we utilized pixel-based tool. There are 11 classes from the land cover interpretation that consist of coastal forest, farmland (plantation), fishpond, grassland, low sparse vegetation, peat swamp forest, palm oil plantation, riparian forest, shrubland, wetland, and water body (table 2).

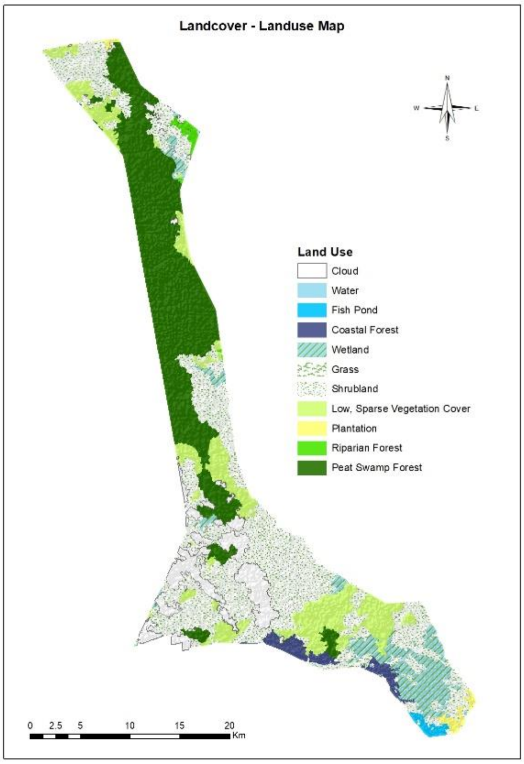


Figure 6 Landcover Map (2017)

Table 2. Landcover Classification

Landcover	**Area (Ha)**
Coastal Forest	1,418.14
Fish Pond	395.11
Grass	329.41
Low, Sparse Vegetation Cover	9,068.94
Cloud	5,518.18

Peat Swamp Forest	18,601.25
Plantation	550.3
Riparian Forest	383.81
Shrubland	23,246.34
Water	44.12
Wetland	4,623.68

Land cover map validation was conducted only for the latest image, 2017. There are 136 random sample plots that have been visited during ground check in May – July 2017. After that, error matrix has been done to calculate overall accuracy, user's accuracy and producer's accuracy and kappa coefficient of agreement.

Table 3. Formula of Accuracy assessment

Name	Formula	References
Overall accuracy	$\frac{1}{N}\sum_{i=1}^{c} n_{ii}$	Story and Congalton (1986)
User's accuracy	$\frac{n_{ii}}{N_i}$	Story and Congalton (1986)
Producer's accuracy	$\frac{n_{ii}}{M_i}$	Story and Congalton (1986)
Kappa coeficient	$\frac{P_o - P_e}{1 - P_e}$	Congalton et al. (1983)

Where N is total number of samples, n_{ii} is the number of samples that correctly classified, N_i is the row totals for class i and M_i is the column totals for class i, P_o is $\frac{1}{N}\sum_{i=1}^{c} n_{ii}$, and P_e is $\frac{1}{N^2}\sum_{i=1}^{c} N_i\, M_i$. Land cover map 2017, was validated through the ground check. Based on the error matrix table (table 4), the Kappa coefficient was 0.91 that means the accuracy of the classification is high. Which mean the landcover map is fit to use in the spatial analysis. These percentage or nominal value of accuracy assessment represent that this classification result has good quality and close to the reality. **Table 4. Error matrix for land cover map 2017**

		Class types determined from reference source										Total (Ni)	User's Accuracy
		PSF	**LSV**	**SL**	**RF**	**PL**	**WB**	**WL**	**FP**	**G**	**CF**		
Class types determined from classified map	**PSF**	49										49	100
	LSV		3									3	100
	SL	5		27				1				33	81.82
	RF				14							14	100
	PL					8						8	100
	WB						13					13	100
	WL			1			1	5				7	71.4
	FP								2			2	100
	G			1	1					1		3	33.3
	CF										2	2	100
	Total	54	3	29	15	8	14	6	2	1	2	134	
	Producer's accuracy	90.74	100	93.1	93.33	100	92.86	83.33	100	100	100		92.6
	Kappa	0.91											

NDVI (Normalized Difference Vegetation Index)

Vegetation cover of the study area is mapped from Landsat 8 image using NDVI, which is the normalized ratio between the reflected radiance in the red channel and the reflected radiance in the infrared channel (Svoray et al., 2005). Values close to zero represent rock and bare soil and negative values represent water and clouds. The formula for NDVI is (NIR band – RED band)/ (RED band + NIR band). Where NIR is near infrared (band 5) and red band is band 4 in Landsat 8 images. the NDVI value were grouped into five classes using natural break jenks, with high score for high NDVI range value. In Study area the value of NDVI range from -0.066 – 0.583 (figure 7). Most area have the high NDVI value located at center part of project area.

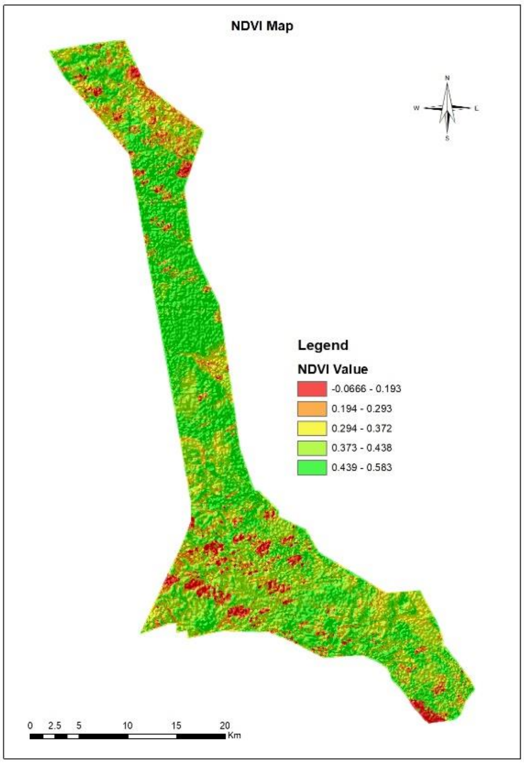


Figure 7 NDVI Map

Fire

Several disturbances occur in this project area. Fire, illegal logging, illegal hunting and property trespassing has often happened. Furthermore, the land cover which was affected by the most significant number of the hotspot is shrubland, followed by wetland, and farmland (plantation). A different pattern took place between 2014 and 2015 due to a significant number of hotspots (figure 8) also affecting the peat swamp forest. In the peat swamp forest, there were only two hotspots in 2014 and became significantly higher in 2015 (99 hotspots), the peak fire was in early November which is the end of rainless period. There was no fire occurred in 2016 and only 2 hotspots occurred in 2017 on shrubland (Table 5). In 2015, the biggest number of hotspots occurred in shrubland. This condition was due to the low level of ground water at the end of the rainless period.

Table 5. Hotspots per land cover type

Landuse	Hotspot 2014	Hotspot 2015	Hotspot 2016	Hotspot 2017
Cloud	4	32	0	0
Coastal Forest	5	16	0	0
Grass	5	1	0	0
Low, Sparse Vegetation	10	2	0	0
Peat Swamp Forest	2	99	0	0
Plantation	2	14	0	0
Riparian Forest	1	6	0	0
Shrubland	90	1	0	2
Wetland	34	121	0	0

Data Derived from Nasa Fire Information for Resource Management System (FIRMS)

In a dry season, shrubland is vulnerable because the shrubland is the source of fuel when it becomes scorched (easy to ignite by small fire). If the communities cannot control the fire, it could spread to the other landcover like peat swamp forest. When the peat dries and ignites the fire, the ground fire will occur and became difficult to extinguished.

Wildfire brought negative impact to the location including the damaged on the peat soil. Physical damaged on soil include the subsidence on peat soil, irreversible drying, peat soil got hydrophobic properties, damaged on peat soil to bind nutrient and decrease water supply horizontally because the peat soil increased its porosity (Noor, 2010). Soil conservation would be a major issue if a farmer or stakeholder would bring back the soil condition, and if it is possible, it will take a long time to restore it. Fires make a direct adverse impact due to the potential of long-term continuous degradation especially in the south part region where seasonally inundated shrubland and grassland are susceptible to fire.

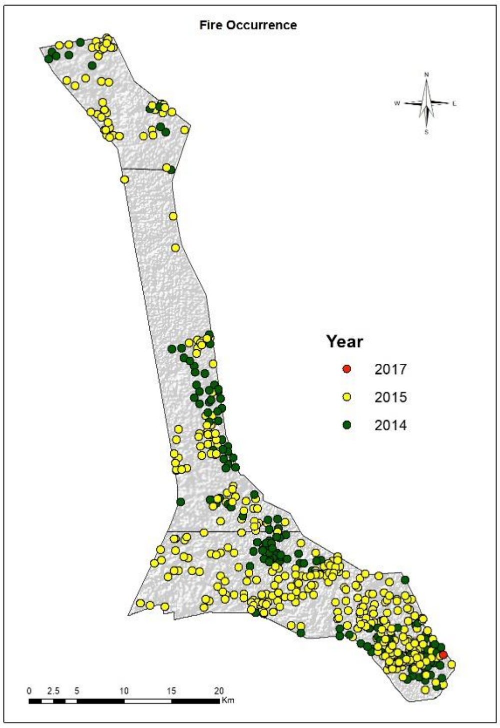


Figure 8 Fire Occurrence

Wildfire occurred because fires that were set by the communities were not well managed. Some traditional farmers thought that burning peat soil would give benefits to them because of the peat ash brought back the nutrient (Noor, 2010). The used of peat ash is popular among traditional farmer in Kalimantan because the ash could bring back the nutrients and make the soil more fertile (table 6).

Those things happened because of the access. New road, hunter path, small river and canal mostly open access to everyone. Accessibility is one thing that can suppressed the forest, in 2015 Rimba Raya also reported that fires are concentrated in the north and south part of the Project Zone and fires have historically been major cause of forest lost.

Table 6. Nutrients from burned peat (Noor, 2010)

Nutrients and pH	Peat soil Ash

pH	6.33
Phosphate (%)	1.2
Nitrogen (%)	1.22
Calium (%)	0.02
Calsium (%)	0.16
Magnesium (%)	0.01

The communities especially in southern part of the project area, also reported that they still logged timber illegally. The local communities also hunt the deer at low levels. However, it even becomes a threat for the conservation area when in the dry season. In the dry season peat soil is vulnerable due to the wildfire.

Village Demographic and Spatial Planning

There are nine villages located in the east part of Rimba Raya within the potential sphere of influence of the project (table 7). Most of the villagers work as traditional farmer, fisherman, palm oil plantation labor, wood crafting, etc. The demographic will generate the movement pattern of the villager to the forest (conservation area) and also could be the direction for where they have the livelihood activities inside the forest. All social data will be collected when the survey is conducted in the site.

Two former concessions, PT Bina Samaktha and PT Mulung Basidi, were occupied Rimba Raya area in 1980s and 1990s and applied selective logging in north part and south part area respectively. PT Bina Samaktha stopped logging in 1998 while PT Mulung Basidi stopped logging in 2000. After that, the abandoned concession became easily accessible by peripheral villagers.

Table 7. Population data (Rimba Raya Biodiversity Reserve 2016)

No	Village	No. of people	No. of Women	No. of Men	Predominant tribe

1	Ulak Batu	181	89	92	Dayak Nadju & Banjar
2	Palingkau	168	77	91	Dayak Nadju & Banjar
3	Cempaka Baru	566	216	250	Dayak & Banjar
4	Telaga Pulang	2313	1008	1305	Dayak & Banjar
5	Baung	2015	992	1223	Dayak & Banjar
6	Jahitan	477	208	269	Dayak & Banjar
7	Muara Dua	523	236	287	Dayak & Banjar
8	Tanjung Rangas	1406	641	765	Dayak & Banjar
9	Pematang Limau	3575	1658	1917	Dayak & Banjar
Total		**11224**	**3467**	**4282**	

Undefined boundary of villages near Rimba Raya Project (figure 9) led to encroachment to the conservation area. That is why participatory mapping program was conducted by Rimba Raya Conservation to reduce the pressure to the forest area and help the regency and village to develop spatial planning.

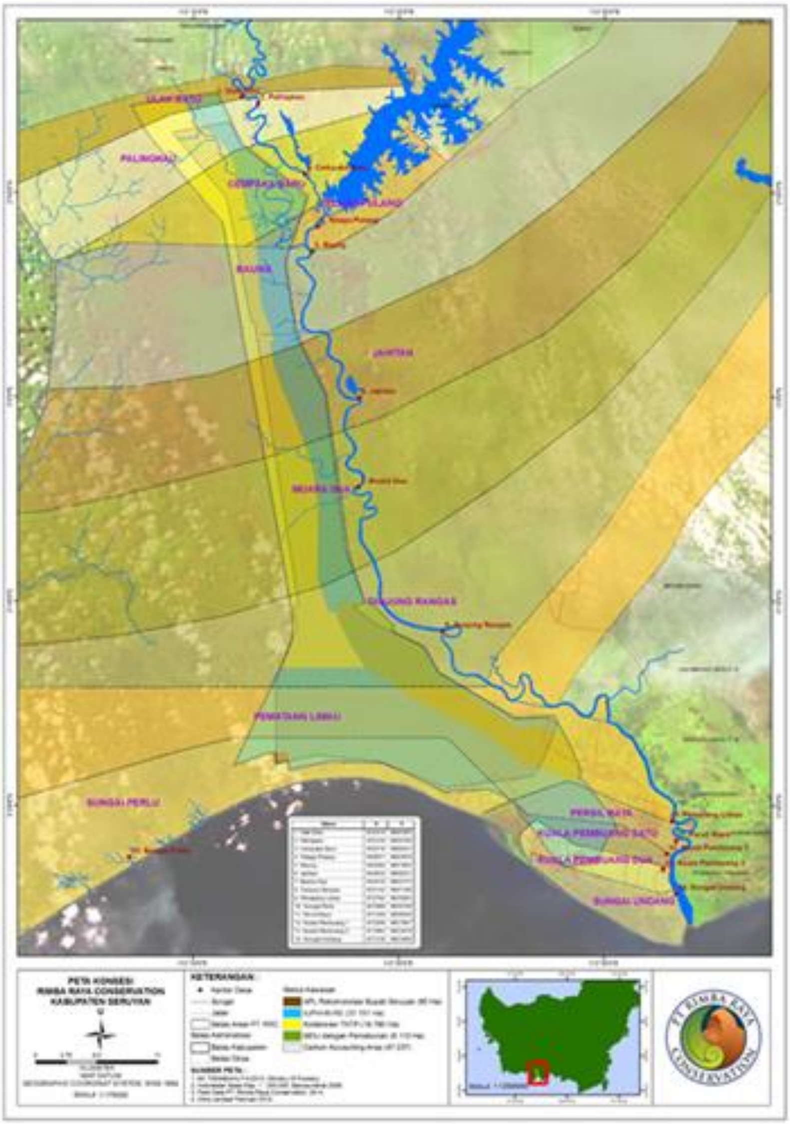


Figure 9 Undefined Village Boundary

Integration of all data (biophysics and socio-economic) from stakeholders are necessary for a participatory mapping. Involvement of government agencies, the private sector, and community are very central in this activity. A participatory rural appraisal is an approach used by non-governmental organizations (NGOs) and other agencies involved in international development. The proposal aims to incorporate the knowledge and opinions of rural people in the planning and management of development projects and programs. Participatory mapping is similar to another mapping that is conducted by the government, but the involvement of the community is the most significant credit.

In the Rimba Raya Biodiversity Reserve area, the regency government doesn't have spatial planning in every village. This condition makes the regency have difficulty to managing their areas and some “trouble” for private enterprise. This activity initiated by Rimba Raya; they intensively communicate with local government and community to conduct this event. In this case, communication is essential to gathering all stakeholder’s opinion. People dealing with the participatory approach in forest management should understand the policies and decision-making processes, so in this program, they also need to develop the answer for some question that arises including:

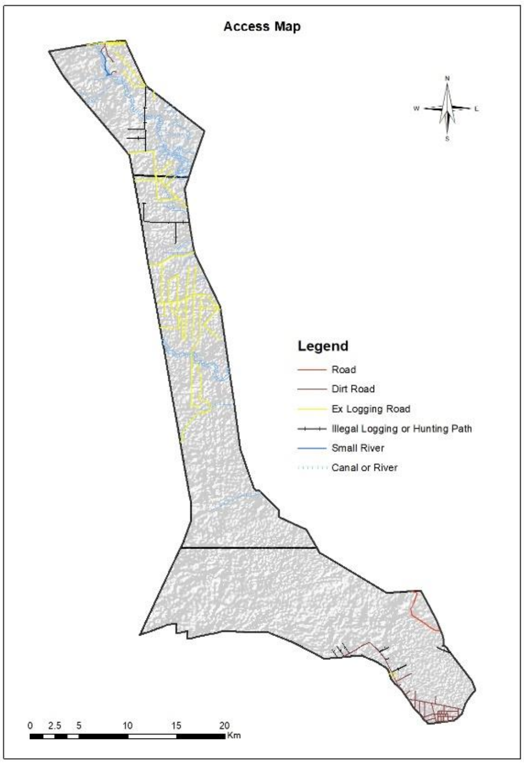
1. How can stakeholders can make a deal with and which policies or methods should be established in response to forest management?
2. How can different people who are involved in management coordinate their actions where there is some conflict arise that overlaps between needs and policies?
3. How can policies be enforced when voluntary efforts are the most important thing to consider?

Developing tools and policies in forest management is mainly like any other sector or the same as natural resources management (Brooks et al., 2013). Therefore, to avoid or minimize conflict consistency in participatory approach and coordination with multi-stakeholder are needed to keep up. Unflexible or undelegated roles in forest resources management could lead to major destruction (Brooks et al,.2013). A participatory approach implies that the perceptions, views, and concerns of all relevant stakeholders or actors must be accommodated.

Besides, Castro and Nielsen (2001) also indicated that one major justification for co-management is the belief that increased stakeholder participation will enhance the efficiency and perhaps the equity of the knotted common property resource management and social systems. Social and biophysical conditions must be considered in the making of regulations. In this case, by giving apparent authority to the community and the mutual needed for natural resources can reduce or avoid forest degradation.

Access and Traditional Land Use Data

Fire, illegal logging and any other illegal activity occurred because of the access (Erten et al., 2004). Roads, hunter path, small river and canal mostly open access to everyone. Accessibility is one thing that can suppressed the forest. Access map data including river, canals, hunter path, distance from village (figure 10 and figure 11) and traditional land use (generated from village spatial planning data). There are 8 of 9 participatory maps. The maps show traditional land use by the communities. These maps were created in Arc GIS 10.5.1 using administrative data from the Rimba Raya Biodiversity reserve data.



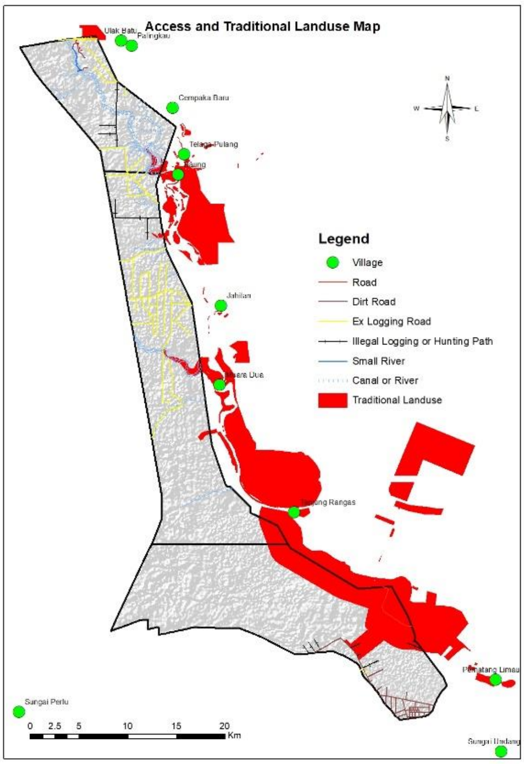


Figure 10 Access Map

Figure 11 Access and Traditional Landuse map

Index-based GIS Modeling

The method that will be used in this research is spatial analysis based on the multi-criteria analysis. This analysis will predict the suitable location for agroforestry areas establishment. This approach required a process to determine the weights of the variables. The qualitative variable must be translated into numerical data and all variables must have the same standard of making weight and score.

In the technique of scoring one of the criteria that have a high suitability value has a high score, as well as the criteria that have a low fitness then also has a low score (Malczweski, 1999), all the data should be reclassified to get the score. To determine score and weight of each criteria in this study, the analysis was built using land use (agriculture criteria) capability in production. Each variable will be described into 5 conformity types that have a range of values 1 to 5 where each range represents the suitability level of agriculture and agroforestry land use (table 8).

Table 8. Suitability Score

Score	Suitability
1	Unsuitable
2	Low suitability
3	Medium
4	High Suitability
5	Very Suitable

Spatial Analysis to Establish Agroforestry Areas as Buffer Zones in Tropical Peatland

In Borneo, peatlands spread of four provinces, the most extensive peatlands in Borneo mainly located in Central Borneo (55,7%) and West Borneo (35,2%) of total peatlands in Borneo Island (Osaki, 2016). Rimba Raya Biodiversity Reserve area mainly forms by peatland ecosystem. However, the complexity of the peatland attributes, a vast area and also external factors including pressure from the local community, make Rimba Raya Biodiversity Reserve challenging to set priorities for conservation efforts. Therefore, GIS and remote sensing method become one of the answers.

It is challenging to access peatlands. The upper layer of tropical peatlands are mostly hidden under forest, and it is difficult to identify and map the boundaries of peatland accurately. Consequently, GIS and remote sensing could be the most effective tools for peat mapping.

Data Analysis Software

The scoring processes for each criterion used ArcGis 10.5.1 software, reclassifying raster data based on suitability score.

The procedure for this method consist of the following phase:

1. Assessment of the suitability structure: Choosing the land use factors and define their importance and how the impact the suitability priority
2. Producing layers of map: data acquisition and making an appropriate GIS data
3. Modeling/ spatial analysis: Defining viable area and combining the suitability factors
4. Sensitivity analysis: signifying the effect of different criterion weights on the spatial pattern of suitability index (Store and Kangas, 2001).

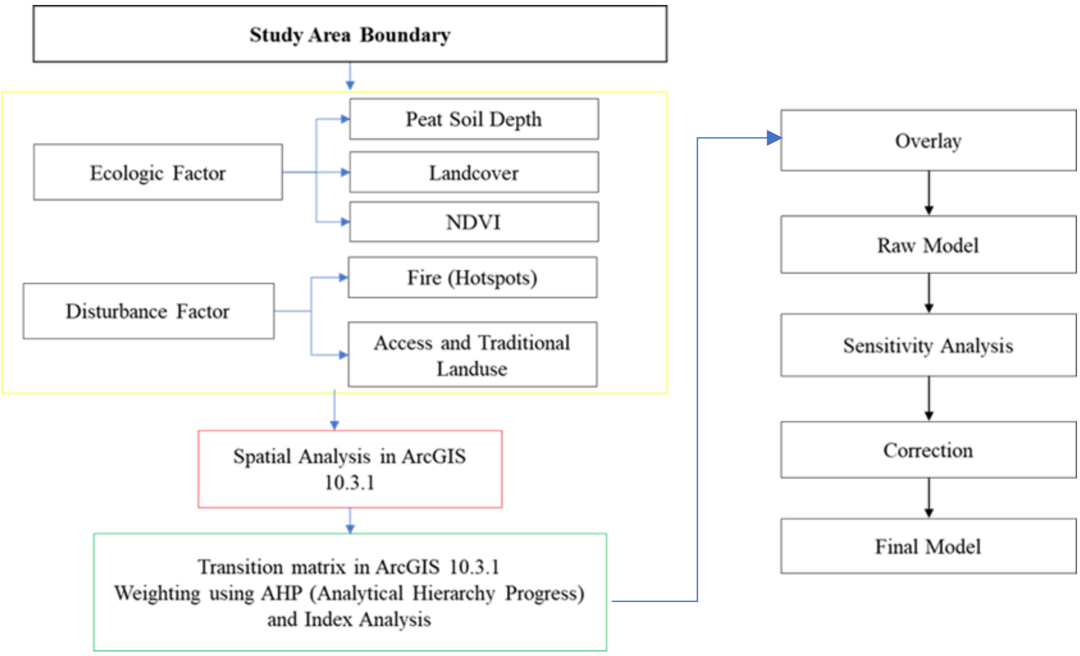


Figure 12 Data Analysis Flow Chart

Ecologic Factor

Peat Soil Depth Scoring

Table 9. Peat Soil Depth Score

Parameter	Range Value	Score	Suitability
Peat Soil Depth	0 - 100	5	Very Suitable
	101 - 200	3	Medium
	>201	1	Unsuitable

Only peat soil depth parameter that use three scores. These were based on the Agriculture Department statement for agricultural cultivation in peat soil. Where peat soil depth within 100 is possible to do the cultivation. In 101 – 200 centimeters, it is still possible, but the maintenance is much more expensive. Peat soil with depth >200 centimeters was considered deep peat soil and use for conservation purposes. Deep peat soil is accumulated in the central part of the Rimba Raya area and shallow peat soil is distribute in southern part of the concession and part of north area (figure 12). From the map of access and traditional land use, many agricultural things activities have massively occurred in the southern part of the Rimba Raya area.

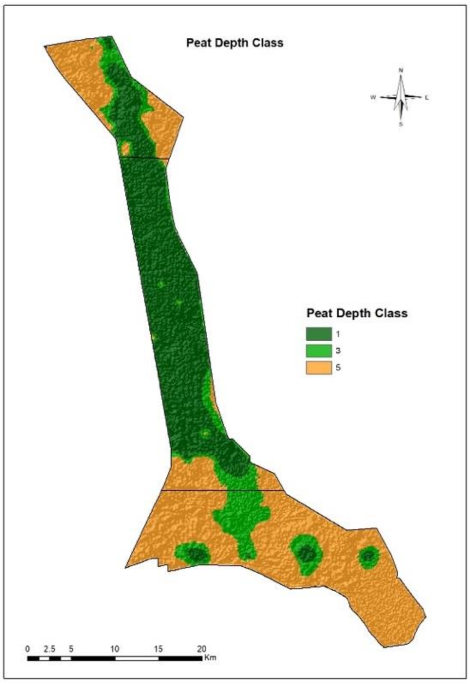


Figure 13 Peat Soil Depth Class

Landcover and NDVI Scoring

The lesser the density the more suitable for agriculture and agroforestry activities. This means that in the future it will be easier for the community to prepare the land. There are 12 classes of landcover. The land cover data is reclassified by 5 classes base on suitability level (figure 13). Suitability level of the landcover is based on accessibility for cultivation or open the area, access to water and vegetation density (similar with NDVI value). the most suitable location is on shrubland and grassland (score 5) and the most unsuitable area is on peat swamp forest (table 10).

Table 10. Landcover Score

Parameter	Range Value	Score	Suitability
Landcover	Peat Swamp Forest, Fish ponds, Wetland, Water and Coastal Forest	1	Unsuitable
	Riparian Forest	2	Low
	Cloud (undetermined landcover)	3	Medium
	Palm oil Plantation, Low Sparse Vegetation	4	High
	Shrubland and Grassland	5	Very Suitable

The description of landcover type is provided to give more comprehensive information (table 11).

Table 11. Landcover Description

Name class	Description	Location
Peat swamp forest	Peat swamp forest, locally "hutan rawa" denoting seasonally wet forests on peat substrate. All peat swamp forests in Rimba Raya are lightly to highly degraded by selective logging.	Project zone and boundary area 
Riparian forest	Forest areas adjacent or near to a river. The areas have mineral soil.	Boundary area 

Coastal forest	It is generally found above the high-tide mark on sandy soil and may merge into agricultural land or upland forest.	Project zone 
Shrub land	Formerly peat swamp forests, these areas were deforested by fire in the last ten years. Seasonally wet areas characterized by shrubby regrowth and scattered remnant trees.	Project zone and boundary area 
Grass land	Ground covered by vegetation dominated by grasses, with little or no tree cover	Project zone 
Oil palm plantation	In the Rimba Raya vicinity, all plantation agriculture is oil palm plantation and is currently confined to the WSSL concession in the north, with some recent expansion into the Project Management Zone.	Boundary area and project zone 

Fish pond	Repeatedly burned cultivation land, locally “ladang”, often abandoned after several years of cultivation. Active cultivation land may appear bright green on imagery from post-fire herbaceous growth. Old ladang often has woody shrubs and scattered trees.	Boundary area 
Wetland	Locally “danau” or seasonal lake, most of these areas were formerly peat swamp forests that have been logged and burned. Where these are adjacent to rivers, flooding may be semi-permanent. Most are sedge-dominated.	Boundary area and project zone 
Low sparse Vegetation	Areas with sparse grass or herb cover or bare ground, usually associated with recent, severe or frequent burning in areas of human activity. Most of these areas have been cleared by fire but are interpreted to be outside cultivation lands.	Boundary area and project zone 
Water body	Deep water with no vegetation	Boundary area and project zone 

(Lemons et al., 2011)

NDVI value linked with canopy cover, the higher the value the denser the canopy cover. Using natural break, value of NDVI was determine also with 5 classes (table 12).

Table 12. NDVI Score

Parameter	Range Value	Score	Suitability
NDVI	-0.067 - 0.19	5	Very Suitable
	0.2 - 0.29	4	High
	0.3 - 0.37	3	Medium
	0.38 - 0.44	2	Low
	0.45 - 0.58	1	Unsuitable

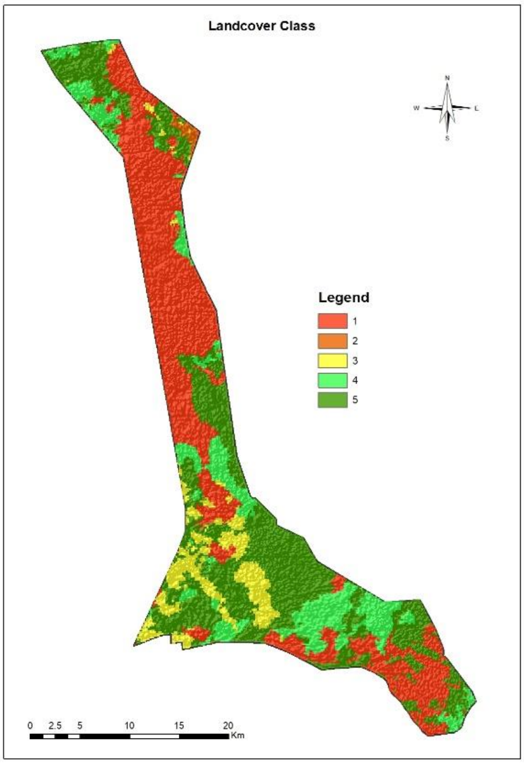


Figure 14 Landcover Class

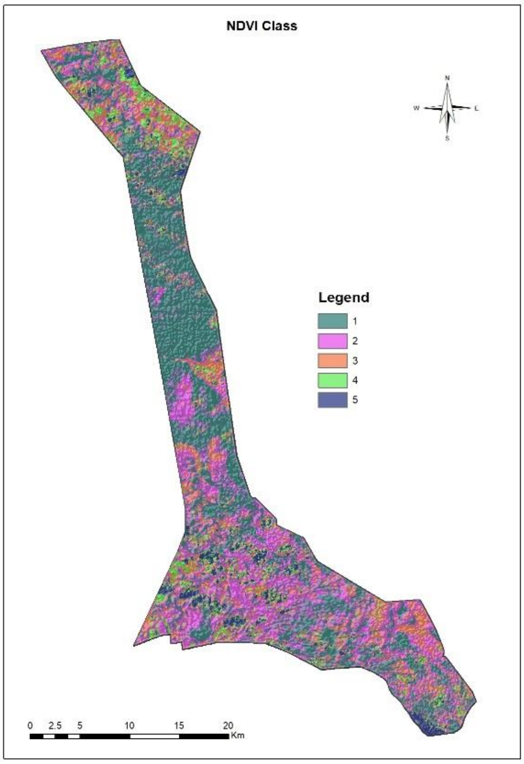


Figure 15 NDVI Class

Disturbance Factor

Fire Density Scoring

Fire density was analyzed using a kernel estimation method to figure out fire affected areas in the last ten years. Moreover, a kernel density estimation method was used to map distribution and concentration of fires within the study area and to indicate areas that had high frequency (and possibly at greater risk) of fires (Asgary et al. 2009). The kernel density estimation is used as analytical method to solve the distribution density function, which is random variable for a distribution of the sample of unknown given data, so that to construct the data samples in a specific space distribution model (Rui et al 2013).

All active fires or hotspots from 2014 to 2017 were combine into one GIS layer then the spatial distribution of fire points was modelled as density kernel function (Takahata et al. 2010). The kernel density was drawn on default setting in ArcGis software.

The kernel density estimation is simply modeled as:

$$\hat{f}_h(x) = \frac{1}{n}\sum_{i=1}^{n} K_h(x - x_i) = \frac{1}{nh}\sum_{i=1}^{n} K\Big(\frac{x - x_i}{h}\Big),$$

where f_h (x_t) is density distribution which used to estimate the weights, x is observed value, K are the Kernel function. h is the width of the Kernel function. The value of the fire density is between 0 to 54068 densities and classify as 5 classes using natural break in ArcGIS (table 13). The higher the value is the more suitable the location. Because those area that burned were mostly changed into farmland.

Table 13. Fire Density Score

Parameter	Range Value	Score	Suitability
Fire Density	0 - 4,876.74	1	Unsuitable
	4,876.75 - 11,661.78	2	Low
	11,661.79 - 22,051.37	3	Medium
	22,051.38 - 36,681.61	4	High
	36,681.62 - 54,068.27	5	Very Suitable

The area heavily damaged by fire occurred in the southern part of Rimba Raya area (figure). Those location experienced of farming activities including rice field, opening canal and road construction.

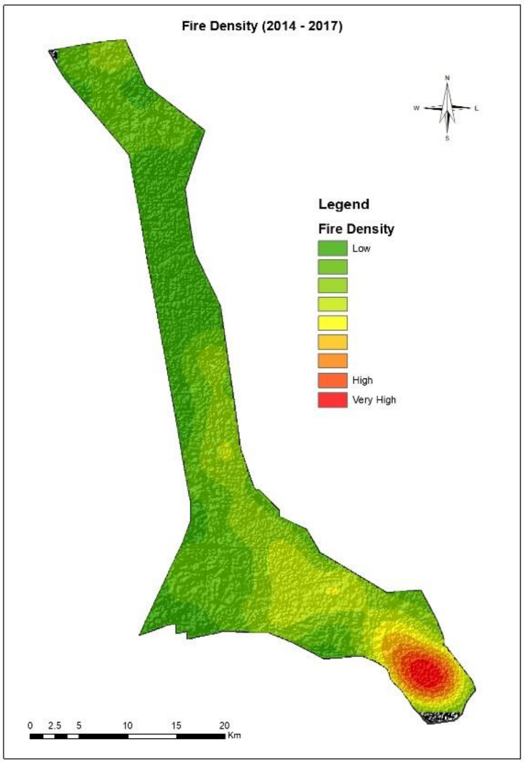


Figure 16 Fire Density Map

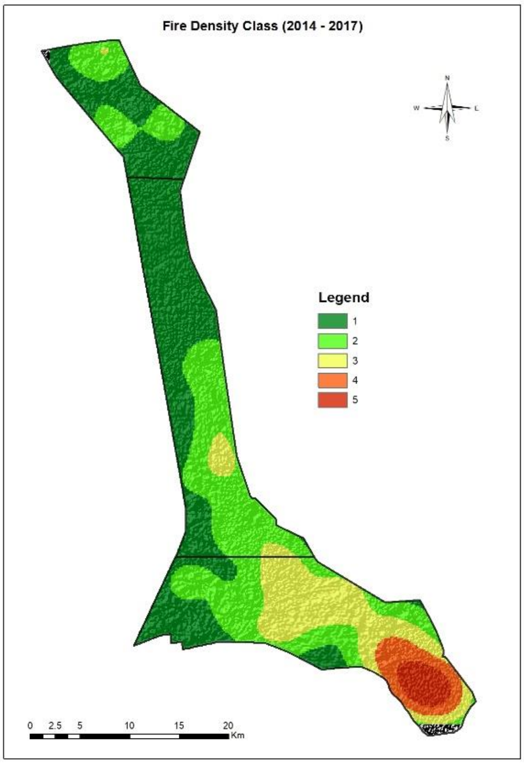


Figure 17 Fire Density Class Map

Access Density Scoring

Access and traditional land use data is used to generate the access (line density) density map. The density value fall from 0 to 0.338 square kilometers (table 14). These values divided into 5 classes by using natural break in ArcGIS software.

Table 14. Access Density Score

Parameter	Range Value	Score	Suitability
Access Density	0 - 0.0292	1	Unsuitable
	0.0293 - 0.0743	2	Low
	0.0744 - 0.125	3	Medium
	0.126 - 0.206	4	High
	0.207 - 0.338	5	Very Suitable

The higher the value, the denser the access in the particular area. It means that the area is accessible by the community and more feasible to cultivate. The access is mostly consisting of ex-logging road, dirt road, illegal logging path and canal inside the project area and more importantly the traditional use by the communities. The access density distributes from northern to southern part of the project area.

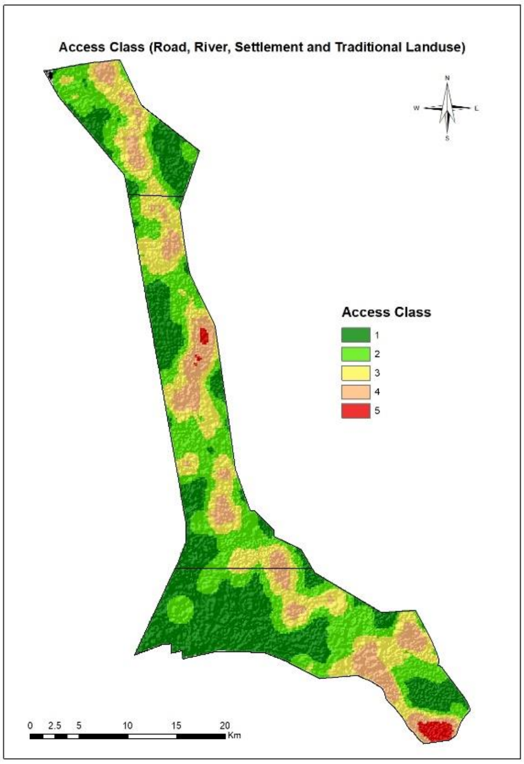


Figure 18 Access Density Class

The data analysis step is being conducted using ArcGIS software. Reclassify and weighting the criteria also using the ArcGIS software in spatial analysis tools. The total weight for the suitability area is equal to 1 or 100%. Each variable first must be weighted. For the ecologic and disturbance factor used equal weight and sub-variable is varied depending on their importance to the suitability analysis (table 15). In this project, the ecologic and disturbance element have the same weight because the assumption is all of the variables have the same influence to determine the suitable location for the establishment of agroforestry areas.

Table 15. Weighted Variables of Agroforestry Suitability Areas

Goal Suitable Agroforestry Areas	Variable	Weight W1	Sub Variable	Weight W2
1	Ecologic	0.5	Peat soil depth	0.33
			Landcover	0.33
			NDVI	0.33
	Disturbance	0.5	Fire	0.5
			Access	0.5

Result and Discussion

Suitability Map

The suitability map of agroforestry areas show that the most suitable area for agroforestry areas located in southern part of the project area and some parts at central and northern part of the project area. To analyze the suitability area, the result was classified into suitability classes (figure 20).

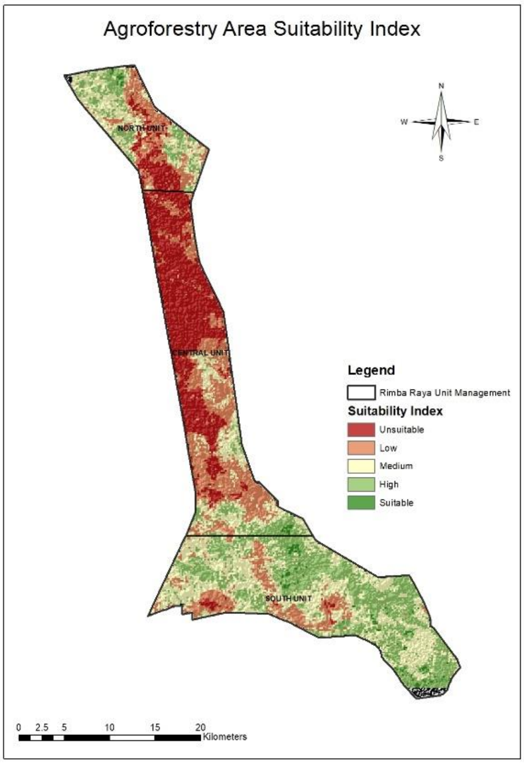


Figure 19 Agroforestry Suitability Index Map (model 1)

In this model, the total area of very suitability areas for agroforestry is about 1.62% (1,044 Ha) of the total of the project area. The high suitability class is 24.1% (15,404 Ha) of the total area. Most of the unsuitable area is located in central part of the project area. The total of the unsuitable area is 20.9% (13,431 Ha) of the total project area. The low suitability also has big regions about 22.7% (14.583 Ha). Medium suitability in this model has the biggest area about 30.7% (19,699 Ha). This number also derived for each unit management. The most significant allocation for agroforestry area located in the southern unit of Rimba Raya Biodiversity reserve where 74%

(11,444 Ha) of the high suitability areas occur at the Southern unit and the amount of most suitable area is 60% (626.6 Ha) (table 16).

Table 16. Agroforestry Suitability Index Area

Unit Management	Suitability Index Area (Hectares)					Total (Ha)
	Unsuitable	Low	Medium	High	Suitable	
Northern Unit	1784.59	3098.59	3627.79	2306.59	160.99	**10978.53**
Central Unit	11270.59	7998.19	4038.19	1546.99	168.19	**25022.13**
Southern Unit	366.19	3498.19	12048.19	11533.39	715.39	**28161.33**
Total	**13421.36**	**14594.96**	**19714.16**	**15386.96**	**1044.56**	**64162.00**

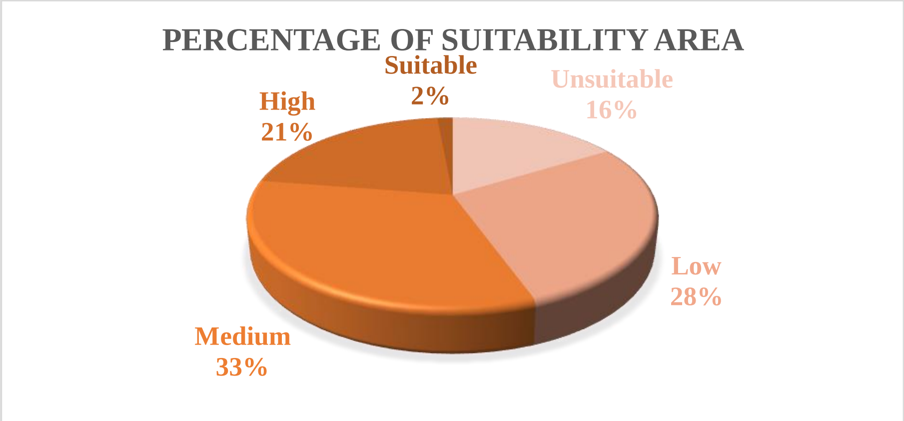


Figure 20 Percentage of Suitability Area in Rimba Raya Biodiversity Reserve Area

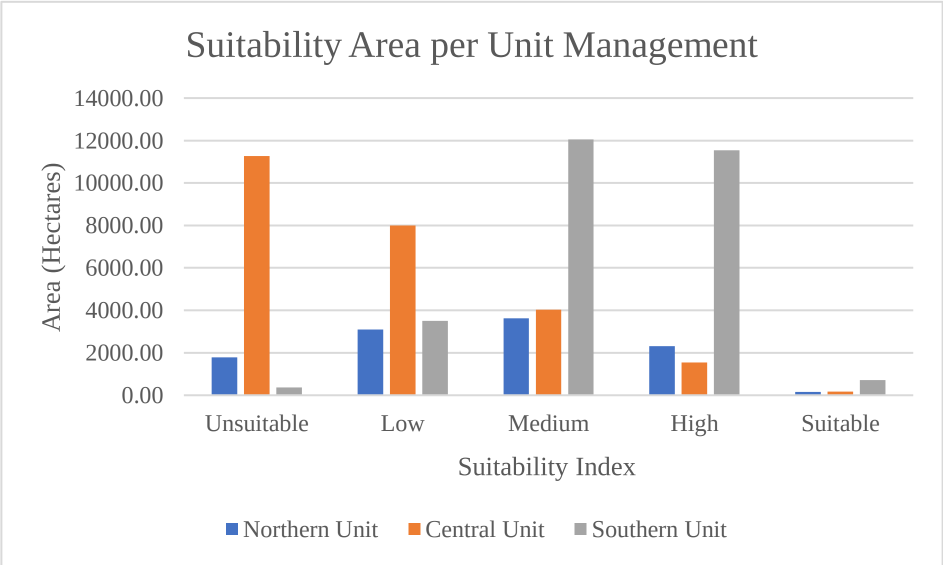


Figure 21 Suitability Area Compare to Unit Management

Sensitivity Analysis

Sensitivity analysis can be used to analyze the influence of different criteria weights on the spatial pattern of the suitability index, and also can help to find alternatives for conservation purposes. Sensitivity analysis was accomplished by applying different weighting scheme for the variables. The results illustrate how changes in weighting affect the optimal choice of areas allocated as agroforestry area. The suitability maps for the weighted system were created and the sensitivity analysis was done by making twenty-five models.

Table 17. Matrix of Sensitivity Analysis

Model	Suitability Level				
	Unsuitable	Low Suitability	Medium	High Suitability	Most Suitable
All Balance	13421.3	14594.9	19714.1	15386.9	1044.5
P50	19414.6	6614.5	8270.8	25017.6	4844.5
N50	17641.0	20682.5	18274.9	6467.9	1095.7
A50	10810.3	29429.7	18062.4	5441.8	417.8
F50	16149.5	20788.8	18157.7	8476.0	590.0
P0	12195.5	19447.6	25006.7	7101.8	410.4
A30F30	11264.7	19070.1	23295.3	9674.3	857.5
A35F35	9069.7	29019.3	17190.2	8146.2	736.6
A35N35	13203.2	27542.5	18949.2	4093.3	373.8
A35P35	12807.5	15057.5	22412.2	12100.2	1784.6
A45P25	9454.4	24753.8	21213.9	7471.9	1267.9
A30N25	11206.1	21932.1	24251.8	6368.9	403.1
N30LC10	14031.4	17179.2	22870.2	9289.5	791.5
P50N30	20125.5	6980.9	8373.4	23196.4	5485.8
P25N50	17721.6	15977.3	18472.8	9656.0	2334.3
P25N45	17124.3	14790.0	19825.0	10366.9	2055.8
P45N25	18531.5	8047.3	9824.6	23933.0	3825.8
A30P30F30	13859.2	16585.6	20374.7	10553.8	2788.7
A30P30N30	13104.3	19249.7	22353.5	8904.8	549.7
A30LC30P30	13265.5	12976.0	16406.0	18447.2	3067.2
LC50P20N20	17106.0	8245.2	11202.4	19454.9	8153.5
LC20P20N50	15651.1	15790.4	20568.9	9263.9	2887.6
LC20P50N20	17025.3	8498.0	9304.2	20180.5	9154.0
LC25P25N25	15610.8	11774.1	19660.1	15893.0	1223.9
LC30P30N30	15951.6	10407.2	14412.5	19227.7	4162.9
Mean	**14627.9**	**16627.1**	**17947.8**	**12556.7**	**2402.6**
St. Dev	**3058.042**	**6691.622**	**5016.943**	**6294.130**	**2398.131**

A: Access, F: Fire, LC: Landcover, N: NDVI and P: Peat
Number after the abbreviation is the weight of each variable

There is a changing pattern between these twenty-five models. Various kinds of output area for each of suitability level will be obtained with these twenty-five models. The least area for a very suitable location is found in model A35N35 (figure 22) with only 378.8 hectares. Model A35N35 meaning that the weight for access and NDVI is 35% off all parameters. Which mean, peat depth, landcover, and NDVI parameter do not have a significant effect on the models. The most area for a suitable location is found in model LC20P50N20 (figure 23) (landcover weight: 20%, peat-depth weight: 50% and NDVI weight: 20%) with 9,154 hectares. This number has occurred because of the proportion of shrubland in the landcover parameter, which has a vast area about 20,000 hectares and also the shallow peat proportion in peat depth parameter. If compared with another model using the same parameter but different weight LC20P20N50 (figure 24), which the weight for NDVI is higher than landcover and peat depth the most suitable area occurred only 2,887.6 hectares, meaning that based on the NDVI the higher the density or canopy cover, is lesser the area that can be open as agroforestry or agriculture area. The smallest unsuitable area is found in model A35F35 (figure 25) (access weight: 35% and fire weight: 35%) with 9,069.7 hectares. It can be defined that most off access and fire occurrence located in shallow peat and less dense canopy cover. The largest area for unsuitable location is found in model P50N30 (figure 26) (peat depth weight: 50% and NDVI weight: 30%) with 20,125.5 hectares. Deep peat and dense canopy cover contribute to the vast area as an unsuitable location for agroforestry or agriculture activity.

Mean, and standard deviation also calculated. The standard deviation value is high, meaning that the data is dispersed or spread and can be explained that each model has a different implication for the total area in each suitability level. Same as mean value standard deviation is sensitive to the extreme value of each model compared.

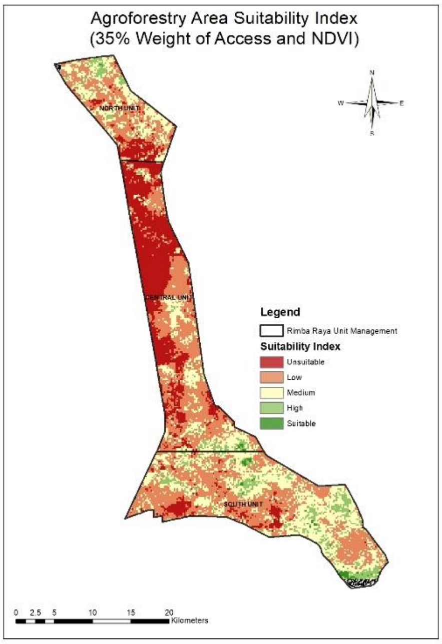


Figure 22 Model A35N35

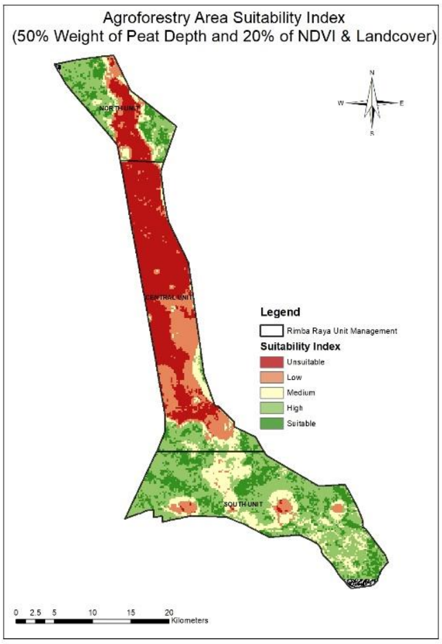


Figure 23 Model LC20P50N20

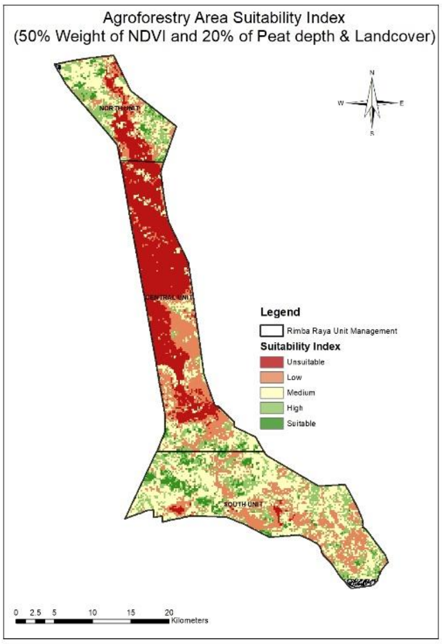


Figure 24 Model LC20P50N20

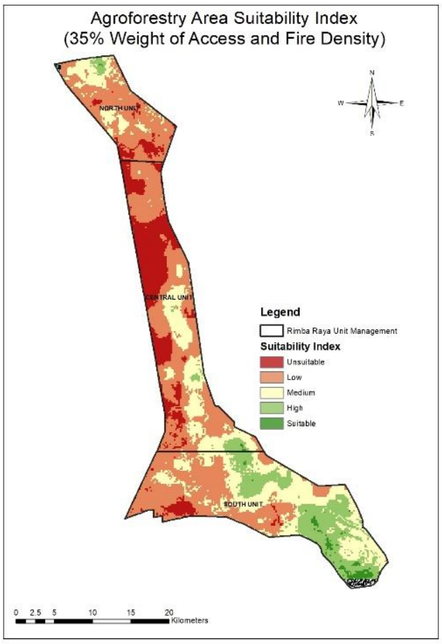


Figure 25 Model A35F35

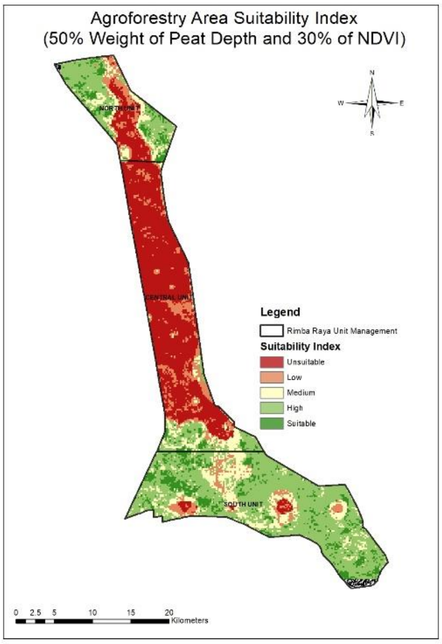


Figure 26 Model P50N30

Overall Conclusion and Future Directions

Agroforestry implementation is important in order to achieve restoration and reforestation goals through an integrated natural forest re-growth plan combined with a community-based cash crop, multi-story mixed agroforestry and low-impact aquaculture. Such an approach will alleviate hunger, poverty, and pressure on the surrounding primary and secondary forests. The establishment of agroforestry practices would become conservation areas buffer zones and protect the remaining natural forests from future encroachment and deforestation.

From the model, the most area with high suitability area is in the southern unit and some parts of the northern unit. In the central unit, there are a few locations that could be the agroforestry area, but the central unit conservation actions should be the priority due to the dense of the forest condition and deep peat soil.

The model was made to be a consideration for Rimba Raya Biodiversity reserve to protect the core area (conservation area) by knowing the suitable location and allocate those areas as the buffer zone. A collaborative zone (the collaboration between company and communities) should be a barrier to the conservation area.

Recommendations and next steps of this research are:

1. Develop other models using additional parameters including the forest inventory data to know the potential forest location for high carbon stock.
2. Add more comprehensive socio-economic data for communities to produce more detailed results in the forest pressure valuation.
3. Develop more sensitivity analysis using different weight in each parameter to predict various conditions that occur in the Rimba Raya Biodiversity Reserve area.
4. Use high-resolution imagery to get a more precise model including drone mapping for affordability reason.

Chapter 3

General Conclusion and Management Implications

Mapping areas suitable for agroforestry buffers is crucial for conservation management especially in the Rimba Raya Biodiversity Reserve, which needs to protect the remaining natural forests. Mapping suitability area using GIS spatial analysis is more effective and efficient compared to traditional surveys. Compared to the index-based modeling, the traditional approach is harder and less reliable due to lack of access to specific locations and lack of resources.

The agroforestry suitability index in this study was analyzed spatially using scoring, weighting and overlaying method. GIS software ArcGIS (Version 10.5.1) was used to produce and examine suitability for agroforestry at the Rimba Raya Biodiversity area. The information about agroforestry area selection was transformed into score values. The score values ranged from 1 to 5, with 1 for the unsuitable area and 5 for very highly suitable for agroforestry. The critical step for mapping suitability area was determining the weight value between variables. This study shows that Analytical Hierarchy Process is an excellent tool to help making the decision, primarily to assess weight value for each variable. To examine the robustness of the weight value, sensitivity analysis was performed using two weighting schemes. Most of the suitable locations were placed in locations that have easy access, less dense canopy cover, and shallow peat depth. Results show that patterns differ from model to model. Each unit management in the project area will have a different approach to managing their territory. The most suitable location appears in the southern unit with 74.6% of total high and most suitable place.

This study is beneficial for decision making and is expected to improve the conservation management together with the communities around.

The approach used in this study also has some limitations. For example, accuracy and resolution of satellite image data can limit the usefulness of the GIS model. In this study, both Landsat-8 and DEM data had a 30m spatial resolution. Using satellite imagery with high spatial resolution can improve the results, but image preprocessing is also needed to improve the accuracy of satellite image data.

References

Asgary A, Ghaffari A, & Levy J. 2010. Spatial and temporal analyses of structural fire incidents and their causes: A case of Toronto, Canada Fire Safety Journal 45 44–57. doi: 10.1016/j.firesaf.2009.10.002

Bergeron, M., Lacombe, S., Bradley, R.L., Whalen, J., Cogliastro, A., Jutras, M.-F., Arp, P., 2011. Reduced soil nutrient leaching following the establishment of tree-based intercropping systems in eastern Canada. Agrofor. Syst. 83, 321–330. https://doi.org/10.1007/s10457-011-9402-7

Brooks K.N, Ffolliot O. F, and Magner. J. A. 2013. Hydrology and the Management of Watersheds, Fourth Edition. Wiley – Blackwell

Cardinael, R., Chevallier, T., Barthès, B.G., Saby, N.P.A., Parent, T., Dupraz, C., Bernoux, M., Chenu, C., 2015. Impact of alley cropping agroforestry on stocks, forms and spatial distribution of soil organic carbon — A case study in a Mediterranean context. Geoderma 259–260, 288–299. https://doi.org/10.1016/j.geoderma.2015.06.015

Clough, Y., Barkmann, J., Juhrbandt, J., Kessler, M., Wanger, T.C., Anshary, A., Buchori, D., Cicuzza, D., Darras, K., Putra, D.D., Erasmi, S., Pitopang, R., Schmidt, C., Schulze, C.H., Seidel, D., Steffan-Dewenter, I., Stenchly, K., Vidal, S., Weist, M., Wielgoss, A.C., Tscharntke, T., 2011. Combining high biodiversity with high yields in tropical agroforests. Proc. Natl. Acad. Sci. 108, 8311–8316. https://doi.org/10.1073/pnas.1016799108

Congalton R G, Oderwald R G, and Mead R A. 1983. Assessing Landsat classification accuracy using discrete multivariate statistical techniques. Remote Sens 49, p 1671-1678.

Erten E, Kurgum V, and Musaoglu N. 2004. Forest fire risk zone mapping from satellite imagery and GIS: A case study. Proceedings of 20th Congress of ISPRS, Istanbul, Turkey.

Feintrenie L, Schwarze S, Levang P. 2010. Are local people conservationist? analysis of transition dynamics from agroforests to monoculture plantation in Indonesia. Ecology and Society 15(4): 37.

Hooijer, A., Page, S., Canadell, J. G., Silvius, M., Kwadijk, J., Wosten, H. and Jauhiainen, J. 2010. Current and future CO2 emissions from drained peatlands in Southeast Asia. Biogeosciences, 7 (5), p 1505-1514, doi: 10.5194/bg-7-1505-2010

Indriatmoko, Y., Atmadja S. S., Ekaputri, A. D., andKomalasari, M. 2014. Rimba Raya Biodversity Reserve Project, Central Kalimantan, Indonesia. Retrieved from http://www.cifor.org/redd-case-book/case-reports/indonesia/rimba-raya-biodiversity-reserve-project-central-kalimantan-indonesia/.

Ismunadji, M., andSoepardi, G. 1984. Peat soils problem and crop production. Philippines: International Rice Research Institute.

Lemons, T., Bolick-L., Reece, J., Procanik, J., Fuad, F., Stanley S, Paoli G, McDermott S. 2011. Project design document: The Rimba Raya Biodiversity Reserve Project. PT. Rimba Raya Conservation.

Longley, P., Goodchild, M., Maguire, D., Rhind, D. 2010. Geographic Information System and Science. USA: John Wiley and Sons.

Malczewski. J. 1999. GIS and Multicriteria Decision Analysis. John Willey & Sons, Inc. Canada.

Merwin, M.L 1997. The status, opportunities, and needs for agroforestry in the United States: A national report. Available at http://www.aftaweb.org/2-uncategorised/35-agroforestry-opportunities.html. Association for Temperate Agroforestry, Center for Agroforestry, University of Missouri, Columbia.

Osaki, M., Tsuji, N. 2016. Tropical Peatland Ecosystems. Tokyo: Springer. Print

Nair PKR. 1993. An Introduction to Agroforestry. Dordrecht (NL): Kluwer Academic Publisher.

Noor, M. 2010. Peatland: Development, Conservation and Climate Change. Yogyakarta: GadjahMada University Press. Print

Page, SE., Rieley, J., Banks, C. 2011. Global and Regional Importance of the Tropical Peatland Carbon Pool. Glob Change Biol 17(2): 798-818

Perfecto I, Vandermeer J. 2008. Biodiversity conservation in tropical agroecosystems, a new conservation paradigm. Annals of The New York Academy of Sciences 1134: 173-200.

Prahasta Eddy. 2009. Sistem Informasi Geografis: Konsep-KonsepDasar (Perspektif Geodesi & Geomatika). Informatika. Bandung.

Quinkenstein, A., Wöllecke, J., Böhm, C., Grünewald, H., Freese, D., Schneider, B.U., Hüttl, R.F., 2009. Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. Environ. Sci. Policy 12, 1112–1121. https://doi.org/10.1016/j.envsci.2009.08.008

Reynolds, P.E., Simpson, J.A., Thevathasan, N.V., Gordon, A.M., 2007. Effects of tree competition on corn and soybean photosynthesis, growth, and yield in a temperate tree-based agroforestry intercropping system in southern Ontario, Canada. Ecol. Eng. 29, 362–371. https://doi.org/10.1016/j.ecoleng.2006.09.024

Rui T, Yang Z, Zhou Y, Fang H, & Zhu J. Target Detection Based on Kernel Density Estimation Combined with Correlation Coefficient. *B. Huet et al. (Eds.): PCM 2013, LNCS 8294*, pp. 769–778, 2013.

Saaty, T., 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.

Schroth, G., da Fonseca, G.A., Harvey, C.A., Gascon, C., Vasconcelos, H.L., Izac, A.-M.N., 2013. Agroforestry and biodiversity conservation in tropical landscapes. Island Press.

Store, R., Kangas, J., 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. Landsc. Urban Plan. 55, 79–93. https://doi.org/10.1016/S0169-2046(01)00120-7

Story M and Congalton R. 1986. Accuracy assessment: a user's prespective. Remote Sens 52, p 397-399.

Svoray, T., Bar (Kutiel), P., Bannet, T., 2005. Urban land-use allocation in a Mediterranean ecotone: Habitat Heterogeneity Model incorporated in a GIS using a multi-criteria mechanism. Landsc. Urban Plan. 72, 337–351. https://doi.org/10.1016/j.landurbplan.2004.05.001

Tawarya K, Takarya Y, Turjaman M, Tuah SJ, Limin SH, Tamai Y, Cha JY, Wagatsuma T, Osaki M. 2003. Arbuscular mycorrhizal colonization of tree species grown in peat swamp forest of Central Kalimantan, Indonesia. For Ecol Manag 182:381-386

Takahata C, Amin R, Sarma P, Banerjee G, Oliver W, Fa J E. 2010. Remotely-sensed active fire data for protected area Management: eight-year patterns in the Manas National Park, India. Environmental Management, 45 p 414–423, DOI 10.1007/s00267-009-9411-8

Young, A., 1989. Agroforestry for soil conservation, Science and practice of agroforestry. C.A.B. International; International Council for Research in Agroforestry, Wallingford, Oxon, U.K.