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Regular Research Article

Evaluating the feasibility of oil palm agroforestry in Harapan Rainforest, Jambi, Indonesia

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Abstract: About 2.5 million hectares of a total of 15 million hectares of oil palm plantation in Indonesia are planted in, or conflict with, the forest zone. Oil palm plantations face a conflict between socio-economic and ecological issues. This study was conducted in the Harapan Rainforest, Jambi to evaluate the potential of oil palm-based agroforestry to reconcile economic and ecological interests, by considering socio-economic and financial feasibility as well as biodiversity and land cover. The financial feasibility of oil palm agroforestry is compared to oil palm monoculture, employing a discounted cash flow approach using three indicators: net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR). Two ecological indicators—biodiversity and land cover—are evaluated in an experimental plot of oil palm agroforestry in Jambi. This study indicates that the NPV, BCR, and IRR of oil palm monoculture are IDR 62,644,836 (US$ 4,476.84), 1.39, and 20.77%, respectively, while the oil palm agroforestry planted in the experimental plot potentially generates much better values of financial indicators with NPV, BCR, and IRR being IDR 209,221,212 (US$ 14,951.76), 1.79, and 24.42%, respectively. Besides evaluating financial feasibility, we also found that the reviewed current studies indicate that the oil palm agroforestry provides positive ecological impacts, such as increased forest land cover, invertebrate fauna, and bird diversity.

Keywords: financial feasibility; land use policy; oil palm agroforestry; sustainable forest management; Harapan Rainforest

1. Introduction

The increasing demand for palm oil globally has led to the rapid expansion of oil palm plantations in the Southeast Asia region (Sequiño & Avenido, 2015). Transformation of complex natural rainforest into an economically purposed production system such as plantation of oil palm *(Elaeis guineensis)* is common, and oil palm is presumed to be a significant driver of biodiversity loss and social crisis in Southeast Asia (Gellert, 2015; Immerzeel et al., 2014; Koh & Wilcove, 2008). In some cases, oil palms are planted in forest zones (Kehati, 2019) and are considered an important driver of forest fires and tenurial conflicts in several regions of Indonesia (Koh & Wilcove, 2009; Lambin & Meyfroidt, 2011).

Conflicts of interest between ecology and economy are found in many places in Indonesia (Adalina et al., 2014; Harbi et al., 2018; Nurrochmat et al., 2017; Nurrochmat et al., 2021). For instance, thousands of hectares in the Harapan Rainforest, Jambi, Sumatera—that are currently under land encroachment by the local communities and converted into oil palm plantations—have been designated by the Indonesian government for restoration of the lowland rainforest ecosystem. The forest is managed by *PT Restorasi Ekosistem Indonesia* (PT REKI), a company holding a license from the Ministry of Environment and Forestry to operate forest ecosystem restoration (IUPHHK-RE). The restoration of the forest ecosystem is not easily implemented because of the increasing

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demand for agricultural land from farmers owning very small tracts—less than a hectare per household (Nurrochmat, 2017). Conflict of interest on forestlands occurs because of the needs of people for more land to generate better income and improve their livelihood (Nurrochmat et al., 2020). The conflict between local communities and companies makes forest management and ecosystem restoration activities ineffective and inefficient (Harbi et al., 2018; Nurrochmat et al., 2017). Some conflicts could be resolved through a national climate financing mechanism, however, many of them cannot be effectively implemented in the fields (Sheriffdeen et al., 2020). Thus, some more evidence-based approaches should be introduced to improve the effectiveness of conflict resolution in the fields.

Several studies have advocated the integration of biodiversity conservation into the management of oil palm plantations to create more diversified oil-palm landscapes in mitigating the negative environmental consequences (Foster et al., 2011; Koh et al., 2009). However, the feasibility and possibility of intercropping other trees amongst oil palm plantations (oil palm-based agroforestry) are questioned due to competition for resources (Koh et al., 2009; Phalan et al., 2009) and the absence of enabling policies (see Erbaugh & Nurrochmat, 2019). Some scientific articles discuss how the enrichment planting of trees affects biodiversity, ecosystems, and the socio-economics of oil palm plantations (Gérard et al., 2017; Teuscher et al., 2016). Enrichment planting of trees in oil palm landscapes (known as oil palm agroforestry) can be integrated with conservation activities and oil palm production. Enrichment planting makes the oil palm landscape more accessible to native species to form clusters of *tree islands* within the plantation (Koh et al., 2009; Phalan et al., 2009). These *tree islands* in agricultural landscapes are a cost-effective measure to enhance biodiversity and ecosystem functions (Cole et al., 2010).

Recent studies reported that an oil palm agroforestry could provide higher economic and ecological benefits than the monoculture oil palm (Khasanah et al., 2020; Teuscher et al., 2016; Yuniati et al., 2018). A research consortium of IPB University and its partners—University of Göttingen (Germany), University of Jambi, and the University of Tadulako, named the Collaborative Research Center 990 (CRC-990)/ Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems **(**EFForTS**)**—has initiated and established an oil palm agroforestry experimental plot in Jambi, Indonesia. The preliminary results of these experiments indicate the possibility of integrating oil palms and trees in the same landscape using an enrichment planting approach (Teuscher et al., 2016). Oil palm agroforestry positively impacts the environment (ecology), characterized by more diverse bird and insect species on the enrichment planting plot compared to monoculture oil palm plantations (Teuscher et al., 2016). The decline in oil palm yields is a controversial issue in long-term plantation management and sustainable palm oil certification (see Sahide et al., 2015a). However, in the short term, it is also noteworthy that in the experimental plot there is no decrease in the yields of oil palm during the first two-year period after enrichment planting of trees between oil palm stands (Gérard et al., 2017)**.** This study aims to fill the knowledge gap by evaluating the financial feasibility and reviewing potential ecological benefits of oil palm agroforestry to provide evidence to reports of previous studies.

2. Contextual Background

About 90% of oil palm plantations in Indonesia are located on Sumatra and Kalimantan islands (Kehati, 2019; Kiswanto et al., 2008), producing 95% of Indonesia's crude palm oil (MoA, 2019). In Jambi, oil palm plantations, mostly practicing monoculture, have rapidly expanded (Widayati et al., 2012). In 2019, the area of oil palm plantations owned by the community (smallholders), large-scale private companies, and the state totaled 682,175, 362,662, and 20,430 hectares, respectively in Jambi Province (BPS, 2020; MoA, 2019).

A large number of forests in Indonesia have been converted into oil palm plantations (Cooper et al., 2019; Sumarga & Hein, 2016; Vijay et al., 2016; Sahide et al., 2015b), with this expansion causing a reduction in forest cover in Jambi (Figure 1) (Drescher et al., 2016). Moreover, the expansion of oil palms into the forest zone also has social impacts such as increased incidence of tenurial conflicts and income inequality in several regions (Koh & Wilcove, 2009; Lambin & Meyfroidt, 2011).

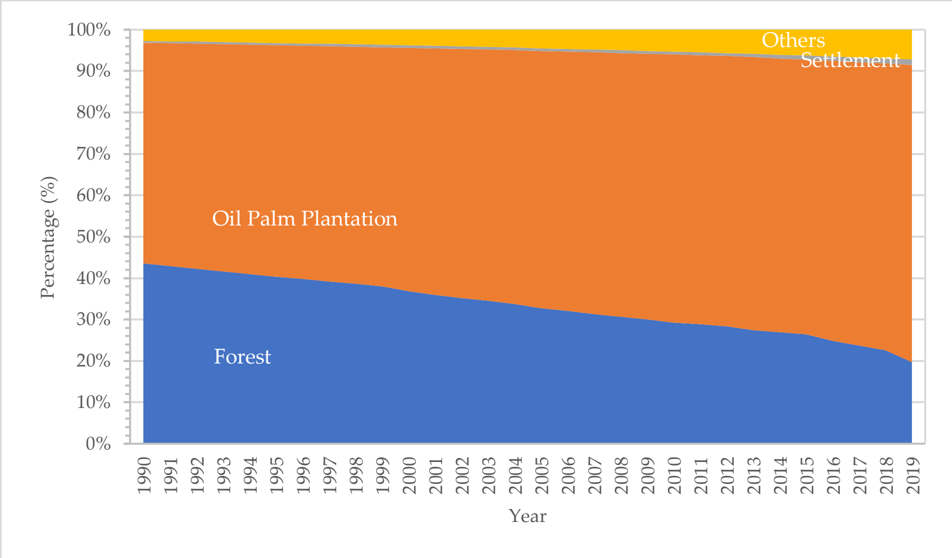

Figure 1. Percentage of land cover in Jambi Province from 1990–2019 (BPS-Jambi, 2020; MoA, 2019; MoEF, 2019).

In Indonesia, 3.4 million hectares of the total 16.8 million hectares under oil palm plantations are located in different forest zones and many of them occur as a result of conflicts over different government regulations (licensed plantations) and land encroachment (unlicensed plantations) (Kehati, 2019) (Figure 2).

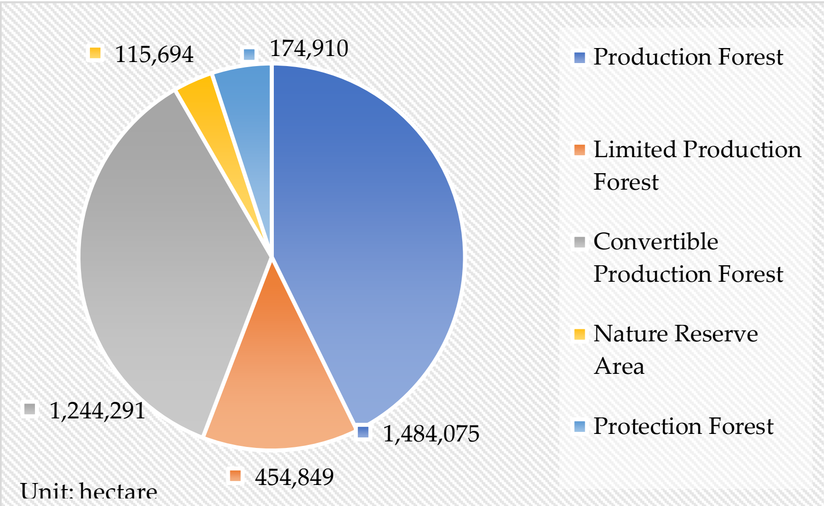

Figure 2. Oil palm plantation coverage in Indonesian forest zones (Kehati, 2019).

In Jambi, about 20,000 hectares of land in Harapan Rainforest, a restoration forest ecosystem managed by PT Restorasi Ekosistem Indonesia (PT REKI) has been encroached on by local communities and converted into oil palm plantations (MoEF, 2018). This situation causes a conflict in land utilization between local communities and companies and hinders the effectiveness and efficiency of the restoration of the forest ecosystem. To reconcile those interests, we consider promoting oil palm agroforestry as conflict resolution in the respective sites. Agroforestry is a spatial land-use system applying various agricultural crops and forestry plants, which are carried out simultaneously or in rotation over a certain period (Nair & Garrity, 2012; Nair, 1993). It is one of the options of multi-business forestry schemes (MoEF, 2020).

According to the Indonesian Minister of Forestry Regulation 14/2004, "a forest is defined as an area that extends more than 0.25 hectare, covering with trees that reach more than 5 meters in height at maturity and with a minimum of 30% canopy cover". As part of forest management, promoted oil palm agroforestry within the forest zone is required to meet this minimum threshold of the forest definition.

3. Methods

This study focuses on evaluating the financial feasibility of oil palm agroforestry and reviewing previous studies on the ecological impacts of oil palm agroforestry. The research framework presented in Figure 3.

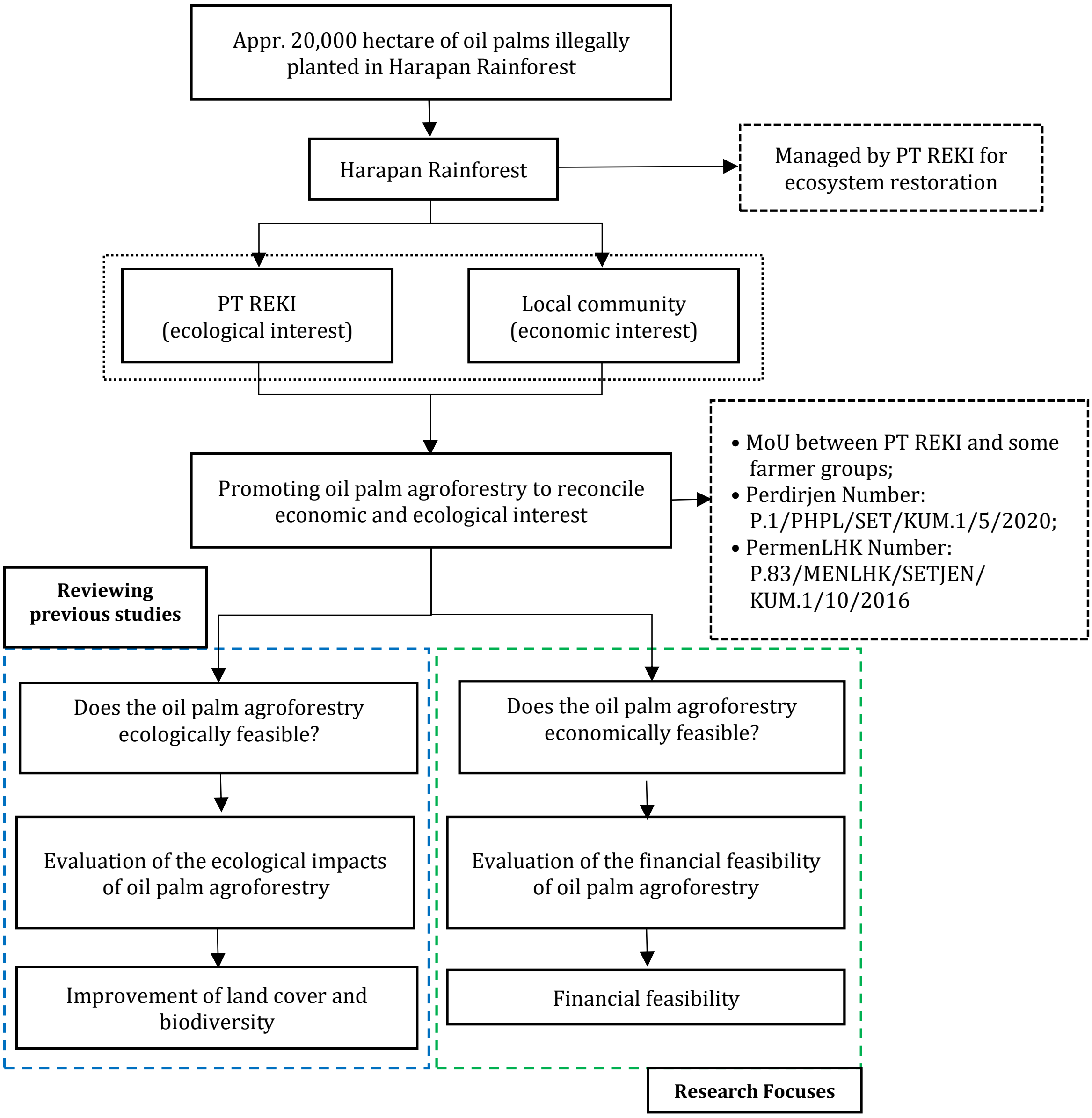

Figure 3. The research framework.

3.1 Study site

This study's sites are located in the experimental plot B-11 of the CRC 990/ EFForTS in the oil palm-plantation area of PT HMS and the villages around the Harapan Rainforest managed by PT REKI in Batanghari District, Jambi Province (Figure 4).

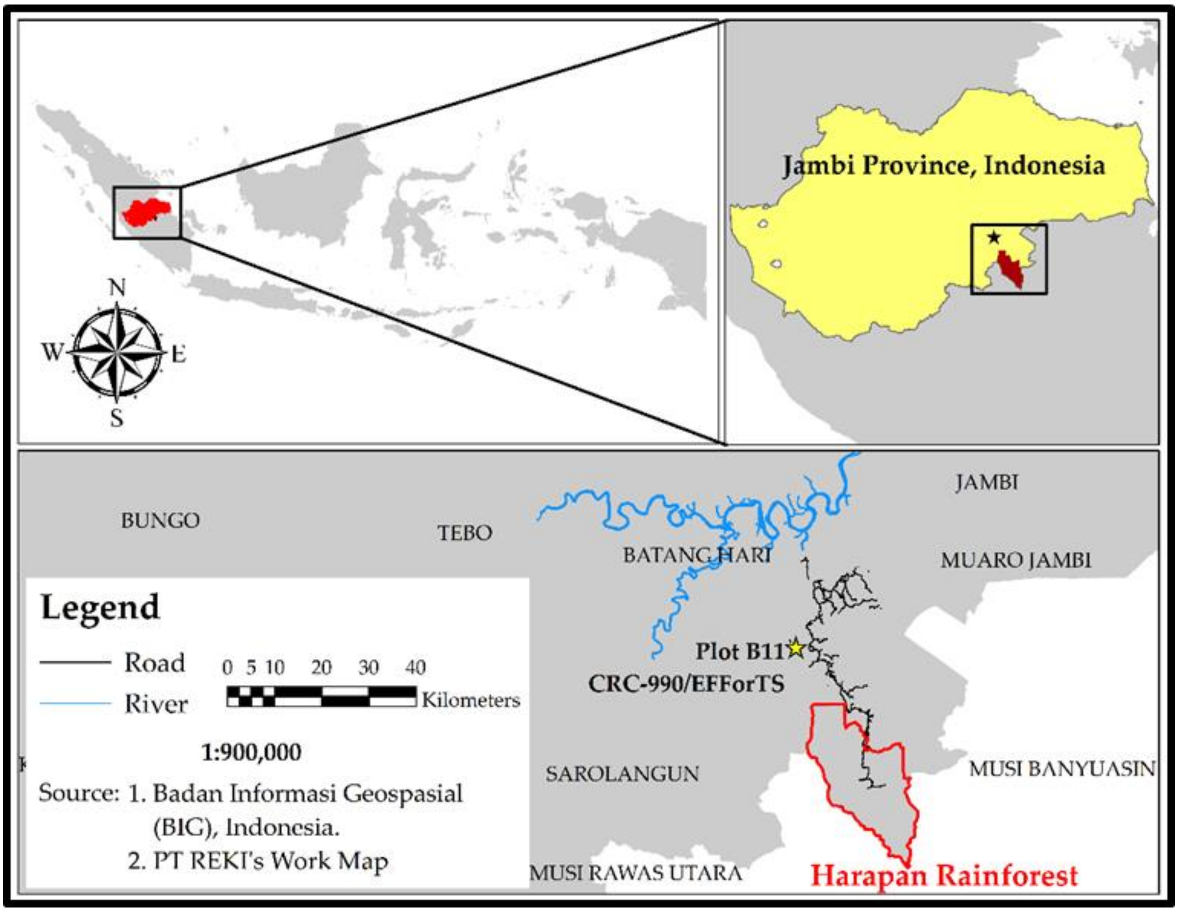

Figure 4. The research site.

Oil palm-based agroforestry has been practiced on the experimental plot of CRC 990/ EFForTS. This existing eight-year oil palm plantation is enriched by planting trees as intercrops (trees planted in between oil palm stands), such as *jengkol* or dog fruit *(Archidendron pauciflorum), petai (Parkia speciosa), durian (Durio zibethinus), sungkai (Peronema canescens), meranti (Shorea leprosula), and jelutong (Dyera lowii).* These plots were established in 2014, laid on the area dominated by a soil type of acrisol clay and surrounded by a lowland rainforest ecosystem (Allen et al., 2015). The number of oil palms per 40x40 sq. meter plot is around 13 trees, with spacing between the intercrops of 2x2 meters. There are approximately 81 oil palms and 2,500 trees (as intercrops) per hectare, although the number of trees used for intercropping in each plot varies by species. There are 56 experimental plots with different plot sizes: 40x40 sq. meter, 20x20 sq. meter, 10x10 sq. meter, and 5x5 sq. meter (Figure 5) and differing degrees of biodiversity within the variety of intercrop trees (Figure 6).

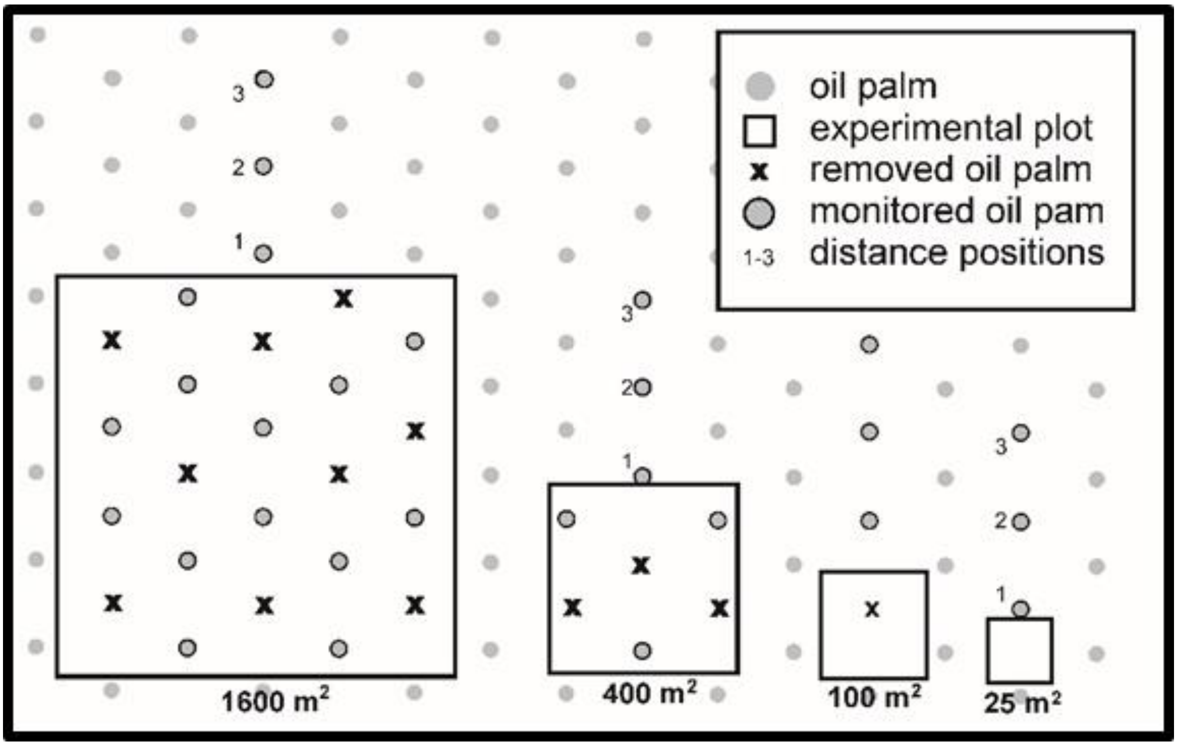

Figure 5. The experimental plots of oil palm agroforestry.

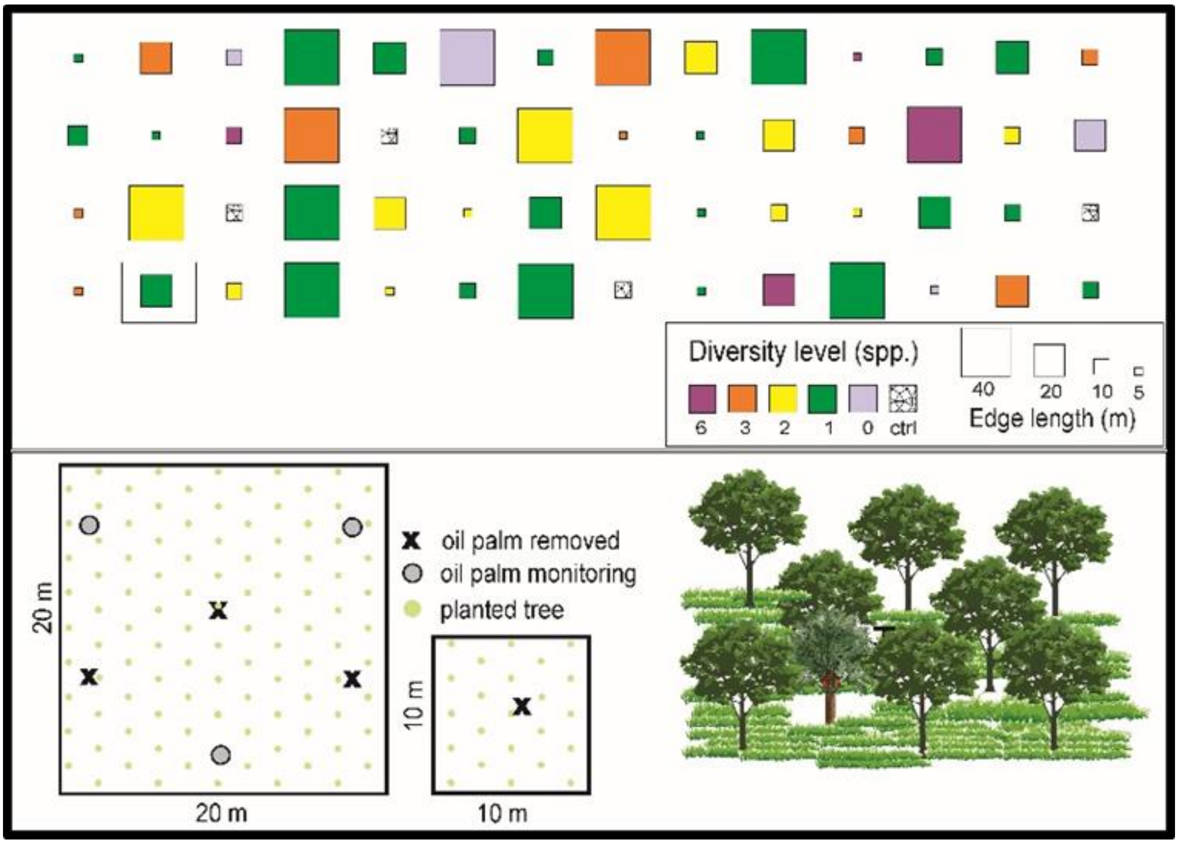

Figure 6. Degree of diversity in the experimental plots (Teuscher et al., 2016).

Harapan Rainforest is the only remaining tropical rain forest on the island of Sumatra, covering an area of 98,555 hectares. Currently, the Harapan Rainforest area is managed by *PT Restorasi Ekosistem Indonesia* (PT REKI) with an ecosystem restoration (RE) scheme since 2007. The main objective of PT REKI for ecosystem restoration is to restore and utilize the integrated natural production forest ecosystem in a sustainable manner, in terms of ecology, social, and economic perspectives (REKI, 2008).

3.2 Data collection

To conduct a financial feasibility analysis, this study collected data on the cost and revenue components of oil palm agroforestry and monoculture-oil palm plantations managed by the community, together with data from the experimental plots of CRC-990/EFForTS. We conducted interviews with 36 households around the Harapan Rainforest and surveyed 23 experimental plots of CRC-990/EFForTS. The socio-economic data on the people who owned oil palm plantations in the Harapan Rainforest were also employed. This study applied three techniques for collecting data, namely: (1) field observation, (2) key person interviews, and (3) gathering information and data from official documents belonging to agencies or companies, as well as scientific journals, books, research articles, proceedings, and digital media (internet sources). Field observations were conducted to obtain firsthand evidence of the existing conditions of the study sites in October 2019. Key person interviews were conducted with key respondents, including CRC-990/EFForTS staff and researchers, communities around the Harapan Rainforest, the management of PT HMS (oil palm company), and PT REKI (restoration ecosystem company) from December 2019 to January 2020. The key person interviews were conducted to explore data and to gather in-depth information for the research, such as cost components, commodity market prices, management issues, and (potential) obstacles in operating oil palm agroforestry. Data and information collected from the official documents, reports, and scientific articles were used to provide more evidence and strengthen the analysis.

Key persons selected as interview respondents included field managers and staff responsible for the management of the experimental agroforestry plot, eight people who owned oil palm plantations surrounding the experimental plot, and 36 people who planted oil palms inside the Harapan Rainforest—30 farmers (divided into five groups) had a Memorandum of Understanding (MoU) with PT REKI, while the balance of six farmers had not yet signed any MoU. Other interviews were conducted with key persons in PT REKI, including the operational director, the deputy manager for community partnership, and some field staffs related to the study.

3.3 Data analysis

This study conducted a discounted financial analysis to evaluate the feasibility of oil palm agroforestry and monoculture-oil palm plantations. The potential income generated from different combinations of oil palm agroforestry patterns were evaluated and compared with the needs of people and their existing income from monoculture-oil palm plantations. All costs and revenue components for a management period of 25 years were entered into a cash flow sheet. All benefits and costs were annually discounted—commonly referred to as discounted cash flow (Gittinger et al., 1993; Kadariah et al., 1999; Sutojo, 2000). The financial analysis indicators included net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR) (Kadariah et al., 1999; Sutojo, 2000). Each of those indicators was used to determine the feasibility of the project, estimate the future benefits of the project, and choose a more profitable project.

3.3.1. Net Present Value (NPV)

NPV is the difference between the present value of revenue and the present value of costs, or discounted future cash flows, yielding a current value. The project is financially feasible if NPV > 0 (Kadariah et al., 1999; Sutojo, 2000). The equation for calculating NPV is:

$$NPV = \sum_{t=0}^{n} \frac{Bt - Ct}{(1+i)^t}$$

where:
NPV is the net present value (IDR);
Bt is gross revenue in *t*-year (IDR/year);

Ct is gross cost in year *t* (IDR/year);
i is the interest rate, used as a discount factor (%);
t is the duration of the project period (in years) from year 0 to year *n*.

3.3.2. Internal Rate of Return (IRR)

IRR is the rate of return on capital in the evaluated project, at discount rate *i*, which makes the NPV equal to zero (NPV = 0)—the value of *i* where NPV = 0. The project is financially feasible if the IRR > *i* (Kadariah et al., 1999; Sutojo, 2000). The equation for calculating IRR is:

$$IRR = i_1 + \frac{NPV_1}{NPV_1 - NPV_2} \times (i_1 - i_2)$$

where:
IRR is the internal rate of return;
i_1 is the interest rate that produces a positive NPV;
i_2 is the interest rate that produces a negative NPV;
NPV_1 is the nominal value of a positive NPV;
NPV_2 is the nominal value of negative NPV.

3.3.3. Benefit-Cost Ratio (BCR)

BCR is a comparison between the value of benefits against the costs seen in the present value (PV) condition. A project is financially feasible if the BCR>1 (Kadariah et al., 1999; Sutojo, 2000). The equation for calculating BCR is as follows:

$$BCR = \frac{\sum_{t=1}^{n} \frac{Bt}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Ct}{(1+i)^t}}$$

where:
BCR is the benefit-cost ratio;
Bt is benefit/revenue in year *t*;
Ct is the cost in year *t*;
i is the interest rate which is used as a discount factor (%);
t is the duration of the project period (in years) from year 0 to year *n*.

After calculating the results of the financial analysis, the next step is to compare the financial indicators of the different land management patterns. In addition to NPV > 0, BCR > 1, and IRR > *i*, the proposed scheme of oil palm agroforestry is feasible if the net benefit derived from the scheme is higher than the existing financial benefit received by people farming a monoculture-oil palm plantation of equivalent land size.

4. Results and Discussions

4.1. Harapan rainforest community socio-economic overview

The communities that live in and around the Harapan Rainforest zone consist of three large-ethnic groups: Migrant, *Batin Sembilan*, and Malay. A large group is further divided into small groups. A small group of Malay, Migrants, and the *Batin Sembilan* formed a farmer group (*Kelompok Tani*/KT) (Table 1). The farmer groups indicated in bold-italics were selected as respondents.

Table 1. Harapan Rainforest Farmer Groups.

No	Community Group	Province	Location	Farmer Group
1	Malay Groups	South Sumatra	Kapas Basin	Sako Suban
2				Rompok Baginde
3				Rompok Aur
4				Rompok Landai

No	Community Group	Province	Location	Farmer Group
5				Rompok Kapas Tengah
6				Rompok Bato
7	Batin Sembilan Groups	Jambi	Simpang Macan Luar	***Simpang Macan Luar Group***
8			Bungin	***Tanding Group***
9				***Gelinding Group***
10				***KT Lamban Jernang***
11			Simpang Macan Dalam	Ruslan Group
12			Simpang Macan Dalam	Herman Group
13			Km. 45	Khotib Group
14			Sei Jerat	Jupri Group
15		South Sumatra	Kapas Basin	Mat Liar Group
16			Meranti Basin	Mat Kecik Group
17			Hulu Badak	Burhan Group
18	Migrant Groups	Jambi	Kunangan Jaya I	***KT Bungin Mandiri***
19				***KT Berkah Jaya***
20				***KT Mekar Jaya Indah***
21			Kunangan Jaya II	***KT Hijau Alam Lestari***
22				***KT Tani Jaya/Eko group***
23			Alam Sakti	Alam Sakti Group
24			Tanjung Mandiri	Tanjung Mandiri Group
25			Sei Jerat	SPI Group
26			Hulu Badak	Bali Group
27			Pangkalan Ranjau	Jupri Migrant Group
28		South Sumatra	Kapas Basin	Trans Bali-Lampung Group

Batin Sembilan is a traditional community native to Jambi and South Sumatra provinces (Syuroh, 2011). Eleven farmer groups are encroaching on the Harapan Rainforest, eight of them located in Jambi and the balance in South Sumatra. We interviewed four groups of *the Batin Sembilan* (*Simpang Macan Luar, Tanding, Gelinding*, and *KT Lamban Jernang*), and five groups of the migrant community (*KT Bungin Mandiri, KT Berkah Jaya, KT Mekar Jaya Indah, KT Hijau Alam Lestari*, and *KT Tani Jaya/Eko*).

The traditional people of *Batin Sembilan* had previously utilized timber, hunted animals, and collected non-timber forest products (NTPFs), but are currently only allowed to collect NTPFs. Many kinds of NTFPs are utilized by the *Batin Sembilan* people including *sialang* honey, fruits (*D. zibethinus*, rambutan, and others), resin stones, and many others. Recognizing the success of their neighbors who planted oil palms in the Harapan Rainforest, the *Batin Sembilan* also planted oil palms in the forestlands. Some *Batin Sembilan* groups currently cultivate rubber plantations with the assistance of PT REKI, instead of extending their oil palms.

Malay people, also known as the *Sako Suban*, mostly live in *Sako Suban* Village. They depend extensively on rivers and forests. The *Sako Suban* use the river for transportation and make their livelihood through fishing and collecting shrimp. They also collect timber and NTFP's such as honey, fruits, game animals, and medicinal plants among others. Some people occasionally hunt illegally. Like other indigenous people in Sumatra, the *Sako Suban* has a historical background of shifting cultivation. However, over the last decade shifting agriculture has been prohibited, particularly after the involvement of PT REKI in the Harapan Rainforest (REKI, 2009).

Unlike the *Batin Sembilan* and *the Sako Suban*, migrants often use forestland for farming. *Migrants* are those who are not included in the *Batin Sembilan* or Malay *(Sako Suban)* ethnicities. Javanese and Bataknese are the dominant ethnicities. The migrants have higher levels of education, knowledge, and skills in modern farming and plantation cultivation compared to the *Batin Sembilan*.

Migrants often demonstrate strong capabilities in managing land and marketing their products. Some migrant groups who have encroached on forestlands have converted them into oil palm plantations. Table 2 shows the characteristics of the 36 respondents gathered from interviews related to land uses in the Harapan Rainforest.

Table 2. Socio-economic characteristics of respondents in Harapan Rainforest.

Respondents' Characteristics	Total (percentage)
Age	
20 to 35 years old	6 people (17%)
36 to 45 years old	16 people (44%)
45 to 60 years old	13 people (36%)
> 60 years old	1 people (3%)
Tribe	
Javanese	25 people (69%)
Batin Sembilan	6 people (17%)
Bataknese	5 people (14%)
Gender	
Male	35 people (97%)
Female	1 people (3%)
Main Job	
Resin collector	4 people (11%)
Farmer (oil palm)	29 people (80%)
Broker (oil palm fresh fruit bunches)	2 people (6%)
Employees of PT REKI	1 people (3%)
Total Monthly Revenue	
< IDR 1,000,000 (US$ 71.46)	0 people (0%)
IDR 1,000,000–3,000,000 (US$ 71.46–214.39)	5 people (14%)
IDR 3,000,000– 5,000,000 ((US$ 214.39–357.32)	16 people (44%)
> IDR 5,000,000 (US$ 357.32)	15 people (42%)
Average monthly expenditure	**IDR 4,100,000 (US$ 293)/household**
Average size of farmlands	
Oil palm plantation	4.85 hectares/household
Rubber plantation	1.75 hectares/household

4.2. Monoculture-oil palm plantation financial feasibility

A financial feasibility analysis was conducted targeting a monoculture-oil palm plantation. The data on costs and revenues were obtained from the interviews with key persons in PT HMS and PT REKI as well as communities who live in and around the Harapan Rainforest. Oil palm is commonly planted at a distance of 9x9 meters in an equilateral triangle pattern—about 135 oil palm trees per hectare. The oil palm usually starts to be fruited after the third year, although these first fruits are still too young and cannot be sold to the palm oil mills, only becoming salable from four years old.

This study applied some definitions and assumptions for the financial analysis of monoculture-oil palm plantation:

- The financial analysis is based on a one-hectare area;
- The productive age of oil palms is 25 years (an investment period of 25 years);
- Land investment and land tax costs are excluded;
- The cost components of land clearing, seedlings, planting, maintenance, and harvesting are assumed as employee expenses or costs incurred by oil palm plantation companies;
- The yield per hectare is 135 oil palms;
- All oil palm trees are deemed to be growing well and fruited normally throughout the period;
- Application of fertilizers and herbicides follows oil palm plantation companies in the research

site;
- The price of oil palm fresh fruit bunches (FFBs) is IDR 1,500 (US$ 0.11)/kg;
- The FFBs are harvested once a month;
- The interest rate, applied as the discount factor, is 9.9%;
- The oil palm productivity curve follows prior research (Sufriadi, 2015).

From the results in Table 3, this study indicates that the monoculture-oil palm plantation is financially feasible because NPV>0, BCR>1, and IRR>*i*. The highest income from the plantation—indicating the peak of oil palm productivity—is reached for palms between the ages of 9 to 15 years. The average potential annual income is IDR 28,452,833 (US$ 2,033.35)/hectare (IDR 2,371,069 or US$ 169.45/hectare monthly). Moreover, the average cost is IDR 16,610,350/hectare/year (IDR 1,384,195/hectare/month). Consequently, the potential net benefit of the monoculture oil palm plantation is only IDR 986,874 (US$ 70.53)/hectare/month.

Table 3. NPV, BCR, and IRR of the monoculture-oil palm plantation.

Indicators	Result
NPV	IDR 62,644,836 (US$ 4,476.84)
BCR	1.39
IRR	20.77%

4.3. Oil palm agroforestry financial feasibility

A financial feasibility analysis was also conducted in the experimental oil palm agroforestry plot. The intercrop trees are planted when the oil palm is eight years old. Initially, the oil palm is planted with a spacing of 9x9 meters in an equilateral triangle pattern. When enrichment planting was applied, about nine oil palm trees were cut down on a 40x40 sq. meter plot, reducing it to only 13 oil palm trees (Figure 3).

According to field observations, the intercropped trees in the experimental agroforestry plot were generally able to grow well. Oil palms in the plot were also fruited regularly. *Jengkol, sungkai,* and *petai* grew well, indicated by their large stem diameter. *Jengkol* had already begun to bear fruit in the fifth year. *Meranti* and *jelutong* were generally growing slightly smaller than *jengkol.* Even though *meranti* is classified as a semi-intolerant plant (Setiawan et al., 2015), their growth height was almost equal to the *jengkol*. The *jelutong* also had a height and diameter of approximately the same as *meranti. Durian* grew slower than other plants. During the long dry season (at the time of field research), the *Durian* shed most of its leaves and appeared to be depressed, indicated by a smaller diameter and height compared to the other plants.

The definitions and assumptions applied for the financial analysis of oil palm agroforestry followed those of the monoculture analysis with the following exceptions:
- The initial number of oil palms is 135 trees per hectare, and after the thinning and enrichment planting (in the eighth year) the remaining oil palms are 81 trees per hectare;
- Planting intercrop trees are conducted when the oil palm is eight years old;
- The total number of intercrops is 2,500 trees per hectare, with the number of each species is around 416–417 trees per hectare;
- All intercrop plants and oil palms can grow and bear fruit normally until the end of the period;
- Fertilization is only applied on oil palm;
- The price of *Petai* follows the price in Batanghari Regency market of IDR 1,000 (US$ 0.071)/piece, and *petai* starts to bear fruit at the age of seven years, will decrease productivity at age;
- The price of *jengkol* follows the price in the Batanghari Regency market of IDR 5,000 (US$ 0.36)/kg (unpeeled), and *jengkol* starts to bear fruit at the age of five years;
- The price of *durian* follows the price in the Batanghari Regency market of IDR 20,000 (US$ 1.43)/piece, and *durian* starts to bear fruit at the age of ten years;
- The price of *sungkai* log follows the price issued by the Indonesian Forestry Concession

Association (APHI) of IDR 1,800,000 (US$ 128.64)/m^3 log, harvested at the end of the investment period;

- The price of *meranti* log follows the price issued by the Indonesian Forestry Concession Association (APHI) of IDR 1,000,000 (US$ 71.46)/m^3 log, harvested at the end of the investment period;
- The price of *jelutong* sap follows the selling price in the Batanghari Regency previous market of IDR 4,000 (US$ 0.29)/kg;
- The productivity of each enrichment plant follows the literature in Table 4;
- Harvest of *petai, jengkol,* and *durian* is conducted once a year.

Table 4. Crop productivity.

Crop	Time to Harvest (years)	Productive age (years)	Productivity per tree	Est. age of declining productivity	Est. annual decline in production	Source
Petai	7	25	60 pcs /year	15	2%	(Sunanto, 1999; Susilo, 2012)
Jengkol	5	20	20 kg/year	12	5%	(Pitojo, 1992)
Durian	10	25	25 pcs /year	18	3%	(Sobir, 2009; Sobir & Napitupulu, 2010)
Sungkai	30	30	0.47 m^3/cycle	-	-	(Wahyudi, 2016; Wahyudi, Damiri, Christopheros, & Pahawang, 2018)
Meranti	35	35	0.47 m^3/cycle	-	-	(Hadi & Napitupulu, 2011)
Jelutong	10	30	18.31 kg/year	15	5%	(Tata et al., 2015)
Oil Palm	4	25	180 kg/year	15	4%	(Lubis & Widanarko, 2012; Sufriadi, 2015; Wijayanti & Mudakir, 2013)

As per Table 5, this study concludes that oil palm agroforestry is financially feasible because NPV>0, BCR>1, and IRR>*i*. Oil palm agroforestry is estimated to produce an average potential annual income of IDR 101,508,766 (US$ 7254.21)/hectare, or an average potential monthly income of IDR 8,459,064 (US$ 604.62)/hectare. The costs incurred for implementing this scheme are quite high with an average cost, IDR 42,404,307 (US$ 3030.38)/hectare/year, or IDR 3,533,692 (US$ 252.53)/hectare/month. Therefore, the potential net profit of the oil palm agroforestry is an estimated IDR 4,925,372 (US$ 351.99)/hectare/month.

Table 5. NPV, BCR, and IRR of the oil palm agroforestry.

Indicators	Result
NPV	IDR 209,221,212 (US$ 14951.76)
BCR	1.79
IRR	24.42%

Oil palm agroforestry is more profitable compared to monoculture-oil palm cultivation. This follows a previous study that reports the application of oil palm agroforestry as much more profitable than monoculture-oil palm cultivation (Yuniati et al., 2018) arising from diversification of products through land management, with a potential increase in the associated income (Muryunika, 2015; Phimmavong et al., 2019; Wanderi et al., 2019). The selection of agroforestry intercrops is an important factor in increasing the probability of successful implementation (Yuniati, 2018). Moreover, site suitability and the price and market for the plant yields are critical.

4.4. Promoting optimal planting in oil palm agroforestry

Based on field observations, there are several findings regarding the spacing of enrichment plants. Narrow spacing causes difficulties in harvesting practices of oil palm fruits and increases harvesting time. Moreover, many intercrop plants were damaged or died due to the falling of oil palm trunks, branches, and fruit while harvesting, thinning, or replanting. Therefore, widening planting space is important to enhance the viability of the intercrops and to facilitate greater safety in oil palm agroforestry management (see Yovi & Nurrochmat, 2018).

Based on insights arising from the experimental plot, oil palm agroforestry stakeholders should consider the optimal planting distance of each plant used for intercropping (Table 6). Securing planting space effectively simplifies the process of maintenance and harvesting. An optimal planting distance increases the chance of intercrops thriving. Thus, we propose six combinations of intercrop spacing in an oil palm agroforestry pattern (Table 7).

Table 6. Optimal spacing for intercrop plants.

Plant	Optimal Planting Distance (sq. meter)	Age can be harvested (year)	Productive age (year)	Source
Petai	3x3 to 5x5	7	25	(Sunanto, 1999; Susilo, 2012)
Jengkol	3x3 to 5x5	5	20	(Pitojo, 1992)
Durian	5x5 to 8x8	10	25	(Sobir, 2009; Sobir & Napitupulu, 2010)
Sungkai	3x3	30	30	(Wahyudi, 2016; Wahyudi et al., 2018)
Meranti	3x3	35	35	(Hadi & Napitupulu, 2011)
Jelutong	3x4	10	30	(Tata et al., 2015)
Oil palm	8x9	4	25	(Lubis & Widanarko, 2012; Sufriadi, 2015; Wijayanti & Mudakir, 2013)

Table 7. Oil palm agroforestry intercropping combinations and plant spacing.

Pattern	Plant combination	Number of plants per hectare (stems)						
		Oil Palm	*Jengkol* (3x3m)	*Petai* (3x3)	*Durian* (5x5m)	*Sungkai* (3x3m)	*Meranti* (3x3m)	*Jelutong* (3x4m)
I	Oil Palm-monoculture	140						
II	Oil Palm and *jengkol*	81	1,111					
III	Oil Palm and *petai*	81		1,111				
IV	Oil Palm and *durian*	81			400			
V	Oil Palm and *sungkai*	81				1,111		
VI	Oil Palm and *meranti*	81					1,111	
VII	Oil Palm and *jelutong*	81						833

The terms and assumptions employed for the financial analysis follow those of oil palm agroforestry in Section 4.3 with the exception that the number of intercrop trees follows the optimal plant distance of each plant as indicated in Table 7. Table 8 shows a comparison of the financial feasibility with income and profit potential of each cropping pattern supported in the Harapan Rainforest.

Table 8. Comparison of the financial feasibility with income and profit potential of each cropping pattern supported in the Harapan Rainforest.

		Financial Feasibility Criteria				
Pattern	**Plant combination**	**NPV (IDR (US$))**	**BCR**	**IRR (%)**	**Potential Income (IDR (US$)/hectare /month)**	**Potential Profit (IDR(US$)/hectare /month)**
I	Oil Palm monoculture	62,644,836 (4,454.49)	1.39	20.77	2,371,069 (168.60)	986,874 (70.17)
II	Oil Palm and *jengkol*	209,996,929 (14,932.30)	2.01	25.83	6,022,434 (428.24)	3,861,744 (274.60)
III	Oil Palm with *petai*	96,743,006 (6,879.11)	1.56	22.94	3,763,134 (267.59)	2,161,076 (153.67)
IV	Oil Palm and *durian*	126,257,866 (8,977.83)	1.65	23.5	5,364,493 (381.45)	3,119,061 (221.79)
V	Oil Palm and *sungkai*	51,634,692 (3,671.59)	1.33	19.2	3,008,877 (213.95)	1,668,908 (118.67)
VI	Oil Palm and *meranti*	32,955,707 (2,343.38)	1.21	17.94	2,367,420 (168.34)	1,035,996 (73.67)
VII	Oil Palm with *jelutong*	55,107,152 (3,918.51)	1.34	19.73	2,826,627 (200.99)	1,342,595 (95.47)

Table 8 shows that all oil palm agroforestry patterns are financially feasible. All financial criteria (NPV, BCR, and IRR) meet the threshold of financial feasibility where NPV> 0, BCR>1, and IRR>i. This supports the previous study (Dhanny Yuniati, 2018), which reported that oil palm agroforestry generates a higher monthly income potential compared to monoculture-oil palm cultivation (Dhanny Yuniati, 2018).

To discuss the economic potential of oil palm agroforestry, it is very important to evaluate the household income and expenditure of the local community around Harapan Rainforest. Assuming the price of oil palm fresh fruit bunches (FFB) is IDR1,100/kg, a farmer will gain IDR1,060,000/ha/month from a monoculture oil palm plantation. According to the household's survey, the average monthly expenditure of a household is IDR4,100,000 (see Table 2), then the farmer has to manage at least 4 ha of oil palm monoculture to get a minimum income. Since people usually have just less than 1 ha of land, then people plant oil palm in the forests to meet the needs of more lands. The introduction of oil palm agroforestry will increase the productivity of the land. This only needs about 2-3 ha of land, or half of land with oil palm monoculture, to meet the household's needs. It means oil palm agroforestry will potentially reduce land encroachment in the Harapan Rainforest.

Considering the different ethnic groups of the local community, it is necessary to use several approaches to introduce the oil palm agroforestry in Harapan Rainforest. *Migrant* people who have better knowledge and skills to practice modern agriculture will be easier to adopt oil palm agroforestry. Different from migrant people, native groups of *Malay* and *Batin Sembilan* are usually still practicing traditional agriculture, some of them are even doing shifting agriculture. Therefore, providing technical assistance and demonstration plots, as well as making social and cultural approaches are required to give a better opportunity on oil palm agroforestry for the native groups.

4.5. Ecological impacts of oil palm agroforestry

The conversion of forests to oil palm plantations causes disturbances to the habitat of certain fauna, such as mammals—including *Sus scrofa, Macaca fascicularis,* and *Macaca nemestrina Trachypithecus obscurus*, *Trachypithecus cristatus*, *Viverra tangalunga*, and *Prionailurus bengalensis* (Azhar et al., 2014)—soil macro-fauna, and birds (Ashton-Butt et al., 2018; Azhar et al., 2014; Teuscher et al., 2016). Thus, large-scale oil palm plantations that are managed using monoculture will potentially damage the landscape and biodiversity. The oil palm plantation companies usually eradicate understory vegetation to increase oil palm yields which decimates in-soil macro-fauna diversity (Ashton-Butt et al., 2018).

Interestingly, there are some impressive effects of enrichment planting affecting birds and invertebrate fauna a year after the establishment of the experimental agroforestry plot. Research confirms an increase in invertebrates present on enrichment planting experimental plots (Teuscher et al., 2016), with most of the insects found in the herb layer (Teuscher et al., 2016). The research also found an increase in bird diversity, probably caused by an overall increase in heterogeneity within the experimental plot (Teuscher et al., 2016). After the first year, some of the planted trees had already reached more than four meters in height (Teuscher et al., 2016) to provide nesting, roosting, and foraging habitats (Thiollay, 1995). The presence of birds and invertebrate fauna can be used as bio-indicators to monitor the improvement in habitat quality (Barnes et al., 2014; Ewers et al., 2015; Sekercioglu, 2006). The invertebrates perform many functions, including litter decomposition, predation, pollination, and herbivory, which are critical for the functioning of the ecosystem (Ewers et al., 2015). The initial positive effects on birds and invertebrates are key to the initiation of natural succession by other organisms that are essential for biodiversity enrichment into the future (Teuscher et al., 2016).

Finally, another interesting point is the impressively increasing oil palm yields, even though it was mitigated by the loss of oil palm yields at the plot scale during the initial experimental stage (Woittiez et al., 2017). The oil palm height as a proxy for the oil-palm age was the most important indicator of yields (Gérard et al., 2017). Therefore, the increased oil palm height (and consequently age) indicates higher oil-palm yields in the experimental plot.

5. Concluding Remarks

This research concludes that the establishment of oil palm agroforestry is promising in reconciling the conflict of interests between PT REKI and the local communities around the Harapan Rainforest. It indicates that oil palm agroforestry provides a higher financial benefit compared to oil palm-monoculture. A combination of oil palm and *jengkol* will produce the highest monthly profits compared to oil palm monoculture and other intercrops. A two-hectare agroforest with a combination of oil palm and *jengkol* will be able to sustain the average monthly expenditure needs of the local community around the Harapan Rainforest.

A relatively wide planting distance enables the maintenance of facilities and effective management activities. The determination of spacing affects costs and income from the applied land management patterns. Moreover, plant spacing also affects plant growth, contributing directly to the success of oil palm agroforestry.

Oil palm agroforestry offers positive ecological impacts, such as improving the flora diversity as the habitat of specific fauna. However, since this requires removing some oil palm trees, not all local communities around the Harapan Rainforest are willing to participate. The increased benefits from intercropping and oil palm yields in the initial stages of agroforestry may compensate for the reduction in yield from the removal of oil palm trees. These potential benefits should be thoroughly explained to the local communities for them to accept and implement oil palm agroforestry.

In conclusion, this study confirms additional benefits in the economic and ecological aspects of oil palm agroforestry compared to oil palm-monoculture. It recommends an optimal combination of crops in oil palm agroforestry. These results provide rational evidence supporting the expansion of oil palm agroforestry in land use planning.

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