What is the impact of RSPO group certification for small scale oil palm farmers?

A thesis research on the impact of RSPO group certification and intercropping on ecosystem services in oil palm smallholdings in Central Kalimantan, Indonesia

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By

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This thesis report is the result of my graduation research for the major specialisation Tropical Forestry of the study Forestry and Nature Management at Van Hall Larenstein University of Applied Sciences. This graduation research is part of the research project "*Sustainable yield and ecosystem services in smallholders' oil palm plantation in Central Kalimantan Province*" by the Socially and Environmentally Sustainable Oil palm Research (SEnSOR) programme. The research project aims to fill the knowledge gap of smallholder group certification by assessing both the socio-economic impact on smallholders and the impact on the ecosystem services of their plantations. This graduation research focuses only on the impact on ecosystem services of smallholder plantations.

I would like to thank my supervisor Dr. Ir. Peter van der Meer from VHL University of Applied Sciences for his feedback and guidance during all stages of the research. I would also like to thank my supervisor Dr. Aritta Suwarno from the SEnSOR research programme with Wageningen University for organising the research fieldwork and for her help keeping my thesis focussed. Finally my thanks go to Prof. Yudi Firmanul Arifin and Prof. Mayang Meilantina and their students from UNLAM and UNPAR Universities and Dr. Dony Rachmanadi from FORDA for their help with the fieldwork.

List of abbreviations and definitions

Organisations

RSPO	Roundtable for Sustainable Palm Oil. RSPO is a certification scheme for sustainably managed oil palm plantations (RSPO, 2018).
SEnSOR	Socially and Environmentally Sustainable Oil palm Research. SEnSOR is an independent research project which was erected by RSPO to improve its standards using scientific evidence (RSPO, 2013).
Ecosystem services team	Team within this SEnSOR project focussing on the oil-palm plantation ecosystem measurements.
Socio-economic team	Team within this SEnSOR project focussing on the socio-economic interviews with oil-palm smallholders.

Definitions

Certification	I use this term for the process of an independent third party giving assurance that a product has been checked and meets the required standards.
Smallholder	I use this term for oil palm farmers who are in possession of their own up to fifty hectare land and make their own management choices.
Ecosystem service	I use this term for products and processes from the natural environment that benefit humans freely.
Intercropping	I use this term for plantation management where oil palm is the main crop but other crops are planted between the oil palms.
Biomass and carbon stock	I use the term biomass for the weight of biological material when water is removed and carbon stock for the weight of carbon (C) stored in this biomass.
Fresh fruit bunches (FFB's)	The harvested clusters of oil palm fruit.

Abstract

The trade-off between high forest and biodiversity loss associated with development of oil palm plantations and their extremely efficient production of vegetable oil supplied the world with cooking oil and biofuel while taking away millions of hectares of forest in Indonesia alone. RSPO certification for sustainable palm oil was developed to address the sustainability issues of palm oil production. RSPO first focussed on the large corporations managing oil palm. However, because smallholders produce a large share (about 40%) of the total production of palm oil (RSPO, 2018), RSPO developed RSPO group certification to make the certification of sustainable palm oil production accessible for smallholders. A management practice of many oil palm smallholder farmers is to grow other crops between the oil palms and is also known as intercropping. Intercropping is known to provide many benefits to smallholders such as income in the early plantation ages (Nchanji, Nkongho, Mala, & Levang, 2016). However it is hard for oil palm farmers to certify their intercropped plantations due to production efficiency requirements. This report assesses whether RSPO group certified plantations have a higher provision of ecosystem services to see where smallholder group certification can improve sustainable oil palm management of its certified smallholders. The report also assesses whether intercropping shows a higher sustainability to see if it is desirable to include intercropping smallholders in smallholder group certification.

The main research question of this study is:
Does (a) RSPO group certification and (b) intercropping positively affect Ecosystem Services in oil palm smallholdings?

The sustainability of group certification and intercropping has been assessed for five ecosystem services by measuring the following indicators: Carbon storage, Biodiversity, Pest regulation, Yield and Pollution. Quantification of the ecosystem service indicators was done by establishing plots in smallholder plantations and with interviews with their owners. This data was collected in two study sites in the province Central Kalimantan, Indonesia. The collected plot and interview data were then analysed to find the effects of certification and intercropping. The results for certification show certified smallholders have significantly lower herb biodiversity than non-certified smallholders. However results also indicate that certified smallholders have lower leaflet herbivory and that their yield is higher. The results for intercropping show plantations with intercrops have significantly lower herb biodiversity than their non-intercropping counterparts and higher tree species richness but no conclusions could be drawn for the other four ecosystem services. To improve the effectiveness of group certification several aspects have to be taken into account. Most importantly it is recommended to improve the sustainability of weed management by implementing grazing cattle. Other recommendations are given to study the trade-off effect of planting densities on carbon storage and yield.

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1 Introduction

Over the last decades the area of oil palm plantation has been expanding rapidly, between 1990 and 2010 the planted area of oil palm in South-East Asia grew from 3.5 to 13.1 million ha (Gunarso, Hartoyo, Agus, & Killeen, 2013). Indonesia lost an estimated 840.000 ha of primary forest per year from 2000 to 2012, adding up to more than six million ha in total which is even faster than deforestation rates in Brazil. Half of the Indonesian forest loss was due to oil palm expansion (Petrenko, Paltseva, & Searle, 2016). The conversion of forest to plantation causes a significant damage to ecosystems, as it brings a loss of biodiversity of herbs, insects, birds and wild animals like the Orang-utan (Foster, et al., 2011). Even after conversion plantations have lower biodiversity, carbon stock and cause fragmentation, biodiversity loss and pollution in adjacent environments (Fitzherbert, et al., 2008).

However there is no easy alternative, the demand for vegetable oils will likely stay high and oil palm produces more oil per hectare and more oil per invested dollar than other high yielding vegetable oil crops (Zimmer, 2010). It is also a major source of income for rural populations in South-East Asia and contributes to their development. In Indonesia alone, 2 to 3 million people work in the oil palm sector (International finance corporation, 2011). This trade-off between the huge benefits of palm oil and ecosystem damages makes it critically important that existing oil palm plantations are managed sustainably to reduce the impact on the environment.

To tackle the problems associated with oil palm plantations, the World Wildlife Fund (WWF) proposed a certification scheme for sustainably managed oil palm plantations in 2002 (RSPO, 2018). They invited several large actors from the oil palm sector together in a meeting to improve the sustainability of palm oil. This actor group consisted of WWF, Unilever, Migros, Aarhus united UK Ltd and the Malaysian Palm Oil Association and was named the Roundtable on Sustainable Palm Oil (RSPO). RSPO aims to improve the sustainability of palm oil by improving economic, social and environmental viability.

During the first decade of RSPO, getting certified was not profitable for small scale oil palm farmers due to the high costs associated with RSPO certification. These smallholders do however produce a large share (40% in 2016) of the total production of palm oil (RSPO, 2018). This led the Dutch ministry of foreign affairs in 2016 to fund a study into the possibilities for smallholders to get certified as well. This research on smallholder certification possibilities ran trials from 2008 until 2013 (Opijnen, Brinkmann, & Meekers, 2013). As a result of this study, RSPO developed group certification. This group certification cuts away the costs of visiting each smallholder individually for assessments. Instead groups are assessed as an entity that has to ensure its own integrity and makes sure its own members adhere to the smallholder specific criteria. The smallholder group certification standard was endorsed by the RSPO in March 2016 (RSPO, 2016).

Assessment of smallholder plantations

In order to get certified, smallholders need to form a management unit that represents the member farmers and then apply for certification with the management unit. After such a smallholder group applies for certification, they need to meet the eligibility criteria. These are meant to prevent eligibility of the worst social and environmental practices. If these are met the smallholder group is officially part of the RSPO system and on the road for certification. Then the smallholder group needs to define the exact extent of the management unit. The smallholder group needs to map their plantation borders and which plantation belongs to which farmer, but also has to map high conservation value areas within their unit. After this they start the continuous improvement phases, these are three gradual phases of about a year in which they work towards 100% compliance with the principles and criteria (P&C) of the smallholder standard (RSPO, 2018). These principles and criteria look at economic, social and environmental sustainability. Once the group is fully compliant they are officially certified smallholders and can sell their fruit bunches as certified sustainable palm oil. After receiving certification the group is assessed in yearly audits to see if the group and its members still comply with the P&C.

Ecosystem services

In order to measure the sustainability of a natural environment, an overview of all processes within that environment is needed. An ecosystem is the term for a natural environment while looking at the processes and interactions between the biological and chemical world. Whenever products and processes from an ecosystem benefit humans they are known as ecosystem services. These ecosystem services are often classified into four classes; Provisioning services, Regulating services, Cultural services and Supporting services (Millennium Ecosystem Assessment, 2005). Provisioning services are the products obtained from ecosystems like food and timber but also less tangible things like drinking water. Regulating services are the processes in an ecosystem that benefit the human living environment like air/water/soil quality regulation, climate regulation, erosion regulation etc. Cultural services are benefits that are not materialistic, like spiritual and religious values, educational opportunities, inspiration and recreation. Finally supporting services are the processes that do not benefit us directly but are necessary for any of the other ecosystem services that do benefit us, think of soil formation, nutrient cycling and provisioning of habitat.

1.1 Problem analysis

Because the smallholder group certification standard has only been available since 2016, it is still continuously improving itself. In order to improve the RSPO smallholder group certification standard, RSPO needs to know how effective it has been already and where it can improve the standard. In order to improve the ecosystem of RSPO certified plantations it is necessary to find where RSPO group certification can be improved to better aid the ecosystems at the plantation level. One area of possible improvement is the stance RSPO currently holds on smallholders practicing intercropping. Experience of SEnSOR team members had indicated that smallholders who started with RSPO group certification were strongly advised against the use of intercropping in order to get the palm oil yield as high as possible. This advice may be counterproductive as intercropping has various benefits to smallholders. One of these benefits is income during the initial growth years of oil palm which allows smallholders to pay for early oil palm plantation inputs (Nchanji, Nkongho, Mala, & Levang, 2016).

1.2 Objective and research questions

This thesis aims to find the impact that RSPO group certification has had so far on the ecosystems of smallholder oil palm plantations and to give advice on improving these ecosystems with RSPO group certification. In this way this study aims to contribute to the objective: sustainable management of smallholder oil palm plantations in Central Kalimantan, Indonesia.

Main research question:

Does (a) RSPO group certification and (b) intercropping positively affect Ecosystem Services in oil palm smallholdings?

This research question is answered by assessing the effect of (a) and (b) on five different ecosystem services:

- *What is the effect of (a) and (b) on the ecosystem service carbon storage?*
- *What is the effect of (a) and (b) on the ecosystem service biodiversity?*
- *What is the effect of (a) and (b) on the ecosystem service pest regulation?*
- *What is the effect of (a) and (b) on the ecosystem service yield?*
- *What is the effect of (a) and (b) on the ecosystem service pollution?*

2 Theoretical framework

This chapter demarcates several key subjects of the research. These subjects are; RSPO certification and SEnSOR research, smallholder oil palm farmers, ecosystem services and intercropping.

2.1 RSPO Certification

The Roundtable for Sustainable Palm Oil (RSPO) is a multilateral organisation that manages the RSPO sustainability label. As RSPO explains on their supply-chains web-page, they have two systems of certification (RSPO, 2018); the first to ensure that palm oil is grown and produced sustainably, the other to ensure that consumer products with the RSPO label actually contain oil from certified oil palm plantations. The first is RSPO producer/grower certification and the second is RSPO supply chain certification. This means that not only the supermarket products need to be certified but all steps leading up to that product like the oil palm plantation, the refinery, the mill and the palm oil traders need to be RSPO certified as well. The certification type looked at in this report is RSPO group certification for smallholder farmers. It is a part of the first producer/grower certification.

RSPO measures the state of a plantation in yearly field audits where plantations have to meet the Principles and criteria that RSPO has prepared. The latest revision to the RSPO P&C was released this year and has almost completely reworked the method of certification for independent smallholders. The new method uses a new standard for certification of independent smallholders with separate principles and criteria specifically for independent smallholders (RSPO, 2018). The principles and criteria from this new standard which are relevant to this report have been added in Appendix V. The new standard is meant to simplify the process for smallholders to become certified, and allow greater numbers of smallholders to become certified.

2.2 Smallholder oil palm farmers

The definition of smallholders as used by RSPO is: "Smallholders are farmers who grow oil palm, alongside with subsistence crops, where the family provides the majority of labour and the farm provides the principal source of income, and the planted oil palm area is less than 50 hectares." (RSPO, 2018). RSPO considers two types of smallholders, independent smallholders and schemed/associated smallholders. The schemed/associated smallholders do not get to choose which crop they grow and how, instead their financer/mill decides plantation management. Independent smallholders on the other hand have freedom in how they utilize their land (RSPO, 2018). Smallholders manage about 40% of the total oil palm plantation area, while responsible for about 35% of the total palm oil yield (Glenday & Paoli, 2015).

Barriers for smallholder certification

Certification has been troublesome for smallholders due to high costs associated with getting certified and those of audits. The extra income from selling certified oil instead of standard oil is a very small amount but enough for some smallholders to cover the recurrent costs of certification. Besides the costs, a lack of organisation makes it difficult for smallholder farmers to comply with legality requirements, official digital map requirements and with the required assessment of high conservation values (Rietberg & Slingerland, Barriers to smallholder RSPO certification, 2016).

Yield gap

Smallholder oil palm farmers are known to have a far lower yield per hectare than plantations managed by the large corporations. In a previous study by SEnSOR into the yield gap, actual oil yield of smallholders was estimated around 3.3 tonnes/ha/year while the potential oil yield is calculated to be more than 8 tonnes/ha/year (Wottiez, van Wijk, Slingerland, van Noordwijk, & Giller, 2017). The smallholder yield gap is attributed to various management differences with the highly productive corporate plantations. The harvesting interval and type of fertilizer are two areas of improvement found in a smallholder yield gap study (Lee, Ghazoul, Obidzinski, & Koh, 2013). Harvesting the fruit bunches multiple times per month was found to significantly improve yearly fruit bunch yield, with harvesting once a month giving the lowest yield and three times a month giving the highest yield. They also found that the quality of fertilizer had a significant effect on the yield.

Ex-Plasma smallholder plantations

Ex-plasma plantations are plantations that used to be managed by a company. The nucleus is the core of a plantation managed by a company and the term plasma is used for plantations at the edge of the company estate. Plasma plantations are initially managed by the core company and when the plantation has been established, control is given back to the farmer who owns the land (Khasanah, van Noordwijk, Ningsih, & Wich, 2015).

2.3 Intercropping

Oil palm intercropping is a plantation management type where oil palm is the main crop but other crops are planted between the oil palms. Smallholder farmers often choose to intercrop food crops between young oil palms as a food source for family use or to trade on the local market as a source of income while the oil palm is not yet old enough to provide income. Intercropping is often thought to inhibit the growth of oil palm, however if the oil palm is planted with correct intercrops and correct planting distances between palms the future yield of the oil palms could be comparable to the yield of regular oil palm plantations (Nchanji, Nkongho, Mala, & Levang, 2016).

The types of oil palm intercropping include, among others; row intercropping, edge intercropping, mixed planting and understory cultivation.

- Row intercropping is a type of intercropping where each crop is planted in rows which alternate in a certain pattern. Farmers use row intercropping for instance by alternating one row of oil palm with one row of banana.
- Edge intercropping is a type of intercropping where the plantation consists of one crop and another is grown on the edge of the plantation, often to indicate the end of one plantation and the start of a neighbouring plantation.
- Mixed planting is a type of intercropping where multiple crops are planted as a mix without any discernible pattern. Often smallholders use this type of intercropping when planting oil palm in their home garden close to their home. Fruit tree saplings are sometimes planted in oil palm gaps and sometimes mature fruit trees are left standing when land is cleared for oil palm.
- Understory cultivation is a type of intercropping where a crop is cultivated under the shade of another crop. This type of intercropping is used for instance with pepper or vanilla growing under or against the trunk of oil palm.

3 Methodology

The impact of group certification on the ecosystem of oil palm plantations is measured with a quantitative study into five ecosystem services. These five measured ecosystem services are carbon storage, biodiversity, pest control, yield and pollution. These five ecosystem services are kept as a structure and are described individually in the following chapters. Although this thesis is separate from the socio-economic study of smallholders, it does use some of the answers from the interviews done by the socio-economic team.

3.1 Study site

Two study sites were chosen in Central Kalimantan because of the network of contacts SEnSOR had already built in the area and the availability of villages with RSPO certified farmer groups. Within these two study sites lie three villages of which two lie close to each other. The two study sites are shown as green dots in Figure 1. The first village is Pangkalan Tiga, a town with about 3000 inhabitants who are for the most part from a transmigration project background. The certified farmer group "KUD Tani Subur" is based in this town but the town also has non-certified smallholders. These non-certified farmers are from an ex-Plasma project which was part of the Sinar Mas corporation which owns the large concession of oil palm West of the village. The other two villages are Sandul and Kalang. Sandul has about 2000 inhabitants who are from a mixed immigration background and Kalang has about 700 inhabitants of an indigenous community background. These two villages are located to the north-east of Pangkalan Tiga and smallholders here do not have certification. A map of the plot locations in Pangkalan Tiga can be seen in Figure 3. The village is located exactly in the middle and is recognizable by the street structure. A map of the plot locations in Sandul and Kalang can be seen in Figure 2. The village Sandul is located next to the river Seruyan in the bottom of the middle of Figure 2 and Kalang also next to the river but just outside the map on the top left. Appendix I shows enlarged versions of these maps.

Figure 1 Borneo, Indonesia. The study sites are shown in green

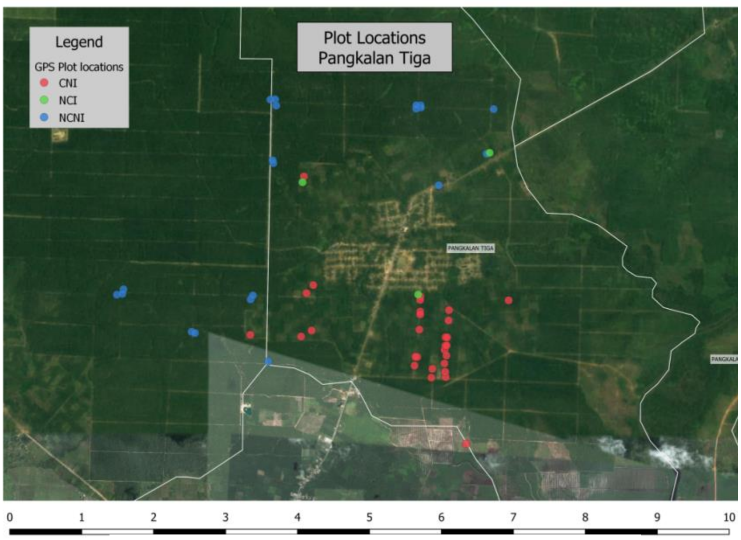

Figure 3 Plot locations in Pangkalan Tiga

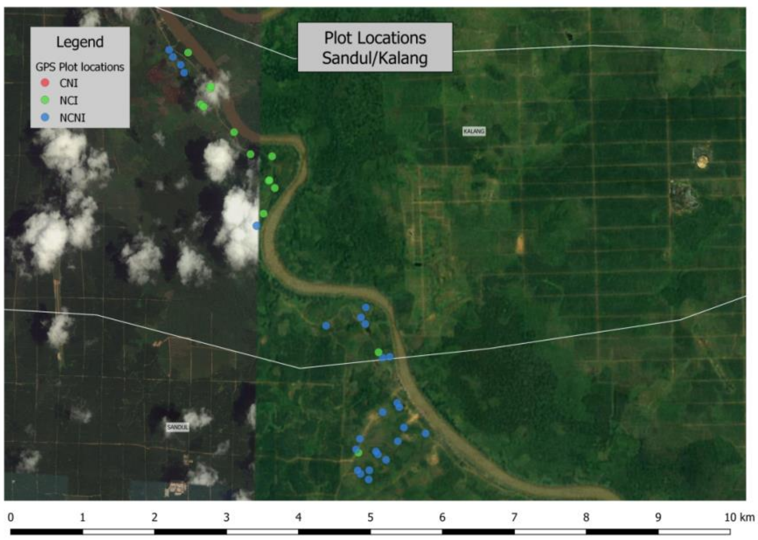

Figure 2 Plot locations in Sandul / Kalang

3.2 Selection of ecosystem services

In order to select ecosystem services that show the impact of RSPO group certification, logical possible influences of this certification were reasoned. This was done with the guidelines for smallholder RSPO members (RSPO, 2018). Appendix II shows a table with the ecosystem services which logically are influenced by certification. The table also shows possible methods for measuring these ecosystem services. Out of the ecosystem services that might logically have been affected, a sub-selection was made based on the importance of the ecosystem services and their measurability. Some of the factors in ecosystem service selection were that the ecosystem services needed to be measurable in a single field visit and that the measurement would not be dependent on the season. This allowed us to measure far more plots by spending less time per plot. Yield, biodiversity and carbon storage were chosen as indicators for the ecosystem services; provisioning of food/raw materials, genetic diversity preservation and climate regulation. After this, more literature was reviewed to look at other ecosystem services that may be affected by RSPO certification. Herbivory and pollution were chosen as indicators of the ecosystem services pest regulation and Air/Soil/Water quality conservation.

After deciding on the final ecosystem services, possible fieldwork measurements for these ecosystem services were chosen. An overview is shown in Table 1, and the methods of measuring these ecosystem services are further described in the following sub-chapter (3.3 Data collection).

Table 1 Final selection of ecosystem services, their indicator and measurement

Type	Ecosystem service	Indicator	Measurement
Regulating	Climate regulation	Carbon storage	Carbon storage (tonnes C/ha)
Supporting	Genetic diversity preservation	Biodiversity	Herb, tree and animal biodiversity (Richness/Shannon index)
Regulating	Pest regulation	Herbivory	Leaflet herbivory (% leaf damage)
Provisioning	Provisioning of food/raw materials	Yield	Oil palm fruit bunch harvest (FFB count and yield in tonnes/Ha)
Regulating	Air/Soil/Water quality preservation	Pollution	Waste objects present (classified)

3.3 Data collection

In this chapter is described how smallholders/plots were selected, how the smallholder data has been collected from the plots and how smallholder data has been gathered from interviews.

3.3.1 Sampling strategy

In order to select plantations for plot establishment, two main factors were taken into account. The first factor was if the plantation was certified and the second factor was if the plantation had crops "intercropped" between the oil palm. This resulted in a stratification based on certification and intercropping. Because there were no certified farmers practicing intercropping, the stratification consists of three groups. The first smallholder group is certified monoculture, the second group is non-certified monoculture and the third group is non-certified intercropping. The intercropping group will be compared with the monoculture group, and the certified group with the non-certified group but the intercropping group will not be compared with the certified group. The stratification based on certification is used to answer the research question whether group certification has a positive effect on ecosystem services in oil palm plantations. The stratification based on intercropping is meant to answer the research question whether intercropping has an effect on the ecosystem services, with the goal of assessing whether smallholders should or shouldn't be advised against intercropping.

Plots were selected before fieldwork with the help of the village head/village elders. They knew the location and types of oil palm plantations in the neighbourhood, and also provided us with the name of the owner of those plantations. The requirements followed during plot selection were oil palm age, plantation size, type of management and type of intercropping.

- The first criterion for plot selection was that the oil palm plantation had to have a minimum stand age of 5 years and a maximum of 10 years. This decision was made because this takes away some of the disturbances from age differences.
- The second criterion was that the oil palm plantation area had to be between 1 to 5 hectares. This selection was made to exclude disturbance of extremely small and large smallholders.
- The third criterion was that the oil palm plantation had to be managed by the smallholder and could not be managed by a corporation. This selection was made because the goal is to find the influence of certification on ecosystem services due to the management choices by smallholders themselves.
- The fourth criterion was that the oil palm plantation could not have edge-intercropping as explained in the theoretical framework (chapter 2.3). Edge-intercropping was excluded because these plantations differed too much from other types of intercropping and resembled monoculture plantations.

The interview data used in this study were collected by a different SEnSOR research group within the same project. During smallholder selection this group took care to include the owners of the measured plots in their interviews. The interviews with other plantation owners were excluded in the results of this thesis report. In total exactly one-hundred plots were established. The amount of plots of each type can be seen in Table 2. The interviews done with plot owners can also be seen in this table. Fifty-two plots were established in Pangkalan Tiga (P.T.) and forty-eight in Sandul and Kalang (S.K.). During data analysis some of the measured plots of non-certified smallholders in Pangkalan Tiga were found to belong to the same owner. This is why eleven of the plots are not linked to a corresponding interview.

Table 2 Distribution of plots and interviews

	Certified		Non-Certified	
	P.T.	**S.K.**	**P.T.**	**S.K.**
Plots	29	0	23	48
Interviews	29	0	12	48

	Intercropping		Monoculture	
	P.T.	**S.K.**	**P.T.**	**S.K.**
Plots	3	22	49	26
Interviews	3	22	38	26

3.3.2 Plot data collection

The shape of a plot for plot measurement can be seen in Figure 4. Plot borders were demarcated with eight poles, one on each corner of the Sub plots (B). After demarcating the plot, GPS coordinates were taken in the middle of the main plot (A). The sub plot types, sizes and their respective measurements can be seen in Table 3.

Table 3 Sub plot types, sizes and measurements

Plot name	Size	Measurement
Main plot (A)	20x50 m	Palms and intercrop trees with DBH ≥ 30 cm
Sub plot (B)	2x 10x20 m	Intercrop trees with DBH ≥ 10 cm
Sub-sub plot (C)	2x 5x5 m	Saplings with DBH 2 – 10 cm
Herb plot (D)	4x 1x1 m	Herb species list + herb cover %

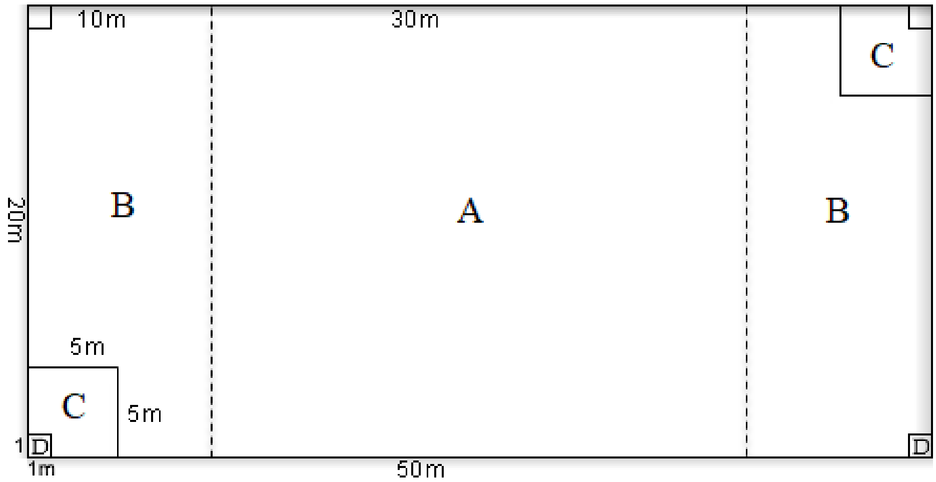

Figure 4 Plot design

In Figure 5 the placement of a plot within a smallholder's plantation is shown. A plot is placed four rows away from the plantation border and four rows away from the road, if the smallholder plantation is too small for this, place the plot in middle of the plantation.

Figure 5 Plot location for plantation plots

When a plot was established various measurements were done of the ecosystem service indicators. The field form used for the field data collection has been added as Appendix III.

Carbon storage

In order to estimate the carbon storage of a plot, the volume of timber and the tree species need to be measured. For calculation of the timber volume, diameter at breast height (DBH) and trunk height are required. The method that was used for measuring the DBH is explained in Figure 6. The trunk height was measured with a clinometer whenever possible. If this was not possible an average was determined of estimations by 2-4 experienced foresters. The tree height and diameter are used to calculate the biomass per tree. For all measured trees above 10 cm, the tree species was identified to species level where possible and otherwise to genus level, family level, or finally dipterocarp/non-dipterocarp. The stand age was also noted on the field form because of the big influence the stand age of the oil palm plantation has on the amount of biomass and other factors that might influence the ecosystem services.

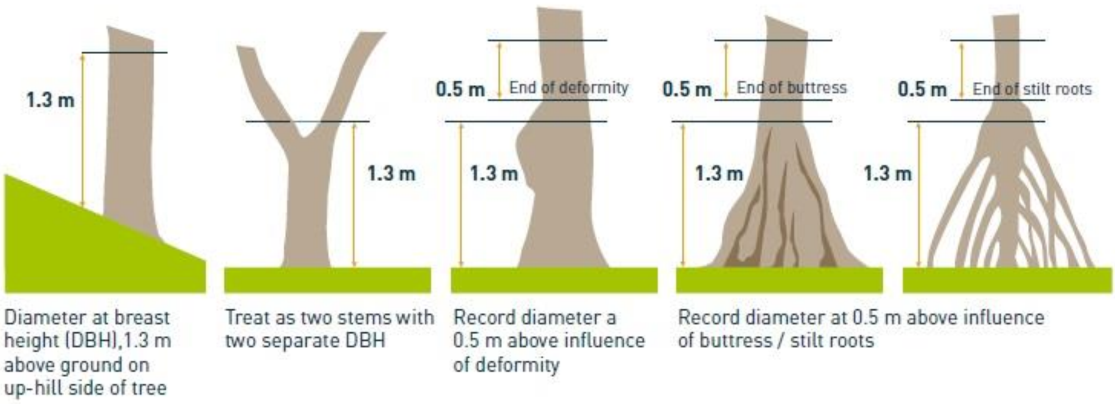

Figure 6 Method of tree DBH measurement (Suwarno, et al., 2018)

Herb biodiversity

For herb biodiversity, each corner of the main plot has an herb plot of 1x1m. In this herb plot one herb of each herb species encountered was collected in a bag labelled with an ID the herb plot. The amount of herb species per herb plot was written down together with a cover percentage of the herb plot. The herb samples were analysed after fieldwork days.

Pest regulation

The amount of herbivory is an indicator that can be measured to quantify ecosystem pest regulation (Flint & Dreistadt, 1998). When an ecosystem has better pest control there will be fewer times where the ecosystem has excessive amounts of herbivory. Per plot three trees were measured for their herbivory percentage. This was done by collecting three leaflets of three leaves per palm. The leaflets were stored in a bag per tree with a label indicating the plot and tree ID's. The leaflet samples were analysed after fieldwork days.

Yield

The yield is mostly quantified using the interview questions however the amount of fruit bunches in the plots can be compared. For each oil palm in a plot the amount of fruit bunches currently growing on the palm was counted.

Pollution

In order to describe the level of pollution the amount of waste present in a plot was described. This was done by giving a short description of the amount of waste objects in the main plot (A).

3.3.3 Interview data collection

Interview data for this research was collected by a different research group from the same SEnSOR project. The group consisted of professors and students from socio-economic studies from Wageningen University and Palangka Raya University. The interviews were done simultaneous to field plot data collection which allowed the socio-economic group to take care to include the owners of the measured plots in their interviews during smallholder selection. The interviews with owners of other plantations were excluded in the results of this thesis report. Please note that because their analysis is not finished yet, the interview results are also preliminary. Several of the interview questions had the aim of measuring the ecosystem service indicators of this study and are listed below.

Carbon storage
No questions were asked relating to carbon storage or biomass.

Biodiversity
Smallholders were asked how they do their weeding, however this did not yield usable results.
Smallholders were asked how often they remove weeds.
Smallholders were asked which species they use for intercropping.
Smallholders were asked which wild animal species they have seen on their plantation.

Pest regulation
Smallholders were asked how often they use pesticide, however this did not yield usable results.

Yield
Smallholders were asked about their yield from oil palm and intercrops.
To be able to convert yield to a per hectare basis, smallholders were also asked how many hectares of oil palm plantation they own.

Pollution
No questions were asked relating to pollution.

3.4 Data analysis

To analyse the effect of certification and intercropping on the five ecosystem services, each of the services will be quantified and compared against certification and then against intercropping. This is done by comparing boxplots of the different smallholder types and by testing if the means of the results differ significantly with a Welch t-test (Ruxton, 2006). The method of quantifying each of the five chosen ecosystem services is detailed in the sub-chapters below.

3.4.1 Carbon storage

The carbon storage was calculated by converting the total dry weight biomass to carbon storage with a carbon content ratio. To do this, first the aboveground biomass for all tree species was calculated using an allometric equation for each of the tree species. Then the belowground biomass was estimated with a shoot-root ratio. After that the total biomass was converted to stored carbon by using species specific biomass to carbon content ratios. Finally the carbon stored per hectare was calculated by summing all tree values and converting to hectares. The carbon stored in undergrowth, dead wood and soil organic carbon is not included in this study.

To calculate the aboveground biomass (AGB), species specific allometric equations are necessary. These relate the diameter/height/density to the expected amount of dry weight biomass (kg/palm). These equations differ a lot between species. Palm trees for example, differ from other trees in that their trunks don't grow in width but just become denser to support the growing length.

The wood density values indicate how much dry weight biomass (g) a tree has per volume ($cm^{3)}$. This density value was combined with the diameter and height values in an allometric equation to calculate the aboveground biomass of each tree that was measured. The wood density value of the tree species was collected from the ICRAF tree functional attributes and ecological database (ICRAF, 2018). If no species density was available the genus average was taken.

Oil palm AGB (Khalid, Zin, & Anderson, 1999):

$$71.797 * H - 7.0872$$

Banana AGB (Hairiah, Sitompul, van Noordwijk, & Palm, 2001)

$$0.03 * D^{2.13}$$

Rubber AGB (Brahma, Sileshi, Nath, & Das, 2017)

$$1.02 * (\exp(-3.31 + 0.95(\ln(D^2 * H))))$$

AGB of other intercrops (Chave, et al., 2014)

$$0.0637 * (\rho * D^2 * H)^{0.976}$$

AGB is the above ground biomass (kg)
ρ is the wood density (g/cm^3)
D is the diameter at breast height (cm)
H is the total tree height (m)

The belowground biomass (BGB) was estimated by applying a ratio of aboveground biomass to belowground biomass ratio. The AGB/BGB ratio is more commonly referred to as the Root to Shoot Ratio (RSR). An RSR of about 0.21 was found for Oil Palm, Rubber and Orchard-and-tree-plantation (Yuen, Ziegler, Webb, & Ryan, 2013).

$$BGB = AGB * RSR$$

BGB is the belowground biomass (kg)
AGB is the aboveground biomass (kg)
RSR is the root to shoot ratio

After calculating the dry matter above and belowground biomass (AGB + BGB), the carbon content per tree can be calculated. This was calculated by multiplying the total biomass of a tree with its species specific carbon fraction (C %). The carbon fraction for oil palm is 0.45 (g C g^{-1} dry matter) (Lamade & Bouillet, 2005), for tropical fruit trees it is also 0.45 (Janiola & Marin, 2016) and for tropical angiosperm trees the carbon fraction is 0.471 (Thomas & Martin, 2012).

$$Carbon\ content = (AGB + BGB) * C\%$$

AGB is the above ground biomass (kg)
BGB is the below ground biomass (kg)
C% is the carbon fraction

After calculating all individual tree/palm carbon contents, the stored carbon of the trees and palms was added together to get the total plot carbon amount (kg). Because a plot is 0.1 Ha, the total plot carbon was multiplied by 10 to get the standardized measurement for carbon storage (tonnes ha^{-1}).

Plot carbon storage was compared with stand age to get the amount of carbon captured per year and with planting density to find whether planting more densely increases the amount of carbon storage. This was then compared between smallholder types.

3.4.2 Plot biodiversity

In order to compare biodiversity between plots, the biodiversity of three different groups were assessed: herbs, trees and animals. Various common methods of quantifying biodiversity were analysed in a literature study with each their own advantage. Two different methods of measuring biodiversity were used in this study. The first was a Richness (R) value (Morris, et al., 2014). This richness is just the amount of species in a plot. This richness value was calculated as;

$$\mathrm{R} = N_i$$

N_i is the total number of species in plot *I*.

The second method of measuring biodiversity that was used is the Shannon's diversity Index *(H')* (Morris, et al., 2014). This Shannon index is valuable because it takes into account the amount of dominance each species in an ecosystem has. In order to calculate this index, the species proportion of all species in a plot needs to be calculated. This species proportion (P_i) in a plot was calculated as;

$$P_i = \frac{N_i}{N_{Sp}}$$

N_i is the number of individuals of species I
N_{sp} is the number of individuals of any species.

After species proportion was calculated, the Shannon's diversity Index *(H')* was calculated. This index was calculated as;

$$\mathrm{H}' = -\sum P_i * \ln(P_i)$$

P_i is the proportion of individuals belonging to species *I*.

Herbs

After a day of fieldwork the bags with herbs from the herb plots were analysed to document their species. The herb species were given ID's and when a new species was encountered it was added with ID and picture to the herbarium. Herb biodiversity was analysed with a Shannon index.

Trees
For each intercropping plot the species used for intercropping were documented in a list. Tree biodiversity was then analysed by comparing tree richness values of the plots.

3.4.3 Pest regulation

The collected leaflets that had been stored in bags and labelled per tree were analysed using the BioLeaf app on android (Machado, et al., 2016). Pictures of the leaflets were taken against a white background and during group gatherings the pictures were copied over to a shared USB device. The pictures were then processed in the app to get an herbivory percentage per leaflet. The steps in the app were to import an image, then to close any open gaps and then the app would calculate the red area percentage of the black area as can be seen in Figure 7. There were nine leaflets of three trees per plot of which the herbivory was averaged per tree. The results were three average leaflet herbivory percentages per plot.

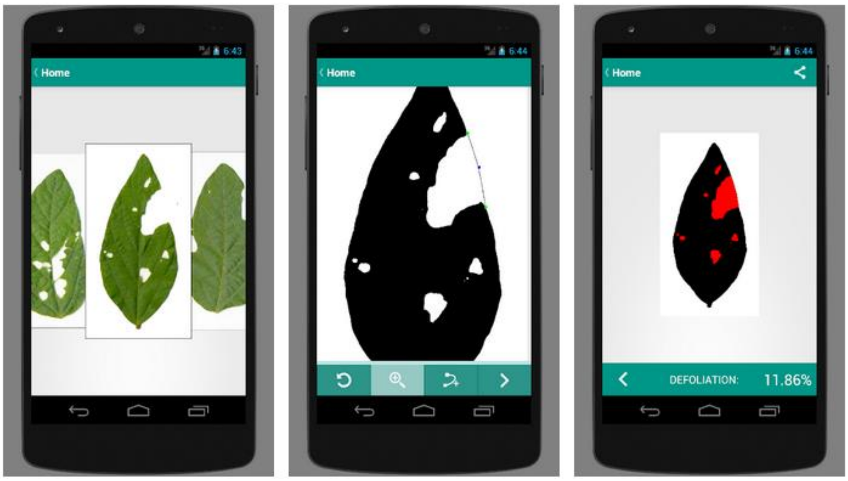

Figure 7 Leaf herbivory analysis with the BioLeaf app (Machado, et al., 2016)

3.4.4 Yield

The amount of fruit bunches growing on the oil palms was averaged for all palms per plot resulting in an average oil palm fruit bunch count per plot. Besides the currently growing FFB's, yield was calculated from interview responses but this is explained below in the interview analysis. The yield from interview analysis was compared with the planting density of oil palms to see if this impacts the amount of yield.

3.4.5 Pollution

The descriptions of waste objects in the plots were classified into three classes; "No waste objects", "Few waste objects" and "Lots of waste objects". Appendix IV shows which descriptions were classified as which classes. These classified plots were then mapped to see if their location showed any patterns. The effect of Certification and Intercropping are also analysed to see if they have an effect on waste classes.

3.4.6 Interview analysis

Some of the interview questions were classified and others received scores based on analysis of multiple interview questions.

Biodiversity

For the question of how often smallholders remove weeds, smallholders were scored from 1 to five. A higher score indicates more frequent weeding.

For the question which wild animal species smallholders have seen on their plantation, smallholders received a sum of the following scores. Smallholders received 1 point on their score if they have seen 3 ordinary species (butterfly, birds, snakes). Smallholders received 2 points on their score if they have seen big mammals (wild dog, monkey, wild pig). Lastly smallholders received 3 points on their score if they have seen both 1 and 2, and additionally a small crocodile, squirrel and a specific endangered bird. These scores were then summed to get a final score.

Smallholders were asked which species they use for intercropping. These answers were not classified or scored but all individual species are listed instead.

Yield

Smallholders were asked how high their yield is. The answers were given regarding all of the plantations the smallholder owns and are divided by their answer of how many hectares of oil palm they own.

4 Results

The ecosystems of three types of smallholder plantations have been assessed by quantifying five selected ecosystem services. In the following five chapters each of the five ecosystem services are shown with their results (Carbon storage, Biodiversity, Pest regulation, Yield and Pollution).

These five ecosystem services are compared between the certified monoculture plantations and non-certified monoculture plantations. In addition the ecosystem services are compared between non-certified monoculture plantations and non-certified intercropping plantations.

4.1 Carbon storage

In Figure 8 you can see the results of how much carbon storage per hectare the measured plantations had. The figure shows much less carbon is stored in the certified monoculture plots than in non-certified monoculture plots. This was tested with a T-test, which showed carbon storage was significantly higher for non-certified smallholders ($p = 0.0001976$). The thin certified monoculture boxplot shows a smaller spread in carbon storage. This low spread matches field observations of more similarity between the certified plantations than between the other types.

The figure also shows that non-certified intercropping smallholders have much lower carbon storage than non-certified monoculture plantations. This was also tested with a T-test, which showed intercropping plots indeed had significantly lower carbon storage than monoculture smallholders ($p = 1.363e{-}08$).

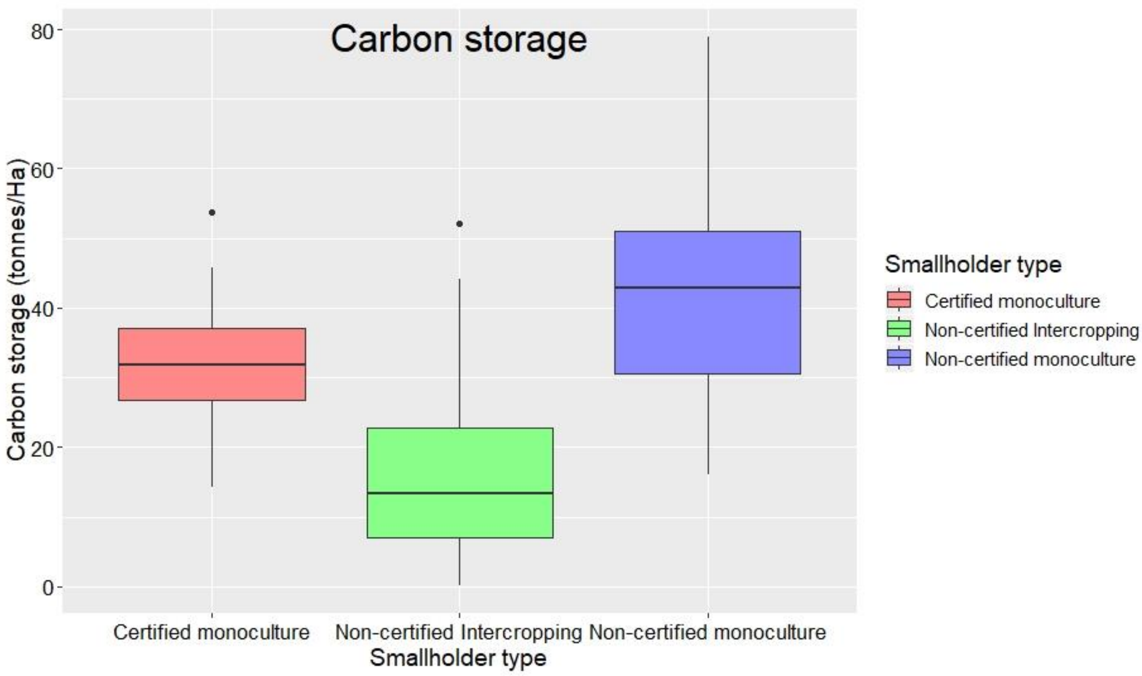

Figure 8 Boxplots of Carbon storage (tonnes/Ha) per smallholder type

Carbon storage per year

To show more clearly if certification and intercropping have an effect on the carbon storage, the amount of carbon that was stored per year is compared. Figure 9 shows that carbon storage per year is lower for certified and intercropping smallholders when compared to the non-certified monoculture plantations. Both of these comparisons were not significantly different.

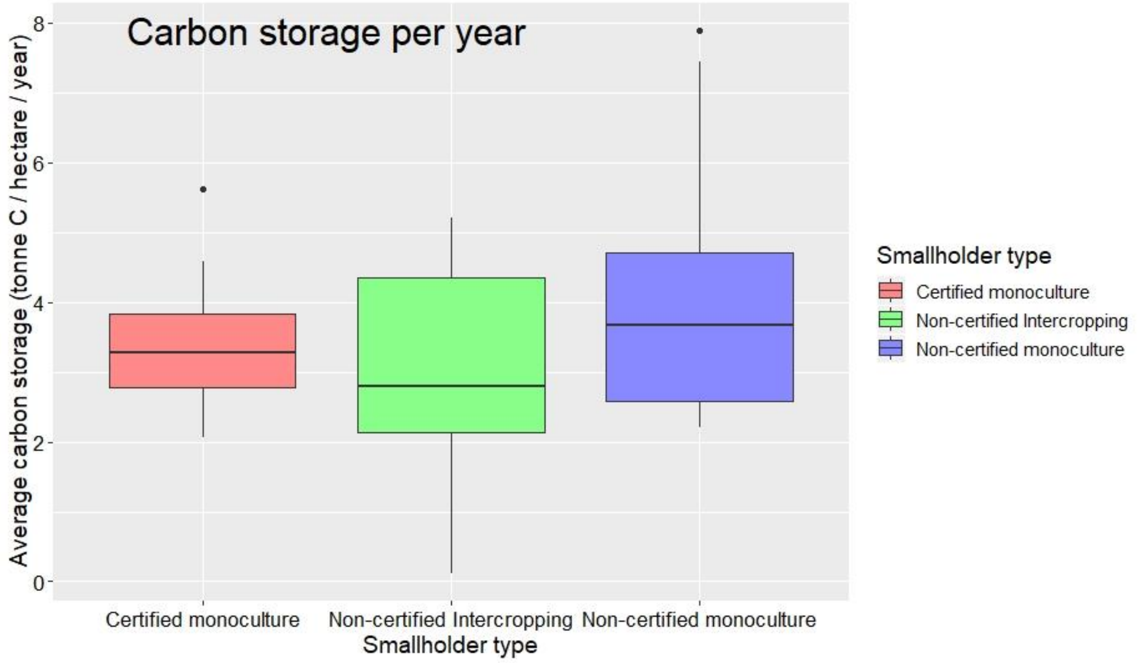

Figure 9 Average carbon storage by smallholder type

Influence of planting density on carbon storage

There is a significant effect of higher oil palm planting density on higher carbon storage ($p = 0.00189$). This effect is visualized in Figure 10.

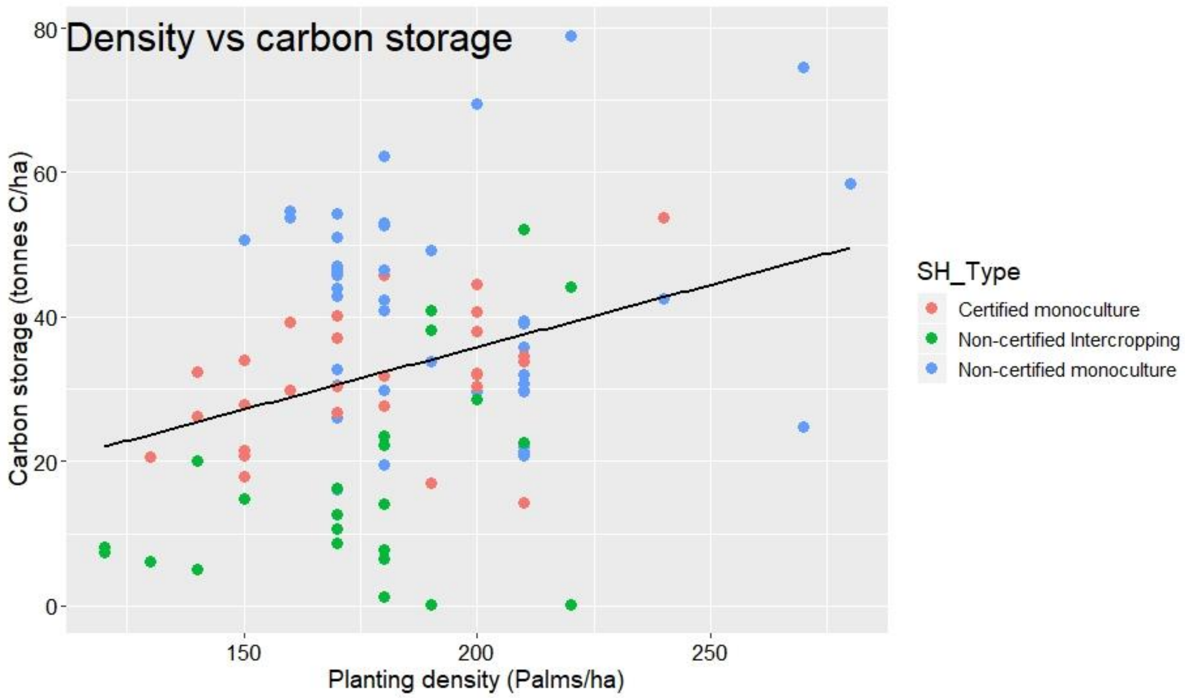

Figure 10 Planting density effect on Carbon storage

4.2 Biodiversity

Biodiversity results consist of herb biodiversity and tree biodiversity data from plot measurements and wild animal biodiversity data from interviews.

4.2.1 Herb biodiversity

The difference in herb biodiversity is visualized with boxplots in Figure 11. Herb biodiversity is expressed in a Shannon index per plot. The boxplot graph shows that certified monoculture plantations (in red) had a lower average biodiversity than non-certified monoculture plantations (in blue). This was tested as highly significantly lower herb biodiversity ($p = 0.008$) with a t-test. The boxplot graph also shows that non-certified intercropping plantations (in green) had a lower average biodiversity than non-certified monoculture plantations (in blue). This was tested as significantly lower herb biodiversity ($p = 0.027$) with a t-test.

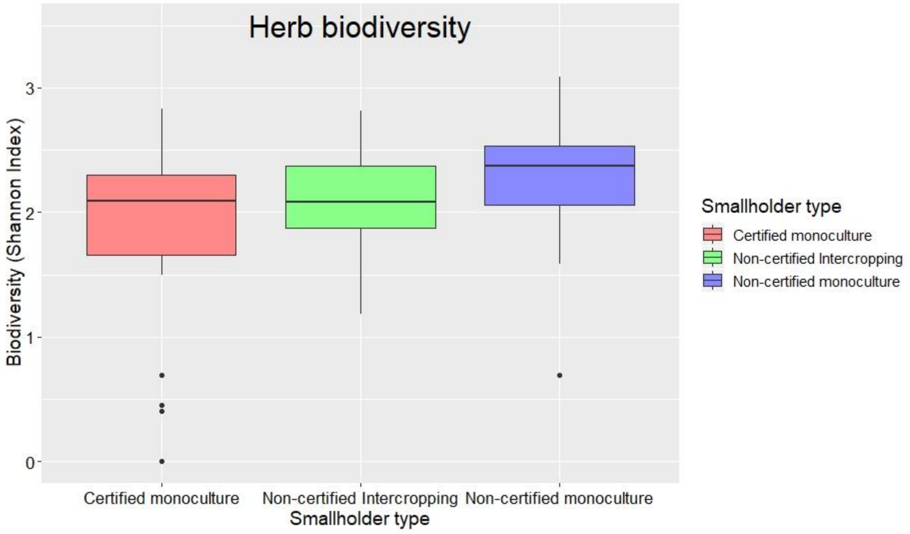

Figure 11 Boxplots of herb biodiversity index per smallholder type

Interview results

The classified weeding frequency of smallholders is shown in Figure 12. When comparing these results with Figure 11, it can be seen that certified monoculture and non-certified intercropping smallholders not only do their weeding more often than non-certified monoculture smallholders, they both also have a lower herb biodiversity than the non-certified monoculture smallholders.

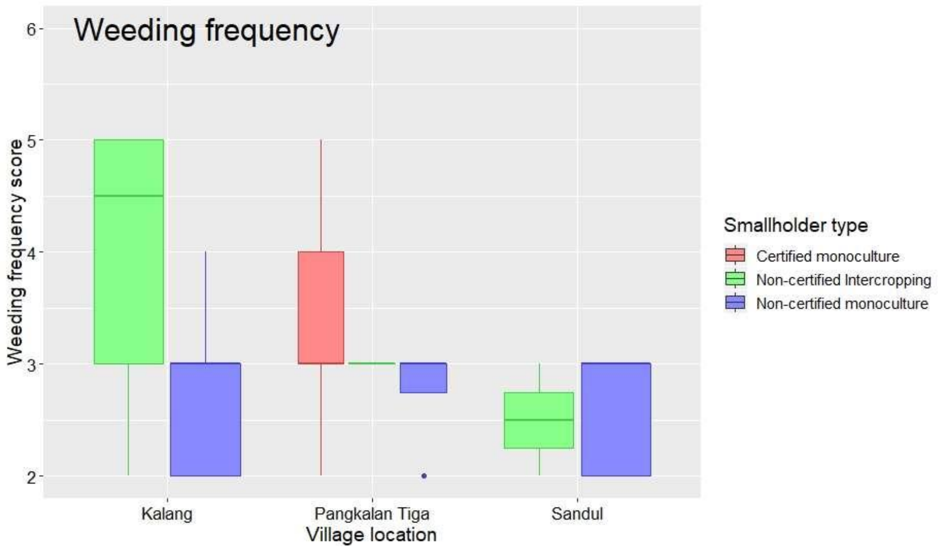

Figure 12 Weeding frequency interview results

4.2.2 Tree biodiversity

Monoculture plots obviously had only one palm tree species on their plots but intercropping smallholders had on average, including oil palm, 2.2 tree species in their plot. The species used for intercropping that were encountered were; rubber, banana, durian, java apple, rambutan, sugar palm, coconut, tamarind, *Artocarpus integer* and an unknown species. In the interviews the smallholder farmers were asked which species they use for intercropping. They answered with the following 14 species; banana, baharu, durian, mango, singkong, rubber, gaharu, pepper, sengon, rambutan, nangka, ketela, coconut and maize. Some of the intercropping smallholders indicated they use vegetables for intercropping.

4.2.3 Animal biodiversity

Smallholders were asked which wild animal species they have seen on their plantation. The scores for animal species richness are shown in the boxplots in Figure 13. It is quite clear that intercropping and certified smallholders answered with having seen more species than the non-certified monoculture smallholders. The median score of certified smallholders is 2 and the median score of both non-certified smallholder types is 0. In a Welch t-test certified smallholders scored significantly higher than non-certified smallholders (p = 0.0005814) however intercropping smallholders did not score significantly higher.

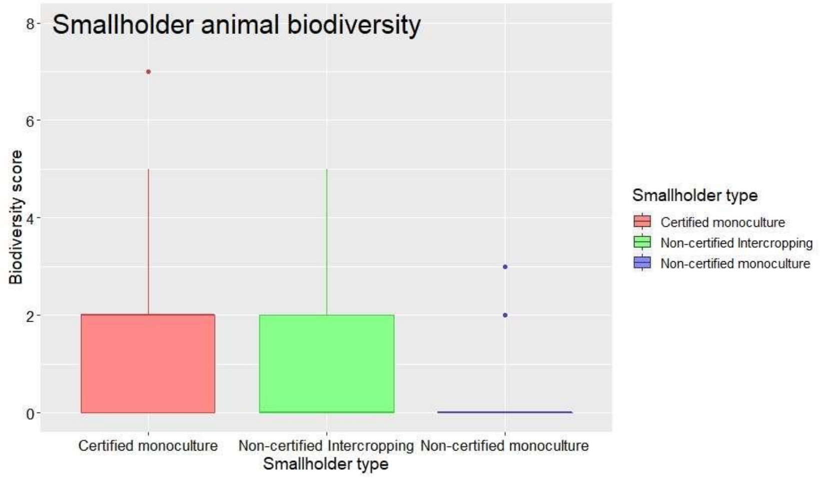

Figure 13 Smallholder animal biodiversity score

4.3 Pest regulation

The difference in average leaflet herbivory of the plantations is shown in Figure 14. Within Pangkalan Tiga the herbivory percentages of certified smallholders are slightly lower however not significantly lower than herbivory percentages of non-certified monoculture plantations. Similarly, the herbivory percentages of non-certified monoculture smallholders in Sandul are lower than those in Pangkalan Tiga but again not significantly lower.

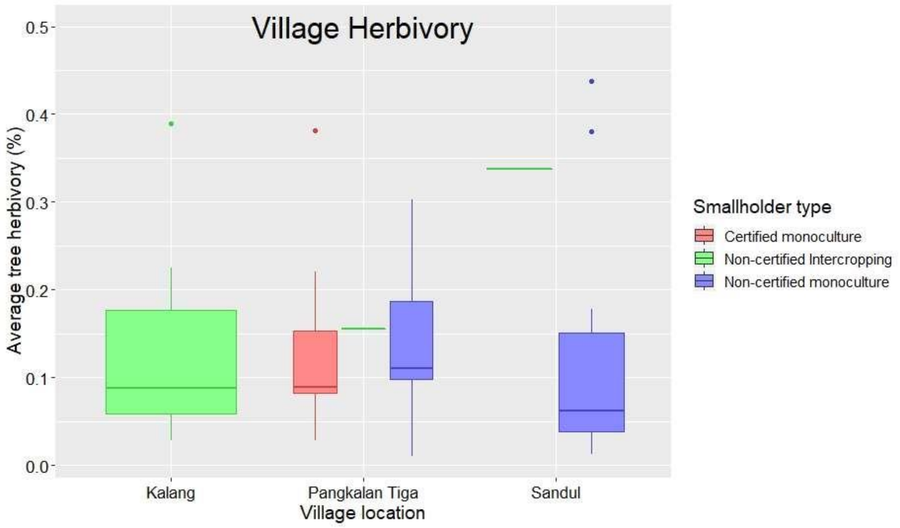

Figure 14 Boxplots of average leaflet herbivory (%) per smallholder type and sorted by the villages

4.4 Yield

The average number of fruit bunches growing on the oil palms of certified monoculture plantations was 3.3 bunches. For non-certified monoculture this average was 3.05. The difference between certified and non-certified smallholders was tested with a t-test but not significant. The answers from the interview questions were calculated to an oil palm yield per hectare per year. The differences in this average yield between the villages and smallholder types are shown in Figure 15. When comparing smallholders within Pangkalan Tiga it can be seen that certified monoculture plantations have a higher yield per hectare than non-certified monoculture plantations (T-test $p = 0.05702$). Intercropping is again ignored as the large majority of intercropping stands were too young to produce fruit bunches.

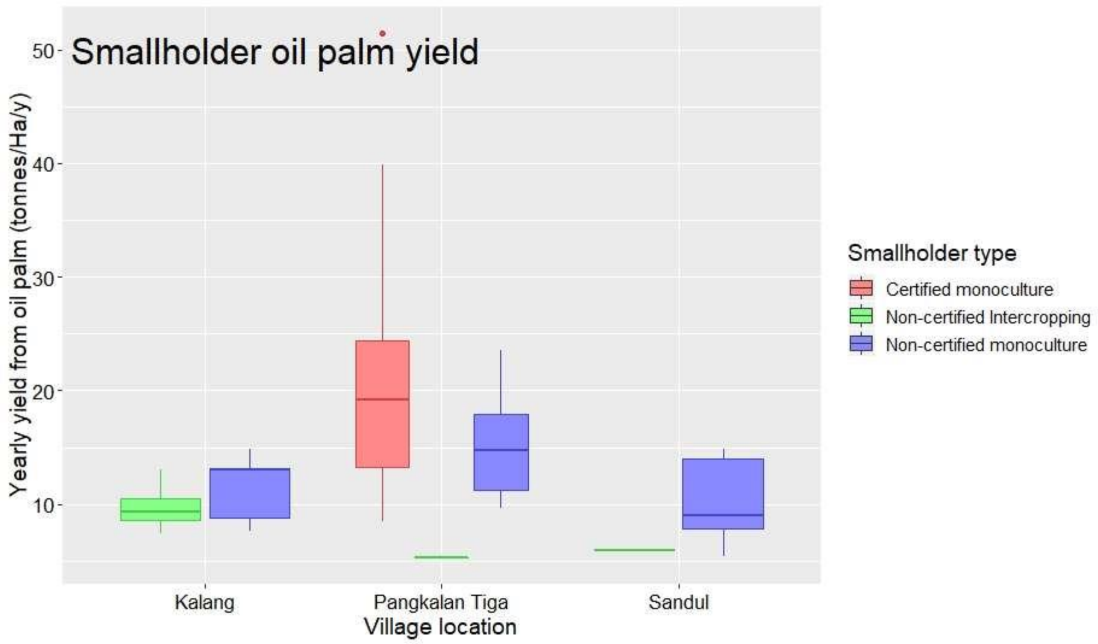

Figure 15 Interview results of smallholder yield (tonnes FFB/Ha/year)

Effect of planting density on yield

There seems to be a negative effect of a higher oil palm planting density on yield, however this effect was not significant ($p = 0.0802$). This effect is visualized in Figure 16.

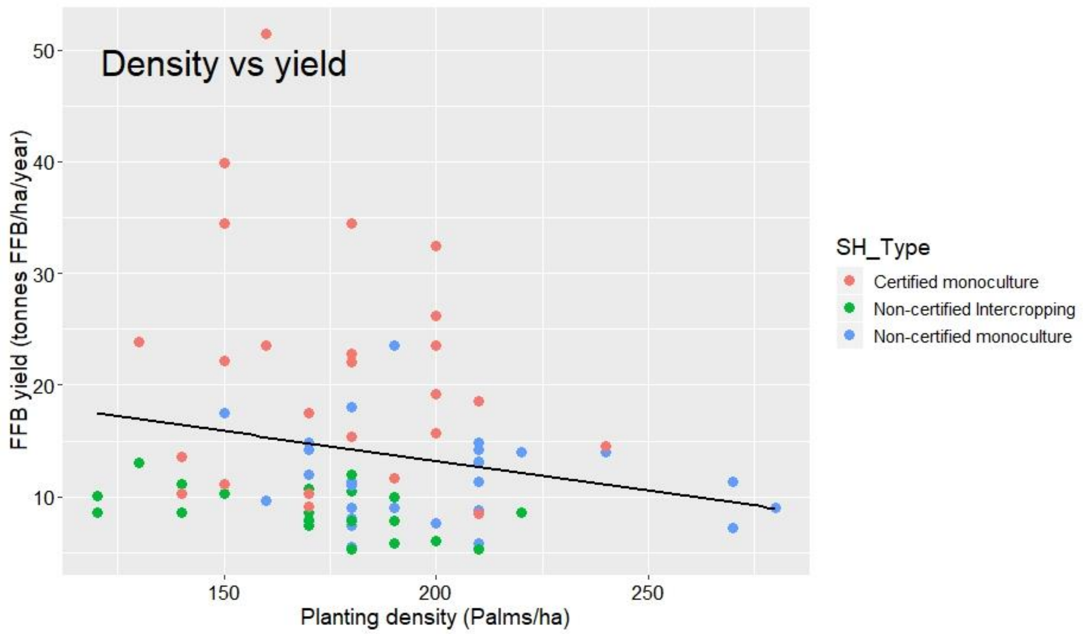

Figure 16 Effect of planting density on yield

4.5 Pollution

The amount of waste pollution was documented in about 50% of the plots for all three types of smallholder. Two examples of plots with the class "Lots of waste" are shown below in Figure 17 and Figure 18. The types of waste most often encountered in Pangkalan Tiga were plastic bags and bottles while the types of waste most often encountered in Sandul and Kalang were bright coloured rectangular packets.

Figure 17 Example of bottle and jerry can waste

Figure 18 Example of packaging waste

The plot locations with the three classes of waste can be seen in Figure 19 and Figure 20.

Figure 19 Pangkalan Tiga plot waste classification

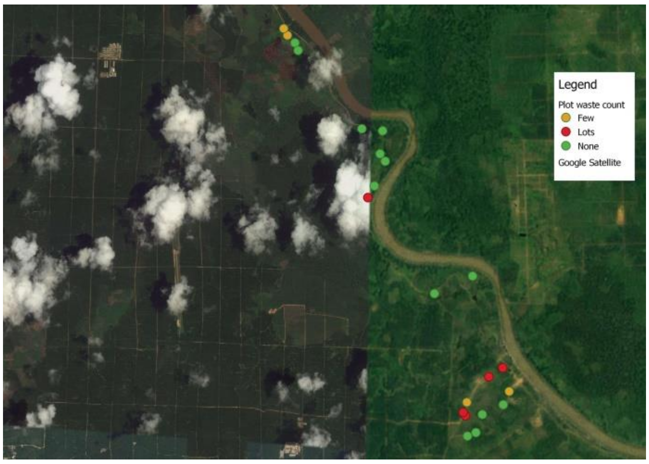

Figure 20 Sandul / Kalang plot waste classification

The results from data analysis of the amount of waste present in the plots are shown in Table 4. Numbers are fairly similar and no significant differences were tested between the smallholder types or between the villages.

Table 4 Waste category distribution of plots

smallholder type (Number of plots)	Amount of plots with no waste	Amount of plots with a few waste objects	Amount of plots with lots of waste	Amount of plot not measured
Intercropping (25)	7 (28%)	1 (4%)	2 (8%)	15 (60%)
Non-I non-C (46)	10 (22%)	8 (17%)	5 (11%)	23 (50%)
Certified (29)	6 (21%)	7 (24%)	2 (7%)	14 (48%)

5 Discussion

The results of quantifying each of the five chosen ecosystem services are assessed for each service individually. Possible causes for the differences that were found between smallholders for the five ecosystem services are explained. Additionally, the limitations of the methodology are described.

5.1 Carbon storage

Although a significantly higher carbon stock was found in the non-certified monoculture plantations than in the certified monoculture plantations and non-certified intercropping plantations, this was most likely due to the older oil palm stand age of those plots. When instead looking at the amount of carbon stored per year, this was also higher for the non-certified monoculture plantations. This may still be due to the older age of non-certified monoculture plantations because at later ages the oil palms have a more efficient carbon capture rate. An assessment by Tan, Kanniah & Cracknell of carbon storage rate of oil palm found an average rate of annual carbon storage of about 2.5 tonnes/ha/year when oil palm is young which gradually goes up to 3 tonnes/ha/year when the palm is about 10 years old and then goes back down to about 2.8 when the palms are 20 years old (Tan, Kanniah, & Cracknell, 2014). The results for annual carbon storage amounts were higher than this expected carbon storage rate. Especially some of the non-certified plantations in Sandul and Kalang have very high yearly carbon storage rates. The high carbon storage rates may be because some older plots were included as ten year old plots during plot-selection as this was the upper age limit. The higher rates might also be because of overestimated heights for young oil-palms.

Higher oil palm planting densities were found to be linked to higher Carbon storage in the plots. This is often the case in plantation forestry but means individual trees have less access to sunlight (Truax, Fortier, Gagnon, & Lambert, 2018).

5.2 Biodiversity

Herb biodiversity

The results showed that herb biodiversity is significantly lower in certified monoculture plots when compared to the non-certified monoculture plots. This is likely due to the frequency with which they use weeding because certified monoculture smallholders responded in the interviews with using weeding more frequently than non-certified monoculture smallholders. This may be a result of RSPO requiring smallholders to keep the ground clean around oil palm as these herbs would take up nutrients the oil palm needs. However RSPO also forbids the use of herbicides for cleaning the undergrowth. This leads to many management problems for the smallholders as they often do not have the time or resources to manually clean the herbs. This perhaps has led them to use herbicide illegally and against RSPO criteria in order to comply with the RSPO criteria.

Herb biodiversity in non-certified intercropping plots was significantly lower than in non-certified monoculture plots. This is likely due to the frequency with which they use weeding because intercropping smallholders responded in the interviews to use weeding more frequently. Intercropping smallholders likely use weeding more frequently to boost the growth and yields of their intercrops and oil palms. If the frequent weeding is indeed meant to promote growth in the early stages, the weeding frequency may decrease after the intercrop is taken out and plantations revert to monoculture.

Tree biodiversity

Results of tree biodiversity showed a higher biodiversity in intercropping plots than in monoculture plots. This was to be expected but these results are still important for the ecosystem functions that can depend on intercropped tree biodiversity like bird biodiversity and soil formation (Thevathasan & Gordon, 2004).

Animal biodiversity

The interview responses showed certified monoculture smallholders answered significantly more often with having seen higher animal biodiversity on their plantations than non-certified monoculture smallholders. The higher outcome for certified smallholders is possibly due to feeling required to answer with high biodiversity answers as they want to stay part of the certified farmer group. The interview outcome for intercropping smallholders was slightly higher than non-certified monoculture smallholders. Although there was not a significant difference it shows follow-up field research can be valuable in showing whether intercropping plantations actually have higher animal biodiversity.

Effect of intercropping types

Two types of intercropping were encountered with a different management of the intercrop. The first intercropping type was smallholders leaving their fruit trees standing when converting to an oil palm plantation. This is done because the fruit trees have a high cultural value. Durian trees for instance may not be cut down in the Dayak beliefs of the people in Kalang. These fruit trees also do not seem to be managed for high productivity. The other type was smallholders planting crops between oil palms at the moment of planting out the oil palm such as Banana. Smallholders practicing this last type remove intercrops around year 5-6 and their following management is similar to monoculture plantations. These two types may have a very different plantation after around five years when the temporary intercrops are removed. The future effect of these intercropping types could not be measured in this study, follow-up research could show if ecosystem services in these plantations have benefitted from intercropping.

Custom calculation of species proportion

In order to calculate species proportion for the Shannon index, the amount of individuals belonging to each species was necessary. Although species abundance was not recorded in the plots, an alternative method of estimating the species proportion was used. The number of herb plots a species appears in combination with herb plot cover percentages were used to calculate the estimated species proportion. There are some flaws to this method like the assumption that every species found in a herb plot appears in equal amounts. However, the Shannon index calculated with this custom species proportion should still adjust the results for some of the differences in species abundance in a plot.

5.3 Pest regulation

Although leaflet herbivory did not differ significantly between the smallholder types, certified monoculture and non-certified monoculture plantations within Pangkalan Tiga show that certified smallholders had less herbivory, although not significantly less. Herbivory results of intercropping plantations had a very large spread which makes it difficult to compare them against plantations in other villages or against monoculture plantations. This large spread might be because of the many types of intercropping that were practiced, further research splitting the different intercropping types might show the actual influence of intercropping on leaflet herbivory.

During the collection of leaflets some problems were encountered. The planned methodology was to try to sample three leaflets of three leaves per palm. However, sometimes it was necessary to take samples of the palm leaves outside the plot and sometimes even of freshly pruned leaves that had been stacked in rows under the palms when the palm leaves grew unreachably high. Due to slow analysis of leaf samples, leaf samples were often stored for days which caused some leaf samples to degrade. As a solution pictures were taken to analyse the leaves later. These pictures were analysed after fieldwork was done. It may be that the corrupted leaves gave different results when analysing their herbivory percentage. This should be the case for all types of smallholders and thus probably only increased the spread of herbivory percentages for all smallholder types.

5.4 Yield

The average fruit bunch counts in the certified and non-certified plots were about the same, with no significant difference. The fruit bunch data of intercropping plots was not usable because the intercropping plots were almost all around 3-5 years old and did not yet bear many fruits. The interview results paint a clearer picture of the yield. Respondents from Pangkalan Tiga had a significantly higher yield than those from the other two villages. Within Pangkalan Tiga certified smallholders had an almost significantly higher yield than non-certified smallholders. Smallholders who practiced intercropping are again ignored as at least a part of their plantation stands were too young to compare their yields with older plantations.

The interview yield results show higher planting densities seem to have a negative effect on fruit bunch yields, however this effect was not significant. A research into planting densities for optimal yield showed that young oil palms have a higher yield at higher planting densities, the space requirement of oil palms then increases with age and older oil palm stands have a higher yield with lower densities (Nazeeb, Tang, Loong, & Shahar, 2008). This shows planting density actually affects yield counts, and may be a reason for RSPO to promote higher planting densities with subsequent thinnings to improve yields for certified smallholders.

5.5 Pollution

A surprisingly large amount of waste was found in the smallholder plantations. The plots with high amounts of waste seem clustered and seem closer to the village. In Sandul and Kalang the waste that was found was mostly small rectangular powder or pill packaging. According to locals the packages were a type of cough medicine that has hallucinogenic properties when taken in large quantities. This cough medicine is possibly a drug which is known as dextromethorphan, and is known in Indonesia as DXM. The extreme amounts of medicine packaging were not present in Pangkalan Tiga. This could be related to a stricter Muslim culture of not drinking alcohol or perhaps because they take different drugs than Sandul and Kalang.

When looking at Table 4 in the pollution results chapter with the distribution of plot waste counts, intercropping smallholders clearly have less waste in their plantations. The reason for this is probably the young age of the plantation and that there is less cover to feel hidden while using the recreational drugs. Another possible reason may be that workers leave the waste during maintenance/harvest. Certification does not seem to have influence on the amount of waste present.

5.6 Limitations of methodology

A problem encountered during plot selection was that plots could not be selected at random. During the design of the study there was no access to a precise map of smallholder plantation borders and the exact locations of certified and intercropping smallholders was unknown. The goal was to establish twenty plots of each of the three smallholder groups in both of the study sites. However this was impossible to do from a map, instead plots were selected before fieldwork with the help of a village elder. This proved to be an efficient method however this limited the possibility to select an equal amount of smallholders from each group.

During plot selection a minimum oil palm stand age of five years and a maximum of ten years was the initial goal. This soon showed to be impossible as most smallholders stop intercropping when the oil palms reach an age of about five years old as by this point they cast too much shade or because intercrops inhibit their growth too much. Only a few plots were encountered above the age of five where large fruit trees were kept standing for fruit harvest. Because of this the decision was made to make an exception for intercropping smallholders and accept three to five year old intercropping plantations for plot selection. The upper limit of ten years old also became problematic but this time in Pangkalan Tiga, where plantation ages were much higher than in Sandul/Kalang. Many non-certified farmers of the ex-Plasma project had oil palm stands with ages around twenty years old. An exception was made for these plantations and they were included for plot selection. The resulting stand ages differ significantly between smallholder groups, and although it has been taken into account in Carbon comparisons it may still have had an unexplained effect in assessment of other ecosystem services.

Misattribution

Certified smallholders may have better management of their oil palm stand and higher yield numbers not because of certification but as a result of the method smallholders received certification. It is likely that smallholder plantations with better management and higher productivity were more likely to get certification before the rest. This may have caused these plantations with better management to be in the certified smallholder group without certification causing the better management or the higher yield.

It may be too soon to attribute any differences between certified and non-certified group smallholders to having received certification. The smallholder group certification standard was endorsed by the RSPO in March 2016

(RSPO, 2016). It is unlikely that certification already has a measurable effect. Another reason the group certification perhaps didn't have an effect yet is because RSPO allowed these smallholders to receive certification when their plantations were already around 8 years old. The establishment of a plantation is when certification can have a big impact on management choices. The establishment phase is also when natural area has to be kept aside for high conservation value forest areas during the planning of maps of the oil palm plantations. The differences that originated during planting out can thus not be attributed to certification.

Another reason differences between certified and non-certified smallholders can be misinterpreted is because everyone in Pangkalan Tiga is on the process of getting certified. Even the non-certified smallholders already get training and support for joining the KUD Tani Subur certified farmers group and may be certified soon. This explains many of the similarities between non-certified and certified smallholders within Pangkalan Tiga.

The different cultural backgrounds of the villages may explain a lot of the differences that were found between plantations. For example the knowledge of oil palm cultivation differed a lot between the two study areas. The farmers of a Javanese background of Pangkalan Tiga have a lot more experience in their families with cultivating oil palm than the indigenous community of Kalang. The migrant farmers also received a larger amount of governmental support than the other villages. These governmental supports included investment and training. Another difference between the two study sites was the distance to the city and the level of development. Pangkalan Tiga was far further developed and closer to the city than the other villages. This may have big impacts on availability/price of machinery and other inputs which in turn impacts management decisions.

6 Conclusions

In this chapter the conclusion per sub-research question is discussed, followed by the conclusion for the main research question.

(a) Does RSPO group certification positively affect Ecosystem Services in oil palm smallholdings?

1 Carbon storage: No influence of smallholder certification on carbon stocks could be concluded.

2 Biodiversity: A significantly lower herb biodiversity was found in certified plantations ($p = 0.008$). Weeding frequency answers of certified smallholders were also higher which shows the biodiversity loss is likely due to more frequent weeding. The lower herb biodiversity scores are contrasted by the answers certified smallholders gave during the interviews on questions about animal observation questions. Significantly higher numbers of animal species observations were given by the certified smallholders during the interviews.

3 Pest regulation: Lower leaflet herbivory percentages were found in certified plantations, although not significant.

4 Yield: Answers from interviews with certified smallholders indicate they have higher yields, although not significantly higher ($p = 0.057$).

5 Pollution: No influence of smallholder certification on Pollution could be concluded.

The main impact of certification on ecosystem services was a lower herb biodiversity. Less strong differences were a lower leaflet herbivory and a higher yield. Although significantly higher animal biodiversity was reported by certified smallholders in interviews, there is a strong doubt that these answers were biased. No conclusions could be drawn on influences on carbon stock or pollution. Overall RSPO group certification seems to have a positive effect on the ecosystem services *"Provisioning of food/raw materials"* and *"Pest regulation".*

(b) Does intercropping positively affect Ecosystem Services in oil palm smallholdings?

1 Carbon storage: No influence of intercropping on carbon stocks could be concluded.

2 Biodiversity: A significantly lower herb biodiversity was found in intercropping plantations ($p = 0.027$). Weeding frequency answers of intercropping smallholders were also higher which shows the biodiversity loss is likely due to more frequent weeding. Tree biodiversity however was higher in intercropping plantations. Intercropping smallholders on average indicated to have seen more animal species in interview questions, but this was not significantly more.

3 Pest regulation: No influence of intercropping on leaflet herbivory could be concluded.

4 Yield: No influence of intercropping on yield could be concluded.

5 Pollution: No influence of intercropping on Pollution could be concluded.

The main impact of intercropping was that a significantly lower herb biodiversity was found in intercropping plantations. The tree species richness on the other hand was obviously higher in intercropping plots. However no conclusions about the influence of intercropping on the other ecosystem services could be drawn. Overall a slight negative effect of intercropping on herb biodiversity, and a positive effect on tree biodiversity was found in oil palm smallholdings.

7 Recommendations

This study contributes to the main objective of this study: sustainable management of smallholder oil palm plantations in Central Kalimantan, Indonesia. The results of this assessment of ecosystem services in smallholder plantations can aid in development of the RSPO group certification standard.

The results of the herb biodiversity assessment have shown that certified smallholders use more intensive weeding to clear their understory vegetation and subsequently have a lower herb biodiversity. Whether this is done with herbicide is hard to assess. A possibility for turning biodiversity impacts related to weeding into an opportunity to improve ecosystem service provision is the possibility of weeding by using grazing cattle. A study on using grazing with cattle has shown grazing to be especially interesting for smallholder farmers as it allows a very profitable alternative form of income to them (Haesra, Novianti, & Wijaya, 2018). A study by Slade et al. into using cattle grazing to improve ecosystem service provision suggests cattle grazing may increase soil biodiversity and help nutrient distribution in soils (Slade, et al., 2014).

The results of the pollution assessment have shown that the types of waste that were found indicate deeper problems with large-scale drug abuse in rural Central Kalimantan villages. In order to improve this waste problem the livelihoods of rural villages will need to be improved first. It is recommended for RSPO to address these drug-related problems when oil palm smallholders in rural villages start forming certification groups.

The results of carbon storage have shown that higher planting densities improve the amount of carbon storage but seem to decrease yields as well. It is recommended for future studies to assess the amount impact on the climate that can be achieved by increasing planting densities of oil palm without hampering the oil palm yields on a national scale like Indonesia.

This study has assessed the situation in two sites in Central Kalimantan which differed in their cultural background, level of development and access to resources like farming knowledge and financial resources. It is recommended for future studies to remove many of the site influences by include more villages. This will make it possible to show more general trends of certification and intercropping.

The ecosystem assessment used in this research was limited to five ecosystem services. In order to give a good overview of the effect on the ecosystem, all important ecosystem services need to be addressed. It is recommended to revisit the same study sites for measurements of different ecosystem services in order to paint a broader picture of the ecosystem. Depending on the addressed ecosystem services this may require multiple visits to the same plantation as many other important ecosystem services like bird biodiversity and insect biodiversity can be very variable depending on the moment of measurement. Some other ecosystem services like groundwater supply are variable over the year and may need seasonal measurements.

The intercropping results of this study show that for future research it would be better to divide palm oil intercropping plantations into plantations with fruit trees for the long-term and plantations with short term crops that will be removed when the oil palm reaches an age of about 5 years old. This subdivision will separate the heavily managed double crop plantations from the plantations with extensively managed fruit trees which are left standing between oil palm. The subdivision of intercropping classes can show more direct effects of intercropping. Furthermore this can provide possibilities for assessing whether early age intercropping of oil palm has longer lasting ecosystem benefits.

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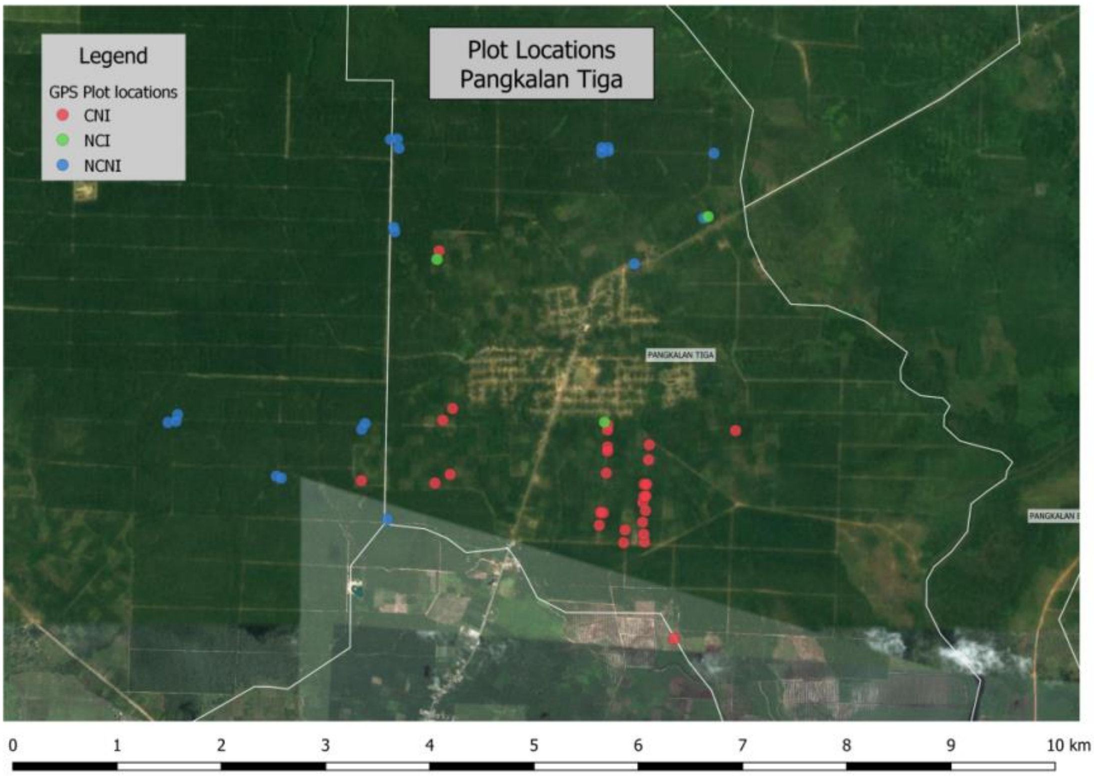
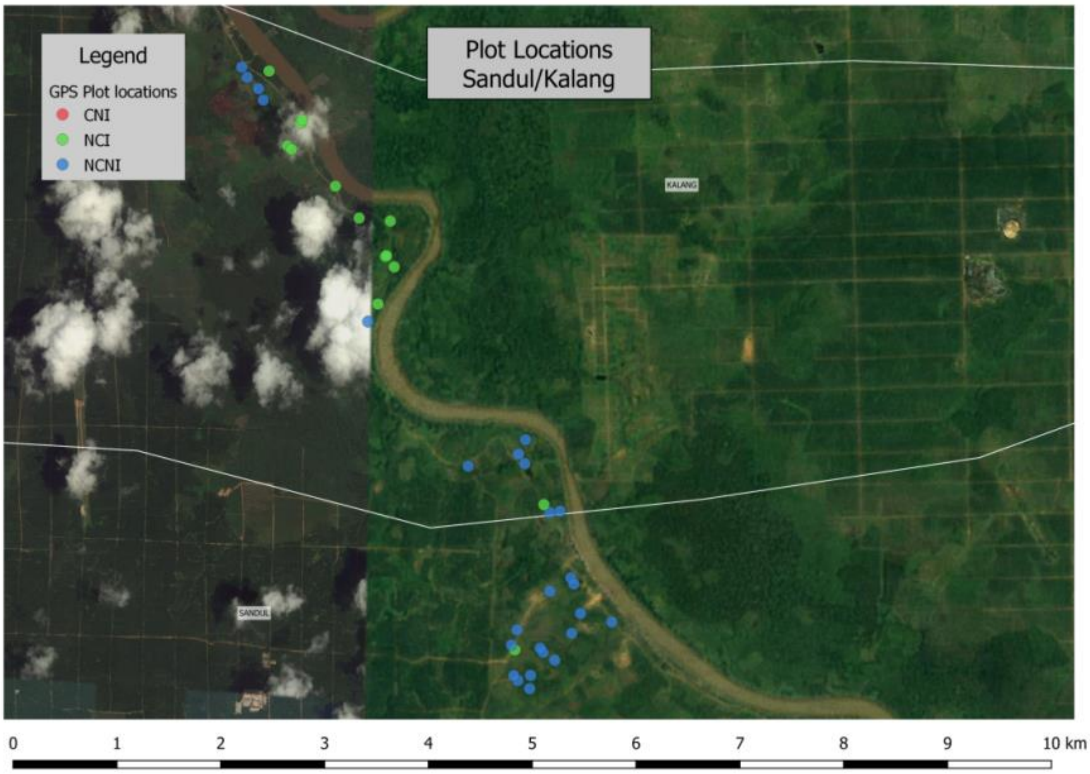
9 Appendices

9.1 Appendix I: Plot locations



Plot locations in Pangkalan Tiga



Plot locations in Sandul / Kalang

9.2 Appendix II: Table of ecosystem services possibly affected by RSPO certification

Criteria	Ecosystem service	Possible measurement
4.5, 5.3	Air/Soil/Water quality	Measure difference in efficiency by calculating pesticide use per hectare
		Measure if fewer waste objects are present
		In interviews ask how many pesticides/herbicides are used
4.5, 5.1	Biodiversity	Measure if biodiversity is higher for certified SH Measure impact of certification on surrounding forest biodiversity. Ask during interview whether the farmer has stopped intercropping
5.5, 7.7	Carbon storage	Perhaps fewer signs of burning near certified SH Measure depth of peat for C storage calculation.
5.2	DNA diversity preservation	Compare the occurrence of a RTE species (perhaps boa constrictor) between certified vs. non-C
4.4, 5.2, 7.2, 7.3	Habitat availability	Measure if the average closest Primary/HCV forest is closer for certified smallholders
		Measure if certified areas have more natural environment within them than uncertified
7.4	Water regulation, Carbon emission	Compare ground water level, perhaps hard to measure
2.1, 3.1, 4.2, 4.4, 4.5, 4.8, 7.2, 7.4, 7.8	Yield	Measure if palm vitality is higher for certified smallholders by measuring leaf health of palms
		Measure if palm mortality is lower for certified smallholders by comparing gap count in rows
		Compare yield of FFB between certified and uncertified smallholders
		Measure if amount of palms per hectare is higher for certified smallholders
		In interviews ask for seedling mortality, to compare between smallholders
		In interviews ask how high FFB yield is, to compare between smallholders
		Measure ratio between male and female flowers. Big indicator for drought and management quality.
		Compare number of FFB currently growing on palms

Possible impacts of RSPO certification on ecosystem services and ways of measuring these impacts

9.3 Appendix III: Plot data collection form

Date			
Interview ID (Also GPS waypoint name)			
Certified? Intercropping?(CNI / NCI / NCNI)			
Distance to forest (<50 / 50-100 / >100m**)**			
Stand age (must be between 5 **-** 10 years)			
Coordinate			
Peat depth (m)	**Palm flowers** (ratio m/f)	**Number of waste objects in the sub-sub-plots (C)**	

Main plot (A) trees (> 30cm), also all Oil Palms			
Species	**DBH** (cm)	**Height** (m)	**N of FFB (Oil Palm)** **If Dead** (SD/U/S)

Sub plot (B) trees (10-30cm)		
Species	**DBH** (cm)	**Height** (m)

Sub-sub plot (C) saplings (<10cm)		
Species	**DBH** (cm)	**Height** (m)

Herb biodiversity				
Plot	**D1**	**D2**	**D3**	**D4**
Herb cover (%)				
Cover per species (%)				
Sp. 1				
Sp. 2				
Sp. 3				
Sp. 4				
Sp. 5				
Sp. 6				

Note species on backside if needed

Herbivory: collect palm leaflet samples and crop leaf samples in plastic bag (label with interview ID)

9.4 Appendix IV Waste classification

The descriptions of waste objects in the plots were classified into three classes; *"No waste objects", "Few waste objects"* and *"Lots of waste objects".*

The descriptions that were classified as *"No waste objects"* were; '0', 'clear', 'clean', 'none', 'clean, no plastic', 'no plastic', 'no plastic waste', 'no waste', 'no trash', 'clean, no plastic bag' and 'clean, no plastic waste'

The descriptions that were classified as *"Few waste objects"* were; 'a little plastic', 'few', 'un-maintained', 'minimal' and 'small objects, not many'

The descriptions that were classified as *"Lots of waste objects"* were; 'many', 'a lot', 'more', 'small items + several plastic bags', 'plastic', 'plastic garbage' and 'a lot of plastic'

9.5 Appendix V: Environmental and sustainability criteria smallholder certification

This appendix shows the new preliminary principles and criteria from the 2018 RSPO smallholder certification standard (RSPO, 2018). Section one *"Legality, Respect for Land Rights and Community Wellbeing"*, section four *"Human Rights and Rights for Workers"*, and section five *"Commitment to Transparency and Traceability",* have been taken out because they are not relevant to the assessment of the impact on the ecosystem in this report.

Principles	**Criteria**	**Key elements to be incorporated at the indicator level (yet to be developed)**
2. Environmental Responsibility, Natural Resource Management and Biodiversity Conservation	<u>For existing plots:</u> 2.1 Where the certification unit is on an area identified as an HCV and cleared after 2005, the certification unit shall determine mitigation plans and practices (tbd) to minimise further negative impact on HCVs, and maintain and or enhance existing HCVs.	• Smallholders are aware of location HCV areas • Awareness of HCV best management practices
	2.2 Where the certification unit exists on peat, subsidence of peat soils shall be minimised by best management practices, including water management, and ground cover.	• RSPO best management practices for oil palm on peat are implemented • Need to address the fact that best management practices need to be applied by the group and cannot be done at the individual plot level only
	2.3 Smallholders do not use fire in preparing for re-planting or for waste management.	
	<u>For new plantings:</u> 2.4 There are no new plantings or expansion of smallholder farms in primary forest, HCV[5] [secondary forest [level/type X]] areas since [cut-off date]; NB: *tbd and exact wording to be further defined in line with outcomes of NPP for smallholder discussion and ongoing discussions around no deforestation.*	• HCV areas are identified, managed and enhanced.
	2.5 There are no new plantings on peat of any depth.	• Farmer commitment
	2.6 There is no use of fire to clear land or in land preparation for new plantings.	• Farmer commitment
3. Sustainable Farming practices	3.1 Smallholders use agrochemicals in ways that do not endanger health or the environment, including responsible usage, storage and disposal of agrochemical and their containers.	• IPM is gradually implemented • Reference to not using pesticides such as paraquat; Specific text to be aligned with 4.6.4 generic P&Cs.
	3.2 Riparian buffer zones are protected and managed to minimise risks of erosion and contamination from agrochemicals affecting downstream water quality	
	3.3 For palm planted on steep slopes, soil conservation practices must be used (e.g., cover cropping, terracing and installation of erosion barriers, (e.g., conservations bunds, silt pits etc.).	Definition of steep slopes
6. Long term livelihood benefits	6.1 Smallholders have a continuous improvement plan based on a gap	• Improvement in yields • Application of fertilizer

	assessment to prioritize key areas of need / improvements.	
	6.2 Farmers have increased capacity to implement good agricultural practices on their smallholder farms.	
	6.3 Smallholders regularly review the performance of their production unit.	• Understand and manage gaps • Set goals
	6.4 Smallholders have improved financial literacy/ understanding of financial management.	• This can include savings and preparation for replanting.