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Assessment on the Suitability of Planting Non-Native Peatlands Species *Falcataria moluccana* (Miq.) Barneby & Grimes in Rewetted Peatlands

Hani Sitti Nuroniah [1], Hesti Lestari Tata [1,*], Mawazin [1], Endri Martini [2] and Sonya Dewi [2]

[1] Forest Research and Development Center, Silviculture Research Group, Jalan Gunung Batu 5, Bogor 16118, Indonesia; hsnuroniah@gmail.com (H.S.N.); mawazin22@gmail.com (M.)

[2] World Agroforestry (ICRAF) Indonesia, Jalan CIFOR, Situgede, Sindangbarang Jero, Bogor 16115, Indonesia; e.martini@cgiar.org (E.M.); s.dewi@cgiar.org (S.D.)

* Correspondence: hl.tata@gmail.com; Tel.: +62-251-863-3234

Abstract: Sengon (*Falcataria moluccana*), a fast-growing timber tree that naturally grows on mineral soils, is currently promoted in peatlands. This study aimed to (1) experimentally test the response of sengon seedlings in waterlogged conditions in the nursery; (2) describe and analyze the biophysical condition of a sengon plantation and its growth; (3) describe sengon farm practices on peatlands; and (4) identify key actor's perception on planting sengon on peatlands. This study combined an experiment in nursery, field measurements, and key-informant interviews. The nursery experiment showed that peat soil affected seedling's growth: survival rates decreased by 25–33% after 3 months of inundation. Sengon growth at age 1–5-years-old in peat soil was slower than that on mineral soils. Sengon growth in peatland was influenced by peat depth and peat maturity. Sengon plantation in Central Kalimantan was driven by market availability and industrial wood demand. Fourty-three percent of respondents thought sengon does not grow well in peat soils, but 57% of respondents thought that additional soil treatment will enhance site suitability. Based on key-informants' experience, 64% disagree with sengon development in peatlands. Our study provides evidence that sengon is predominantly not suitable to be planted on peatlands. Therefore, cautions need to be taken when planting sengon on peatland areas.

Keywords: sengon; species suitability; peat; rewetted

Citation: Nuroniah, H.S.; Tata, H.L.; Mawazin; Martini, E.; Dewi, S. Assessment on the Suitability of Planting Non-Native Peatlands Species *Falcataria moluccana* (Miq.) Barneby & Grimes in Rewetted Peatlands. *Sustainability* **2021**, *13*, 7015. https://doi.org/10.3390/su13137015

Academic Editor: Jun-Ichi Sakagami

Received: 21 April 2021
Accepted: 15 June 2021
Published: 22 June 2021

1. Introduction

The tropical peatlands of Indonesia are categorized based on their functions, which are protection and cultivation. The Peatland Restoration Agency of Indonesia, which is now known as *Badan Restorasi Gambut dan Mangrove (BRGM)*, issued a scheme to implement degraded peatland restoration through the concept of groups of activities in 3R, namely: Rewetting, Revegetation, and Revitalization. Rewetting is an effort to restore the hydrology of peatlands by canal blocking to increase the water level [1]. Referring to the government regulation no PP.71 the year 2014 and amended to PP.57 the year 2016, in rewetting activities, water levels need to be maintained at a minimum of 40 cm of the peatland surface, and it is mandatory, particularly in areas under cultivation function [2]. Revegetation is an effort to replant degraded peatlands with native and suitable plant species in the rewetted peatlands. Finally, revitalization in the 3R refers to enhancing the livelihoods of the communities living on peatlands through sustainable peatland management [1].

Restoration efforts with the 3R scheme impact cultivation activities, an in particular the drained peatlands must be rewetted. Meanwhile, restoration activities should also fulfill the socioeconomic aspects of the community in order to revitalize the communities where they can get benefits and increase their income from these activities [3]. The cultivation systems in wet and rewetted peatland is known as paludiculture. Paludiculture is one of the peatland rehabilitation and restoration techniques done by restoring the condition of the peatlands to remain wet by blocking the canal [4,5]. The species selection is important for the paludiculture system because it should match the site's soil conditions and hydrological properties. Native peatland plant species on peatland restoration does not need drainage. With this technique, the restoration efforts can be carried out and community income will also be maintained [6–8]. Several native peatland plant species have been used in paludiculture for degraded peatland restoration, such as sago (*Metroxylon sagu*), *Shorea balangeran*, jelutong (*Dyera polyphylla*), and others [9–12].

Falcataria moluccana (Miq.) Barneby & Grimes (synonym: *Paraserianthes falcataria* (L) Nielsen) belongs to the Fabaceae family, which is known locally as sengon. Sengon grows naturally in primary and secondary rainforests, on river flood terraces and sandy soils [13]. Its natural distribution in Indonesia covers the area of South Sulawesi, Moluccas and Papua [14]. Sengon is a superior fast-growing timber tree, that can be harvested in 4–7 years [15]. Therefore, the demand for it continues to increase, and marketing is relatively easy [16]. Moreover, sengon is also planted for forest rehabilitation and restoration because sengon is: (1) able to grow on a variety of soil types, including dry, moist and even acidic soils as long as the drainage is sufficient [17–19]; (2) easy to adapt to various environmental conditions because the roots associate with rhizobium bacteria to form nodules [20,21]; (3) a tolerant species that can grow on open land, and once sengon grow, it accelerates land cover [22–24]; and (4) able to improve environmental quality such as increasing soil fertility and improving water management [25–27].

In Java Island, sengon is a dominant tree in the community forests [28,29], becoming the primary producer of light timber, amounting to 61.21% [30]. The success of sengon community forest development and the sengon industry in the Java Island has inspired other areas outside Java. A plywood factory was built in the Pulang Pisau district in Central Kalimantan Province in 2016. It uses sengon wood as raw materials and exported 10,000 m^3 wood per month to Japan and the USA [31]. With the emergence of the plywood industry, the people's enthusiasm in Central Kalimantan to plant sengon has increased [32]. Sengon is promoted as a potential timber commodity to be developed in Central Kalimantan by the MoEF Indonesia [33] and Provincial Forestry Office [34].

Sengon grows in mineral soils and dry land on Java Island. Meanwhile, the Central Kalimantan Province covers 2.66 million ha of peatlands, which reaches 55.7% of the area of Central Kalimantan Province [35]. About 1.1 million ha of total peatlands area in Central Kalimantan is categorized as degraded [36]. Since the era of peatland restoration in 2016, a large area of degraded peatlands (1568 ha) has been restored as of 2019 [37]. However, peatlands have different characteristics than mineral soils [38,39], which may affect the growth and production of sengon. However, reports about sengon growth on peatlands and rewetted peatlands are limited.

This study aims to answer three questions: (1) Can *F. moluccana*, a non-native peatland tree species, grow on rewetted peatlands? (2) What is the growth performance of sengon in Central Kalimantan? (3) How well do sengon farms and sengon plantations work on peatlands? We have explored three assessments with subsequent steps of research.

The objectives of the research were to:

(1) Experimentally test the response of sengon seedlings in the waterlogged condition in the nursery to understand whether sengon can grow on rewetted peat soil;
(2) Describe and analyze the biophysical conditions of sengon plantation and its growth;
(3) Understand the perception of the stakeholders (government and farmers) about sengon plantation on peatlands.

2. Materials and Methods

2.1. Study Area

The study was conducted in Palangkaraya city and Pulang Pisau district of Central Kalimantan province, Indonesia (Figure 1). The total area of the Pulang Pisau district is 8977 km^2 [40]. It has the largest peatland area in Central Kalimantan province, which is

5911 km^2 [41]. In general, the soils of Pulang Pisau district consist of Entisol, Ultisol and Histosol types. There are two main rivers in the district, viz. Kahayan and Sebangau rivers [42]. Total annual rainfalls in the year of 2010–2020 ranged from 2334 to 4508 mm year^{-1}; while total days of rain ranged from 174 to 205 days [43].

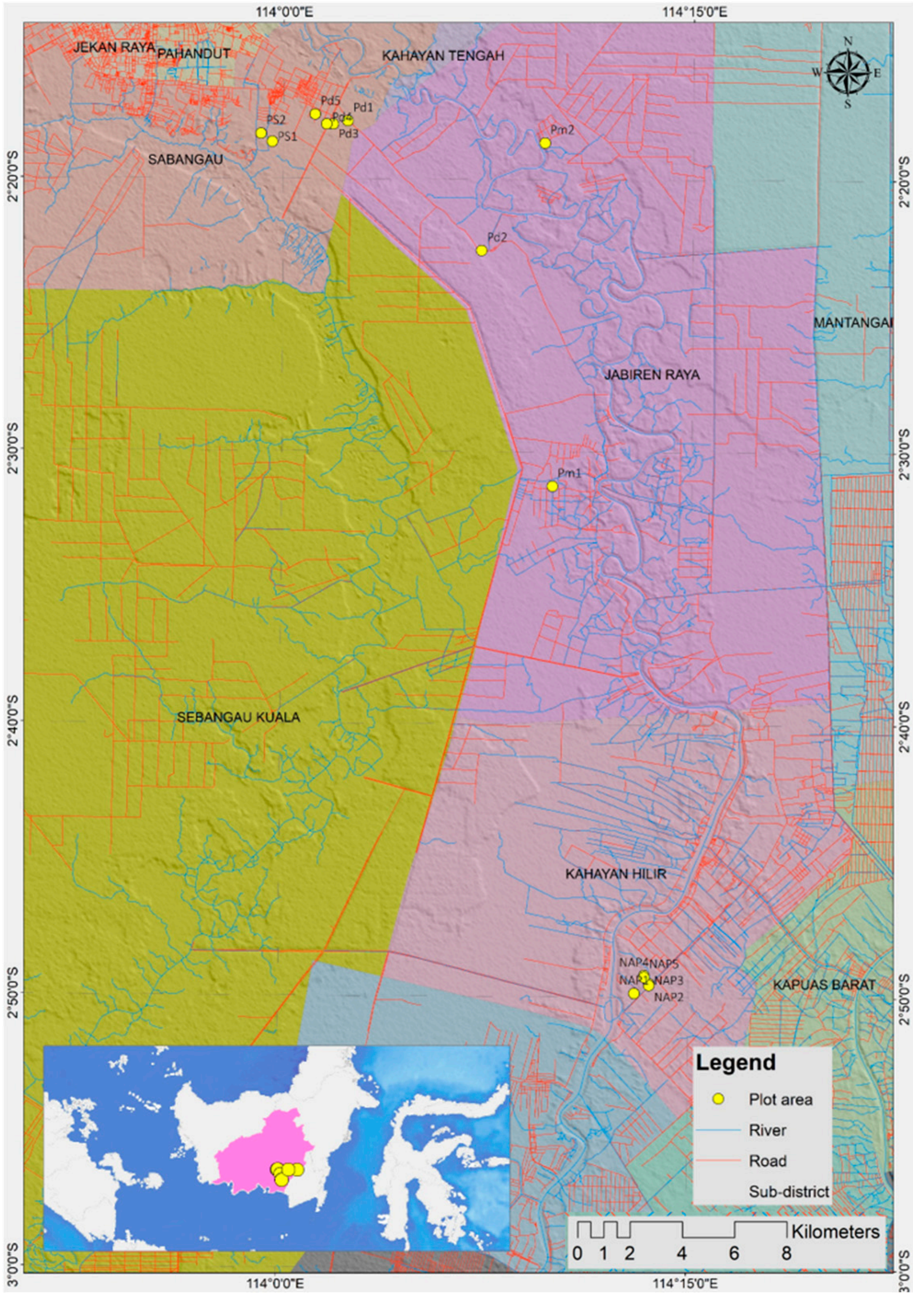


Figure 1. Study sites in Palangkaraya City and the Pulang Pisau district of Central Kalimantan, Indonesia.

Nine sengon farms were selected purposively based on the year that sengon was planted on the peatland farms or the age of the stands. The age of the stands varied from 1 to 5 years old after being planted in the farms. The sengon farms were positioned at Kalampangan and Misik Kameloh in Palangkaraya City, and in the Taruna, Tumbang Nusa and Jabiren villages in the Pulang Pisau district. In addition, we also collected data from the sengon plantation of PT Nagabhuana Aneka Piranti (NAP) in Mentaren village, Pulang Pisau district. The GPS coordinates of sengon farms and the plots of the NAP plantation are shown in Table 1.

Table 1. Observation plots of sengon growth in Palangkaraya City and Pulang Pisau district, Central Kalimantan.

Site Location/Village	GPS Point	Farm Type	Planting Year	Age (Year)	Soil Type—Code of Plot
Kalampangan	S 02°18′41″ E 113°59′33″	Monoculture	September 2018	5	Peatland-PS1
Kalampangan	S 02°18′21″ E 113°59′09″	Monoculture	September 2018	2	Peatland-PS2
Taruna	S 02°17′54.2″ E 114°02′21.3″	Monoculture	2018	1–2	Peatland-Pd1
Tumbang Nusa	S 02°22′36.3″ E 114°07′15″	Sengon + jelutong + pineapple	2016	3	Peatland-Pd2
Misik Kameloh	S 02°18′1.1″ E 114°01′46.6″	monoculture	2016	3	Peatland-Pd3
	S 02°18′01.1″ E 114°01′33″	Sengon + dragon fruit	2016	3	Peatland-Pd4
	S 02°17′38″ E 114°01′10″	Monoculture	2016	3–4	Peatland-Pd5
Jabiren	S 02°31′14″ E 114°09′53″	Monoculture	September 2015	5	Peatland-Pm1
	S 02°18′41″ E 114°59′33″	Monoculture	September 2018	2	Peatland-Pm2
Mentaren	S 02°49′52″ E 114°13′00″	Monoculture	March 2020	0.25	Mineral soil-NAP1
	S 02°49′31″ E 114°13′32″	Monoculture	November 2018	1.7	Mineral soil-NAP2
	S 02°49′33″ E 114°13′33″	Monoculture	November 2018	1.7	Mineral soil-NAP3
	S 02°49′13″ E 114°13′21″	Monoculture	October 2017	2.75	Mineral soil-NAP4
	S 02°49′14″ E 114°13′22″	Monoculture	October 2017	2.75	Mineral soil-NAP5

Note: PS = peaty soil (peat depth <50 cm), Pm = moderate peat depth (peat depth >100–200 cm), Pd = peat depth (>300 cm), NAP = mineral soil at Nagabuana Aneka Piranti.

The peat soils for experiment in the nursery were collected from Misik Kameloh, whilst the mineral soil sample was collected from Bogor, West Java province.

2.2. Method

2.2.1. Mesocosm Study in the Nursery

Sengon seeds were bought from a vendor in Bogor, West Java, and were germinated in sterilized sands. After germination, seedlings with a minimum of two leaves were transferred into polybags. Three months after germination, the seedlings were used for the experiment. Two planting media were used, i.e., mineral soil and peat soil. Mineral soil was taken from Bogor, West Java, at <0.5 m depth. The peat soil was taken from Misik Kameloh, Palangkaraya City, Central Kalimantan and has a hemic-sapric maturity level. Peat soil samples were analyzed at the Soil Laboratory of IPB University, Bogor.

The treatment was carried out based on soil types of planting media and inundation. The polybags were stored in a plastic reservoir. The inundation treatment using artificial rainwater [44] was given as high as the medium, so the seedling was constantly being inundated. Five treatment combinations were tested in this experiment (Table 2). Unflooded seedlings were watered every day in their field capacity with artificial rainwater.

Table 2. Sengon inundation trials in the nursery.

Code	Treatment	Number of Seedlings
PIo	Peat soil, no inundation	12
PIr	Peat soil, inundation with artificial rainwater	12
SIo	Mineral soil, no inundation	12
SId	Mineral soil, inundation with distilled water	14
SIr	Mineral soil, inundation with artificial rainwater	14

Seedlings were observed and measured every week for 12 weeks. The growth parameters were survival rate, height and stem diameter. Plants are considered alive if the stems are still green. Plants are considered dead if the stems are brown and rotten. The plant's height was measured from the base to the shoot tip and the diameter was measured at the stem base.

2.2.2. Sengon Observation and Measurement in the Field

Field research was carried out in October 2019 and July 2020 in the Palangkaraya and Pulang Pisau districts, Central Kalimantan Province. The plots were chosen purposively. Sengon stands are classified based on soil type (peat or mineral soils) and age class (Table 1). The sengon growth in three plots, namely Pd1, Pd4 and Pd5, were measured twice in 2019 and 2020.

The observed sengon stands consisted of 14 plots: 9 plots belong to smallholder farmers and 5 plots belong to industrial forest plantation (*Hutan Tanaman Industri, HTI*). Sengon stands at HTI of PT Nagabhuana Aneka Piranti (NAP) were planted on mineral soils, while the farmers' sengon stands were planted on peatlands. The peat depth level is divided into peaty soil (peat depth: <50 cm), shallow peat (peat depth: 0.5–100 cm), medium peat (peat depth: >100–200 cm), slightly deep peat (peat depth: >200–300 cm) and deep peat (peat depth: >300 cm) [45]. The peat depth was measured using an Eijkelkamp peat auger. Based on its depth, the farmers' plots were divided into three groups, namely PS: peaty-soil, Pm: Peat-moderate, Pd: Peat-deep. Plant age varies from 3 months to 5 years. The planting pattern is generally monocultural and two plots are mixed planting with agricultural plants. The description of each plot can be seen in Table 1. A monocultural sengon farm on peatlands is shown in Figure 2.

Figure 2. Sengon plantation on drained peatland. A ditch inside the plot (Pd1 plot).

The plant growth was assessed by measuring total height and stem diameter at breast height (DBH). In addition, tree height measurements were carried out using a Hagameter. The diameter of the plants' height <130 cm was measured at 10 cm above the ground. The measured plants were varied between 30 and 50 plants per plot.

Soil samples were collected from two positions at each plot using a peat auger at 0–50 cm depth. Soil samples were analyzed for their chemical properties, such as pH, contents of carbon, nitrogen, phosphor and ash and cations exchange capacity (CEC) in the Soil Laboratory of IPB University, Bogor. However, the soil samples' physic properties were not analyzed due to some technical constraints.

The peat depth of the plot was measured using the Eijkelkamp peat auger at one position in the center of the plot. The water level was measured using tape meter at a single measurement.

2.2.3. Perception Study about Sengon Plantation on Peatlands

A structured interview was conducted to collect information about silvicultural practices and sengon plantation management on peatlands. The interview using a questionnaire about the socioeconomic aspects, sengon cultivation and their perception about sengon plantation was carried out to 14 farmers who lived in Palangkaraya City and the Pulang Pisau district. The respondents were selected purposively using the snowball method. The questionnaire was consisted of 41 questions, which covered some information about technical aspects on sengon management, farmer's knowledge about peatland environments and their livelihoods. The interview was conducted during the COVID-19 pandemic in 2020, therefore, to minimize physical contact, the interviews were carried out online using a Google Form. The time length for filling in the questionnaire was approximately 20 min.

In addition, nine respondents from a unit of the central government, e.g., Watershed Management and Protection Forest (known as *Balai Pengelolaan Daerah Aliran Sungai dan Hutan Lindung, BPDASHL*) of Kahayan (5 respondents), and representatives of local governments, namely from the Forestry Service of Central Kalimantan province (2 respondents), the Forestry Service of Pulang Pisau district (1 respondent), and the Environment Service of Pulang Pisau district (1 respondent), were interviewed as resource persons about sengon plantation program in Central Kalimantan province.

2.2.4. Data Analysis

Sengon seedling growth was calculated to obtain survival rate, the mean and the standard deviation of the height and stem diameter. Growth data were analyzed using General Linear Model (GLM) with multivariate analysis of two factors, namely soil type and inundation. Owing to the high mortality of seedlings on the peat soils, only height and diameter at the age of 10 weeks after transplanting were analyzed. Duncan's multiple range test was used as a post hoc test.

Sengon growth in the field was analyzed using GLM multivariate analysis and regression analysis. Sengon growth in the mineral soils was used as the standard to compare sengon growth in peatlands. Sengon growth in the mineral soils was taken from the growth of sengon in two forest plantations (hereinafter is called HTI), namely PT Belantara Subur Kalimantan Timur (BSKT) [46], and PT Nagabhuana Aneka Piranti (NAP) (this study).

Soil data that were collected from sengon farms on peatlands and mineral soils were analyzed using GLM with univariate analysis of soil type factor. SPSS statistical analysis version 22 was employed for data analysis.

The interview data were tabulated and analyzed descriptively.

3. Results

3.1. Sengon Seedlings Growth

The mesocosm experiment in the nursery showed that the media have more of an effect than inundation. Dry shoots and leaves felt down after one week of treatment inundation. The stem dried starting from the shoot tip and creeping into the base of the stem, followed by seedling death. The surviving seedling arose a new shoot.

The effect of inundation on the viability of sengon was observed on sengon in peat media after 1 month of treatment (Figure 3). The survival rate immediately decreased after 1 month to 42% of 12 seedlings in peat media inundated by artificial rainwater.

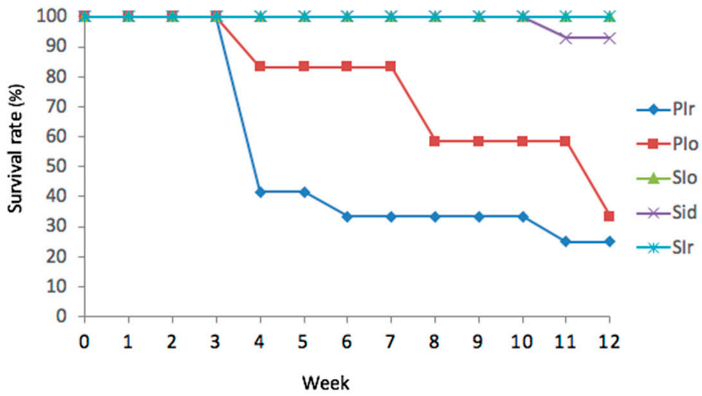


Figure 3. The survival rate of sengon against inundation treatment for 3 months. SIo: Soil + no inundation; SId: Soil + distilled water inundation; SIr: Soil + rainwater inundation; PIr: Peat + rainwater inundation; PIo: Peat + no inundation.

Based on this experiment, the planting media have more impact than the inundation process. After twelve weeks of treatment, the sengon in mineral soil had a survival rate >90%, while the sengon grown in peat media persisted in the range of 25 to 33%.

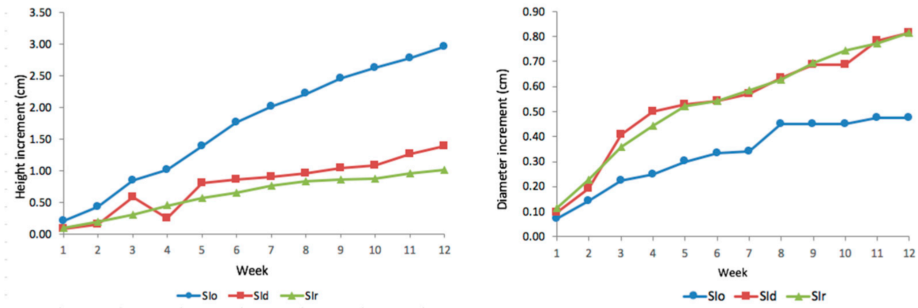
Sengon seedlings planted in peat soil media have a high mortality (Figure 3). The surviving sengon seedlings on peat soil medium have bad growth performance compared to sengon seedlings in the mineral soil medium. The height of growth and stem diameter at the age of 10 weeks is shown in Table 3. The height and diameter increment of sengon seedlings in peat medium is slower than that of soil medium.

Table 3. Growth increment of sengon seedlings at the age of 10 weeks on two types of media and inundation treatment.

Treatment	ΔH (cm)	ΔD (cm)
Soil + no inundation	2.63 ± 1.13 a	0.45 ± 0.21 b
Soil + distilled water inundation	1.11 ± 4.94 a	0.70 ± 0.28 a
Soil + rainwater inundation	0.88 ± 0.05 b	0.74 ± 0.43 a
Peat + rainwater inundation	−2.80 ± 2.55 c	0.05 ± 0.26 c
Peat + no inundation	−7.51 ± 9.54 cd	0.30 ± 0.19 b

Note: ΔH: height increment, ΔD: diameter increment, the value followed by different letter in the same column is significantly different at $p < 0.05$.

The effect of inundation on sengon seedlings' growth in the soil medium is shown in Figure 4. Sengon without inundation showed a better height increment than the inundated sengon, but the diameter increment of the inundated sengon was better than that of non-inundated sengon.



(**a**) (**b**)

Figure 4. Effect of inundation to sengon seedlings in mineral soil media. (**a**) Height increment; (**b**) Diameter increment. SIo: Soil + no unindation, SId: Soil + distillated water unindation, SIr: Soil + rainwater unindation.

3.2. *Sengon Growth Performance in the Field*

3.2.1. Soil Chemical Properties

The chemical characteristics of the samples that were used in the mesocosm study are shown in Table 4. The peat soil sample has a lower pH value than that of the mineral soil from Bogor. However, it has higher content values of C, N and P.

Table 4. The chemical properties of soil samples used in the mesocosm study.

Soil Properties	Peat-Soil of Misik Kameloh	Mineral Soil of Bogor [47]
pH H_2O	3.39	5.80
pH KCl	3.18	4.85
C organic (%)	54.96	2.15
N total (%)	0.55	0.19
C/N ratio	99.93	11.32
P available (ppm)	19.36	17.00
CEC (cmol kg^{-1})	95.97	n.a.
Ash content (%)	0.30	n.a.

Note: n.a.: not available.

The chemical properties of soil from 14 sengon plots are shown in Table 5. All variables of soil properties were affected by soil type. Peat soils have lower pH H_2O and pH KCl than that of mineral soils. The C-organic, N total and P-available contents of peat soils are higher than that of mineral soils. The CEC of peat soils is higher than that of mineral soils, while ash content of peat soils is lower than that of mineral soils.

Table 5. Soil chemical properties of sengon plots on peat soils and mineral soils in Central Kalimantan.

No	Plot	pH_H_2O	pH KCl	C-Org (%)	Ntot (%)	Pavailable (ppm)	C/N	CEC (cmol/kg)	Ash Content (%)
1	Pd1	2.91 c	2.80 c	57.78 a	1.53 a	12.39 d	37.76 c	184.19 b	0.38 d
2	Pd2	2.89 c	2.75 c	56.84 a	0.65 b	45.98 a	87.45 a	279.24 a	2.01 d
3	Pd3	2.92 c	2.78 c	50.81 a	0.97 a	36.81 b	52.38 b	205.97 a	12.40
4	Pd4	2.93 c	2.85 c	48.94 a	0.76 b	42.63 a	64.39 b	213.82 a	15.62
5	Pd5	2.97 c	2.85 c	45.04 b	0.81 b	49.97 a	55.60 b	161.52 b	22.35
6	Pm1	3.83 b	3.59 b	21.40 c	0.74 b	19.80 cd	35.96 c	65.44 c	63.11 b
7	Pm2	3.70 b	3.10 b	27.54 c	0.75 b	17.90 cd	36.72 c	90.69 c	52.52 b
8	PS1	3.64 b	2.24 d	42.16 b	1.10 a	18.60 cd	38.33 c	131.94 b	27.32 c
9	PS2	3.59 b	1.98 d	46.53 b	1.16 a	26.60 c	40.29 c	172.54 b	19.79 c
10	NAP1	4.52 a	3.81 a	3.26 d	0.22 c	17.50 cd	14.82 d	20,49 d	88.42 a
11	NAP2	4.13 a	3.64 a	2.82 d	0.30 c	19.95 cd	9.40 d	23.30 d	88.79 a
12	NAP3	4.07 a	3.62 a	3.87 d	0.31 c	17.65 cd	12.48 d	28.71 d	87.81 a
13	NAP4	4.04 a	3.92 a	5.11 d	0.23 c	19.70 cd	22.22 d	41.15 d	77.73 a
14	NAP5	4.10 a	3.75 a	5.11 d	0.23 c	17.10 cd	22.22 d	38.90 d	85.91 a

Note: The value followed by different letter in the same column is significantly different at $p < 0.05$. Pd1–Pd5: peat deep; Pm1–Pm2: moderate peat depth; PS1–PS2: peaty soil; NAP1–NAP5: mineral soils. Plot features refer to Table 1.

3.2.2. Sengon Growth Performance in the Community Forestry and Plantation

Sengon stands varied in age from 3 months to 5 years. All observed sengon farms were from drained peatlands (Figure 1). Usually, one narrow ditch inside the farm (locally known as '*parit cacing*') and a ditch in front of the farm were established prior to farm development to drain the peat water. The sengon growth and characteristics of the plots are described in Table 6. The growth of sengon trees in the fields were affected significantly by soil type.

Table 6. Sengon growth performance and characteristics of the plots.

Plot	Age (Year)	Growth		Peat Depth (m)	Water Level (m)	N
		Diameter (cm)	Height (m)			
Pd1	1	2.43 ± 0.63 ef	2.93 ± 0.74 e	3.9	1.05	30
Pd1	2	4.21 ± 0.88 e	3.73 ± 0.87 e	3.9	n.a.	30

Table 6. *Cont.*

Plot	Age (Year)	Growth		Peat Depth (m)	Water Level (m)	N
		Diameter (cm)	Height (m)			
Pd2	3	5.62 ± 1.30 e	4.83 ± 1.13 de	5.4	0.89	40
Pd3	3	6.90 ± 2.70 e	5.45 ± 1.64 de	3.6	>3.60	30
Pd4	3	8.71 ± 1.96 c	8.60 ± 2.24 c	3.8	2.54	30
Pd4	4	12.08 ± 2.44 b	11.70 ± 2.82 b	3.8	n.a.	30
Pd5	3	8.79 ± 2.87 c	8.02 ± 2.65 c	3.9	2.3	30
Pd5	4	13.08 ± 3.95 b	11.57 ± 3.87 b	3.9	n.a.	30
Pm1	5	16.11 ± 5.05 a	17.40 ± 3.84 a	1.3	0.8	30
Pm2	3	12.84 ± 2.57 b	13.85 ± 2.62 a	1.3	0.92	30
PS1	5	16.84 ± 3.74 a	16.40 ± 3.60 a	0.25	0.48	30
PS2	2	4.58 ± 0.81 e	4.23 ± 0.51 de	0.28	n.a.	40
NAP1	0.25	0.91 ± 0.33 f	1.05 ± 0.32 e	0	n.a.	50
NAP2	1.7	7.60 ± 1.92 d	7.39 ± 1.65 d	0	n.a.	50
NAP3	1.7	9.96 ± 2.93 c	8.38 ± 1.63 c	0	n.a.	50
NAP4	2.75	12.77 ± 3.40 b	15.35 ± 2.87 a	0	n.a.	50
NAP5	2.75	11.19 ± 4.19 b	12.78 ± 3.42 ab	0	n.a.	50

Note: The value followed by a different letter in the same column is significantly different at $p < 0.05$. Pd1–Pd5: peat deep; Pm1–Pm2: moderate peat depth; PS1–PS2: peaty soil; NAP1–NAP5: mineral soils. Plot features refer to Table 1. N = number of samples; n.a.: not available.

3.2.3. Sengon Growth Performance in Kalimantan

Graphs of sengon growth in Kalimantan Island are presented in Figures 5 and 6. As a growth reference for sengon on peatlands, we use data of sengon growth on mineral soils at forest plantation of NAP (this study) and BSKT [47]. Sengon stands in both areas were planted from the same seed source, the same cultivation technique and have various age classes. Sengon growth data from peatlands consisted of five age groups (1–5 years old); however, replication varies between 1 and 3 plots. Therefore, the sengon growth curves are generated in combinations of two soil types (peatlands and mineral soils).

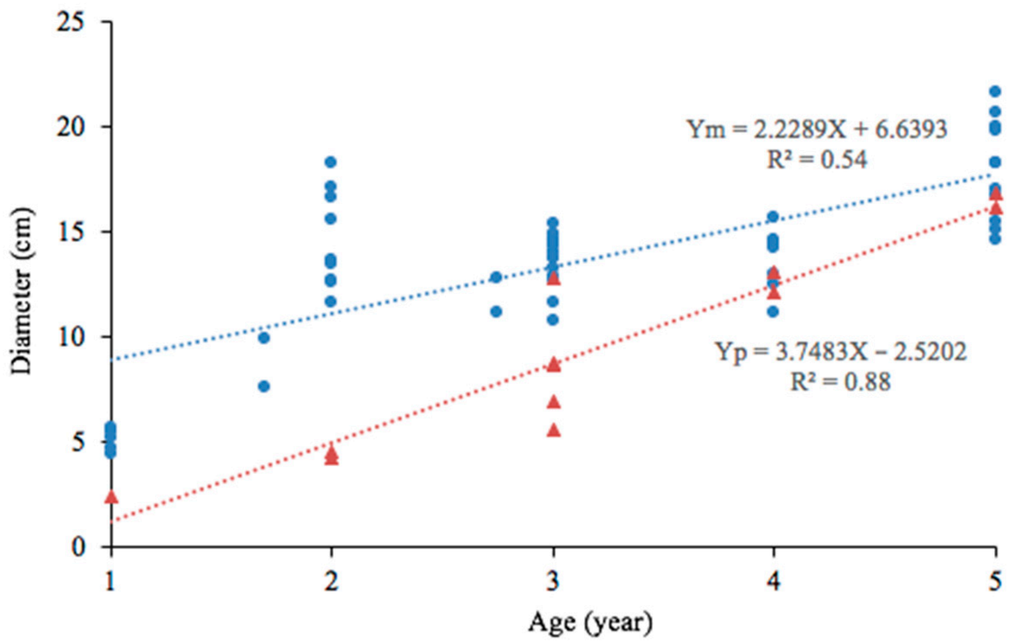


Figure 5. Stem diameter growth of sengon on peatlands (Yp) and mineral soils (Ym). Plots on peatlands: Pd1, Pd2, Pd3, Pd4, Pd5, Pm1, Pm2, PS1 and PS2; Plots on mineral soils: NAP and BSKT [46]. Reprinted with permission from ref. [46]. Copyright 2021 I.N.S. Jaya.

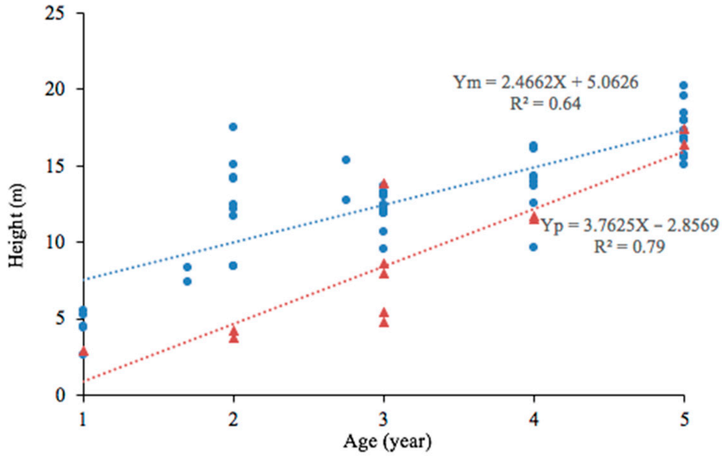


Figure 6. Height growth of sengon on peatlands (Yp) and mineral soils (Ym). Plots on peatlands: Pd1, Pd2, Pd3, Pd4, Pd5, Pm1, Pm2, PS1 and PS2; Plots on mineral soils: NAP and BSKT [46]. Reprinted with permission from ref. [46]. Copyright 2021 I.N.S. Jaya.

Sengon growth in peatlands was entirely slower than sengon growth on mineral soils. Sengon growth in the peatlands that reached sengon growth in NAP plots was sengon on plots PS1, Pm1, and Pm2. Sengon growth in plot PS2 showed quite similar performance with sengon in plot Pd1, although it has different condition.

3.3. Sengon Community Forest Practices in Central Kalimantan

3.3.1. Characteristics of the Respondents

Respondents consisted of 14 farmers: 12 respondents were male, and 2 respondents were female. The majority of the respondents' highest level of education was senior high school (43%). The main occupation of the respondents was farmers (50%). Thirteen respondents experienced sengon cultivation, only one respondent did not have a sengon farm, but he was actively involved in sengon nursery and seedling distribution. Forty-three percent of respondents own sengon farms both on peatlands and mineral soils, and 50% of farmers own sengon stands on peatlands only.

3.3.2. Perception on Sengon Plantation on Peatlands

Most respondents (93%) believed that sengon grow better on dryland than on wetland. Only 7% of respondents supposed that sengon on wetland can grow as well as it does on dryland. However, 57% of respondents believe that sengon can be cultivated on wetland (peatland) with additional treatment, such as trenching ditches and mounding the seedlings. Forty-three percent of respondents believed that sengon cannot grow on peatlands.

The perception of the respondents on the successful factors of sengon plantation on peatlands are presented in Figure 7. The majority of respondents stated that sengon will grow well in non-acidic soils, fertile soils, and in the absence of pyrite.

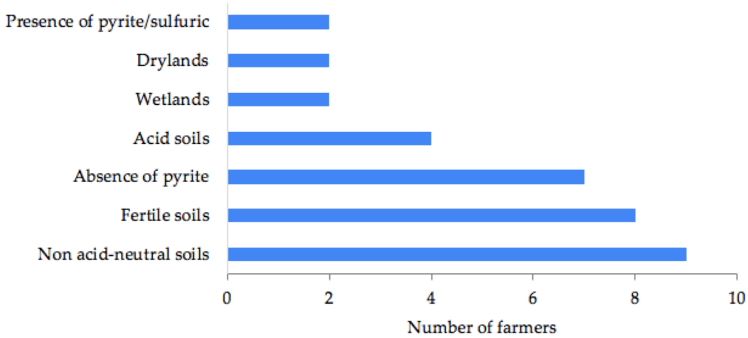


Figure 7. Supported factors for sengon cultivation. Based on interview with local actors.

3.3.3. Perception on Sengon Plantation on Peatlands

Sengon cultivation on peatlands by smallholder farmers is described in Table 7. The seeds were obtained by purchasing from local vendors (79%). All respondents applied spacing planting in the establishment of sengon community forestry. The majority of farmers did not consider restraining pest and disease attacks. All farmers recognized the importance of fertilization, and 86% of farmers once added fertilizer.

Table 7. Sengon cultivation practiced by smallholder farmers on peatlands.

Activity	Answer	Number of Farmers
Seedling procurement	Purchase	10
	Self-producing	1
	Government subsidy	1
	No answer	2
Spacing	3 m × 3 m	10
	2 m × 2 m	2
	2 m × 3 m	1
	4 m × 4 m	1
Pest eradication	Untreated	8
	Treated	6
	Pruning/mechanized	1
	Girdling/killed	1
Fertilization	Yes, irregular	9
	Routine	3
	Never	2

Note: Based on interview with local actors.

3.3.4. Technical Conditions of Respondents

According to respondents, they planted sengon without prior technical knowledge. The majority of farmers conducted the sengon cultivation manually. Marketing relied on collectors, and only two farmers had access to wood processing. All farmers used their own capital, and only one respondent received a subsidy from the government. Details of the technical conditions of farmers are presented in Table 8.

Table 8. Technical aspects of sengon management.

Aspect	Answer	Number of Respondents
Technical training	Yes	0
	No	14
Planning and accountancy	Yes	4
	No	10
Mechanization	Land preparation	1
	Cultivation	2
	None/manually	11
Marketing	Collector	12
	Processor	1
	Collector + processor	1
Transportation quality	None	2
	Low	6
	Medium	3
	Good	2
	Excellent	1
Financing	Own capital	14
	Subsidy from government	1

Note: Based on interview with local actors.

3.3.5. Environmental Conditions of Sengon Farms on Peatlands

Farmer perceptions of the environmental conditions in the last three years are presented in Figure 8. Based on farmers' observations, flooding and fires are not a threat because there had never been floods and fires in their sengon farms in the last three years. The majority of respondents also stated that the peatland condition was moderate, meaning that it was not much changed from time to time. The occurrence of pest and disease attacks is moderate. Farmers' knowledge of subsidence is uneven.

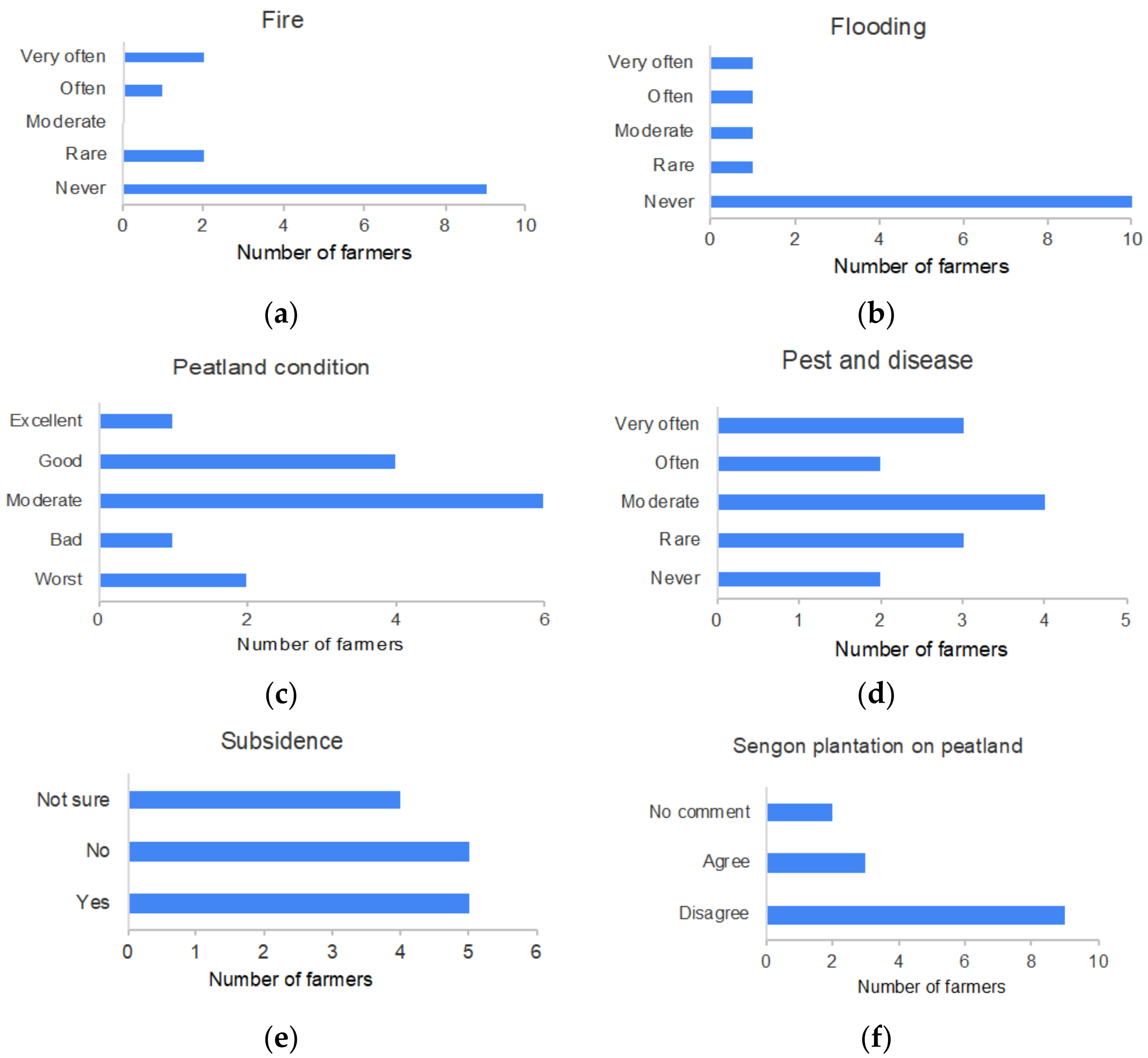
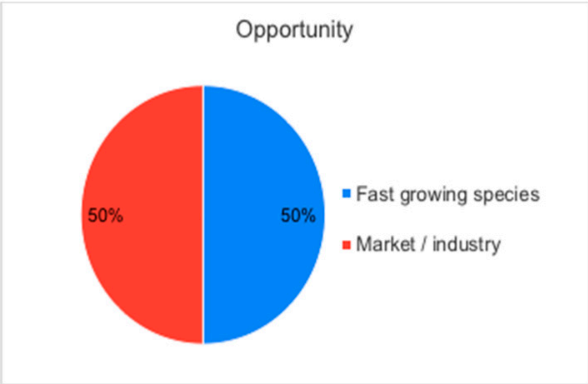


Figure 8. Perception of local actors on the current environment peatland conditions: (**a**) Fire, (**b**) flooding, (**c**) peatland condition, (**d**) pest and disease, (**e**) subsidence, (**f**) sengon plantation on peatlands. Based on interview with farmers.

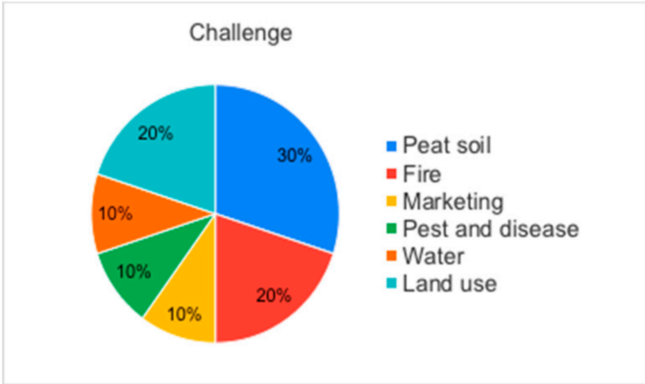
If a sengon plantation program on peatlands will be implemented, only 21% of respondents will support the program, and 64% of respondents disagree with the development of sengon on peatlands.

3.3.6. Opportunities and Challenges for Sengon Development on Peatlands

The local government stated that there are two main reasons why local communities were enthusiastic about developing sengon plantations in Central Kalimantan, namely, sengon growth is fast and the availability of markets or industries. However, the challenges of sengon plantation development consisted of wet peatland, fire, and competition for land use (Figure 9). Up to now, no legal policy at the national or local level has been issued for the development of sengon plantation on peatlands.



(**a**)



(**b**)

Figure 9. Sengon plantation development on peatlands. (**a**) Opportunities; (**b**) Challenges, based on interview with government officers.

4. Discussion

The findings of the three experiments that we conducted have answered our research questions. First, the mesocosm experiment in the nursery showed that the media take more effect than inundation. Dry shoots and leaves fell down after one week of inundation treatment. The stem dried starting from the shoot tip and creeping into the base of the stem, followed by seedlings death. The surviving seedling arose a new shoot. The survival rate of sengon seedlings in peat media decreased to 25–33% after three months of inundation treatment. This showed that sengon seedlings have poor adaption in peat soil. In contrast, sengon seedlings grew better in mineral soils, whether inundated or not, and had a survival rate >90%. Peat soils that were used as planting media in the nursery had lower pH levels than the mineral soil (Table 3). We expect that the low soil pH affected the survival and growth of the sengon. In its natural distribution, sengon trees also grows on river flooded terraces [13]. Water saturation conditions, such as hypoxia (lack of oxygen) or anoxia (no oxygen), cause disturbances in respiration and nutrient uptake [48–50]. Developing horizontal roots and aerenchym to obtain more oxygen is a strategy for legume species, such as sengon, against flooding [51].

The permanent nursery in Tumbang Nusa village, Pulang Pisau district, uses mineral soil as the main planting media in seedling production, even though the nursery is located in a peatland area. The seedlings are usually sold and distributed to consumers at 30–40 cm height. Based on the National Standard of Indonesia (known as *Standar Nasional Indonesia*, *SNI*) no. 8420 on the quality standards for sengon seedlings, planting material should have a height of ≥35 cm and a diameter ≥4 mm [52]. In practice, seedlings height of less than 20 cm is already in demand by farmers. The seedlings produced by Watershed Management and Protection Forest of Kahayan (BPDASHL Kahayan) and seedlings produced by PT NAP were planted at <20 cm high.

The 14 sengon farms observed were grouped into four categories, namely Pd (Peat-deep, peat depth >300 cm), Pm (Peat-moderate, peat depth >100–200 cm), PS (peaty soil, peat thick <50 cm) and mineral soil (NAP plots). The Pd, Pm and PS groups showed the chemical characteristics of peat soils, i.e., a very acidic pH, low total N values, high C-organic content and high CEC values [38,39,53]. The total nitrogen (N) content of peat soils in Indonesia is classified as low, ranging between 0.3 and 2.1%, and the available N-mineral for plants is less than 1% [53]. Nine sengon farms located in peatlands have N total levels of 0.55–1.53%, indicating that the N total content is low. A high CEC indicates high cations in the soil, but low pH decreases nutrients uptake by plants [39,54]. Therefore, farmers added soil ameliorant to raise soil pH.

The Pd group had a high C-organic content with low ash content. It showed fibric peat characteristics that were generally found in young gardens, recently cleared peatlands or recurrent fire lands [54,55]. The Pm and PS groups had high ash content and low C-organic levels, which means that the decomposition of carbon has been processed or a long cultivated land history [55].

The growth performance of sengon stands in HTIs of NAP and BSKT showed that sengon growth in mineral soils of Kalimantan Island can grow as well as sengon growth in Java Island. Sengon in Pare (Java Island) from the age of 3 to 5 years showed a diameter growth from 11.3 to 18.8 cm and a height growth from 11.7 to 20.5 m [56]. In its natural habitat, sengon grows in areas with elevations up to 500 m asl, rainfall of 2000–4000 mm a year^{-1}, good drainage, deep soil, neutral pH soil and high fertility soils [13,57]. The last five years of annual rainfall in Palangkaraya ranged 2334–3610 mm year^{-1} [43]; hence, this meets the basic requirement for sengon growth. The limiting factors for sengon plantation are soil type, the level of acidity, and soil fertility.

Based on this study, sengon growth on peatlands is mostly lower than sengon growth on mineral soils (Figures 5 and 6). However, sengon growth in PS1, Pm1 and Pm2 reach sengon growth in NAP. The characteristic of these plots is shallow to medium peat depth (peat depth < 200 cm), and the pH ranged from 3.64 to 3.83. High ash content and low C-organic levels indicate the maturity of well-decomposed peat (sapric and hemic peat). The more mature the peat, the better peatlands to be cultivated.

The growth of sengon on peatland at age of 4 years after planting of this study at two plots of Pd4 and Pd5 (Table 6) was similar to sengon's growth at 4.5 years old on peatland, as reported by Safitri [58] that dbh (diameter at breast height) growth was 13.51 cm and the total height was 11.73 m. Mounding treatment resulted positive effect on the growth of dbh and the total height. However, peat depth and peat soil characteristics were not reported.

The sengon stands in plot PS2 showed similar growth performance with sengon stand in plot Pd1. The farmer of PS1 sengon farm practiced good cultivation techniques; seedlings were provided by the community nursery (*Kebun Bibit Rakyat*, *KBR*) scheme, monoculture stand with 3 m × 3 m in an area of 5 ha, and fertilizer addition manure + NPK. The different soil chemical content of PS1 plot compared to the Pm plots is ash content. Ash content is a characteristic of soil fertility, and low ash content indicates low fertility [45,54].

The sengon stands in the Pd2 farm have inferior growth, dry stems, fewer leaves and nearly dead trees. Figure 10 shows the roots of a four-year-old sengon tree at the Pd2 farm, where the water level was 89 cm below the surface. The roots developed horizontally and did not have a vertical root; thus the plant can easily fall. There is a tendency that plants on peatlands produced more roots to get more oxygen [59]. Sengon have shallow root systems that spreads horizontally at a soil depth of 0 to 30 cm [23,60,61]. Although the horizontal roots were concentrated up to 63%, the vertical root of the sengon can reach to a depth of 120 cm in mineral soils [23,61].

Farmers cultivate sengon because it is easy to plant, easy to maintain, can be harvested quickly, and there is a market demand. Farmers plant sengon on their own land and are willing to use their own capital for sengon plantation. A study reported that peatland suitability class for sengon was classified as unsuitable ("N" code), with the heaviest constraints being the soil pH and peat maturity. By conducting land improvement, the peat suitability class can be improved to marginally appropriate ("S3" code) [62]. The majority of farmers (>50%) understood that sengon grows well on non-acidic land, fertile soil and in the absence of pyrite. Most sengon farms are drained peatland in the field, where a ditch is usually established prior to land preparation (Figure 2). The sengon farm of Pd1 was a recently opened peatland and first used for cultivation. The reality in the field showed that sengon cultivation on peatland is implemented on drained peatland. Cultivation practices with drained peatland cannot be classified as paludiculture [63]. Most farmers implement fair silvicultural techniques. They performed the land preparation (e.g., land clearing, drying and liming), plant spacing and irregular fertilization, at least once in the sengons' lifetime (Table 6). However, farmers generally do not apply intensive farm management. Only three farmers stated that they do routine fertilization. Farmers also rarely take preventive or eradicative measures to control pests and diseases (Table 6). We found that some sengon farms were established far from settlements. In this situation, the farm is extensively managed. The sengon stands on the observed plots did not have serious problems with pests and diseases, so farmers also tended to ignore pests and diseases. In Java Island, in contrast, sengon are particularly attacked by a gall rust disease caused by *Uromycladium falcatarium* and mainly thrive in locations with low temperatures and high rainfall [64].

Figure 10. Root of 4-year-old sengon planted in peatland (photo taken from Pd2 plot).

Sengon plantation on dryland (mineral soil) is a priority in forest plantation development as stated in the Decree of Minister of Environment and Forestry of Indonesia no. P.62 year 2019. According to the resource persons of BPDASHL Kahayan, the demand of sengon seedlings was very high. Within 3 years (2018–2020), BPDASHL Kahayan has distributed 1.95 million sengon seedlings freely to farmers and communities. Another activity for providing seedlings is through the smallholder nurseries, which is known as the *Kebun Bibit Rakyat (KBR)* scheme. In the 2018–2020 period, a total of 68 farmer groups were involved in creating KBR. Farmer groups managed by the KBR with funding from the government for nursery and planting activities. This aligns with Government Regulation (*Peraturan Pemerintah*, PP) no. 88 year 2018 to form community empowerment in forest and land rehabilitation.

Until recently, there has been no legal policy for sengon plantation development on peatlands. However, the communities were very enthusiastic about planting sengon in mineral soil and in peatlands. The local government stated that there were two main reasons, namely: its rapid growth and the availability of markets or industries. Despite the opportunities, there are also challenges in developing sengon, especially soil type (peat soil), fire, and land use competition (Figure 9). Peat restoration in Indonesia depends on land use policy [65]. Based on respondents' experience, only 21% of them stated their support for the sengon development on peatlands, and 64% did not agree with sengon development on peatlands. This indicates that the development of sengon plantation on peatlands should be done carefully in the coming years.

5. Conclusions

Sengon seedlings showed poor adaption in peat soils, which usually have very low pH. The growth performance of sengon in peatlands is slower than its growth in mineral soils. Sengon growth in peatlands was influenced by peat depth and peat maturity. Sengon plantation on deep peatlands (peat depth $\geq$ 300 cm) resulted in poor growth performance. Better performance growth was indicated by sengon farms on shallow to moderate peat depth ($\leq$200 cm). Sengon needs drainage. The plantations with good growth performance were found only on drained peatlands.

Planting non-native peatland species in rewetted peatlands, as part of restoration efforts, needs careful consideration. When selecting non-native species to be planted in rewetted peatland, one needs to consider its species responses to peatland biophysical characteristics and the local knowledge of people who have tested planting the species. In addition, the development of tree species, which are adaptive to rewetted peatlands, on peatlands as an alternative for timber with a solid market support is recommended.

Author Contributions: Conceptualization, H.S.N. and H.L.T.; methodology, H.S.N. and H.L.T.; software, H.S.N. and H.L.T.; validation, H.S.N. and H.L.T.; formal analysis, H.S.N. and H.L.T.; investigation, H.S.N., H.L.T. and M.; data curation, H.S.N., H.L.T. and M.; writing—original draft preparation, H.S.N. and H.L.T.; writing—review and editing, H.S.N. and H.L.T.; visualization, H.S.N. and H.L.T.; project administration, E.M.; funding acquisition, S.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Partnership for Enhanced Engagement in Research (PEER) USAID, grant number 2000008728 on the Developing Biodiverse Agroforests on Rewetted Peatlands in Indonesia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects (e.g., respondents) involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: This study was part of a research collaboration between the Forest Research and Development Center and the World Agroforestry Center (ICRAF) Indonesia, funded by the Partnership for Enhanced Engagement in Research (PEER) USAID, grant number 2000008728 on the Developing Biodiverse Agroforests on Rewetted Peatlands in Indonesia. The authors acknowledge the principal data owner: I Nengah Surati Jaya, Head of the Laboratory of Forest Resources Inventory, Department of Forest Management, Faculty of Forestry and Environment, IPB University for giving us permission to use data of Al-Hadad (2017) as a complementary data of this study. We also thank Arga Pandiwijaya for creating a map of the study area, and three anonymous reviewers for their valuable inputs and comments.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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