p.272-289

Vol. 2 No. 3- December 2021

E-ISSN: 2722-0842 | P-ISSN: 2721-8309

JISDeP The Journal of Indonesia Sustainable Development Planning

Available online at
journal.pusbindiklatren.bappenas.go.id

Kementerian PPN/ Bappenas

Research Paper

The Potency of *Cratoxylum arborescens* Blume (Geronggang) and *Combrecarpus rotundatus* Dans (Tumih) as Natural Regeneration in Degraded Tropical Peat Swamp Forest

David Suwito[1,2*], Suratman[3] and Erny Poedjirahajoe[4]

The Doctoral Program of Environmental Science, Gadjah Mada University[1]
The Ministry of Environment and Forestry, Republic of Indonesia[2]
Faculty of Geography,Gadjah Mada University [3]
Faculty of Forestry,Gadjah Mada University[4]
Email: [1]david.suwito@mail.ugm.ac.id, [2]ratman_woro@ugm.ac.id, [3]er_pjr@yahoo.com

)Corresponding Author

ABSTRACT

The massive forest fire disasters have left an enormous area of degraded peatland. This study aims to analyze the performance of two species, namely C. arborescens and C. rotundatus, as the natural regeneration post forest fires. This research was conducted in 5 different locations that experienced severe fires in 2006. We made a total of 25 plots for each location to measure biodiversity at four growth levels. We analyzed the data with vegetation analysis formulas from Magurran. The results show that at the tree growth level, C. rotundatus can withstand the fires in 2006 and is currently still growing in more significant numbers than C. arborescens. At the pole, sapling, and seedling growth levels, these species perform well as natural regeneration species with many individuals, but C. arborescens is a bit more dominant. Both species are suitable for natural regeneration after fires in degraded peat swamp forests based on survived and existing individuals. On the other hand, both species could not improve the vegetation diversity in the whole ecosystem. These two species can be the option for natural regeneration if there a limited budget and the degraded areas are in a very remote location.

Keywords: forest fire, natural regeneration, performance, peat swamp forest

ARTICLE INFO

Received: September 8, 2021
Received in revised form: November 4, 2021
Accepted: December 26, 2021

doi: 10.46456/jisdep.v2i3.185

JISDeP - The Journal of Indonesia Sustainable Development Planning
Published by Centre for Planners' Development, Education, and Training (Pusbindiklatren),
Ministry of National Development Planning/ National Development Planning Agency (Bappenas), Republic of Indonesia

Address: Jalan Proklamasi 70,
Central Jakarta, Indonesia 10320
Phone: +62 21 31928280/31928285
Fax: +62 21 31928281
E-mail:
journal.pusbindiklatren@bappenas.go.id

Supported by Indonesian Development Planners Association (PPPI)

1. Introduction

Indonesia is a country blessed with the largest area of tropical peatlands in the world, where almost 70% of the total global tropical peatlands are in Indonesia, spread over the islands of Sumatra, Kalimantan, and Papua (Hooijer et al., 2012; Miettinen, Shi, et al., 2012; S. E. Page et al., 2007). Indonesia's tropical peatlands primarily consist of forested wetland areas and are called tropical peat swamp forests (Könönen et al., 2016). These fragile and unique ecosystems have vital roles for human life with various ecological, economic, and socio-cultural benefits. On the global scale, tropical peat swamp forests are highly concerned because of their high carbon stock inside (Ahirwal et al., 2021; Kimmel & Mander, 2010; Osaki & Tsuji, 2015), which means that they are associated with global carbon emissions, forest fires, and air pollution (Couwenberg, 2010; Hooijer et al., 2012; Murdiyarso et al., 2019). These ecosystems also have high biodiversity values , such as various species that are endemic, rare, and endangered (Posa et al., 2011; Symes et al., 2018; Yule, 2010), as well as a source of livelihood for local people (Chokkalingam et al., 2005; Silvius & Diemont, 2007; Taufik et al., 2019)

Central Kalimantan, Indonesia, is where most tropical peat swamp forests can be found (Miettinen, Shi, et al., 2012; S. E. Page et al., 2007). However, these unique and priceless ecosystems have been experiencing deforestation and degradation for various reasons until now. One of the causes of degradation and deforestation in peat forests is fire (Couwenberg, 2010; Dohong, 2016; Lestari et al., 2021; Pindilli et al., 2018). These forest fires are always accompanied by other impacts, such as converting peatlands into plantation and agricultural areas and the drought (Cole et al., 2021; Hooijer et al., 2010; Jauhiainen et al., 2014; Uda et al., 2020)

Degradation and deforestation of peat swamp forest due to fires caused a lot of neglected peat swamp forest. Therefore, the government must address this area immediately because it is prone to repeated forest fires with local and global impacts (S. E. Page et al., 2007; Wösten et al., 2008). The efforts to restore the peat swamp forest ecosystem after the fire are conducted through ecosystem restoration. This restoration consists of hydrological restoration, vegetation restoration, revitalization, or restoration of its economic and ecological functions (Dohong et al., 2018; Badan Restorasi Gambut Republik Indonesia, 2016; Giesen & Meer, 2009; Yuliani, 2017).

Restoration of peat swamp forest is a part of peatland restoration in a specific type of ecosystem, i.e., forest ecosystem. Several forest fires have caused large areas of degraded peat swamp forests (PSFs) and need to be restored (Hooijer et al., 2012; Jauhiainen et al., 2014; Koh et al., 2011; Könönen et al., 2018; Suding et al., 2015). Peatland ecosystem restoration consists of vegetation restoration, hydrological restoration, and revitalization.

Vegetation restoration is conducted by either revegetation/planting or natural regeneration, while the restoration on hydrology is undertaken by rewetting peatland. Management and restoration of tropical peat ecosystems is not a small and simple thing, with a carbon stock of 3000 mg C Ha-1. However, the loss rate is also high at around 20 Mg C Ha-1 due to various things, especially oil palm plantations and industrial forest plantations development, and continues to grow (Murdiyarso et al., 2019). As a result, accelerated degradation started in the last decade, even compared to tropical peatlands in other areas such as Peru in South America (Lilleskov et al., 2019). Therefore, various evidence-based policies and strategies are needed.

Ecosystem restoration must also involve local communities, especially in hydrological restoration, which are rejected or accepted by local farmers in the form of existing blocking canals. It affects their accessibility to the area, where canals are their transportation route. Better understanding is needed to improve restoration success (Ward et al., 2021)

On the one hand, during the Covid-19 era, the management and conservation of peat areas also have impacts and potential impacts such as air pollution, socioeconomic, livelihoods, and food security (Harrison, Wijedasa, et al., 2020). However, on the other hand, even planting project activities also encounter many obstacles; therefore, natural regeneration is an essential alternative for restoration at this time.

In particular, for vegetation restoration, two options are available, namely planting and natural regeneration. Natural regeneration, the spontaneous recovery of plant or animal species after damage or disaster, continues to be promoted as a low-cost strategy for large-scale forest restoration (Chazdon & Uriarte, 2016). This method is suitable because of the high cost associated with restoring peat swamp forest vegetation (Blackham et al., 2014), and the extent of neglected degraded areas after the forest and tropical peatland fires in Kalimantan (Cole et al., 2021; S. E. Page et al., 2007; Toriyama et al., 2014)

Vegetation restoration in the degraded peat swamp forest is challenging in many aspects as peatlands have unique characteristics in terms of geology and ecosystems. Previous studies on degraded land conditions have found that degraded peatlands pose many obstacles in natural regeneration and revegetation (Di Sacco et al., 2021; Wijedasa et al., 2020). Many degraded peat swamp forest areas are not in the right way to be restored naturally (Miettinen, Shi, et al., 2012). From ecological aspects, there are several limiting factors in the regeneration and revegetation of degraded peat forest areas, such as water level fluctuations, poor nutrient cycles, a remarkable change in temperature (Wösten et al., 2008)

The uncontrolled drainage systems, drought, and forest fires also stop natural regeneration by eliminating sources of seeds that have fallen to the ground (Graham et al., 2013). From a biological perspective, plant or tree species that are natural sources of seeds carried by wind and animals are also significant for natural regeneration in peat swamp forests. Still, the diversity of these seed-producing species is also low (Blackham et al., 2014).

Due to its geographical location, peat swamp forests located at the equator have high temperatures, especially in open areas due to conversion or fires (Miettinen, Shi, et al., 2012; Osaki et al., 2012). During the day at the end of the dry season, the temperature of the open area in peat swamp forest reaches 40 degrees, causing severe drying of seedlings planted for vegetation restoration purposes, thereby increasing seedling mortality (Lampela et al., 2018). High temperatures and drought also trigger repeated forest fires, killing the natural regeneration process and revegetation regeneration. Due to the distance from natural seed sources, regeneration is disrupted because the area will be dominated by shrubs and grasses (Graham et al., 2013; Könönen et al., 2018; S. Page et al., 2008)

Various NGOs have also carried out revegetation activities both in joint projects and independently. For example, in the peat swamp forest of Central Kalimantan, *Dyera polyphylla* (synonym: *Dyera lowii*) and *Shorea balangeran* have been planted (Giesen & Meer, 2009). These species were chosen because they are endemic to Central Kalimantan's peat swamp forest. *Dyera Polyphylla* was selected because it has high economic value as a sap producer. At the same time, *Shorea balangeran* is an endemic species most often found as the dominant species in the tree category in Central Kalimantan peat swamp forest (Mawazin & Subiakto, 2013; Tan et al., 2021; Tata, 2019). However, the area that has not been planted yet is massive. Therefore, natural regeneration is the choice to restore the vegetation diversity in degraded peat swamp forests after fires.

The study conducted by Lampela et al. (2017) found 21 species of peat swamp forest trees. The study also showed that *S. balangeran, A.pavonia, D. rostrate*, and *L. dasytachys* are the most suitable species for vegetation restoration. However, *A. pneumatophora* and *D. polyphylla* are still recommended with certain restrictions (Lampela et al., 2017).

The golden rule in vegetation restoration: select suitable species for restoration areas, use natural regeneration whenever possible, and select suitable species to maximize biodiversity(Di Sacco et al., 2021). Natural regeneration and assisted natural regeneration are the two recommended methods for ecosystem restoration after a fire (Scheper et al., 2021), considering that forest fires and land conversion usually produce different vegetation and soil microbial activity (Ahirwal et al., 2021).

The Previous study have found 59 challenges in tropical forest and peatland conservation: economic, legal, social, logistical, and research (Harrison, Ottay, et al., 2020). Ecologically, there are many barriers to various peat restoration techniques (Dohong et al., 2018). For example, logistical problems and high costs are common problems for vegetation or replanting (Blackham et al., 2014; Graham et al., 2013). Another problem is the vast area of degraded peatland because of fires (Koh et al., 2011; Miettinen, Hooijer, et al., 2012). Therefore, natural regeneration is one of the alternatives that researchers should study carefully to solve these barriers.

There has also been much research in Central Kalimantan on species and methods for peat restoration. Some also suggest paludiculture with three main species, namely Jelutung, Ramin, and balangeran, as woody plants (Budiman et al., 2020). Another study indicated that adapted agroforestry models are recommended to attract local communities and investors (Applegate et al., 2021). However, this is for peat areas, not in forest areas located in rural areas.

With the many obstacles and challenges in carrying out revegetation in the form of planting the large area of land that has been degraded by forest and land fires, one of the cheapest and easiest alternatives is to rely on natural regeneration. Natural regeneration of the most common species is needed to measure whether these species are suitable and reliable as species for vegetation restoration.

Natural regeneration can be assessed by measuring species that are not planted but grow naturally in degraded peat swamp forest areas. This study was conducted to determine the performance of 2 species of woody species, namely *C. arborescens* and *C. rotundatus,* as the species for natural regeneration after the forest fire disaster in tropical peat swamp forest. These species grow most commonly in peat swamp forests in Central Kalimantan. The purpose of this research is to compare the performance of these two species for natural regeneration, namely *C. arborescens* and *C. rotundatus*, as the species for natural regeneration after the forest fire disaster in tropical peat swamp forest.

The study results on the performance of species post-fires will be beneficial in deciding the alternative option of vegetation restoration methods. For example, whether planting is necessary for all locations, enrichment planting is sufficient, or some species can be relied on in natural regeneration without planting with human assistance. The result would be significant as degraded peatlands are massive, and restoration requires a high cost, especially in the remote areas of peat swamp forest.

2. Methodology

This research was conducted in the peat swamp forest of Central Kalimantan, which administratively belongs to the Forest Management Unit (KPH) area, namely the Kapuas-Kahayan KPHL (formerly known as the Kapuas Model KPHL). Geographically, the research location is located at coordinates: 1° 47'37.8" SL- 2° 13'48.6" SL 114°23'28.1EL - 114°43'5.1" EL, located in the former MRP area Block E and Block A to the right of the Kapuas River. The KPHL area has an area of 105,772 ha consisting of more than 94% of the peat swamp forest area. This research area is also a peat swamp forest area left over from the former 1 million Mega Rice Project in Peatland (MRP) in the 1990s.

This peat swamp forest area was chosen because it is a protected forest with characteristics as thick peatland with high degradation and degradation because of forest fires in 2006. Moreover, this area is an area that has implemented various ecosystem restoration techniques since the 2000s with three main activities: hydrological restoration, vegetation restoration, and revitalization. However, there were also the massive areas without any human-assisted revegetation and relied on natural regeneration with two main species, i.e., *C. arborescens and C. rotundatus.* The research map can be seen in the following figure.

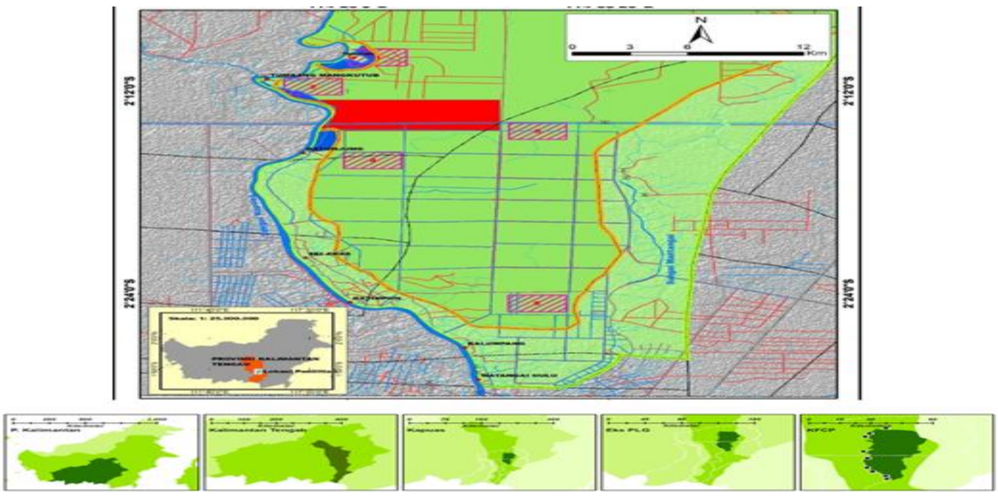

Figure 1. Research location

The plots were made in the main plot of 1 hectare for each location. In one hectare, the are 25 measuring sub-plots with different sizes as follows: 20 m x 20 m for tree growth level, 10 m x 10 m for pole growth level, 5 x 5m for sapling growth level, and 2 x 2m for seedlings ferns and understorey plants. Square plots are randomly placed on five different locations in the degraded post-2006 fires, where no replanting was conducted, and the whole vegetation depends on natural regeneration.

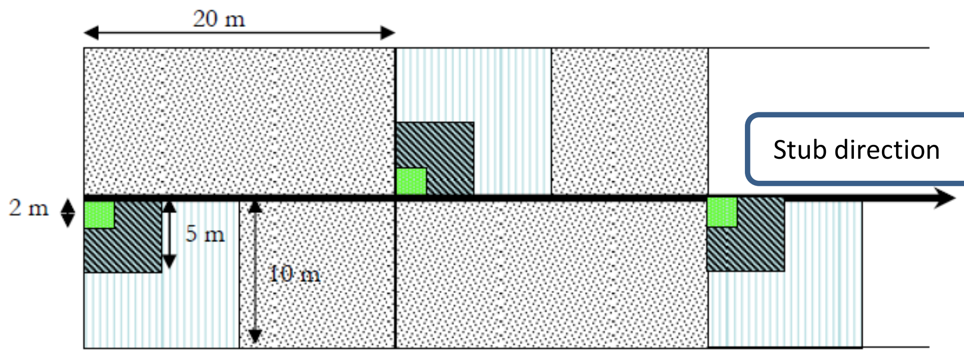

Figure 2: Plot design for seedling, sapling, pole, and tree

Data collected included species and number of plants and diameter for trees and poles. Data were analyzed by vegetation analysis to obtain important value index (IVI), Shannon diversity index (H'), species richness index (R1), and evenness index (E).

2.1 Analysis

Collected data consisted of the species name (botanical and local), a number of individuals in each plot for seedling, sapling, pole, tree, diameter, and height for pole and tree growth level. Analysis data was done after all data from the field was completed.

For data analysis, we used the following formulas from Magguran (Magurran, 2004; Magurran & McGill, 2011) and put the result on the table. The vegetation data analysis is as follows:

a. Important Value Index

The Important value index formulas are divided into two categories, i.e.:

For Pole and Tree growth levels:

$$IVI = RD + RF + RDm \tag{1}$$

For sapling, seedling, and understorey growth level

$$IVI = RD + RF \tag{2}$$

IVI = important Value Index

RD = Relative Density

RF= Relative Frequency

RDm = Relative Dominance

b. Shannon–Weiner diversity index (H'*)*

$$H' = -\sum_{i=1}^{n} \frac{ni}{N} \times log\ log \left(\frac{ni}{N}\right) \tag{3}$$

Where *ni* is the total number of species-i, *N* is the total number of all species in the plots

c. Richness Index

$$R1 = \frac{S-1}{loglog\ N} \tag{4}$$

Where R1 is the richness index for a plot, S is the total number of species, and N is the total of individuals in the plot

d. Evenness Index

$$E = \frac{H'}{log log\, S} \quad (5)$$

Where E = Evenness index, H' is diversity index for a species, S is a total number of species found in the plot

3. Results and Discussion

3.1.Performance of C. arborescens and C. rotundatus in pole growth level

Vegetation diversity and vegetation analysis results for tree growth level for two species are presented in the following table.

Table 1: Species and values of IVI, H', R1 dan E for tree growth level

Location	Species	Local Name	NS	NI	IVI	H1	R1	E
A-1	*C. arborescens*	Geronggang	2	1	21,4	0,01	0,87	0,04
A-2	*C. rotundatus*	Tumih	2	13	278,6	0,08	0,87	0,26
B-1	*C. arborescens*	Geronggang	2	5	58,7	0,15	0,74	0,49
B-2	*C. rotundatus*	Tumih	2	17	241,3	0,09	0,74	0,29
C-1	*C. arborescens*	Geronggang	2	2	25,3	0,12	1,13	0,40
C-2	*C. rotundatus*	Tumih	2	12	274,7	0,06	1,13	0,19
D-1	*C. arborescens*	Geronggang	2	13	53,2	0,14	0,56	0,48
D-2	*C. rotundatus*	Tumih	2	12	246,8	0,18	0,56	0,28
E-1	*C. arborescens*	Geronggang	1	0	0	0	0	0
E-2	*C. rotundatus*	Tumih	1	13	300	0	0	0

A-B-C-D-E = plot locations (Tuanan, Mangkutup, Katunjung, Sungai Mantangai and Mantangai Hulu)
NS = number of species found on the plot
NI = Number of Individual
IVI = Important Value Index
H = Shannon Index of Diversity
R1 = Richness Index
E = Evenness Index

The research is located on the Protected Forest Managemen Unit of Kapuas Kahayan, especially in the area that burned with the heaviest damage in 2006. The observation plots size is 1 hectare containing 25 sub-plots which are placed in 5 different locations, namely in Tuanan (A), Tumbang Mangkutup (B), Katunjung (C), Sungai Mantangai D, and Mantangai Hulu (E). Observation plots are placed in areas where hydrological restoration (canal blocking) has been carried out without any human-assisted revegetation.

Observations at tree stages with a diameter of 20 cm up also showed fire-resistant species or survived the 2006 big fires. Of the eight most common species, only *C. arborescens and C. rotundatus* were found in this burned area. *C. arborescens* is found in 4 of 5 total plots, while *C. rotundatus* is found in all fields. Thus, it can be seen that *C. arborescens* and *C. rotundatus* are fire-resistant species.

Forest fires are indeed one of the leading causes of species loss in peat swamp forests. In general, the species of trees that survive after the fire is *C. rotundatus* or Tumih in the local language. This species has a much higher number of individuals than *C. arborescens*. However, the total number of trees in a one-hectare plot is minimal and far from a recovering forest. Peat swamp forests are also rich in species diversity in primary forest conditions; for example, in Sebangau National Park, with the same type of ecosystem as the research locations, 133 species consisting of 34 families have been found.

This species dominates the tree species that survived severe fires with an IVI value ranging from 141.4 to 300, a maximum of 300. It appears that *C. rotundatus* is a fire-resistant tree species that grows in damp areas all year round. The community has never chosen this species as a species planted for peat ecosystem restoration. It is not a commercial species, low-quality wood, non-cylindrical wood shape, and is not a food-producing species for humans and wildlife.

Most of the ecosystem is dominated by various species of ferns and shrubs. The diversity index of these species ranges from 0.01 to 0.18. This range can be categorized as a shallow species richness index (H') and indicates that the area has a tiny number of species and a tiny number of individuals. This low richness index suggests that a few species survive after a forest fire in the peat swamp forest. These species were found next to the edge of small rivers and canals, indicating their roots in wet soil during the forest fire. From this H index indicator, it can be seen that forest fires in 2006 have eliminated almost all species where only two species remain.

Based on the richness index (R1), the values of R1 in locations A, B, C, D, and E are lower than 3.5, indicating species richness is also very low. This value means that the ecosystem has small numbers of species, and each species has a small number of individuals. Thus, the two surviving species in the degraded area after the fire are still inadequate for natural regeneration with a limited number of each species; however, these species are essential for producing seed for natural regeneration (see. Figure 3)

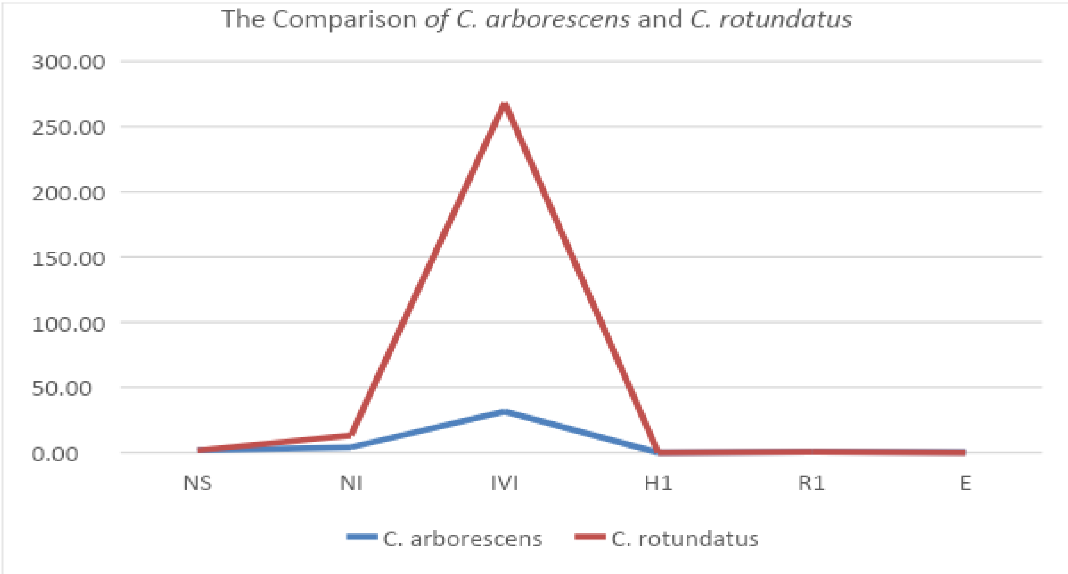

Figure 3. The Comparison of *C. arborescens* and C. *rotundatus* in tree level

Meanwhile, based on the evenness index (E), *C. arborescens* has a medium evenness index in 3 locations and a low evenness index in 2 areas. While for *C. rotundatus*, it was found that this species has a low evenness index at all locations. These common indexes mean that *C. rotundatus* tend to be more evenly distributed in all observation locations than *C. arborescens*, primarily concentrated in certain places. The evenness index describes how a species is dispersed in all the subplots in the observation plot. This low value indicates that the two species tend to be close in certain sub-plots and not in other sub-plots. Both species also tend to be found in inundated areas throughout the year or near canals/rivers.

Peat swamp forest in natural conditions that are not degrading is a unique forest area with high biodiversity. Previous studies have shown that forest and land fires cause degradation and deforestation because fire can wipe out various species. Still, forest fires that have occurred repeatedly since 1997 have a significant impact on biodiversity flora and leave many degraded regions. The number of trees recorded in the plot's observations shows the more fire-resistant species after forest and land fires. It was seen that only two species *C. arborescens* and *C. rotundatus*, can survive. Forest fires in 2006 showed that fires were the most destructive cause of degradation and deforestation in peat swamp forests, especially from the perspective of vegetation biodiversity. Vegetation does not always return naturally and reduces the chance of natural regeneration (Könönen et al., 2016). Forest fires also remove seeds that fall and are stored on the forest floor. It is a matter that must be considered in ecosystem restoration because usually, peat swamp forest burns to make the damaged area very large and far from parts of the forest. Forests that contain seed-producing trees become an obstacle in the distribution of seeds for natural regeneration.

The tiny number of species and the tiny number of individuals indicate that the fires in 2006 were very severe. Forest fires, especially repeated forest fires, have long been a barrier to natural regeneration and revegetation. The previous study in degraded but unburned areas of peatlands in Sumatra also showed the loss of many species

3.2 Performance of C. arborescens and C. rotundatus in pole growth level

The vegetation analysis results for two species at pole growth level can be found in the following table.

Table 2: Species and values of IVI, H', R1 dan E for poles growth level

Loca tion	Species	Local Name	N S	NI	IVI	H1	R1	E
A-1	*C. arborescens*	Geronggang	7	776	16,83	0,16	22,6	0,19
A-2	*C. rotundatus*	Tumih	7	728	117,8 4	0,16	2,26	0,19
B-1	*C. arborescens*	Geronggang	8	760	137,2	0,16	1,91	0,20
B-2	*C. rotundatus*	Tumih	8	600	99,8	0,16	1,91	0,21
C-1	*C. arborescens*	Geronggang	7	776	101,2 4	0,16	6,63	0,19
C-2	*C. rotundatus*	Tumih	7	728	98,66	0,16	6,63	0,19
D-1	*C. arborescens*	Geronggang	7	624	111,1	0,16	2,29	0,19
D-2	*C. rotundatus*	Tumih	7	668	118,8	0,16	2,29	0,19
E-1	*C. arborescens*	Geronggang	7	776	118,8	0,16	1,50	0,23
E-2	*C. rotundatus*	Tumih	7	728	114,0	0,16	1,50	0,23

A-B-C-D-E = plot locations (Tuanan, Mangkutup, Katunjung, Sungai Mantangai and Mantangai Hulu)
NS = number of species found on the plot
NI = Number of Individual
IVI = Important Value Index
H = Shannon Index of Diversity
R1 = Richness Index
E = Evenness Index

The pole growth level is a growth stage of woody species whose diameter is 10 cm to less than 20 cm. This growth level is well known as the "young tree." For this research location, pole growth level is essential because it shows the success of natural regeneration just after forest fires in 2006 as the species grow immediately after fires.

Seven species have been found in locations A, C, D, and E, while eight species have been recorded in Location B. This number of species shows that although the study locations are in various areas and separated, the vegetation condition after forest and forest fires has similarities in terms of species composition. For example, both species *C. arborescens* and *C. rotundatus* were found in all observation plots at all locations. These two species that appeared in all areas indicated the most common species growing naturally in peat swamp forests after the fire.

Vegetation conditions at the growth level of poles or young trees with a diameter of less than 20 cm indicate the success of natural regeneration after a fire. Therefore, in terms of diameter, it can be seen that this species is a species that grows right after the occurrence of forest and land fires.

Based on IVI (see Figure 4), *C. arborescens* or Geronggang has a slightly higher IVI than *C. rotundatus* or Tumih species, but the difference is tiny and insignificant. *C. arborescens* has an average IVI of 116.93% out of 300 from the 5 locations, while *C. rotundatus* or Tumih has an average IVI of 109.82 out of 300. Thus, these two species have an IVI of around 100 out of 300 or dominate 1/3 of the total species. If the values of these two species are combined, it can be seen that both species dominate the entire vegetation in the ecosystem.

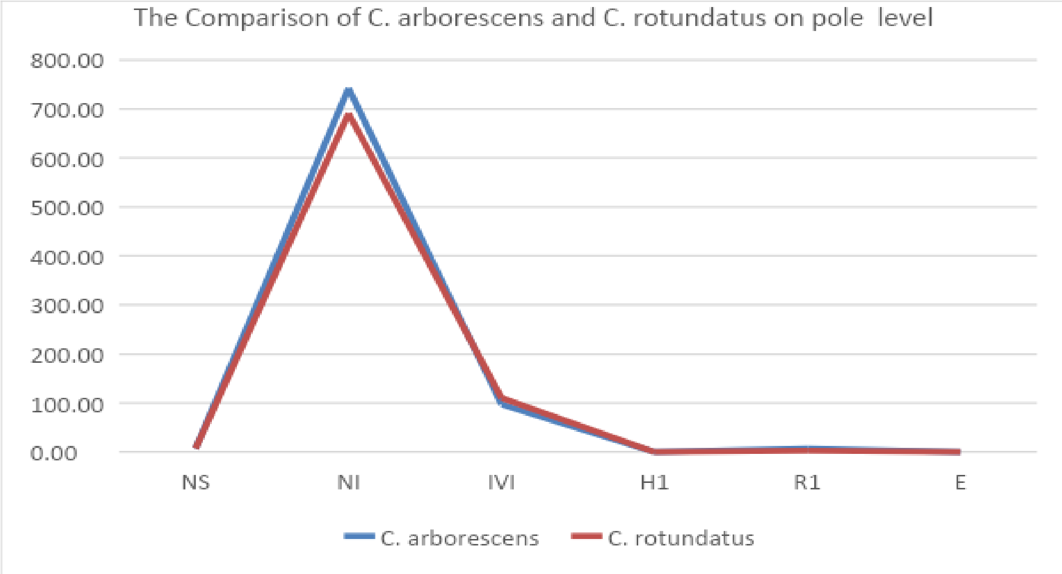

Figure 4. The comparison of *C. arborescens* and *C. rotundatus* on pole level

The IV value of these two species, which can be seen in Figure 4 at the pole stage, shows good performance as a reliable species in post-fire natural regeneration. These two species arise because few trees of these two species survive fires to produce seeds and grow. Therefore, the existence of trees as a source of seeds is vital for natural regeneration.

C. arborescens or Geronggang shows a reasonably good growth ability as a species of natural regeneration. This species usually has seeds spread by various animals such as birds; they can be found in measuring plots but have a low E index. In addition, these species tend to grow in clusters at specific fields, not evenly distributed.

Species richness index can be used as an indicator for a species performance in natural regeneration. Species richness indicates whether a species has a large enough number in the ecosystem. The observation and vegetation analysis results show that the species richness index (H') value is found between 0.01-0.16. This range of numbers indicates that all species in all locations have a low species diversity. The low species diversity index means that although they dominate in number, these two species still show a common species diversity index. This result is related to the unique condition of peat swamp forest, which has many barriers such as the fluctuation of the water table, high temperature, the scarcity of seed source, and the loss of soil seed bank because of forest fire for natural regeneration. This low diversity index of these two species can prove that natural regeneration needs a long time to be restored.

Based on the value of species richness (R1), it is found that in location A, B, D, and E, with a value of (1.5-2.9), species richness are very low to low, but in location C or Katunjung, the species richness is 6.61 or high. At locations A.B, D, and E, it can be seen that all species have small numbers, while at location C or Katunjung, it is otherwise. The low richness index proves that natural regeneration in this area had not restored species richness as a peat swamp forest ecosystem before it was burned.

Based on the species evenness index with a value of 0.01-0.19, all species in all conditions at A, B, C, D have a common species evenness index, meaning that these species tend to be unevenly distributed and concentrated in certain areas. Based on the vegetation analysis result, it can be seen that the two species *C. arborescens* and *C. rotundatus* can be relied on for natural regeneration with human assistance or hydrological restoration can be carried out at first. However, although both species show an encouraging performance, in terms of the biodiversity of the ecosystem vegetation, these two species are too dominant, so that the diversity value is low.

It should be underlined that the two species *C. arborescens* and *C. rotundatus*, have shallow evenness index values, meaning that these two species tend to cluster in one place and are not evenly distributed.

C. arborescens tends to have a high density in certain areas, while *C. rotundatus* is usually concentrated in wet places throughout the year.

Based on the number of individuals in one hectare, these two species can be relied on by comparing the success of revegetation according to the Ministry of Environment and Forestry, which requires a minimum of 500 woody plants per hectare for natural regeneration. However, the main prerequisite must be rewetting activities (canal blocking) to improve the hydrological conditions of the peat soil. In terms of species richness, both species were not successful in enhancing species richness in the ecosystem. Thus, natural regeneration with these two species remains reliable in natural revegetation.

The study plot, which is filled with ferns and some species, can be seen in Figure 5 below :

Figure 5. C. arborescens at pole growth level in degraded peat-swamp forest post fires

We also compared the two species in the ecosystem at pole growth level to make comparison easier between two species and the other species in the same Table 3:

Table 3. IVI of Species at Pole growth level in 5 location A, B, C, D, and E

Species	A	B	C	D	E	Total	Avarage
Shorea balangeran Burck	0	1,4	0	1,5	0	2,9	0,58
C. arborescens	**116,83**	**137,2**	**101,24**	**111,1**	**118,3**	**584,67**	**116,93**
C. rotundatus	**117,84**	**99,8**	**98,66**	**118,8**	**114**	**549,1**	**109,82**
Macaranga hypoleuca	42,14	39,4	58,13	52	44,4	236,07	47,214
Shorea oligunosa Foxw	1,41	1,4	2,6	1,5	1,4	8,31	1,662
Stemonurus scorpiodes Becc.	1,41	1,4	2,6	0	1,4	6,81	1,362
Dyera polyphylla Steenis	1,63	3,4	2,81	1,7	1,6	11,14	2,228
Alstonia scholaris	18,75	16	33,96	13,5	18,8	101,01	20,202
Total	300	300	300	300			

3.3. Performance of C. arborescens and C. rotundatus in Sapling growth level

The Vegetation diversity and vegetation analysis results at the sapling growth level can be found in the following table.

Table 4: Species and values of IVI, H', R1 dan E for Sapling growth level

Location	Species	Local Name	NS	NI	IVI	H1	R1	E
A-1	*C. arborescens*	Geronggang	8	1664	48,3	0,15	2,71	0,17
Location	Species	Local Name	NS	NI	IVI	H1	R1	E
A-2	*C. rotundatus*	Tumih	8	2000	53,8	0,16	2,71	0,18
B-1	*C. arborescens*	Geronggang	5	1888	66,5	0,16	1,60	0,23
B-2	*C. rotundatus*	Tumih	5	2096	70,7	0,16	1,60	0,23
C-1	*C. arborescens*	Geronggang	7	2144	65,3	0,16	6,61	0,19
C-2	*C. rotundatus*	Tumih	7	2032	63,4	0,16	6,61	0,19
D-1	*C. arborescens*	Geronggang	5	2192	61,2	0,16	1,53	0,23
D-2	*C. rotundatus*	Tumih	5	2160	60,7	0,16	1,53	0,23
E-1	*C. arborescens*	Geronggang	5	128	11,3	0,16	1,91	0,23
E-2	*C. rotundatus*	Tumih	5	768	68,8	0,15	1,91	0,23

A-B-C-D-E = plot locations (Tuanan, Mangkutup, Katunjung, Sungai Mantangai and Mantangai Hulu)
NS = number of species found on the plot
NI = Number of Individual
IVI = Important Value Index
H = Shannon Index of Diversity
R1 = Richness Index
E = Evenness Index

Subsequent observations were conducted at the sapling growth level. Sapling is a growth level for the woody species with a height of more than 150 cm to a tree with a trunk diameter of less than 10 cm. The sapling stage in locations A, B, C, D, and D relies on natural regeneration. The species found in location A are eight species, while the lower number of species, seven, are found in location C. The B, D, and E locations have five species. However, the two species *C. arborescens* and *C. rotundatus* were found as the two highest individuals comparing the other species. Both species have more than 100 individuals, but there is an anomaly at location E where all species, including these two species, are very few.

Based on the IVI value, *C. rotundatus* seemed to dominate all locations with an IVI value of 53.8-70.7. Therefore, the second rank was filled by *C. arborescens* except at location E, where *Macaranga hypoleuca* has more individuals. The comparison between the two species is presented in Figure 6.

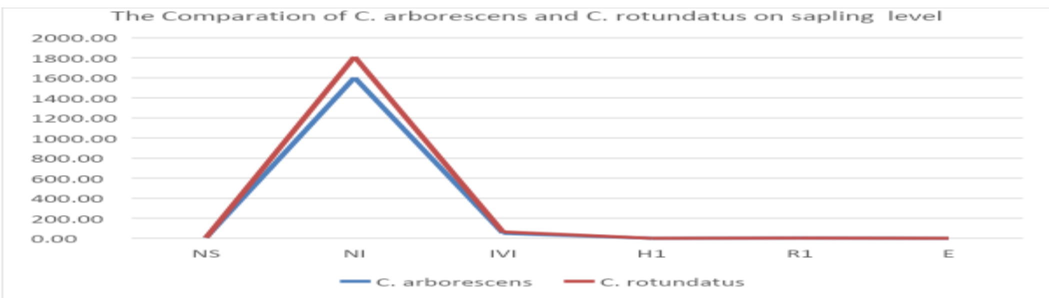

Figure 6. The Comparison of *C. arborescens* and *C. rotundatus* on sapling level

The diversity index value at the sampling stage ranged from 0.01 to 0.16. It can be seen that all species in all locations show low species diversity, meaning that only a few species are found in those areas. Even though the number of individuals from each species was quite large, the diversity index is still low. Low species diversity means that the high number of individuals does not reflect the species richness. On another aspect, the two species, *C. rotundatus,* and *C. arborescens* showed good regeneration ability on burnt areas but could not produce high species richness.

Another indicator that can be used to see the performance of various species on natural regeneration after heavy fires is the richness index. Observations found that species richness is low in locations A, B, D, and E (0. 53-2.71), but in C or Katunjung, the species richness is high (6, 61). A low richness index means that, in general, the majority of the ecosystems assessed show typical species richness. However, areas with high species richness, namely location C, located close to primary forest, estimated that this location are assumed to receive seeds from wind, water flow, or animals from nearby trees.

Species performance can also be assessed from the evenness index value; how often a species appears in each measurement plot. The results of observations at the sapling level show that the evenness indexes of all saplings and all locations are low (0.01-0.23). A low evenness index indicates that these species tend to be unevenly distributed and clustered a lot in specific measuring plots. The Low evenness index means that several species, including two species that focus on observation, tend to be concentrated in one place only.

3.4. Performance of C. arborescens and C. rotundatus in seedling growth

The vegetation diversity and vegetation analysis results at seedling growth level can be found in the following table.

Table 5: Species and values of IVI, H', R1 dan E for seedling growth level

Location	Species	Local Name	NS	NI	IVI	H1	R1	E
A-1	*C. arborescens*	Geronggang	14	4700	15,6	0,05	4,39	0,04
A-2	*C. rotundatus*	Tumih	14	4200	15,1	0,05	4,39	0.04
B-1	*C. arborescens*	Geronggang	14	4400	15,4	0,06	4,40	0,06
B-2	*C. rotundatus*	Tumih	14	5000	17,6	0,07	4,40	0,06
C-1	*C. arborescens*	Geronggang	16	4400	20,2	0,08	15,64	0,01
C-2	*C. rotundatus*	Tumih	16	2300	14,1	0,05	15,64	0,07
D-1	*C. arborescens*	Geronggang	16	3500	15,1	0,06	5,20	0,05
D-2	*C. rotundatus*	Tumih	16	4200	16,6	0,07	5,20	0,06
E-1	*C. arborescens*	Geronggang	8	2200	30,7	0,06	2,26	0,08
E-2	*C. rotundatus*	Tumih	8	1100	14,5	0,04	2,26	0,05

A-B-C-D-E = plot locations (Tuanan, Mangkutup, Katunjung, Sungai Mantangai and Mantangai Hulu)
NS = number of species found on the plot
NI = Number of Individual
IVI = Important Value Index
H = Shannon Index of Diversity
R1 = Richness Index
E = Evenness Index

We counted very woody flora less than 150 cm tall in this growth level, including all ferns and understorey species. Based on the number of species and the number of individuals, it can be seen that ferns are very dominant and invasive species in the burned areas post fires in tropical peat swamp forest in Central Kalimantan.

Three species of ferns dominated the area, *G. linearis*, *N. biserrate*, and *S. palustris*. *G. linearis* usually grows in the rarely flooded part and *N. biserrate* usually grows in wet and sometimes inundated areas. In contrast, *S. palustris* grows in the wet areas only.

On the other hand, according to Dohong et al (2017)., various dominant fern species threaten the successful restoration of vegetation. It is one of the main biological obstacles in the natural succession process of degraded ecosystems (Dohong et al., 2018). This study reinforces previous studies in peat swamp forests of Central Kalimantan and Sumatra, which found that ferns are the species that block woody plant species for natural regeneration due to competition for sunlight and nutrients (Blackham et al., 2014; van Eijk & Leenman, 2004). Based on IVI, it can be seen that these three species of ferns are too dominant over other types of ferns and shrubs, including seedlings of woody plant species.

The existence of ferns is very dominant because of the ability of the fern species to use N and P efficiently. This ability supports the rapid growth of ferns in N and P soils in the early stages of succession (Zhaojun et al., 2011). However, ferns are more likely to dry and flammable species in the dry season, thereby increasing the potential for repeated fires at the site. Once a fire occurs, natural regeneration will return to zero, and ecosystem restoration will become even more difficult. The high number of fern species is a significant challenge when planting and natural regeneration. The massive ferns make the tree seedlings hardly receive enough amount of nutrients and sunlight.

There are only three species with many seedlings for woody plants: *C. arborescens, C. rotundatus*, and *Macaranga hypoleuca*. These three species were found in all observation sites with small numbers compared to the number of ferns but constituted the top 3 of the number of woody plants. Based on IVI, these three species have values equal to and less than 20 out of a total of 200. However, this finding confirms that the two main species, namely *C. arborescens* and *Combrecarpus rotundatus*, grow together with pioneer ferns and can be used for natural regeneration. Furthermore, from the location, it can be seen that most of these woody species also develop around the primary forests. Still, regrowth species are dominated by a few abundant wind-dispersed species (particularly *Combretocarpus rotundatus*), and most other species were potentially dispersed by bulbuls (Pycnonotidae) and other small- to medium-sized birds (Blackham et al., 2014). However, species such as *Dyera polyphylla* have very light seeds and are spread by the wind, with low seedlings. This is possible because the areas studied are areas far from the natural forest where trees produce seeds. Therefore, distance and seed sources significantly affect the number of species that grow in degraded areas in the natural regeneration processes (Chazdon & Uriarte, 2016; Lestari et al., 2021; Wijedasa et al., 2020).

C. arborescens is a tree species (woody species) with the highest number of seedlings in all locations and has a higher IVI than all other species. This similar condition is also found at different levels of growth. These species also tend to be pioneers for natural regeneration (see fig 7.)

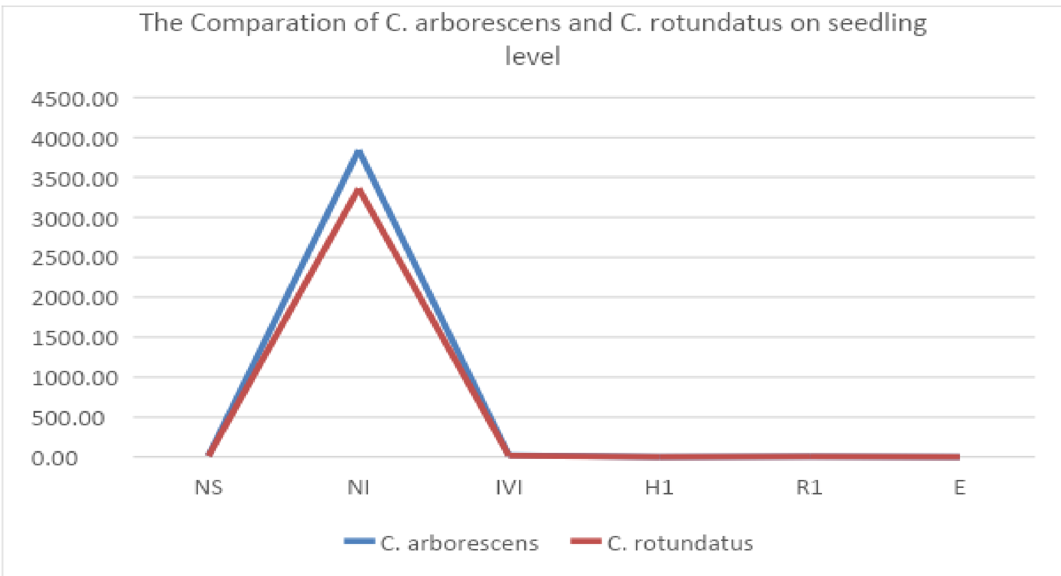

Figure 7. The Comparison of C. arborescens and C. rotundatus on seedling level

In addition to the number of individuals, *G.linearis, N. biserrate*, and *S.palustris* are the three dominant species with a much higher IVI than other species. At the same time, *C. arborescens* or Geronggang is a tree species having the highest IVI value than other tree woody seedlings.

Species performance at the seedling level can be seen from the richness of the species (see table 5). The calculations and vegetation analysis results show that the species richness index (H') in all location species ranges from 0.01 to 0.29. A low diversity index means that the species found are limited. This value proves that although many species were found, none of the species showed high species richness.

Based on the richness index of Magurran (2004) criteria, the value of R1 <3.5 indicates low species richness, R1 = 3.5 - 5.0 reveals moderate species richness, and species richness is high if it is> 5.0. Observations and vegetation analysis of 5 observation locations showed different results. Locations A, B, and E are three observation locations with a low wealth index. The number of species and the number of individuals of each species cannot make the ecosystem highly diverse. Surprisingly, a high species richness index was found at location D, which is located far in the middle of the region with a wealth index value of 5.20, which means that the number of species at this location is diverse numerous. At location D, which is next to the central-primary canal, it can be seen that the richness index is very high (15.64). However, this value is not the only indicator for richness because the ferns are vibrant and diverse.

The performance of species can be assessed from the evenness of these species growing in an ecosystem. The calculation results show that the species' evenness index value ranges from 0.01-0.25, indicating the evenness species is high: all species in all conditions show low evenness, meaning that these species tend to cluster in a few places. The lower the evenness index, the more unevenly a species is distributed in the ecosystem. Observations show that many species are very clearly concentrated in certain places.

Because ferns were very dominant in the early years of degraded land after the fire, revegetation or planting activities required maintenance by cleaning the planted area from ferns. However, if natural regeneration is not carried out without planting, cleaning activities would not be needed. Still, it would be essential to prevent repeated forest fires because ferns in the dry season are the massive and dangerous fuels for forest fire in peatlands.

Conclusions

C. rotundatus were found at all observation locations from five different and far apart locations, while *C. arborescens* at 4 locations except at location E (Sungai Mantangai) at the tree growth level. These areas were all badly burned, and either canal damming or hydrological restoration was carried out afterward. In general, these two species filled the tree level in the area degraded by forest fires in 2006. Indexes of species diversity, richness, and evenness also show insufficient individuals, meaning that these two species survived the 2006 fires.

C. rotundatus was the dominant species at tree and sapling growth levels with better performance than *C. arborescens* based on the number of survived and existing individuals. At the same time, *C. arborescens* has a better performance than *C. rotundatus,* with a slight difference in dominance at pole level growth and seedling level growth. However, Both species have a low diversity index and a low evenness index in an ecosystem with a low richness index. Still, there are differences in location C (Katunjung) with a high species richness index. The Low diversity index means that this species is individually abundant but is not evenly distributed with high density in certain places.

Based on the minimum number of individuals, both species are successful and suitable for natural regeneration post forest firest in peat swamp forest as long as the area is rewetted by hydrological restoration (canal blockings). Therefore, natural generation by these species is one option that can be selected for vegetation restoration, especially for the remote areas that need high cost. In general, *C. arborescens* has a bit better performance than *C. rotundatus* in degraded peatland post fires.

Acknowledgements

We would like to thank those who have supported us during the study:

1. Bayu Nugroho, Head of Kapuas Kahayan Protected Forest Management Unit
2. Indonesia Endowment Fund for Education (LPDP Scholarship) as the sponsor
3. The Borneo Orang Utan Survival Foundation
4. Local people of Katunjung Village, Mantangai Sub-District, Central Kalimantan

References

Ahirwal, J., Kumari, S., Singh, A. K., Kumar, A., & Maiti, S. K. (2021). Changes in soil properties and carbon fluxes following afforestation and agriculture in tropical forest. *Ecological Indicators*, *123*, Article 107354. https://doi.org/10.1016/j.ecolind.2021.107354

Applegate, G., Freeman, B., Tular, B., Sitadevi, L., & Jessup, T. C. (2021). Application of agroforestry business models to tropical peatland restoration. *Ambio*, *2*. https://doi.org/10.1007/s13280-021-01595-x

Blackham, G. V., Webb, E. L., & Corlett, R. T. (2014). Natural regeneration in a degraded tropical peatland, Central Kalimantan, Indonesia: Implications for forest restoration. *Forest Ecology and Management*, *324*, 8–15. https://doi.org/10.1016/j.foreco.2014.03.041

Budiman, I., Bastoni, Sari, E. N., Hadi, E. E., Asmaliyah, Siahaan, H., Januar, R., & Hapsari, R. D. (2020). Progress of paludiculture projects in supporting peatland ecosystem restoration in Indonesia. *Global Ecology and Conservation*, *23*, Article e01084. https://doi.org/10.1016/j.gecco.2020.e01084

Chazdon, R. L., & Uriarte, M. (2016). Natural regeneration in the context of large-scale forest and landscape restoration in the tropics. *Biotropica*, *48*(6), 709–715. https://doi.org/10.1111/btp.12409

Chokkalingam, U., Kurniawan, I., & Ruchiat, Y. (2005). Fire, livelihoods, and environmental change in the Middle Mahakam Peatlands, East Kalimantan. *Ecology and Society*, *10*(1). https://doi.org/10.5751/ES-01320-100126

Cole, L. E. S., Willis, K. J., & Bhagwat, S. A. (2021). The future of Southeast Asia's tropical peatlands: Local and global perspectives. *Anthropocene*, *34*, Article 100292. https://doi.org/10.1016/j.ancene.2021.100292

Couwenberg, J. (2010). Greenhouse gas fluxes from tropical peatlands in south-east Asia. *Global Change Biology, 16*(6),. 1715–1732. https://doi.org/10.1111/j.1365-2486.2009.02016.x

Di Sacco, A., Hardwick, K. A., Blakesley, D., Brancalion, P. H. S., Breman, E., Rebola, L. C., Chomba, S., Dixon, K., Elliott, S., Ruyonga, G., Shaw, K., Smith, P., Smith, R. J., & Antonelli, A. (2021). Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. *Global Change Biology*, *27*(7), 1328-1348. https://doi.org/10.1111/gcb.15498

Dohong, A. (2016). *An assessment of hte restoration efforts of degraded peatland in Central Kalimantan Indonesia* [Doctoral dissertation, The University of Queensland]. UQ eSpace. https://doi.org/10.14264/uql.2016.771

Dohong, A., Aziz, A, A., & Dargusch, P. (2018). A review of techniques for effective tropical peatland restoration. *Wetlands*, *38*, 275-292. https://doi.org/10.1007/s13157-018-1017-6

Dohong, A., Aziz, A. A., & Dargusch, P. (2017). A review of the drivers of tropical peatland degradation in South-East Asia. *Land Use Policy*, *69*, 349–360. https://doi.org/10.1016/j.landusepol.2017.09.035

Lestari, D. P., Darusman, T., Harsanto, F. A., Ariyyadi, D., Ginanjar, G. (2021). Understanding natural regeneration in burned tropical peatland: A strategy to accelerate the forest recovery process. *BIOTROPIA - The Southeast Asian Journal of Tropical Biology*, *0*(0), 1–16. https://doi.org/10.11598/btb.0.0.0.1330

Badan Restorasi Gambut Republik Indonesia. (2016, November). *Rencana strategis badan restorasi gambut tahun 2016 – 2020*. https://brg.go.id/rencana-strategis-badan-restorasi-gambut-2016-2020/

Giesen, W., & Meer, P. V. D. (2009). *Guidelines for the Rehabilitation of degraded peat swamp forests in Central Kalimantan.*Master Plan for the Conservation and Development of the Ex-Mega Rice Project Area in Central Kalimantan. https://edepot.wur.nl/175467

Graham, L., Page, S., & Pickerill, J. (2013). *Regeneration Barriers Facing Rehabilitation of Degraded*

Tropical Peatland: An Alternative Approach to Considering Just the Ecological [PowerPoint slides]. DocPlayer. https://docplayer.net/10072536-Regeneration-barriers-facing-rehabilitation-of-degraded-tropical-peatland-an-alternative-approach-to-considering-just-the-ecological.html

Harrison, M. E., Ottay, J. B., D'Arcy, L. J., Cheyne, S. M., Anggodo, Belcher, C., Cole, L., Dohong, A., Ermiasi, Y., Feldpausch, T., Gallego-Sala, A., Gunawan, A., Höing, A., Husson, S. J., Kulu, I. P., Soebagio, S. M., Mang, S., Mercado, L., Morrogh-Bernard, H. C., … van Veen, F. J. F. (2020). Tropical forest and peatland conservation in Indonesia: Challenges and directions. *People and Nature*, *2*(1), 4–28. https://doi.org/10.1002/pan3.10060

Harrison, M. E., Wijedasa, L. S., Cole, L. E. S., Cheyne, S. M., Choiruzzad, S. A. B., Chua, L., Dargie, G. C., Ewango, C. E. N., Coronado, E. N. H., Ifo, S. A., Imron, M. A., Kopansky, D., Lestarisa, T., O'Reilly, P. J., van Offelen, J., Refisch, J., Roucoux, K., Sugardjito, J., Thornton, S. A., … Page, S. (2020). Tropical peatlands and their conservation are important in the context of COVID-19 and potential future (zoonotic) disease pandemics. *PeerJ*, *8*, 1–44. https://doi.org/10.7717/peerj.10283

Hooijer, A., Page, S., Canadell, J. G., Silvius, M., Kwadijk, J., Wösten, H., & Jauhiainen, J. (2010). Current and future CO 2 emissions from drained peatlands in Southeast Asia. *Biogeosciences*, *7*(5), 1505–1514. https://doi.org/10.5194/bg-7-1505-2010

Hooijer, A., Page, S., Jauhiainen, J., Lee, W. A., Lu, X. X., Idris, A., & Anshari, G. (2012). Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences*, *9*(3), 1053–1071. https://doi.org/10.5194/bg-9-1053-2012

Jauhiainen, J., Kerojoki, O., Silvennoinen, H., Limin, S., & Vasander, H. (2014). Heterotrophic respiration in drained tropical peat is greatly affected by temperature - A passive ecosystem cooling experiment. *Environmental Research Letters*, *9*(10). https://doi.org/10.1088/1748-9326/9/10/105013

Kimmel, K. & Mander, U. (2010). Ecosystem services of peatlands : Implications for restoration. *Progress in Physical Geography: Earth and Environment*. https://doi.org/10.1177/0309133310365595

Koh, L. P., Miettinen, J., Liew, S. C., & Ghazoul, J. (2011). Remotely sensed evidence of tropical peatland conversion to oil palm. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(12), 5127–5132. https://doi.org/10.1073/pnas.1018776108

Könönen, M., Jauhiainen, J., Laiho, R., Spetz, P., Kusin, K., Limin, S., & Vasander, H. (2016). Land use increases the recalcitrance of tropical peat. *Wetlands Ecology and Management*, *24*(6), 717–731. https://doi.org/10.1007/s11273-016-9498-7

Könönen, M., Jauhiainen, J., Straková, P., Heinonsalo, J., Laiho, R., Kusin, K., Limin, S., & Vasander, H. (2018). Deforested and drained tropical peatland sites show poorer peat substrate quality and lower microbial biomass and activity than unmanaged swamp forest. *Soil Biology and Biochemistry*, *123*, 229–241. https://doi.org/10.1016/j.soilbio.2018.04.028

Lampela, M., Jauhiainen, J., Sarkkola, S., & Vasander, H. (2017a). Promising native tree species for reforestation of degraded tropical peatlands. *Forest Ecology and Management*, *394*, 52–63. https://doi.org/10.1016/j.foreco.2016.12.004

Lampela, M., Jauhiainen, J., Sarkkola, S., & Vasander, H. (2018). To treat or not to treat ? The seedling performance of native tree species for reforestation on degraded tropical peatlands of SE Asia. *Forest Ecology and Management*, *429*, 217–225. https://doi.org/10.1016/j.foreco.2018.06.029

Lilleskov, E., McCullough, K., Hergoualc'h, K., Torres, D. D. C., Chimner, R., Murdiyarso, D., Kolka, R., Bourgeau-Chavez, L., Hribljan, J., Pasquel, J. D. A., & Wayson, C. (2019). Is Indonesian peatland loss a cautionary tale for Peru? A two-country comparison of the magnitude and causes of tropical peatland degradation. *Mitigation and Adaptation Strategies for Global Change*, *24*(4), 591–623. https://doi.org/10.1007/s11027-018-9790-3

Magurran, A. E. (2004). *Measuring Biological Diversity*. Blackwell Publishing.

Magurran, A. E., & McGill, B. J. (2011). *Biological diversity: frontiers in measurement and assessment*. Oxford University Press. http://www.amazon.co.uk/dp/0199580677

Mawazin, & Subiakto, A. (2013). Species diversity and composition of logged over peat swamp forest in Riau. *Indonesian Forest Rehabilitation Journal*, *1*(1), 59–73. http://ejournal.forda-mof.org/ejournal-litbang/index.php/IFRJ/article/view/521

Miettinen, J., Hooijer, A., Wang, J., Shi, C., & Liew, S. C. (2012). Peatland degradation and conversion sequences and interrelations in Sumatra. *Regional Environmental Change*, *12,* 729–737. https://doi.org/10.1007/s10113-012-0290-9

Miettinen, J., Shi, C., & Liew, S. C. (2012). Two decades of destruction in Southeast Asia' s peat swamp forests. *Frontiers in Ecology and the Environment, 10*(3), 124–128. https://doi.org/10.1890/100236

Murdiyarso, D., Lilleskov, E., & Kolka, R. (2019). Tropical peatlands under siege: The need for evidence-based policies and strategies. *Mitigation and Adaptation Strategies for Global Change*, *24*(4), 493–505. https://doi.org/10.1007/s11027-019-9844-1

Osaki, M., Hirano, T., Inoue, G., Honma, T., Takahashi, H., Takeuchi, W., Kobayashi, N., Evri, M., Kohyama, T., Ito, A., Setiadi, B., Sekine, H., & Hirose, K. (2012). Sensing / monitoring networks on carbon balance and biodiversity in tropical peatland. In S. Nakano, T. Yahara, & T. Nakashizuka (Eds.), *The Biodiversity Observation Network in the Asia-Pacific Region* (pp. 350-373). https://doi.org/10.1007/978-4-431-54032-8

Osaki, M., & Tsuji, N. (2015). *Tropical peatland ecosystems*. Springer. https://doi.org/10.1007/978-4-431-55681-7

Page, S. E., Banks, C. J., & Rieley, J. O. (2007). Tropical peatlands: Distribution, extent and carbon storage – uncertainties and knowledge gaps. *Peatlands International*, *2*(2), 26–27.

Page, S., Hosciło, A., Wösten, H., Jauhiainen, J., Silvius, M., Rieley, J., Ritzema, H., Tansey, K., Graham, L., Vasander, H., & Limin, S. (2008). Restoration ecology of lowland tropical peatlands in Southeast Asia: Current knowledge and future research directions. *Ecosystems*, *12*(6), 888–905. https://doi.org/10.1007/s10021-008-9216-2

Pindilli, E., Sleeter, R., & Hogan, D. (2018). Estimating the societal benefits of carbon dioxide sequestration through peatland restoration. *Ecological Economics*, *154*, 145–155. https://doi.org/10.1016/j.ecolecon.2018.08.002

Posa, M. R. C., Wijedasa, L. S., & Corlett, R. T. (2011). Biodiversity and conservation of tropical peat swamp forests. *BioScience*, *61*(1), 49–57. https://doi.org/10.1525/bio.2011.61.1.10

Scheper, A. C., Verweij, P. A., & van Kuijk, M. (2021). Post-fire forest restoration in the humid tropics: a synthesis of available strategies and knowledge gaps for effective restoration. *Science of The Total Environment*, *771*, Article 144647. https://doi.org/10.1016/j.scitotenv.2020.144647

Silvius, M., & Diemont, H. (2007). Peatlands, climate change, poverty, biofuels, pulp and reduced emissions from deforestation and degradation. *Institute for Environmental Studies.*. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.552.3571&rep=rep1&type=pdf

Suding, K., Higgs, E., Palmer, M., Callicott, J. B., Anderson, C. B., Baker, M., Gutrich, J. J., Hondula, K. L., LaFevor, M. C., Larson, B. M. H., Randall, A., Ruhl, J. B., & Schwartz, K. Z. S. (2015). Committing to ecological restoration. *Science*, *348*(6235), 638–640. https://doi.org/10.1126/science.aaa4216

Symes, W. S., Edwards, D. P., Miettinen, J., Rheindt, F. E., & Carrasco, L. R. (2018). Combined impacts of deforestation and wildlife trade on tropical biodiversity are severely underestimated. *Nature Communications*, *9*(1). https://doi.org/10.1038/s41467-018-06579-2

Tan, Z. D., Lupascu, M., & Wijedasa, L. S. (2021). Paludiculture as a sustainable land use alternative for tropical peatlands: A review. *Science of the Total Environment*, *753*, Article 142111. https://doi.org/10.1016/j.scitotenv.2020.142111

Tata, H. L. (2019). Paludiculture: Can it be a trade-off between ecology and economic benefit on peatland restoration? *IOP Conference Series: Earth and Environmental Science*, *394*(1). https://doi.org/10.1088/1755-1315/394/1/012061

Taufik, M., Veldhuizen, A. A., Wösten, J. H. M., & van Lanen, H. A. J. (2019). Exploration of the importance of physical properties of Indonesian peatlands to assess critical groundwater table depths, associated drought and fire hazard. *Geoderma*, *347*, 160–169. https://doi.org/10.1016/j.geoderma.2019.04.001

Toriyama, J., Takahashi, T., Nishimura, S., Sato, T., Monda, Y., Saito, H., Awaya, Y., Limin, S. H., Susanto, A. R., Darma, F., Krisyoyo, & Kiyono, Y. (2014). Estimation of fuel mass and its loss during a forest fire in peat swamp forests of Central Kalimantan, Indonesia. *Forest Ecology and Management*, *314*, 1–8. https://doi.org/10.1016/j.foreco.2013.11.034

Uda, S. K., Schouten, G., & Hein, L. (2020). The institutional fit of peatland governance in Indonesia. *Land Use Policy*, *99*, Article 103300. https://doi.org/10.1016/j.landusepol.2018.03.031

van Eijk, P., & Leenman, P. (2004). *Regeneration of fire degraded peatswamp forest in Berbak National Park and implementation in replanting programmes*. T Water for Food & Ecosystems Programme project on "Promoting the river basin and ecosystem approach for sustainable management of SE Asianlowland peatswamp forest" Case Study Air Hitam Laut river basin, Jambi Province, Indonesia..

Ward, C., Stringer, L. C., Warren-Thomas, E., Agus, F., Crowson, M., Hamer, K., Hariyadi, B., Kartika, W. D., Lucey, J., McClean, C., Nurida, N. L., Petorelli, N., Pratiwi, E., Saad, A., Andriyani, R., Ariani, T., Sriwahyuni, H., & Hill, J. K. (2021). Smallholder perceptions of land restoration activities: Rewetting tropical peatland oil palm areas in Sumatra, Indonesia. *Regional Environmental Change*, *21*(1). https://doi.org/10.1007/s10113-020-01737-z

Wijedasa, L. S., Vernimmen, R., Page, S. E., Mulyadi, D., Bahri, S., Randi, A., Evans, T. A., Lasmito, Priatna, D., Jensen, R. M., & Hooijer, A. (2020). Distance to forest, mammal and bird dispersal drive natural regeneration on degraded tropical peatland. *Forest Ecology and Management*, *461*, Article 117868. https://doi.org/10.1016/j.foreco.2020.117868

Wösten, J. H. M., Rieley, J. O., Page, S. E. (Eds.). (2008). *Restoration of Tropical Peatlands.* ALTERRA. https://www.wur.nl/upload_mm/e/5/a/4d874adb-f5e6-4da4-9f8a-79114e7b2291_RestorationBook5.pdf

Yule, C. M. (2010). Loss of biodiversity and ecosystem functioning in Indo-Malayan peat swamp forests. *Biodiversity and Conservation*, *19*(2), 393–409. https://doi.org/10.1007/s10531-008-9510-5

Yuliani, F. (2017). Pelaksanaan cannal blocking sebagai upaya restorasi gambut di Kabupaten Meranti Provinsi Riau. *Spirit Publik,* *12*(1), 69–84. https://jurnal.uns.ac.id/spirit-publik/article/view/11746/10404

Zhaojun, B., Joosten, H., Hongkai, L., Gaolin, Z., Xingxing, Z., Jinze, M., & Jing, Z. (2011). The response of peatlands to climate warming : A review. *Acta Ecologica Sinica*, *31*(3), 157–162. https://doi.org/10.1016/j.chnaes.2011.03.006