Jurnal Lahan Suboptimal : Journal of Suboptimal Lands
ISSN: 2252-6188 (Print), ISSN: 2302-3015 (Online, www.jlsuboptimal.unsri.ac.id)
Vol. 12, No.2: 209-218 Oktober 2023
DOI: 10.36706/JLSO.12.2.2023.584

Revegetation of Tropical Peat Swamp Forest of Former Fires Using Local Tree Species in South Sumatra (Indonesia)

Revegetasi Hutan Rawa Gambut Bekas Kebakaran Menggunakan Jenis Pohon Lokal di Sumatera Selatan (*Indonesia*)

Bastoni Bastoni[1*)], Raissa Anjani[2], Andika Imanullah[3]

[1]Research Center for Ecology and Ethnobiology, National Research and Innovation Agency, Cibinong 16911, Bogor, West Java, Indonesia
[2]Research Center for Environmental and Clean Technology, National Research and Innovation Agency, Bandung 40135, West Java, Indonesia
[3]Research Center for Applied Zoology, National Research and Innovation Agency, Cibinong 16911, Bogor, West Java, Indonesia
[*)]Corresponding author: bastonibrata3@gmail.com

(Received: 27 February 2023, Accepted: 20 September 2023)

Citation: Bastoni B, Anjani R, Imanullah A. 2023. Revegetation of tropical peat swamp forest of former fires using local tree species in South Sumatra (Indonesia). *Jurnal Lahan Suboptimal : Journal of Suboptimal Lands.* 12 (2): 209-218. DOI: 10.36706/JLSO.12.2.2023.645.

ABSTRAK

Revegetasi hutan rawa gambut tropis (HRG) bekas kebakaran dengan jenis pohon lokal mempunyai nilai strategis untuk pemulihan HRG yang sebagian besar telah hilang dan terdegradasi berat oleh penebangan hutan, konversi, drainase dan kebakaran berulang. Pemulihan HRG akan diikuti oleh peningkatan tutupan hutan, sekuestrasi CO_2, produksi O_2 dan biodiversitas ekosistem gambut. Penelitian bertujuan untuk menganalisis pertumbuhan tanaman revegetasi pada HRG bekas kebakaran. Penelitian menggunakan rancangan percobaan lapangan dengan 4 jenis pohon lokal gambut, yaitu ramin (*Gonystylus bancanus*), punak (*Tetramerista glabra*), tembesu (*Fragraea. fragrans*) dan pulai (*Alstonia pneumatophora*). Hasil penelitian sampai umur 2 tahun menunjukkan daya hidup tanaman revegetasi berkisar antara 92,56%–94,69%, riap tinggi 32,53–44,94 cm/tahun dan riap diameter 0,87–1,21 cm/tahun. Pertumbuhan tanaman revegetasi masih mengalami fase percepatan pada pengamatan sampai umur 3 tahun. Penelitian ini memberikan optimisme bahwa revegatasi HRG yang telah terdegradasi oleh kebakaran dapat dilakukan dengan hasil yang memuaskan.

Kata kunci: hutan rawa gambut, jenis pohon lokal, daya hidup, riap tinggi, riap diameter

ABSTRACT

Revegetation of tropical peat swamp forests (PSF) from former fires with local tree species has strategic value for the recovery of PSF, which has been largely lost and severely degraded by logging, conversion, drainage, and repetitive fires. The PSF recovery will be followed by increased forest cover, CO_2 sequestration, O_2 production, and peat ecosystem biodiversity. The method of revegetation that guarantees successful planting is still very lacking and has not been widely publicized. The study aimed to analyze the growth of revegetated plants on PSF of former fires. It used a field experiment design with four types of local peat plants, namely *ramin* (*Gonystylus bancanus*), *punak* (*Tetramerista glabra*), *tembesu* (*Fragraea fragrans*), and *pulai* (*Alstonia pneumatophora*). The results of the study showed that until the age of 2 years, the survival rate of revegetated plants ranged from 92.56%–94.69%, with growth of 32.53–44.94 cm/year and diameter growth of 0.87–1.21 cm/year. The growth of revegetated plants still accelerated in observations until the age of 3 years. This study provides optimism that PSF revegetation degraded by the fires could be carried out with satisfactory results.

Keywords: peat swamp forests, local tree species, survival rate, height growth, diameter growth

INTRODUCTION

Tropical peat swamp forests (PSF) widely found in Southeast Asia, mainly in Indonesia where forty-seven percent of PSF was lost between 1990 and 2015, only 29% was found as primary forest in 2015 (Miettinen et al., 2016). Peatlands decreased by about 1.47 M ha between 2013 and 2019 in Indonesia (Anda et al., 2021). PSF is a type of swamp forest with a specific and fragile ecosystem (Osaki et al., 2021), both in terms of land habitat in the form of peat with high organic carbon content and a thickness ranging from less than 0.5 m to a depth of more than 20 m (Daryono, 2009; Page et al., 2002). PSF stores large amounts of carbon in its peat, but peat degradation causes high greenhouse gas emissions (Graham et al., 2017; Ma et al., 2022).

PSF degradation is caused by three main factors: logging, fires and land conversion, followed by peat drainage (Mishra et al., 2021; Osaki et al., 2021). Degraded PSF directly increases fire susceptibility (Dohong et al., 2017; Mishra et al., 2021). Fires are a huge source of carbon emissions (CO_2); for example, peatland fires in Central Kalimantan in 1997 were estimated to release 0.19–0.23 G tons of carbon emissions from a burned area of 0.73 million ha (Page et al., 2002). Recurrent fires are also directly correlated with increased bulk density of peat soils and decreased biodiversity (Wijedasa, 2016). Repeated fires slow down the speed of peat recovery due to the damage to soil physical properties (Hoscilo et al., 2011; Sinclair et al., 2020) and damage to seed sources and mother trees (Blackham et al., 2013) and increase the density of naturally growing pioneer species from the remaining forest stands (Blackham et al., 2014; Posa et al., 2011). Microtopographic changes in burnt peat areas into basins where the standing water stunts the natural species (Lampela et al., 2016).

Indonesia has a target to restore 2.4 million ha of degraded peat in seven provinces affected by fires (Dohong et al., 2018; Wicaksono & Zainal, 2022). Restoration consists of three main activities: rewetting, revegetation and revitalization. Rewetting is an effort to increase groundwater levels on peatlands that have already been drained through the construction of canal bulkheads and canal stockpiling, and revegetation of peatland that was burnt through replanting local tree species. Revitalization aims to improve the livelihoods of local communities (Dohong et al., 2018; Mishra et al., 2021; Yuwati et al., 2021). Revegetation has a strategic goal in PSF recovery because it will be able to restore forest cover, increase carbon dioxide (CO_2) sequestration (Budiman et al., 2020), produce oxygen (O_2), and increase the biodiversity of flora and fauna (Smith et al., 2022). Revegetation still faces considerable problems because although the costs incurred are quite significant, it still does not guarantee the success of revegetation due to the threat of repeated fires and soil damage less supportive of plant growth (Graham et al., 2017; Smith et al., 2022). The method of revegetation that guarantees successful planting is still very lacking and has not been widely publicized (Graham et al., 2017). This study aimed to analyze the growth of 4 species of local peat trees from PSF revegetation activities on the former fires in OKI District, South Sumatra.

MATERIALS AND METHODS

Research Site

The research site was located in the Limited Production Forest (LPF) of Pedamaran (Figure 1). The research activities were carried out from October 2016 to December 2019. LPF of Pedamaran was in the Peat Hydrological Unit (PHU) of Burnai River – Sibumbung River, Ogan Komering Ilir District, South Sumatra. The research area was a former fire of PSF in 2012. GPS site 3°31’27.6’’ S, 105°01’07.7 E.

Materials

The research materials consisted of 4 species of peat local tree seedlings, namely: *ramin* (*Gonystylus bancanus*), *punak* (*Tetramerista glabra*), swamp *pulai* (*Alstonia pneumatophora*), *tembesu* (*Fragraea fragrans*); NPK compound fertilizer (15:15:15), bamboo stakes. The tools comprised a compass, calipers, meters. and land preparation tools.

Methods

The research plot was designed in the species trial method (Wahno et al., 2022) and built on an area of 1.6 ha divided into 16 treatment plots. The size of each treatment plot was 40 m x 25 m (Figure 2).

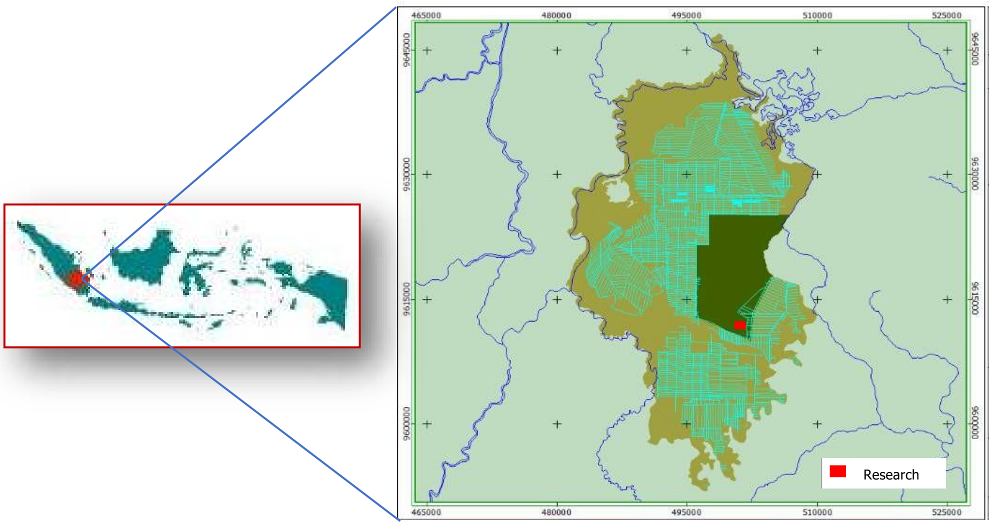

Figure 1. Research site in LPF of Pedamaran, OKI District, South Sumatra (Ngudiantoro, 2022)

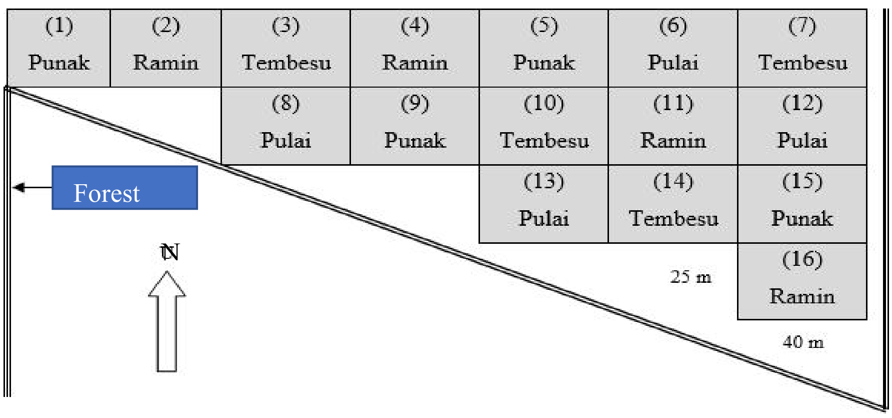

Figure 2. Layout of research plots in an area of 1.6 hectares

The observation and measurement of several variables of vegetation, soil, and hydrology (Hanum et al., 2019), on a plot area of 1.6 ha were carried out to find out the characteristics of peatlands of former fires, followed by total clearance activities of the understorey. The planting distance was 5 m x 4 m in which one treatment plot consisted of 50 plants. At each plant stake, the roots of undergrowth and wood left over from the forest fires were cleaned. After that, peat mounds were made to collect peat soil mass and raise part of the soil, so the tree seedlings were not submerged in the rainy season. The next stage was planting activities conducted at the beginning of the rainy season before entering the peak of inundation, followed by root plant clearance activities and NPK fertilization dose 20 g/stem at the ages of 4 months, 8 months, 12 months, 18 months, 24 months, 30 months, and 36 months after planting. Growth observations and measurements were carried out once every 6 months until the plant reached 3 years old.

Experimental design and data analysis

This field research used a completely randomized trial design because the land conditions were relatively uniform (homogeneous) with flat topography (< 3%). The growth variables measured were survival rate, height growth, and diameter growth. Growth measurement data were analyzed using analysis of variance (ANOVA) and then continued with Duncan's Multiple Range Test (DMRT) for growth variables significantly different from the analysis of variance. The plants whose growth was measured were those in the middle of the treatment plot, as many as 8 x 3 = 24 plants per plot.

RESULT AND DISCUSSION

Land Characteristics

The results of observations and measurements of land characteristics were presented in Table 1.

Revegetated Plants Survival Rate

The survival rate of plants was an important indicator that shows the adaptability of plants to the conditions of their growing environment. The result of variance analysis in very deep PSF (Table 2 & 3).

Viability shows species adaptability to grow in some environmental conditions and could be used as indicator for species selection in rehabilitation. The results of the viability among 4 species of revegetated plants in very deep PSF could be seen in Table 4.

Tabel 1.Characteristics of very deep peat (> 300 cm) in burn-affected PSF revegetation plots in Ogan Komering Ilir District, South Sumatra

Land Characteristics	Very deep peat (> 300 cm) LPF of Pedamaran
A. Land	Typic Tropohemist
Land Type	410 – 625 cm (very deep) Hemic
Peat Thickness	Ombrogenic (low fertility)
Peat Maturity	3.4 (very acidic)
Peat Type	
pH peat	10 – 18 cm (shallow)
B. Hidrology	45 – 63 cm (medium – deep) 9 months (long)
Peak water level during the rainy season	3.7 (very acid)
Depth of groundwater end of dry season	
Duration of waterlogging	Beriang (*Ploiarum alternifolium*) Perepat (*Combretocarpus rotundatus*) Gelam (*Melaleuca leucadendron*) Gelam tikus (*Eugenia* sp.)
Water pH	
C. Vegetation results from natural succession	
Tree	Pakis udang (*Stenochlaena palustris*) Pandan duri (*Pandanus* sp.)
Understorey	Purun tikus (*Eleocharis dulcis*)

Revegetated Plant Height Growth

The results of the variance analysis of the height growth of 4 species of revegetated plants on very deep PSF were presented in Table 5 and 6. The results of the variance analysis showed that the height of the four species of plants for very deep PSF revegetation was significantly different. The comparison of the height of the four species of plants was presented in Table 7.

Diameter Growth of Revegetated Plants

The results of the variance analysis of diameter growth of 4 species of revegetated plants in very deep PSF presented in Table 8 and 9. The results of the variance analysis showed that the diameter growth of the 4 species of plants selected for very deep PSF revegetation was significantly different at the age of 12 months and insignificantly different at the age of 24 months. A comparison of the growth diameters of the four types of plants was presented in Table 10.

Growth of Revegetated Plants in Very Deep PSF According to Age

The height and diameter growth of 4 species of revegetated plants in very deep PSF (> 300 cm) was presented in Figure 3 & 4.

Table 2. Analysis of variance of the survival rate of 4 species of plants revegetation aged 12 months on very deep PSF (> 300 cm)

Source of Variance	dF	SS	MS	F-count
Plant species	3	70.312	23.438	0.59 ns
Galat	12	478.125	39.844	
Total	15	548.437		

Note: ns = insignificantly different at the 5% test level

Table 3. Analysis of variance of the survival rate of 4 species of revegetated plants aged 24 months on very deep PSF (> 300 cm)

Source of Variance	dF	SS	MS	F-count
Plant species	3	149.563	49.854	1.88 ns
Galat	12	318.85	26.573	
Total	15	468.438		

Note: ns = insignificantly different at the 5% test level

Table 4. Duncan's Multiple Range Test (DMRT) for the viability of 4 species of revegetated plants in very deep PSF (> 300 cm)

Species of Revegetated Plants	Survival Rate (%)	
	Aged 12 Months	Aged 24 Months
Punak (*T. glabra*)	97.50_a	96.87_a
Pulai (*A. pneumatophora*)	95.62_a	93.75_a
Ramin (*G. bancanus*)	93.75_a	90.87_a
Tembesu (*F. fragrans*)	91.87_a	88.75_a
Avarage	94.69	92.56

Note: numbers followed by the same letter in columns, insignificantly different according to DMRT test at 5% test level

Table 5. Analysis of variance of height growth of 4 species of revegetated plants aged 12 months in very deep PSF (> 300 cm)

Source of Variance	dF	SS	MS	F-count
Plant species	3	2515.009	838.336	8.28^{**}
Galat	12	1215.139	101.261	
Total	15	3730.147		

Note: ** = significantly different at 1% test level

Table 6. Analysis of variance of the height growth of 4 species of revegetated plants aged 24 months on very deep PSF (> 200 cm)

Source of Variance	dB	SS	MS	F-count
Plant species	3	4641.850	1547.283	6.68 **
Galat	12	2778.736	231.561	
Total	15	7420.586		

Note: ** = significantly different at 1% test level

Table 7. Duncan's Multiple Range Test (DMRT) of height growth of 4 species of revegetated plants on very deep PSF (> 300 cm)

Species of Revegetated Plants	Height Growth (cm/year)	
	Aged 12 Months	Aged 24 Months
Tembesu (*F. fragrans*)	49.14_a	66.59_a
Punak (*T. glabra*)	40.10_a	56.35_a
Pulai (*A. pneumatophora*)	21.55_a	25.74_a
Ramin (*G. bancanus*)	19.30_a	31.07_a
Avarage	32.53	44.94

Note: numbers followed by the same letter in columns, insignificantly different according to DMRT at 5% test level

Table 8. Analysis of variance of the diameter growth of 4 species of revegetated plants aged 12 months on very deep PSF (> 300 cm)

Source of variance	dF	SS	MS	F-count
Plant species	3	0.6702	0.2234	2.14^*
Galat	12	1.2503	0.1042	
Total	15	1.9205		

Note: * = significantly different at 5% test level

Table 9. Analysis of variance of the diameter growth of 4 species of revegetated plants aged 24 months on very deep PSF (> 300 cm)

Source of variance	dF	SS	MS	F-count
Plant species	3	1.141	0.380	1.86_{ns}
Galat	12	2.456	0.205	
Total	15	3.598		

Note: ns = insignificantly different at 5% test level

Table 10. Duncan's Multiple Range Test (DMRT) of diameter growth of 4 species of revegetated plants on very deep PSF (> 300 cm)

Species of Revegetated Plants	Diameter Growth (Cm/Year)	
	Aged 12 Months	Aged 24 Months
Punak (*T. glabra*)	1.11_a	1.48_a
Tembesu (*F. fragrans*)	0.95_{ab}	1.21_a
Pulai (*A. pneumatophora*)	0.80_{ab}	1.37_a
Ramin (*G. bancanus*)	0.55_b	0.78_a
Avarage	0.87	1.21

Note: numbers followed by the same letter in columns, insignificantly different according to DMRT test at 5% test level

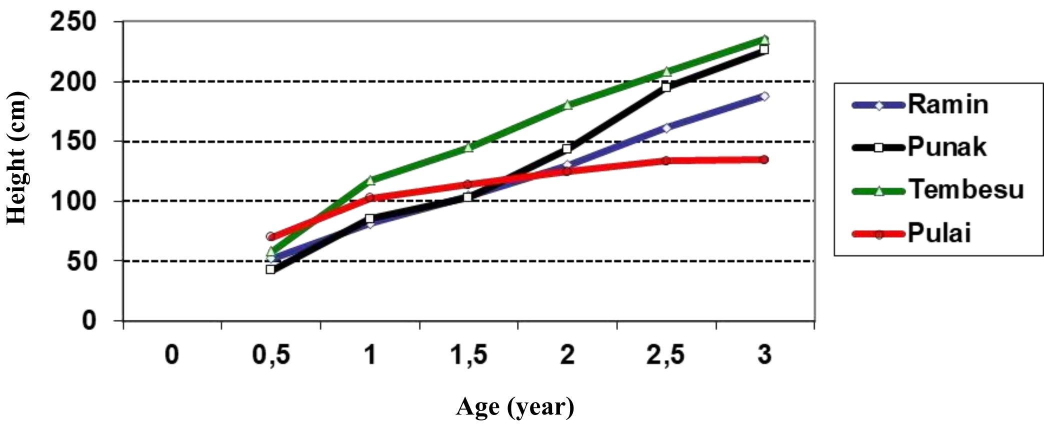

Figure 3. The height of 4 species of revegetated plants until the age of 3 years after planting in very deep PSF in LPF of Pedamaran, OKI District - South Sumatra

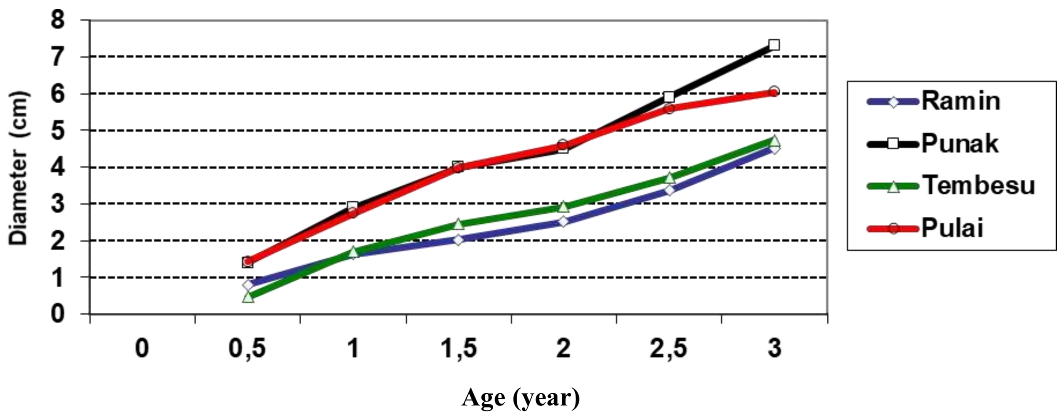

Figure 4. The diameter of 4 species of revegetated plants until the age of 3 years after planting on very deep PSF in the Pedamaran LPF area, OKI District - South Sumatra

DISCUSSION

Based on the observed variables, the peatland characteristics of 4 years after the fire in the study area already existed a natural succession of vegetation from both tree strata and understorey (Table 1). The intensity of fires was relatively low, so there was still vegetation of tree strata that was not burned to death and recovered after the fire (Giesen & Sari, 2018). The relatively long duration of waterlogging with shallow waterlogging and moderate groundwater levels (Table 1) could also prevent high-intensity fires resulting in land conditions to be not degraded heavily. These conditions supported the growth of revegetated plants planted in PSF of former fires (Blackham et al., 2013, 2014; Hoscilo et al., 2011; Posa et al., 2011; Sinclair et al., 2020; Wijedasa, 2016).

The results of the analysis of variance (ANOVA) showed that the survival rate of the four species of revegetated plants aged 12 and 24 months was not significantly different (Table 2 & 3), with an average survival rate of 94.69 % at 12 months of age and 92.56 % at 24 months of age (Table 4). This shows that the four species of rehabilitation plants have high viability and good adaptability to growing environmental conditions and can be selected for the rehabilitation of very deep (> 300 cm) peat swamp forests after fires. The results of a revegetation study of 141 plant species at 92 sites in the Southeast Asia region obtained an average survival rate of 62 % (Smith, 2022), lower than the results of this study. Another study showed that the viability of PSF revegetation plants in

Central Kalimantan was < 50% (Tata & Pradjadinata, 2016). The high viability of the results of this study is in line with and supported by the characteristics of the land in the study area (Table 1) which are not heavily degraded.

The results of ANOVA showed that the height increment of revegetated plants was highly significant at 12 and 24 months after planting (Table 5 & 6). The height growth of the 4 species of revegetated plants varied from 19.30 – 49.14 cm/year at 12 months to 31.07 – 66.59 cm/year at 24 months of age. The growth sequence from the highest to the lowest was tembesu (*F. fragrans*), punak (*T. glabra*), island (*A. pneumatophora*) and ramin (*G. bancanus*) (Table 7). The difference in height growth between the plant species occurred because each type had a different growth character, ranging from fast to slow growth. In this case *ramin* was classified as a slow-growing species. The average height growth of revegetated plants increased from 35.53 cm/year at 12 months of age to 44.94 cm/year at 24 months of age; this shows that revegetated plants still underwent a growth acceleration phase. Data and information about the height increment of revegetated plants up to 24 months of age is minimal. Several publications provide the growth data at <12 months after planting (Santosa et al., 2020; Tata & Pradjadinata, 2016).

The results of ANOVA of the diameter growth of the four species of revegetated plants were slightly different from the high growth. The growth diameter significantly differed at 12 months and insignificantly at 24 months (Table 8 & 9). The diameter growth of the 4 species of revegetated plants varied from 0.55 – 1.11 cm/year at 12 months of age to 0.78 – 1.48 cm/year at 24 months of age. The sequence of growth from the highest to the lowest is *punak* (*T. glabra*), *pulai* (*A. pneumatophora*), *tembesu* (*F. fragrans*) and *ramin* (*G. bancanus*) (Table 10). The average growth diameter of revegetated plants increased from 0.87 cm/year at 12 months of age to 1.21 cm/year at 24 months of age. This indicated that revegetated plants still underwent an accelerated growth phase. From the results of this study, the pattern of growth in height and growth in diameter of revegetated plants is relatively the same. Increasing the growth of revegetated plants can be done by applying AeroHydro Culture Technology (Osaki et al., 2021).

The results of observations and measurements of plant height and diameter up to 3 years after planting showed that the revegetated plants in the fire-affected PSF at LPF Pedamaran had satisfactory growth performance (Figure 3 & 4). This gives optimism that revegetation of degraded PSF is relatively not as tricky as the research results published (Smith et al., 2022; Tata & Pradjadinata, 2016). Various post-fire peat land and forest biophysical constraints (Blackham et al., 2013, 2014; Hoscilo et al., 2011; Lampela et al., 2016; Posa et al., 2011; Sinclair et al., 2020; Wijedasa, 2016) need to be anticipated by applying land preparation, planting, and maintenance techniques appropriate to site conditions.

CONCLUSION

The growth of 4 species of local peat trees for revegetation of burn affected PSF in South Sumatra showed very satisfactory results with a high survival rate (> 90%). Revegetated plants still underwent an accelerated growth phase, as shown by the height growth and diameter growth, which increased up to 3 years of age after planting.

ACKNOWLEDGEMENTS

The authors would like to express gratitude for the research funding support granted by the Agency of Research Development and Innovation, Ministry of Environment and Forestry. The authors are also very grateful to the Head of the Office of Forestry of OKI District and the Head of the Forest Management Unit of Region V Lempuing – Mesuji who have given permission for the research location at the Pedamaran LPF.

REFERENCES

Anda M, Ritung S, Suryani E, Sukarman, Hikmat M, Yatno E, Mulyani A, Subandiono RE, Suratman, Husnain. 2021. Revisiting tropical peatlands in Indonesia: Semi-detailed mapping, extent and depth distribution assessment. *Geoderma*. 402 (June): 115-235. DOI: 10.1016/j.geoderma.2021.115235.

Blackham GV, Thomas A, Webb EL, Corlett RT. 2013. Seed rain into a degraded tropical peatland in Central Kalimantan, Indonesia. *Biological Conservation*. 167: 215–223. DOI: 10.1016/j.biocon.2013.08.015.

Blackham GV, Webb EL, Corlett RT. 2014. Natural regeneration in a degraded tropical peatland, Central Kalimantan, Indonesia: Implications for forest restoration. *Forest Ecology and Management*. 324: 8–15. DOI: 10.1016/j.foreco.2014.03.041.

Santosa BP, Andriani S, Ardhana A, Syaifuddin. 2020. Effect of Land Mounding on Seedling Growth of Gemor (Nothaphoebe coriacea, Kosterm.) on Peat Swamp Forest. *IOP Conference Series: Earth and Environmental Science*. 499 (1). DOI: 10.1088/1755-1315/499/1/012015.

Budiman I, Bastoni, Sari EN, Hadi EE, Asmaliyah, Siahaan H, Januar R, Hapsari RD. 2020. Progress of paludiculture projects in supporting peatland ecosystem restoration in Indonesia. *Global Ecology and Conservation*. 23: e01084. DOI: 10.1016/j.gecco.2020.e01084.

Daryono H. 2009. Potential, problems and policies needed in sustainable forest and peat swamp land management. *Jurnal Analisis Kebijakan Kehutanan*. 6: 71–101.

Dohong, A., Abdul Aziz, A., & Dargusch, P. 2018. A Review of Techniques for Effective Tropical Peatland Restoration. *Wetlands*. 38 (2): 275–292. DOI: 10.1007/s13157-018-1017-6.

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

Hanum FI, Yusoff FM, Fitrianto A, Ainuddin NA, Gandaseca S, Zaiton S, Norizah, K., Nurhidayu S, Roslan MK, Hakeem KR, Shamsuddin I, Adnan I, Awang Noor AG, Balqis ARS, Rhyma PP, Aminah IS, Hilaluddin F, Fatin R, Harun NZN. 2019. Development of a comprehensive mangrove quality index (MQI) in Matang Mangrove: Assessing mangrove ecosystem health. *Ecological Indicators*. 102: 103–117. DOI: 10.1016/j.ecolind.2019.02.030.

Giesen W, Sari ENN. 2018. Tropical Peatland Restoration Report: the Indonesian case. In *Kemitraan Kesejahteraan Hijau (Kehijauan Berbak)* (Issue March). DOI: 10.13140/RG.2.2.30049.40808.

Graham LLB, Giesen W, Page SE. 2017. A common-sense approach to tropical peat swamp forest restoration in Southeast Asia. *Restoration Ecology*. 25 (2): 312–321. DOI: 10.1111/rec.12465.

Hoscilo A, Page SE, Tansey KJ, Rieley JO. 2011. Effect of repeated fires on land-cover change on peatland in southern Central Kalimantan, Indonesia, from 1973 to 2005. *International Journal of Wildland Fire*. 20 (4): 578–588. DOI: 10.1071/WF10029.

Lampela M., Jauhiainen J, Kamari I, Koskinen M, Tanhuanpaa T, Valkeapaa A, Vasander H. 2016. Ground surface microtopography and vegetation patterns in a tropical peat swamp forest. *Catena*. 139: 127–136. DOI: 10.1016/j.catena.2015.12.016.

Ma L, Zhu G, Chen B, Zhang K, Niu S, Wang J, Ciais P, Zuo H. 2022. A globally robust relationship between water table decline, subsidence rate, and carbon release from peatlands. *Communications Earth and Environment*. 3 (1): 1–14. DOI: 10.1038/s43247-022-00590-8.

Miettinen J, Shi C, Liew SC. 2016. Land cover distribution in the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2015 with changes since 1990. *Global Ecology and Conservation*. 6: 67–78. DOI: 10.1016/j.gecco.2016.02.004.

Mishra S, Page SE, Cobb AR, Lee JSH, Jovani-Sancho AJ, Sjögersten S, Jaya A, Aswandi, Wardle DA. 2021. Degradation of Southeast Asian tropical peatlands and integrated strategies for their better management and restoration. *Journal of Applied Ecology*. 58 (7): 1370–1387. DOI: 10.1111/1365-2664.13905.

Ngudiantoro. 2022. Peat restoration. in Y. Lisnawati & B. Nasrul (Eds.), *Peat Restoration Lessons from the Sumatra Region* (p. 51). IPB Press.

Osaki M, Tsuji N, Foead N, Rieley J. 2021. Tropical Peatland Eco-management. In *Tropical Peatland Eco-management*. DOI: 10.1007/978-981-33-4654-3.

Page SE, Siegert F, Rieley JO, Boehm HDV, Jaya A, Limin S. 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*. 420 (6911): 61–65. DOI: 10.1038/nature01131.

Posa MRC, Wijedasa LS, Corlett RT. 2011. Biodiversity and conservation of tropical peat swamp forests. *BioScience*. 61 (1): 49–57. DOI: 10.1525/bio.2011.61.1.10.

Sinclair AL, Graham LLB, Putra EI, Saharjo BH, Applegate G, Grover SP, Cochrane MA. 2020. Effects of distance from canal and degradation history on peat bulk density in a degraded tropical peatland. *Science of the Total Environment*. 699: 134-199. DOI: 10.1016/j.scitotenv.2019.134199.

Smith SW, Rahman NEB, Harrison ME, Shiodera S, Giesen W, Lampela M, Wardle DA, Chong KY, Randi A, Wijedasa LS, Teo PY, Fatimah YA, Teng NT, Yeo JKQ, Alam MJ, Brugues Sintes P, Darusman T, Graham LLB, Katoppo DR, Lee JSH. 2022. Tree species that 'live slow, die older' enhance tropical peat swamp restoration: Evidence from a systematic review. *Journal of Applied Ecology*. 59 (8): 1950–1966. DOI: 10.1111/1365-2664.14232.

Tata HL, Pradjadinata S. 2016. Native Species for Degraded Peat Swamp Forest Rehabilitation. *Journal of Tropical Silviculture*. 7 (3): S80–S82. DOI: 10.29244/j-siltrop.7.3.s80-s82.

Wahno I, Nugraheni M, Herdyantara B, Gafur A, Tjahjono B. 2022. Re-wetted peatland management through selection of native species in Sinarmas Forestry. *IOP Conference Series: Earth and Environmental Science*. 1025 (1): 0–7. DOI: 10.1088/1755-1315/1025/1/012022.

Wicaksono A, Zainal. 2022. Peatlands Restoration Policies in Indonesia: Success or Failure? *IOP Conference Series: Earth and Environmental Science*. 995 (1). DOI: 10.1088/1755-1315/995/1/012068.

Wijedasa LS. 2016. Peat soil bulk density important for estimation of peatland fire emissions. *Global Change Biology*. 22 (9): 29-59. DOI: 10.1111/gcb.13364.

Yuwati TW, Rachmanadi D, Pratiwi, Turjaman M, Indrajaya Y, Nugroho HYSH, Qirom MA, Narendra BH, Winarno B, Lestari S, Santosa PB, Adi RN, Savitri E, Putra PB, Wahyuningtyas RS, Prayudyaningsih R, Halwany W, Nasrul B, Bastoni, Mendham D. 2021. Restoration of degraded tropical peatland in indonesia: A review. *Land*. 10 (11): 1–33. DOI: 10.3390/land10111170.