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Vegetation composition on peatlands with different fire frequency in Musi Banyuasin, South Sumatra

Awaludin Jamil[a], Yudi Setiawan[abc], Lilik Budi Prasetyo[bc]

[a] Natural Resources and Environmental Management Study Program, Graduate School, IPB University, IPB Darmaga Campus, Bogor, 16680, Indonesia
[b] Department of Forest Resources Conservation and Ecotourism, Faculty of Forestry and Environment, IPB University, IPB Darmaga Campus, Bogor, 16680, Indonesia
[c] Environmental Research Center, IPB University, IPB Darmaga Campus, Bogor, 16680, Indonesia

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Corresponding Author:
Awaludin Jamil
Natural Resources and Environment Management, IPB University;
Tel. +6281284303867
Email:
awaljamil8@gmail.com

Abstract. *Peatlands can recover their ecosystem after the occurrence of fire through a process of vegetation succession. Areas with different fire frequencies had different vegetation dominance. We made several observations on areas that were burnt once, twice, three, and four times. The purpose of this study was to explain the differences in vegetation composition in areas with different fire frequencies. Saplings and understoreys were found in all fire frequency classes, seedlings were found in the once and three-times-burnt, poles were found in the once-burnt, and trees were only found in the once and twice-burnt. Exbucklandia populnea species dominated saplings that were observed in the once-burnt. In the twice-burnt, they were dominated by Malicope glabra, in the three-times-burnt was dominated by* Alstonia pneumatophora *and* Exbucklandia populnea. *In the four-times-burnt, the domination was by Exbucklandia populnea. The understoreys in the once, twice, and three-times-burnt were dominated by* Asplenium longissimum *whilst* Athyrium esculentum *dominated the four times-burnt.*

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INTRODUCTION

Peat forest has a fairly broad function and role in the aspects of environmental, social, and economic. In terms of ecology, peat swamps have an important role in maintaining biodiversity, hydrology, climate, and terrestrial carbon storage (Setiawan *et al.* 2016). The high rate of land and forest fires recurrence causes huge ecological, economic, health, and social deprivation to such an extent that a management system is needed to control the fire (Rianawati *et al.* 2016; Rezainy *et al.* 2020). One effort that can be made to minimize these risks is a social approach to agricultural production models on shallow peatlands (Gunawan *et al.* 2020). The ecological disadvantage of moderate to high-intensity fires in peat swamp forest is the increase in the number of dead trees and shrubs and a decrease in tree species diversity at all growth stages (Malkisnon *et al.* 2011). However, forests will naturally recover after a fire period, forming secondary vegetation until it reaches a climax state through a succession process, where it takes 15 to 20 years until it forms a young secondary forest which will later develop into an old secondary forest after passing 50 years (Saharjo and Gago 2011). Secondary vegetation that developed after the fire could be categorized into three different classes of vegetation types, namely secondary forest, trees and non-timber mix vegetation and fern-dominated non-timber vegetation (Hoscilo *et al.* 2011).

Forest fires are a process inherent to the ecological system that initiates the process of vegetation's succession and recovery (Malkisnon *et al.* 2011). Increasing fires' frequency and severity can change the tree's density and basal area (Gandiwa 2011). Areas that have experienced fires will form different communities and vegetation structures from those that do not (Firdaus *et al.* 2017). Each type of plant has a unique tolerance level to the environment to maintain its life, therefore, exceeds in the tolerance level will result in species mortality in a habitat. The fire frequency area is dominated by species that have fire resistance and the ability to grow quickly (Makumbe *et al.* 2020). This study aims to explain the differences in vegetation that compose areas with different fire frequencies.

METHODS

Study Site

The research was conducted in the concession area of PT Global Alam Lestari, which intersects the administrative areas of Banyu Asin and Musi Banyu Asin Regencies of South Sumatra Province, Indonesia, and is geographically located at a position of 2°4'25"–1°57'7" south latitude and 104°2'55"–104°144'28" east longitude (Figure 1). The research was conducted from September 2019 to December 2019.

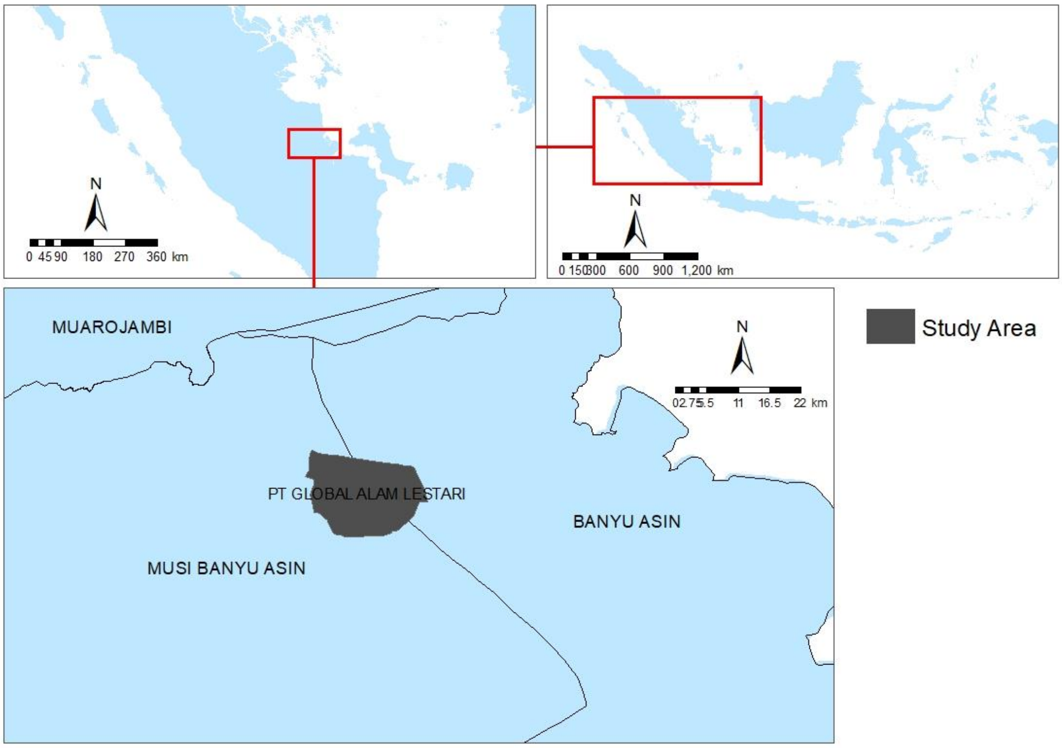

Figure 1 Map of study area

Data Collection

We used Landsat 5 TM, Landsat 7 TM, and Landsat 8 OLI images for this study, where all were obtained from http://glovis.usgs.gov. The vegetation observations were carried out by observing the understoreys, seedlings, saplings, poles, and trees in the observation plot. The data we retrieved were names and number of species for understoreys, seedlings, and saplings, species, population size, diameter, and height for poles and trees. Vegetation data collection was carried out by making sample plots on burnt areas using purposive sampling with an observation plot size of 20 x 20 m. Afterward, the plot was divided into subplots using the nested sampling method, where the subplot sizes were 20 x 20 m for the trees, 10 x 10 m for poles, 5 x 5 m for the saplings, and 2 x 2 m for seedlings and understoreys (Silviana *et al.* 2019). At each location, the vegetation was observed once, twice, three, and four times. A total of 7 observation points were placed on the once-burnt, 3 on the twice-burnt, 4 on the three-times-burnt, 2 on the four-times-burnt, and lastly, 4 points on the unburned area as a control parameter. The number of observation points was adjusted to the total size of each area as well as the field access.

Data Analysis

The burnt areas were detected using a remote sensing approach using Landsat 5 TM, Landsat 7 TM, and Landsat 8 OLI images data. Landsat data was chosen because it provides complete time-series data from 1997 to 2015. Burnt areas were detected using the NBR equation (Indratmoko and Rizqihandari 2019):

$$\mathrm{NBR} = \frac{\rho\mathrm{NIR} - \rho\mathrm{SWIR2}}{\rho\mathrm{NIR} + \rho\mathrm{SWIR2}}$$

The terms ρNIR and ρRED represent the corrected reflections that were obtained from near-infrared (NIR) and red band sensors on Landsat 5 TM, Landsat 7 TM, and Landsat 8 OLI. The images of burnt areas each year were used to determine the fire frequency in the study area. Fire frequency information was used as the basis for determining the point of vegetation data collection. To assess the vegetation structure at each sampling site, we measured several parameters of vegetation data such as density, relative density, frequency, relative frequency, dominance, and relative dominance following equations below:

$$\text{Density (D)} = \frac{\text{Total individuals of a species}}{\text{Total plot area}}$$

$$\text{Relative Density (RD)} = \frac{\text{Species density}}{\text{Total species density}}$$

$$\text{Frequency (F)} = \frac{\text{Number of plots occupied by a species}}{\text{Total number of observation plots}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Species frequency}}{\text{Total frequency of all species}}$$

$$\text{Dominance (Dc)} = \frac{\text{Total surface coverage of a species}}{\text{Total plot area}}$$

$$\text{Relative Dominance (RDc)} = \frac{\text{Dominance of a species}}{\text{Total dominance of all species}}$$

The importance Value Index (IVI) for a species is a sum of its relative density (RD), relative dominance (RDc), and relative frequency (RF) (Soerianegara and Indrawan 1988), which can be used to determine the influence given by a species to its community in an area. The species diversity is important parameter in forest management (Firdaus and Nakagoshi 2018). Species diversity was determined using a Shannon-Wienner Diversity Index (Supriatna 2018). Where H’ = Plant Diversity, Pi = Ni/N, Ni = Number of individuals of each species, N = Total number of individuals from all species

$$\text{Shannon Indeks H}' = -\sum_{i=1}^{s} pi \ln pi$$

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The Shannon Evenness Index (E') is used to know the relative abundance of the different species of an ecosystem with the equation (Firdaus and Nakagoshi 2018):

$$\text{Shannon Evennes indax (E}') = \frac{\text{H}'}{\ln \text{S}}$$

Species richness index does a relationship between the number of species and the number of individuals. Species richness was calculated using Margalef index (Kanieski *et al.* 2018):

$$\text{Margalef Index (R)} = \frac{\text{S} - 1}{\ln \text{N}}$$

Sorensen Index was used to determine the similarity species composition of the two communities being compared (Masyithoh *et al.* 2020). Sorensen index has the equation (Belguidoum *et al.* 2021):

$$\text{Sorensen Index (SI)} = \frac{2\text{c}}{\text{S1} + \text{S2}}$$

Where: S1 = Number of species for site 1, S2 = Number of species for site 2, c = Number of common species between two sites.

RESULTS AND DISCUSSION

Fire Frequency

Peatlands in South Sumatra were recorded to experience frequent fires from 1997 to 2015, including the study area of this research that is noted to have experienced repeated fires during that period. Based on the results of the Landsat images analysis, the research area is categorized into four classes in terms of fire frequency. The fire in the once-burnt emerged in 2015; while for the twice-burnt they were in 2006 and 2015; then in the three-times-burnt, they occurred in 2006, 2012, and 2015; lastly, in the four-times-burnt, they occurred in 1997, 2006, 2012 and 2015 (Figure 2). In 2015, fires occurred in almost all observed areas and were noted as the worst fires to emerge during the 1997 to 2015 period. The increase in fire frequency can affect the vegetation composition in one area, where the number and type of vegetation tend to decrease along with the increase of fire frequency.

The four-times-burnt was only covered with saplings and understorey vegetation, while poles, trees, and seedlings were not found at all. The three-times-burnt was found to have saplings, seedlings, and understorey vegetation with no pole or tree. The twice-burnt was found to have poles, saplings, and understoreys, although trees and seedlings were hardly observed there. Once-burnt were vegetated with vegetation from all growth stages from the understorey, seedlings, saplings, poles, and trees (Figure 3). This can be due to the high intensity of fires and its repeated occurrence that changed the hydrological conditions (Brown *et al.* 2015) and chemical properties (Jones *et al.* 2014) of the peat soil in such a manner that resulted in areas with higher burning frequency having fewer vegetation species than areas with lower fire frequency. Posa *et al.* (2011) explained that extreme hydrological conditions and chemical characteristics in peat swamp forests are factors that limit tree species diversity.

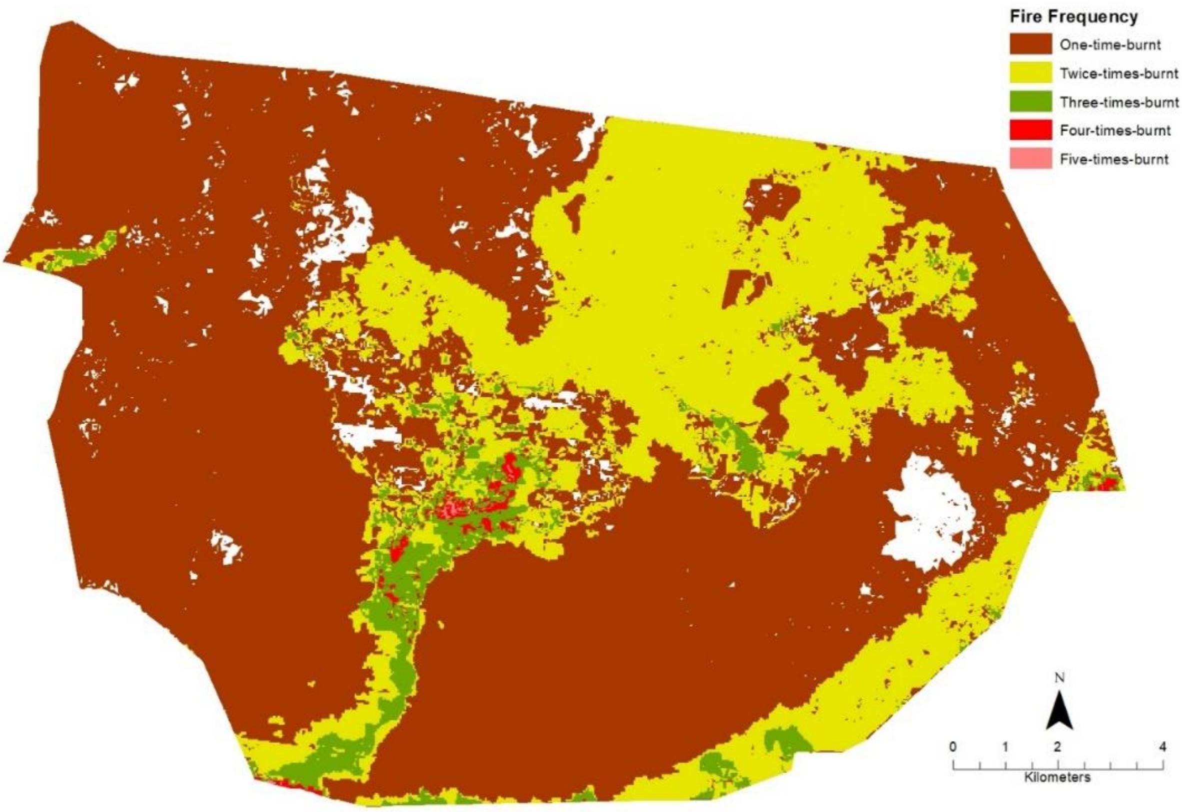

Figure 2 Fire frequency

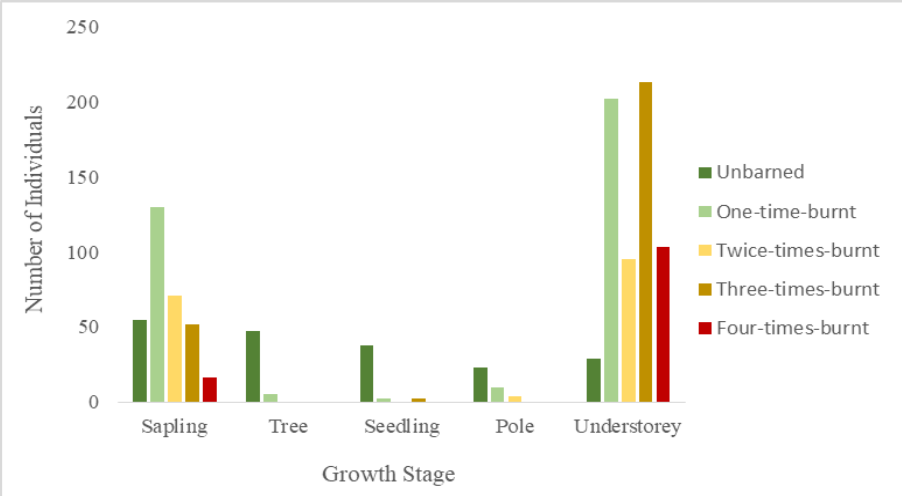

Figure 3 Graph of vegetation growth rate in various fire frequencies

Importance Value Index (IVI)

The composition and dominance of species in areas with different fire frequencies can be indicated by the IVI (Ismail *et al.* 2017). The trees found in the once-burnt were dominated by the species *Xylophia altissima*, *Macaranga pruinosa,* and *Cryptocaria griffithiana*, with IVI of 94%, 84%, and 62%, respectively, although none were observed the twice, three and four-times-burnt. The poles in the once-burnt were dominated by *Xylophia altissima*, *Macaranga pruinosa* and *Shorea parvifolia* species with IVI of 61%, 130%, and 68%, respectively, while in the area of twice-burnt only *Macaranga pruinosa* was found and then in the three and four-times-burnt no pole species were found. According to Yule (2010), vegetation from the genus *Macaranga* has the potential to dominate degraded peatlands. The saplings in areas with different fire frequencies are dominated by different species, e.g., the once-burnt is dominated by the *Exbucklandia populnea* with an IVI of 98%, and the twice-burnt was dominated by *Malicope glabra* with an IVI of 55%, then areas of three-times-burnt was dominated by *Alstonia pneumatophora* and *Exbucklandia populnea* with an INP of 100% and four-times-burnt were dominated by the species of *Exbucklandia populnea* with IVI of 147%. The understoreys in the once, twice, and three-times-burnt were dominated by the species *Asplenium longissimum* with an IVI of 81%, 64%, and 52%, respectively, while the four-times-burnt was dominated by the species *Athyrium esculentum* with an IVI of 51% (Table 1).

Table 1 The three highest IVI values in each fire frequency

Growth Stage	Species Name		Importance Value Index (%)			
	Local	Scientific	One-time-burnt	Twice-times-burnt	Three-times-burnt	Four-times-burnt
Tree	Jangkang	*Xylophia altissima*	94	-	-	-
	Mahang	*Macaranga pruinosa*	84	-	-	-
	Medang pelam	*Cryptocaia griffithiana*	62	-	-	-
Pole	Jangkang	*Xylophia altissima*	61	-	-	-
	Mahang	*Macaranga pruinosa*	130	300	-	-
	Meranti	*Shorea parvifolia*	68	-	-	-
Sapling	Bangun bangun	*Malicope glabra*	-	80	-	-
	Bengkal	*Nauclea orientalis*	-	22	-	-
	Dara-dara	*Gymnacranthera forbesii*	13	-	-	-
	Mahang	*Macaranga pruinosa*	-	55	-	53
	Pahit pahit	*Quasia borneensis*	19	-	-	-
	Pulai	*Alstonia pneumatophora*	-	-	100	-
	Sepongol	*Exbucklandia populnea*	115	-	100	147
Understorey	Belidang	*Eleusine indica*	-	56	32	29
	Pakis Begelung	*Asplenium longissimum*	81	64	52	50
	Pakis Gajah	*Athyrium esculentum*	64	15	15	51
	Paku	*Stenochlaena palustris*	45	32	42	44

Diversity of the Vegetation Species

Peatlands that have experienced fires will likely have a decrease in species diversity, where greater frequency and severity of fires result in a greater number of species mortality (Balch *et al.* 2013). The vegetation diversity index in unburned areas is greater than in burnt areas (Gandiwa 2011). The species diversity of trees in the once-burnt was classified as moderate (H' = 1,33), while the vegetation of this stage was barely found in the twice, three, and four-times-burnt. The species diversity of poles in the once-burnt was noted as moderate (H' = 1), in the twice-burnt, it was noted as low (H' = 0), while in the three and four-times-burnt no vegetation at this growth stage was spotted. The poles and trees found in a burnt area are likely of fire-resistant species. The species diversity of saplings in the once, twice, three, and four-times-burnt was classified as low, each having a value of H' = 0,69; H' = 0,9; H'= 0,69; and H' = 0,5 (Table 2). This proves that the increase in fire frequency will be followed by the same increase in species mortality as well as the decrease in species diversity of poles, trees, and saplings (Morgan *et al.* 2015; Strand *et al.* 2019). The fires that occurred in 2012 and 2015 have time intervals that had led to an increase in vegetation mortality due to not being able to survive the extreme environment. Additionally, three years is considered a relatively short interval for vegetation to reach the growth stage of saplings and even more poles and trees after a fire occurrence. Malkisnon *et al*. (2011) explained that repeated fires with short time intervals resulted in significant changes in the plant community, for instance, a decrease in the number of trees and vegetation.

The diversity of understorey species in the once, twice, three, and four-times-burnt was classified as moderate, each having a value of H' = 1,1; H' = 1,26; H' = 1,64; H' = 1,44 respectively. The understorey tends to increase significantly in the early years after a fire which is a natural cycle in the succession process. The greater the fire severity, the higher the number of pioneer plants that will grow (Dzwonko *et al.* 2018). The once, twice, three, and four-times-burnt were dominated by understoreys with ferns from the herbaceous plant group. This is following previous research which showed that areas with a high fire frequency could eradicate non-fire resistant species, and in the first seven years after the fire, the areas will be dominated by herbaceous species, which indicates a very slow recovery process in areas with high fire frequency (Gandiwa 2011; Malkisnon *et al.* 2011).

Table 2 Plant diversity index in areas with different fire frequencies

No	Growth Stage	Index	One-time-burnt	Twice-times-burnt	Three-times-burnt	Four-times-burnt
1	Tree	R	3,74	-	-	-
		H’	1,33	-	-	-
		E’	0,26	-	-	-
2	Pole	R	3,74	0,74	-	-
		H’	1	0	-	-
		E’	0,18	0	-	-
3	Sapling	R	10,74	4,74	1,74	1,74
		H’	0,69	0,9	0,69	0,50
		E’	0,01	0,19	0,05	0,46
4	Seedling	R	0,74	-	-	-
		H’	0	-	-	-
		E’	0	-	-	-
5	Understorey	R	3,74	5,74	6,74	4,74
		H’	1,1	1,26	1,64	1,44
		E’	0,25	0,2	0,15	0,19

The Similarity of Vegetation Community

Vegetation community similarity indicates the level of closeness of vegetation communities in two areas or more. The community is determined to have low similarity when the value is below 50% (Ariyo *et al.* 2013), a moderate similarity when the value is between 50%–75%, and a high similarity when the value is higher than 75%. Areas that were burnt once and twice were noted to have low similarity at the sapling stage (13%). A low similarity was also found between the sapling communities in areas that were burnt once and twice (16%), once and four times (33%), twice and three times (0%), and twice and four times (28%). Vegetation communities that were moderately similar at the sapling stage were found in areas that were burnt three and four times (50%). A total of 10 species of saplings were found in the once-burnt, and then the number decreased to 5 species in the twice-burnt and again depleted to 2 species in the three and four-times-burnt. This shows that repeated fires could reduce the quality of structure and composition of the vegetation and increase species mortality (Malkisnon *et al.* 2011; Balch *et al.* 2013), that the constituent vegetations are dominated by fire-resistant species (Makumbe *et al.* 2020). The vegetation community similarity index (IS) at the sapling stage of each fire frequency class is presented in Table 3.

Table 3 The similarity (SI) of sapling community in areas with different fire frequencies

No	Species Name			
1	*Palaquium ridleyi*	*Melicope glabra*	*Alstonia pneumatophora*	*Macaranga pruinosa*
2	*Xylophia altissima*	*Nauclea orientalis*	*Exbucklandia populnea*	*Exbucklandia populnea*
3	*Macaranga pruinosa*	*Melaleuca cajuputi*		
4	*Cryptocarya crassinervia*	*Macaranga pruinosa*		
5	*Quasia borneensis*	*Leea indica*		
6	*Parkia speciosa*			
7	*Gluta renghas L.*			
8	*Gymnacranthera forbesii*			
9	*Dillenia ecxcelsa Gilg.*			
10	*Exbucklandia populnea*			
	1x	**2x**	**3x**	**4x**
1x	*	0,13	0,16	0,33
2x		*	0	0,28
3x			*	0,5
4x				*

1x = One-time-burnt, 2x = Twice-times-burnt, 3x = Three-times-burnt, 4x = Four-times-burnt

Table 4 The similarity (SI) of unserstorey community in areas with different fire frequencies

No	Species name			
1	*Asplenium longissimum*	*Eleusine indica*	*Imperata cylindrica*	*Eleusine indica*
2	*Athyrium esculentum*	*Asplenium longissimum*	*Eleusine indica*	*Asplenium longissimum*
3	*Lygodium flexuosum*	*Athyrium esculentum*	*Asplenium longissimum*	*Athyrium esculentum*
4	*Stenochlaena palustris*	*Stenochlaena palustris*	*Athyrium esculentum*	*Stenochlaena palustris*
5		*Alpinia galanga*	*Equisetum hyemale*	*Melastoma malabathricum*
6		*Melastoma malabathricum*	*Stenochlaena palustris*	
7			*Melastoma malabathricum*	
	1x	**2x**	**3x**	**4x**
1x	*	0,6	0,55	0,67
2x		*	0,62	0,73
3x			*	0,83
4x				*

1x = One-time-burnt, 2x = Twice-times-burnt, 3x = Three-times-burnt, 4x = Four-times-burnt

In contrary to the sapling community, the higher the fire frequency, the higher the number of understorey species found. A moderate similarity was found between the understorey communities in the once and twice-burnt (60%), once and three-times-burnt (55%), once and four-times-burnt (67%), and twice and three-times-burnt (62%), twice and four-times-burnt (73%). High similarity was found between the understorey communities in the three-time-burnt and four-time-burnt (83%). In the once burnt, 4 understorey species were found; and then the number increased to 6 species in the twice-times-burnt and 7 species in the three-times-burn. Lastly, in the four-times-burnt, 5 species were found (Table 4). The similarity of the understorey community in all fire frequency classes was higher than the similarity in the tree, pole, sapling, and seedling community. This could be due to the fact that understoreys are pioneer plants that grow significantly in the early post-fire years as part of the natural cycle of the succession process. Field data collection was carried out four years later after the occurrence of repeated fires, this period is the ideal time for understoreys to dominate the burnt area, which is in accordance with the findings of previous studies, which stated that the first to seven years after the fire, pioneer plants from the herbaceous group would dominate the burnt area (Malkisnon *et al.* 2011; Dzwonko *et al.* 2018).

CONCLUSIONS

Based on the study results, the frequency of fires greatly affects the type of vegetation that dominates a peatland area. The higher the fire frequency resulted in an increase in the number of individual mortality and a decrease in the species diversity at the tree, pole, sapling, and seedling stages. On the contrary, an increase in the fire frequency was followed by an increase in the number of understorey species; this is because the understorey species in the research area are pioneer plants that grow rapidly and dominate the damaged areas at the beginning of the succession process. The species of understorey that dominates the once, twice, and three-times-burnt is *Asplenium longissimum*, while the four-times-burnt is dominated by *Athyrium esculentum*.

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