Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

ORIGINAL RESEARCH PAPER

Connectivity of vegetation diversity, carbon stock, and peat depth in peatland ecosystems

R. Garsetiasih, N.M. Heriyanto, W.C. Adinugroho, H. Gunawan, I.W.S. Dharmawan*, R. Sawitri, I. Yeny, N. Mindawati, Denny

Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia

ARTICLE INFO

Article History:
Received 27 August 2021
Revised 08 Nivember 2021
Accepted 12 December 2021

Keywords:
Carbon stock
Connectivity
Diversity
Peat depth
Sustainability

ABSTRACT

BACKGROUND AND OBJECTIVES: Peat swamp forest ecosystems are fragile ecosystems with different peat depths according to the level of peat formation. Moreover, a peat swamp forest can have diverse vegetation and high carbon stocks. Thus, caution should be taken in the sustainable management of a peat swamp forest. However, the connection between vegetation diversity, carbon stocks, and peat depths has not been widely studied in efforts to conserve vegetation and peatlands. This study aimed to analyze the connection between vegetation diversity, carbon stocks, and peat depths in the Kahayan Sebangau Peat Hydrology Unit.

METHODS: Plots at the peat depths of four sites were studied: site 1 (<50 cm), site 2 (393-478 cm), site 3 (479-564 cm), and site 4 (565-649 cm).

FINDINGS: : This study discovered that diverse vegetation at the tree, sapling, and seedling levels and the species richness at different peat depths were significantly different due to various nutrient contents and distances from the river. The number of species found varied at various peat depths, with 20, 28, 32, and 19 species at peat depths of 565 cm, 479-<565 cm, 393-<479 cm, and <50 cm, respectively. In addition, the highest carbon stock was 95.2 ± 19.52 Mg C/ha, which was found at a peat depth of 479 – 564 cm and a vegetation diameter of ≥10 cm. The tree species *Combretocarpus rotundatus* (Miq.) Danser, *Maclurodendron porteri* (Hook. f.) T.G. *Hartley, Tetramestra glabra* Miq, and *Horsfieldia irya* (Gaertn.) Warb. had high survival rates and grew at a peat depth of <50 cm. The study results confirmed that peat thickness could not directly affect the vegetation dynamic in terms of vegetation diversity. The vegetation changes were influenced directly by changing other characteristics of peat hydrology, peat chemistry, and peat organic matter.

CONCLUSION: All Pearson correlation values between peat depth, vegetation diversity, and carbon stock were positive with each other. This shows that peat depth, vegetation diversity, and carbon stock are interdependent and connected to one another.

DOI: 10.22034/gjesm.2022.03.06

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
47	9	8

*Corresponding Author:
Email: *salifa03@yahoo.co.id*
Phone: +6282173073981
ORCID: 0000-0002-7007-393X

Note: Discussion period for this manuscript open until October 1, 2022 on GJESM website at the “Show Article”.

INTRODUCTION

Peat swamp forests in Indonesia are scattered across Riau, Jambi, South Sumatra, Southeast Sulawesi, Kalimantan Island, and Maluku Island, with a total area of 149,056 km^2 (Warren *et al.,* 2017). Peat swamps are important ecosystems, providing environmental services, creating diversity among the tree species and wildlife, and contributing to the mitigation of climate change and thus to a reduction in global warming (Osaki *et al.,* 2021). Climate change also affects hydrological aspects of peatland forests. Peat swamps are important ecosystems globally because their functions are primarily related to hydrology, carbon cycling, and biodiversity regarding tree species and wildlife and they contribute to climate change mitigation, thus reducing global warming (Hirano *et al.,* 2014; Osaki *et al.,* 2021; Sefidi *et al.,* 2015). They are also especially sensitive to climate dynamics, such as changes in precipitation and the flood regime (Fenner and Freeman, 2011). These environmental factors are interrelated and interact, which ultimately affect the composition and pattern of vegetation diversity (Afrianto *et al.,* 2016). These areas possess a unique and fragile ecosystem with certain characteristics. One of the functions of forests, such as peat swamps, is carbon cycling by absorbing or sinking carbon dioxide (CO_2) from the air. Carbon dioxide storage is closely correlated with standing biomass (Dargie *et al.,* 2017). The amount of biomass in an area is obtained by calculating the biomass density and number of tree species. Peat swamp forests, especially in Kalimantan, have been significantly degraded and fragmented from 1990 to 2010 (Dohong *et al.,* 2017) because peat swamp forests have been extracted since the establishment of forest concession rights (Miettinen and Liew, 2010). The most degrading factors of this peat forest are illegal logging, land conversion, and forest fire. The conversion of peat swamps increases the amount of carbondioxide (CO_2). According to Hooijer *et al.* (2010), emissions related to changes in peat swamp use and management are estimated to be 50% of Indonesia's total national emissions. Tree growth in tropical regions is generally faster than that in sub-tropical regions (Russel and Raich, 2012). Therefore, developed countries are highly concerned about tropical forest preservation because forests can absorb gas emissions and prevent climate change (Harrison *et al.,* 2019). The third-largest tropical forest in the world is located in Indonesia, after those in Brazil and Kenya (Kusmana and Hikmat, 2015), so we must obtain basic data about how much carbon can tropical forests absorb, especially lowland peat swamp forests. Peat swamp is a soil material not easily weathered and consists of organic materials mostly not decomposed and accumulated in aerobic conditions (Dommain *et al.,* 2015). Peat swamp forests have an important global ecological function as carbon sinks and stocks and significantly contribute to global carbon cycles (Osaki *et al.,* 2021). On the other hand, logging and fires threaten biodiversity loss in peat swamp forests (Posa *et al.,* 2011). These two reasons are the triggers for this research, which investigates tree species and carbon stocks at various peat depths. In this regard, the research gaps were found between vegetation diversity, carbon stock, and peat depth in the peatland forest ecosystem. Rieley *et al.* (1996); Page *et al.* (1999); Lahteenoja *et al.* (2009a, 2009b); Astiani *et al.* (2016) stated that varying responses to local gradients in hydrology, nutrient availability, and depth of peat affect vegetation changes. Meanwhile, more in-depth analyses between vegetation diversity and its connection to carbon stock and peat depth are needed. Specifically, this study aims to investigate the vegetation diversity and carbon stock at several peat depths as well as to analyze the connection/correlation between vegetation diversity, carbon stock, and peat depths to provide recommendations for peat swamp forest conservation. This study was carried out in the peat hidrology unit (PHU) of Kahayan, Sebangau River, Pulang Pisau Regency, Central Kalimantan Province, in 2020.

MATERIALS AND METHODS

Description of the study area and context

The study location is categorized as a peat swamp forest by the Peat Hidrology Unit (PHU) of Kahayan, Sebangau River, Pulang Pisau Regency, Central Kalimantan Province. In this research, the location is divided into four sites: site 1 (2° 28'55.04 " S and 114° 7'15.13" E), site 2 (2° 21 ' 6.18 " S and 114 ° 2'6.77" E), site 3 (2° 21'8.25" S and 114° 5'29.86" E), and site 4 (2° 22'48.05 " S and 114° 9'4.70 " E). These sites are presented in Fig. 1.

The study sites are located ± 7-25 m above

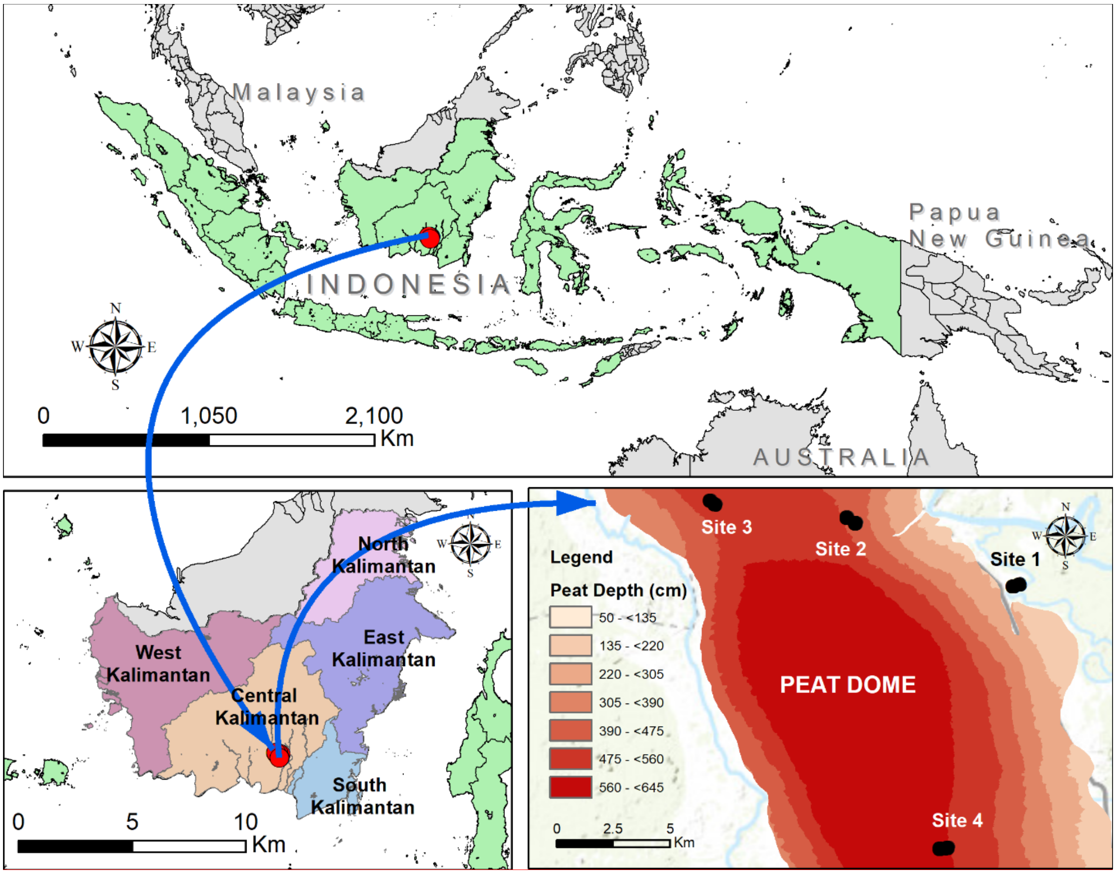

Fig. 1: Geographic location of the study area in the Kahayan Sebangau Peat Hydrology Unit in Indonesia.

sea level, and their topography is flat, with slopes between 0 and 8%. The soil of the study sites include Tropochemist, Troposaprist, and Tropofibrist/Saprik Peat, which continuously rot and are made of old alluvium materials. The stone components including clay, silt, gravel, plant debris, and sand are dark brown to black, and when they are squeezed, their fiber content is less than 15% (Soil Survey Staff, 2014). For an illustration of the study methodology from preparation until data analysis, a flow diagram for the overall methodology in this study is shown in Fig. 2. The approach used in this research was a field survey, which was then analyzed quantitatively using a statistical approach. The study used primary data and a number of relevant secondary data. The primary data consist of measurement data for the forest stand parameters, namely diameter, height, and species obtained through measurements on an observation plot.

Survey and sampling designs

The vegetation diversity and carbon stock were analyzed on sample sites from peat domes to shallow peats. The study used stratified random sampling in the research design. The research location was stratified by peat category, namely shallow peat (edge), between shallow and peat dome, and peat dome. Then, the sampling plots were determined randomly for each stratum in several classes of peat depth based on the peat depth map issued by the Peatland Restoration Agency. In each of the shallow peat and peat dome strata, 10 observation plots were made, while between the shallow peat and peat dome, 20 observation plots were made. Site 1 was at a peat depth < 50cm (shallow peat), and then, 2 sites are shallow peat to peat domes, namely site 2 (393-478 m) and site 3 (479 – 564 m), while site 4 was a peat dome with a depth of 565 – 649 m (Fig. 1). The sample unit was a square with

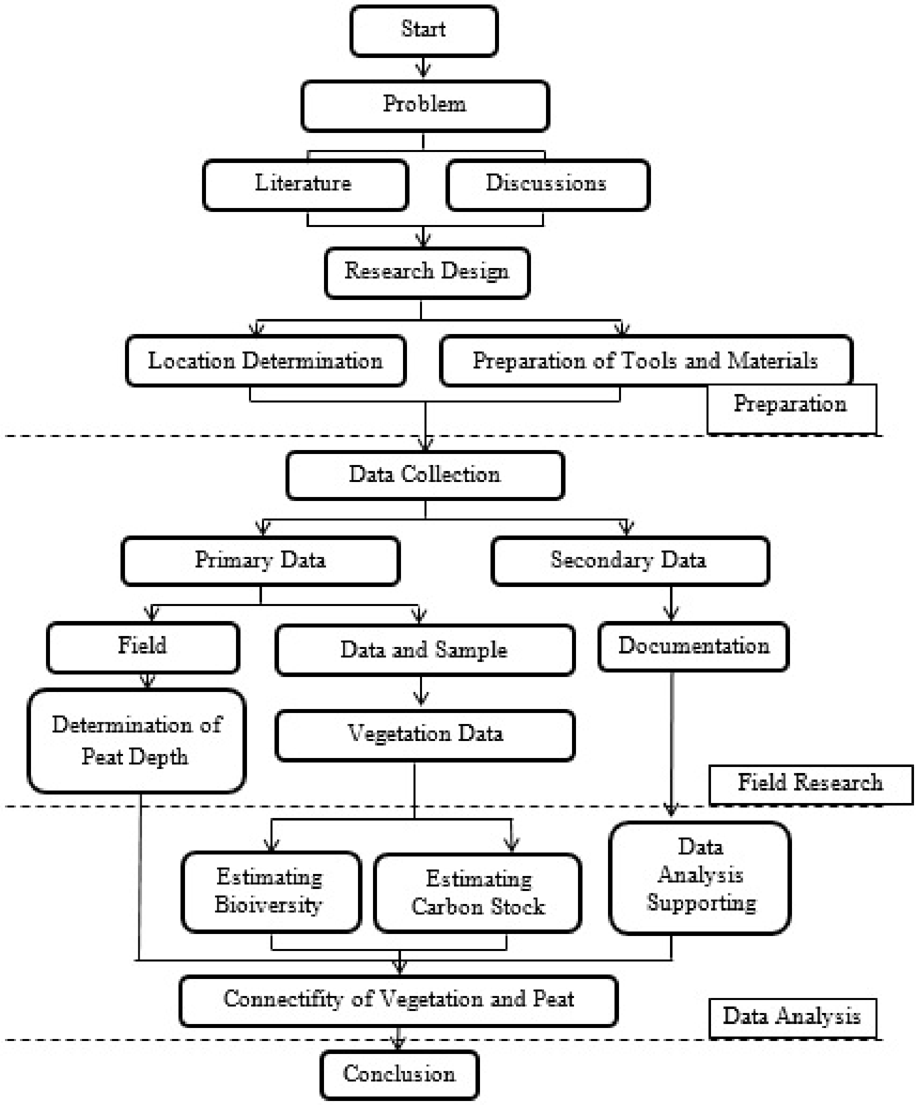

Fig. 2: Flow diagram for the overall methodology

a size of 20 m x 20 m (0.04 ha) and nested with a different size plot for different growth stages. The plots were repeated ten times at each site. A plot of 20 m x 20 m was established for the tree inventory, a plot of 5 m x 5 m for the sapling inventory, and a plot of 2 m x 2 m for seedlings inventory (Haryadi *et al.,* 2019). These plots are presented in Fig. 3. This study employed a global positioning system (GPS) to measure devices, tape diameters, plastic ropes, tree height measurement tools, and herbarium tool kits. The diameters, height, and species of all trees and saplings were recorded, while species' numbers and names were recorded for seedlings. These kinds of materials were sampled and identified at the Herbarium Laboratory of Forest Research and Development Center, Bogor. The criteria for tree, sapling, and seedling are as follows (Mansur and Kartawinata, 2017). The trees' diameter was 1.3 m $\geq$10 cm at breast height. If they contained a buttress, the diameter was measured 20 cm above the buttress. Those criteria were recorded in the plot size of 20 m x 20 m (Afzanizam *et al.,* 2019).

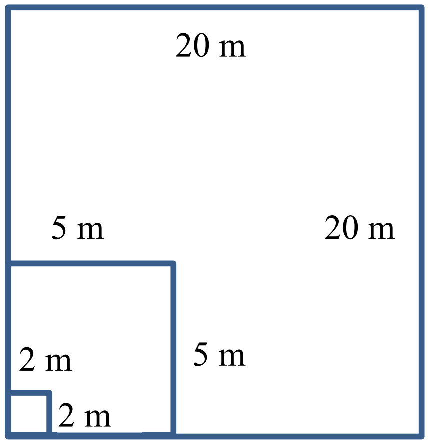

Fig. 3: Measurement plots.

Saplings, namely natural regeneration with a height of > 1.5 m to a young tree with a diameter <10 cm, were recorded in a plot size of 5 m x 5 m. Seedlings, natural regeneration from sprouts to <1.5 m high, were recorded in a plot size of 2m x 2m (Haryadi *et al.,* 2019).

Estimating peat depth

The peat depth information was obtained based on the peat depth map issued by the Peatland Restoration Agency. The plot coordinates from the survey determined using GPS were then overlaid with a peat depth map to determine the peat depth in the plot observation. The peat depth map was generated from sampling measurements of the peat depth in the field. The peat depth was estimated using peat auger until the mineral soil was reached. The depth of peat was estimated from the length of the peat auger (6 m extension rods plus sampler) inserted into the mineral soil surface. When the peat depth exceeded the length of the extension rod, one meter was added to the measured depth.

Estimating biodiversity

Data of the vegetation analyses were calculated to obtain values for relative frequency, relative density, and relative dominance; they were then summed into an index of importance value (Mueller-Dombois and Ellenberg, 2016). The important value index (IVI) and its components (relative density (D_R), relative frequency (F_R), and relative dominance (Dom_R)) are shown in Eqs. 1, 2, 3, and 4, respectively.

$$D_R = \frac{ni}{N} 100\% \quad (1)$$

$$F_R = \frac{Fi}{\sum Fi} 100\% \quad (2)$$

$$Dom_R = \frac{Gi}{G} 100\% \quad (3)$$

$$IVI = D_R + F_R + Dom_R \quad (4)$$

where *ni* is the number of individuals for a species, *N* is the total number of individuals for all species in the plot, *Fi* is the frequency of a species, *Gi* is the total base area of a species, and *G* is the total base area of all species.

The density of the trees describe the forest structures from the diameter classes 0-10 cm, 10-20 cm, 20-30 cm, and above 30 cm. The diversity parameter consists of Shannon's diversity index, Simpson's diversity index, Fisher's alpha, Rarefied species richness, and Pielou's evenness; those diversity parameters were calculated using R v. 3.6.3 (R Core Team, 2020). The diversity parameter consists of Shannon's diversity index, Simpson's diversity index, Fisher's alpha index, Pielou's evenness index, and Rarefied species richness (R), provided in Eqs. 5, 6, 7, 8, and 9, respectively.

$$H' = -\sum_{i=1}^{T} pi\, lnpi \quad (5)$$

$$D = \sum_{i=1}^{T} \frac{ni(ni-1)}{N(N-1)} \tag{6}$$

$$S = \alpha \, ln\left(1 + \frac{N}{\alpha}\right) \tag{7}$$

$$e = \frac{H'}{\ln S} \tag{8}$$

$$R = \frac{S}{\sqrt{N}} \tag{9}$$

where *H'* is Shannon's diversity index, *D* is Simpson's diversity index, *S* is Fisher's alpha index, *e* is Pielou's evenness index, *R* is the Rarefied species richness, *pi* is the number of individuals for a species over the total number of individuals, *ni* is the number of individuals for a species, *N* is the total number of individuals, and *S* is the number of different species.

Non-metric multidimensional scaling (MDS) with the vegan package was used to analyze the response of plant species composition to peat depth (Oksanen et al., 2019). To analyze whether species composition, species richness, and species diversity were statistically different among depth categories, a multivariate permutation analysis of variance (n = 1000) was performed using the vegan package. Ordination was performed using a species matrix containing several plant species in each plot, using the default mono MDS function, which included the double-Wisconsin square root transformation and the Bray–Curtis difference index. The ordination was presented graphically using the package ggplot (Wickham, 2016), and a visual display of each plot was color-coded based on the levels of each peat depth.

Estimating carbon stock

The biomass of a live tree was estimated using the allometric equations for mixed species of Indonesian peat swamp forests using Eq. 10 (Manuri *et al.*, 2017).

$$Y = 0.088 \, x \left(\left(D^2\right) x \, H \, x \, WD\right)^{0.954} \tag{10}$$

where *Y* is the aboveground biomass (kg), *D* is the diameter at breast height (cm), *H* is the height (m), and *WD* is the wood density (g/cm^3).

The total aboveground tree biomass for each plot was calculated by adding up all of the estimated aboveground biomass values of each tree in the plot expressed in Mega gram (Mg). The root biomass was calculated using the allometric model using Eq. 11 (Niiyama *et al.*, 2010).

$$Y = 0.02186 \, x \, D^{2.487} \tag{11}$$

where *Y* is the belowground biomass/roots (kg) and *D* is the diameter at breast height (cm).

Carbon pools that are not measured directly are thought to use the relationship between aboveground tree biomass and other carbon pools that have been developed from previous research. The aboveground biomasses for understorey, litter, and deadwood were estimated using the ratio to aboveground biomass from previous research in Central Kalimantan by Krisnawati *et al.* (2021). The estimated ratio value of understorey biomass, litter, and deadwood to aboveground tree biomasses were 2.4%, 1.6%, and 18.5%, respectively.

The carbon contained in the aboveground biomass was approximately 47% or Mg biomass = 0.47 Mg C (Manuri *et al.*, 2017). In contrast, those in the the roots were approximately 39% and 50% for litter and deadwood. Carbon stocks in the organic soil carbon pools (Mg C/ha) were calculated using a fixed depth method, using Eq. 12.

$$C_{peat} = BD \, x \, h \, x \, C \tag{12}$$

where *BD* is the peat bulk density (g/cm^3), *h* is the peat depth (cm), and *C* is the peat carbon content (%). The values of BD and carbon content of peat at the research sites were 0.14 g/cm^3 and 41.73%, respectively.

The total carbon in the peat swamp forests was estimated as the amount of carbon aboveground biomass, belowground biomass/roots, litter, deadwood, and soil. Their values were equivalent to the carbon dioxide values in the atmosphere by multiplying the carbon stocks by a factor (44/12). The depth categories, analysis of variance, and comparison of mean values were performed

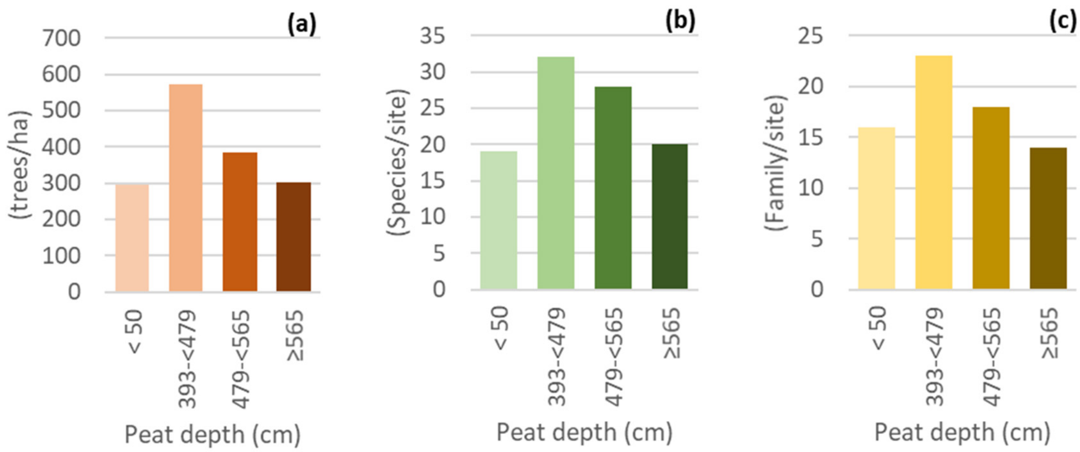

Fig. 4: Number of trees per hectare (a), species (b), and family (c) at the study sites

to determine whether the carbon stocks were statistically different.

RESULTS AND DISCUSSION

Species composition

Vegetation observations were used to identify the species and families of plants at the research sites. The identification of plant species and families at the research sites is presented in Fig. 4.

Fig. 4 shows that 23 families are in the forest with a peat depth of 393-478 cm, dominated by Lauraceae. Meanwhile, 28 families are in the forest with a peat depth of 479-564 cm and with a peat

depth 565 – 649 cm, and 19 families are in the forest with a peat depth <50. Myrtaceae dominated all peat depths. The diverse species of Lauraceae and Myrtaceae represent anthropogenic disturbance and degraded, previously burnt, peat swamp forests (Kalima *et al.,* 2020). At the research sites, the peat depths of 565-649 cm and 393-478 cm were dominated by *Combretocarpus rotundatus* (Miq.) Danser (IVI = 66.85% and 89.80%), the peat depths of 479-564 cm were dominated by *Mezzettia umbellata* Becc. (IVI = 47.78%), and the peat depths <50 cm were dominated by *Macaranga pruinosa* (Miq.) Muell. Arg. (IVI = 58.31%). The species potentially replacing future stands were sapling-level stands, and the peat depths of 565-649 cm were dominated by *Angelesia splendens* Korth. (IVI = 24.99%) and *Baccaurea polyneura* Hook.f. (IVI = 22.68%). The peat forests with 479-564 cm were dominated by *Mezzettia umbellata* Becc. (IVI = 67.23%) and *Stemonurus scorpioides* Becc. (IVI = 51.17%). Peat depths of 393-478 cm were dominated by *Combretocarpus rotundatus* (Miq.) Danser (IVI = 40.20%) and *Horsfieldia crassifolia* (Hook. Fil. and Thoms.) Warb. (IVI = 29.73%). The peat depth <50 cm was dominated by *Tetramerista glabra* Miq. (IVI = 120.19%) and *Dyera polyphylla* (Miq.) Steenis (IVI = 26.61%). These species, especially *Combretocarpus rotundatus* (miq.) Danser and anthropogenic peat swamp fragmentations such as *Callophyllum inophyllum,* indicated highly degraded forests due to forest fires (Nelson *et al.,* 2021; Astiani, 2016). The peat depth significantly affected the peat swamp forest species composition. The ordinance analysis discovered a large difference among peat depths of <50 cm, 393-<479 cm, 479-<565 cm, and ≥ 565 cm. The community composition among plots (points) became less similar because their distance increases stress by 0.15. These results are presented in Fig. 5.

Species richness, diversity, and evenness

Biodiversity plays several important roles in the biosphere and is usually measured by proxy indexes to reveal changes in ecosystems. A biodiversity index is the simplest way to describe the richness of biota and challenges ecologists to explain the diversity of an area (Kusmana and Hikmat, 2015). In its development, several indices can be used to analyze an area's biodiversity, such as the species richness, rarefied richness index, Shannon index,

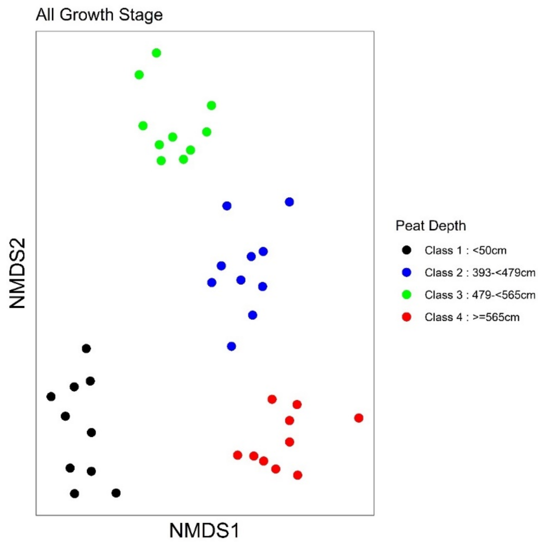

Fig. 5: The non-metric multidimensional scaling (NMDS) plot for the composition of tree species at peat depths of <50 cm, 393-<479 cm, 479-<565 cm, and ≥565 cm

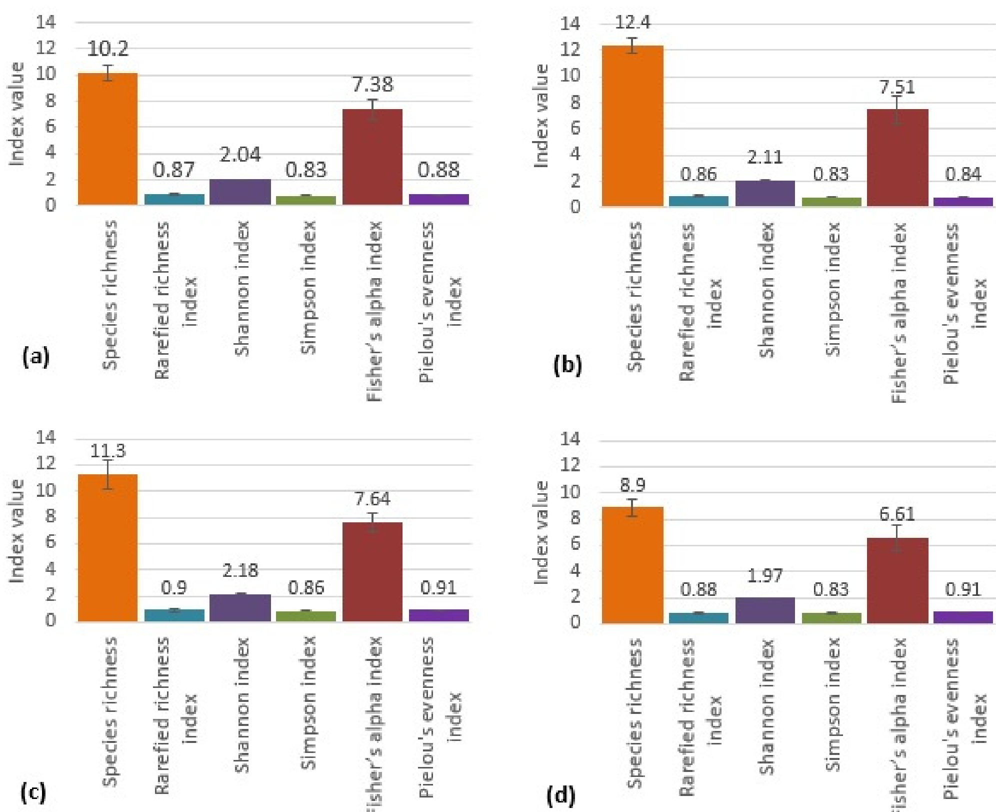

Fig. 6: Species richness, rarefied richness, Shannon index, Simpson index, Fisher's alpha, and evenness in the peat depths of <50 cm (a), 393-<479 cm (b), 479-<565 cm (c), and ≥565 cm (d) (error bars represent std. errors of means).

Table 1: F-values of multivariate diversity in different taxons and peat depths.

Diversity indexes	Species		Genus		Family	
	F-values	Pr(>F)	F-values	Pr(>F)	F-values	Pr(>F)
Species richness	3.984	0.015*	3.79	0.0185*	3.041	0.0413*
Rarefied richness index	1.358	0.271	0.477	0.7	0.465	0.709
Shannon index	1.455	0.243	0.896	0.452	0.692	0.563
Simpson index	0.91	0.446	0.132	0.94	0.106	0.956
Fisher's alpha index	0.262	0.853	0.514	0.676	0.557	0.647
Pielou's evenness index	4.517	0.00866**	2.433	0.0808	2.144	0.112

Table 2: F-values of multivariate diversity at different growth stages and peat depths.

	Trees		Sapling		Seedling	
	F-values	Pr (>F)	F-values	Pr (>F)	F-values	Pr (>F)
Species richness	8.836	0.00016***	5.04	0.00511**	2.275	0.097
Rarefied richness index	6.056	0.0019**	1.533	0.223	4.82	0.00651**
Shannon index	8.325	0.000246***	4.388	0.00989**	2.578	0.0692
Simpson index	5.407	0.00356**	3.452	0.0264*	3.325	0.0307*
Fisher’s alpha index	1	0.404	0.667	0.578	1.568	0.214
Pielou's evenness index	6.884	0.000879***	0.473	0.703	0.957	0.425

Table 3: Nutrient availabilities at various peat depths.

No.	Peat depths (cm)	Distance from rivers (m)	Nutrient availability					Ash content (%)
			Mg mg/100 g	Ca mg/100 g	K mg/100 g	P mg/100 g	C-organic (%)	
1	<50	< 200	5.13	9.60	6.01	1.83	41.15	20.91
2	393 - 478	2800 - 3000	1.68	0.39	0.14	0.33	51.37	1.26
3	479 – 564	400 - 600	1.65	0.50	0.15	0.34	51.52	1.00
4	565 – 649	1000 - 1600	1.86	0.62	0.15	0.35	51.61	0.80

Simpson index, Fisher’s alpha index, and Pielou’s evenness index. The biota diversity at the research sites is presented in Fig. 6.

Generally, Fig. 6 and further variant analyses discovered that peat depths had significantly different species richness index, and the Pielou’s evenness index was significantly different (Table 1). Vegetation diversity at the tree, sapling, and seedling levels of the peat depths was significantly different (Table 2). This difference showed that the peat depths of various nutrient contents and distances from the river (Table 3) influenced the diversity of vegetation at the tree, sapling, and seedling levels, and that condition makes vegetation more adaptable (Minayeva *et al.,* 2017). The distance from the river affects the role of hydrology, which is related to the flow of water to peatlands. In this study, the furthest distance of a plot from the river was 3000 m, and still, it obtained water flow from the river. Pages *et al.* (1999) stated that the peat gradient in a peatland distance from the river < 5500 m in the Sebangau Peatland Forest, Central Kalimantan, still allows the flow of water from the river to the peatland to run well. The water supply from this river carries the river's alluvial soil deposits along with seeds that allow various types of plants to grow so that it increases vegetation diversity, the growth of biomass, and carbon stock (Aravind *et al.*, 2015). The continuity in the water flow allows the thickness of the peat as well as the peat mass to be maintained properly. The relationship between hydrology, vegetation composition, and peat depth is closely related to restoration efforts. The study by Schulte *et al.* (2019) reinforced the assumption that, the wetter the peat, the deeper the peat thickness. In addition, during the rainy season, peatland also receives river floodwater containing dissolved nutrient components. The nutrient content provides nutrient inputs for vegetation development from seedling to the tree levels. This condition agrees with the results of the research by Astiani *et al.* (2016), stating that various responses to the local gradients in hydrology, nutrient availability, and peat depths affect vegetation changes. This evidence strengthens the research results of Page *et al.* (1999), confirming that peat thickness could not directly affect the vegetation dynamic. The vegetation changes were influenced directly by changing other characteristics of peat hydrology, peat chemistry, and peat organic matter (Morton and Heinemeyer, 2019). The research sites have various nutrient availabilities according to the peat depths, as shown in Table 3.

The decreasing contents of Mg, Ca, K, and P at deeper peat depths are associated with alluvial mineral soil deposits from the river. A peat depth < 50 m has a river distance of < 200 meters, and a mixture of many alluvial soils at the peat depth is assumed as the ash content is higher. The peat depth < 50 cm has an ash content of 20.91%, declining to 0.80% at a depth of 565 – 649 cm. In contrast, the smaller the ash content, the higher the organic C in the deeper peat depth. This fact is in line with the findings of Page *et al.* (1999) in the Sebangau Peatland Forest, where the contents of Mg, Ca, K, and P decreases with deeper peat depths.

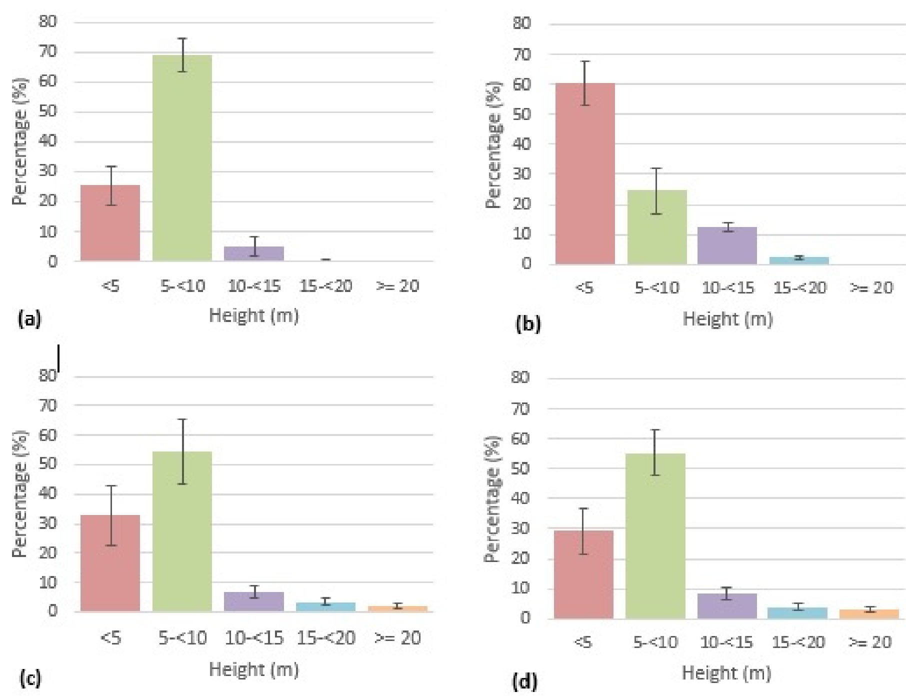

Fig. 7: Height distributions of stands at peat depths of <50 cm (a), 393-<479 cm (b), 479-<565 cm (c), and ≥565 cm (d) (error bars represent std. errors of means).

Stand structure and regeneration

Forest stand structures constitute the distribution of individual plants in the crown layer and can be illustrated as the tree distribution in each area with various diameters (Laumonier *et al.*, 2010). The canopy structure and vertical distribution are significant components of the dynamics of a forest ecosystem and appropriate habitat. Various vegetation structures indicate that they are interdependent with peat thickness and related to the physical, chemical, and hydrological properties of peat conditions. Fig. 7 shows the distribution of the vegetation canopy height at several peat depths.

The dominant species were *Combretocarpus rotundatus, Cratoxylum glaucum, Syzygium* spp., *Tristaniopsis* sp., and *Calophyllum* sp, as shown

Table 4: Dominant trees by height at the research sites

	Peat depth and tree species			
Tree height (m)	Peat depth 565-649 cm	Peat depth 479-564 cm	Peat depth 393-478 cm	Peat depth <50 cm
>20	*Combretocarpus rotundatus* *Syzygium zeylanicum*	*Callophillum sclerophyllum* *Mezzetia umbellate*	*Shorea teysmanniana* *Horsfieldia crassifolia*	--
>15	*Horsfieldia irya*/kumpang *Syzygium zeylanicum*	*Mezzetia umbellate* *Diospyros borneensis*	*Shorea teysmanniana* *Combretocarpus rotundatus*	*Combretocarpus rotundatus* *Syzygium zeylanicum*
>10	*Calophyllum sclerophyllum* *Lithocarpus dasystachyus*	*Shorea teysmanniana* *Gonystylus bancanus*	*Campnosperma coriaceum* *Cratoxylum glaucum*	*Cratoxylum glaucum* *Maclurodendron porter*
<10	*Combretocarpus rotundatus* *Litsea* sp.	*Dyera polyphylla* *Gonystylus bancanus*	*Garcinia bancana* *Combretocarpus rotundatus*	*Tetramerista glabra* *Macaranga pruinosa*

Table 5: Dominant trees by diameter at the research sites

	Peat depth and tree species			
Diameter class (cm)	Peat depth 565-649 cm	Peat depth 479-564 cm	Peat depth 393-478 cm	Peat depth <50 cm
10-19	*Combretocarpus rotundatus* *Xylopia fusca*	*Mezzetia umbellate* *Stemonurus scorpioides*	*Combretocarpus rotundatus* *Cratoxylum glaucum*	*Macaranga pruinosa* *Tetramerista glabra*
20-29	*Callophillum sclerophyllum* *Baccaurea polyneura* Hook.f.	*Mezzetia 5mbellate* *Gonystylus bancanus*	*Cratoxylum glaucum* *Combretocarpus rotundatus*	*Macaranga pruinosa* *Melaleuca leucadendra*
30-39	*Syzygium zeylanicum* *Litsea* sp.	*Mezzetia umbellate* *Callophillum sclerophyllum*	*Combretocarpus rotundatus* *Cratoxylum glaucum*	*Combretocarpus rotundatus* *Eugenia paludosa*
40-49	*Combretocarpus rotundatus* *Shorea smithiana*	*Combretocarpus rotundatus* *Horsfieldia crassifolia*	*Shorea teysmanniana* *Maclurodendron umbellate*	*Dyera polyphylla*
≥50	*Combretocarpus rotundatus* *Litsea* sp.	*Combretocarpus rotundatus* *Callophillum sclerophyllum*	*Garcinia bancanus*	--

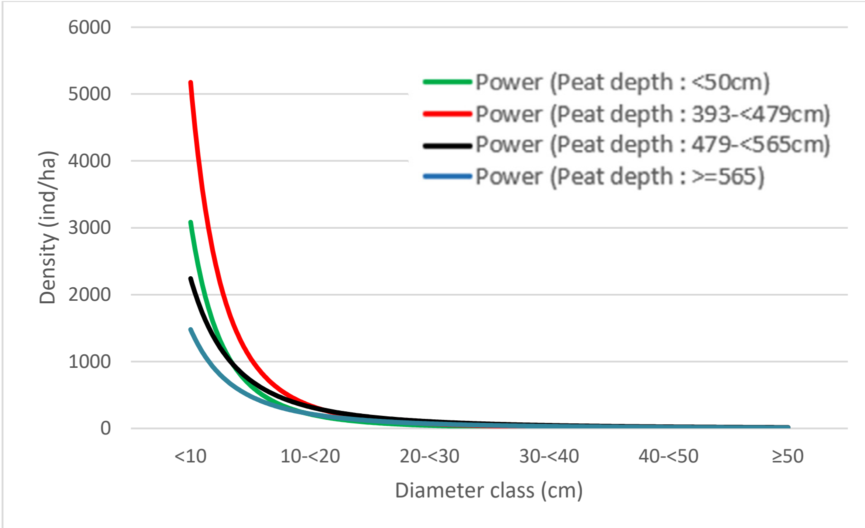

Fig. 8: Diameter distributions of stands at the peat depths of <50 cm, 393-<479 cm, 479-<565 cm, and ≥565 cm

in Tables 4 and 5. The presence of those species show that the studied area is a disturbed/degraded peat swamp forest (Graham and Page, 2014). The presence of Shorea, Eugenia, Calophyllum, Tetramerista, Gonystylus, and Diospyros indicated that the forest in this area is a mixed peat swamp forest. The pioneer species in the studied area are native species. Therefore, they can be used to restore degraded peat swamp forests, such as *Shorea teysmannia*. The density distribution according to diameter could describe the vegetation structures, as shown in Fig. 8. The distribution of diameters also showed whether the forest regeneration process was running normally or disturbed because the trees had different abilities in utilizing solar energy, nutrients, minerals, and water as well as in natural competition. Consequently, the trees in the forest stand had various diameters and the forest stand structures at the study location were generally dominated by *Combretocarpus rotundatus* and *Mezzetia umbellate*.

In natural forests, the small diameter class is more dominant than the large diameter class. Species such as *Combretocarpus rotundatus* and *Mezzetia umbellate* have a wide and dominant distribution until the peat depth of 649 cm. Similarly, the *Combretocarpus rotundatus* species is the dominant species in Central and East Kalimantan and in West Kalimantan in peatlands after fires; thus, this species can be used to enrich, rehabilitate, and restore peatlands. *Combretocarpus rotundatus* species can grow in peat depths of up to 10 m and is the main species that grows on the peat swamplands of Kalimantan (Qirom and Lestari, 2016). Regeneration is an organism's mechanism for maintaining and continuing its presence, and forest stands are reflected by complete profiles of individuals along with a gradient of diameters from seedlings to trees, with the largest diameter. The dominant species of complete plant regeneration, presented in each stratum of trees, saplings, and seedlings, are presented in Table 6.

The species present are strongly affected by their place of growth, including peat depths. Table 6 shows different types of plants at each peat depth and their regeneration. The tree species *Combretocarpus rotundatus* (Miq.) Danser, *Maclurodendron porteri* (Hook. f.) T.G. Hartley, *Tetramestra glabra* Miq, and *Horsfieldia irya* (Gaertn.) Warb. had high survival rates and growth in a peat depth of <50 cm.

Biomass and carbon stock

Important carbon pools of forest ecosystems include biomass, dead organic matter, and soil organic matter. A credible approach to calculating changes in biomass and carbon stock is to consider all relevant carbon pools, including AGB, BGB (roots), DOM (deadwood), litter, and soil (Lepotin

Table 6: Tree species with complete regeneration at the research sites.

Location/sites	Botanical names	Family	IVI (%)		
			Seedlings	Saplings	Trees
Peat depths of 565-649 cm					
1	*Horsfieldia sp*.	Myristicaceae	6.28	32.96	13.94
2	*Horsfieldia irya* (Gaertn.) Warb.	Myristicaceae	15.44	12.34	33.06
3	*Syzygium zeylanicum* (L.) DC.	Myrtaceae	10.56	10.65	10.83
Peat depth 479-564 cm					
1	*Syzygium zeylanicum* (L.) DC.	Myrtaceae	31.42	14.98	2.29
Peat depth 393-478 cm					
1	*Garcinia bancana* (Miq.) Miq./Manggis Hutan	Clusiaceae	14.15	11.69	10.51
2	*Horsfieldia crassifolia* (Hook. fil. and Thoms.) Warb.	Myristicaceae	8.34	29.73	20.15
3	*Campnosperma coriaceum* (Jack) Hallier f.	Anacardiaceae	3.54	8.92	21.83
Peat depth <50 cm					
1	*Combretocarpus rotundatus* (Miq.) Danser	Anisophylleaceae	8.76	24.99	41.03
2	*Maclurodendron porteri* (Hook. f.) T.G. Hartley	Rutaceae	12.76	18.58	39.60
3	*Tetramerista glabra* Miq.	Tetrameristaceae	23.94	120.19	37.84

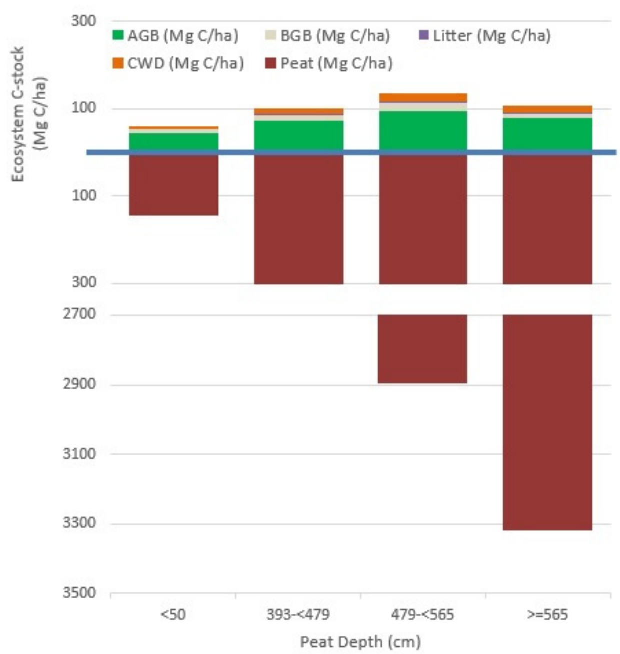

Fig. 9: Profiles of ecosystems of carbon stock at different peat depths.

Table 7: Carbon stock (Mg C/ha) in each carbon pool at different peat depths.

Peat Depth (cm)	AGB (Mg C/ha)	BGB (Mg C/ha)	Litter (Mg C/ha)	CWD (Mg C/ha)	Peat (Mg C/ha)
<50	42.4±7.05	9.8±1.78	0.7±0.12	8.2±1.35	146.1±0
393-<479	73.7±7.93	12.3±1.45	1.2±0.13	14.2±1.52	2642.4±19.78
479-<565	95.2±19.52	19±5.74	1.6±0.32	18.3±3.75	2894.2±2.49
>=565	79.2±17.41	10±2.18	1.3±0.29	15.2±3.35	3317.8±11.03

*Values in means, ± se

et al., 2019). The carbon stock profiles at various peat depths of the research sites are presented in Fig. 9. The contributions to the carbon pools from peat include the peat swamp forests' carbon stock, 71-97%; that from AGB, 2-20%; and those from the roots, litter, and deadwood, the remainder. Roots and deadwood significantly contributed to shallow peat (<50 cm), by 4-5%. In general, the carbon stock in peats and at peat depths increased, and this condition impacted the diversity of carbon pools contributing to the carbon stock ecosystems. Novita *et al.* (2020) investigated peat swamp forests in Tanjung Putting, Central Kalimantan, and found the C stock total to be 1038 Mg C/ha at the Pesalat site (peat depth = 155 cm) and 2502 Mg C/ha in Beguruh (peat depth = 290 cm). The average amount of carbon stock in each carbon pool at various peat depths in KHG Kahayan, Sebangau, is presented in Table 7.

The highest carbon stock in the AGB carbon pool was found at a peat depth of 479-<565 cm (95.2 ± 19.52 Mg C/ha). In contrast, the smallest was found at a peat depth of <50cm (42.4 ± 7.05 Mg C /ha). However, the one-way ANOVA analysis showed that peat depths did not significantly affect the carbon stock in the AGB carbon pool (F_{value} = 2.4498, P_{value} = 0.0793). The amount of carbon stock in AGB was influenced by the basal area of the stands that make up the ecosystems and had a basal area ranging from 18.6 to 32 m^2/ha. This study found that the carbon stock estimation of the AGB carbon pool was slightly lower than that of Krisnawati *et al.* (2021), who investigated the same KHG location. Krisnawati *et al.* (2021) reported that the carbon stock of the AGB carbon pool in primary peat swamp forests in Tumbang Nusa was 105.5-125.7 Mg C/ha. Meanwhile, the secondary forest was affected by the frequency of fires and logging, and the secondary length of undisturbed forests was 79.9-126.9 Mg C/ha. The carbon stocks in other carbon pools, besides peats, insignificantly contribute to the carbon stock ecosystem. The belowground biomass/roots carbon pools have the highest carbon stocks, 19±5.74 Mg C/ha, at a peat depth of 479-<565 cm. The carbon pools for litter and CWD were 1.6±0.32 Mg C/ha and 18.3±3.75 Mg C/ha, respectively. Generally, the smallest carbon stock was found in thin peat depths <50cm. Relatively deep peat with a high concentration of C produced a high soil carbon stock, while shallow peat depths with a lower concentration of C produced a lower soil carbon stock of C. This finding shows the importance of considering peat depths and utilizing peat swamp forests. Deeper peats produced higher carbon stocks. The risk of exploitation occurred because carbon stocks were potentially released. A peat dome is a critical area that must be protected because it has the largest carbon stock, and this study found more than 3000 Mg C ha^{-1} in these areas.

Connection between vegetation diversity, carbon stock, and peat depth

The deeper the peat, the greater the diversity of vegetation and carbon stock. Deeper peats make peat vegetation grow optimally because those plants will have greater adaptation. Shallow peat is dominated by shrubs so the vegetation is less diverse and the carbon stock value is smaller. On the other hand, plants that grow optimally on deeper peats produce higher carbon stock values than shallow peat. The connection between vegetation diversity, carbon stock, and peat depth assessed through Pearson correlation values between those parameters is shown in Table 8. All correlation values between peat depth, vegetation diversity, and carbon stock are positive with each other. This shows that peat

Table 8: Pearson correlation values between peat depth, vegetation diversity, and carbon stock.

Parameter	Depth (cm)	Car-bon stock (Mg C/ha)	Species richness	Shannon index	Simpson index	Rarefied richness index	Fisher's alpha index	Pielou's evenness index
Depth (cm)	1	0.994**	0.449**	0.424**	0.372*	0.332*	0.084	0.127
Carbon stock (Mg C/ha)		1	0.485**	0.451**	0.390*	0.339*	0.063	0.129
Species richness			1	0.915**	0.763**	0.662**	0.037	0.437**
Shannon index				1	0.953**	0.901**	0,074	0.741**
Simpson index					1	0.975**	0.121	0.846**
Rarefied richness index						1	0.237	0.907**
Fisher's alpha index							1	0.223
Pielou's evenness index								1

* Correlation is significant at the 0.05 level (two-tailed).
** Correlation is significant at the 0.01 level (two-tailed).

depth, vegetation diversity, and carbon stock are interdependent and connected to one another. In this study, a peat depth that is maintained properly is one of the ecological characteristics that has an important role in ensuring the sustainability of biodiversity as well as carbon stock. In maintaining peatland forests in good condition, protecting and conserving carbon stock and its ecosystem structure, including biodiversity and peat depth conditions, is necessary. This is confirmed by the results of research by Kareksela *et al.* (2015), which states that the recovery of conditions for increasing carbon stock/sequestration and ecosystem structure is very necessary in order to support restoration activities.

Implications for conservation

The landscape of peat swamp forests is fragile. The slightest disturbance in vegetation and hydrology can have an adverse effect (Anshari, 2021). The peat swamp forest ecosystem is currently facing threats from forest exploitation and use for cultivation. The exploitation and conversion of peat swamp forests can increase carbon emissions into the atmosphere. Therefore, carefully utilizing peat swamps, for example, to develop food estates extensively, is necessary. Besides preventing recurring peat swamp fires and avoiding bigger disasters, the Indonesian government has set a moratorium on peat swamp forest exploitation and designated peat swamp forests as protected areas. Moreover, the government has issued various regulations to improve peat governance through the implementation of rewetting, revegetation, revitalization of local livelihoods, and institutional strengthening to achieve peatland sustainability (Yuwati *et al.,* 2021). This study shows that the Kahayan-Sebangau landscape has secondary peat swamp forest vegetation that also need to be regulated before sustainability can be achieved. Of the four observation plots at different peat depths, some areas still have good vegetation and need to be maintained as protected areas, especially peats with depths of four and six meters. A heavily degraded area is indicated by low species diversity due to frequent fires or intensive use and can be rehabilitated. Peatlands can be rehabilitated by revegetating or replanting, conducting silviculture, creating agroforestry, enriching species, rewetting, and building dams in fire-prone areas (Yuwati *et al.,* 2021), whereas heavily degraded peatlands must be restored. The alternative is to rehabilitate degraded shallow peatlands and to develop productive agricultural cultivation through recommended paludiculture techniques (Triadi, 2020). In selecting the species, the dominant species around the area or local species with a high index value must be considered to successfully grow and quickly adapt to the local environment. Using local species for peat rehabilitation and restoration can be promoted due to similar benefits, especially in biodiversity and ecosystem services (Lof *et al.,* 2019). To improve an environment's sustainability, the degraded areas of peatland need to be restored with types of vegetation that are suitable for each peat depth as well as improved hydrology condition by maintaining ground water level as height as the ground level and can store/absorb of carbon. Carbon stock can be improved by maintaining plant diversity and planting native plant species. Paludiculture is an alternative solution for sustainable peatland management. The types of species that are suitable for peatland can be seen in areas that have not been degraded. To maintain these areas, especially medium peat depth and peat dome areas, they need to be protected. Restoring heavily damaged peat can maintain and save biodiversity, reduce emissions, increase carbon sequestration, and improve people's living standards.

CONCLUSION

The diverse vegetation at the tree, sapling, and seedling levels and the species richness of the peat depths were significantly different due to the various nutrient contents and distances from the river. This study revealed several species with various peat depths: 20 species with a peat depth of 565 cm, 28 species with 479-<565 cm, 32 species with 393-<479 cm, and 19 species with <50 cm. The tree species *Combretocarpus rotundatus* (Miq.) Danser, *Maclurodendron porteri* (Hook. f.) T.G. Hartley, *Tetramestra glabra* Miq, and *Horsfieldia irya* (Gaertn.) Warb. had high survival rates and grew at a peat depth of <50 cm. Those species could be used for rehabilitation in degraded peatland forest as pioneer species. The presence of Shorea, Eugenia, Calophyllum, Tetramerista, Gonystylus, and Diospyros indicated that the forest in a certain area was a mixed peat swamp forest. In addition, the highest carbon stock was 95.2 ±19.52 Mg C/ha, found at a peat depth of 479-564 cm and a vegetation diameter of ≥10 cm. The study results confirmed that peat thickness could not directly affect the vegetation dynamic in terms of vegetation diversity. The vegetation changes were influenced directly by changing other characteristics of peat hydrology, peat chemistry, and peat organic matter. All Pearson correlation values between peat depth, vegetation diversity, and carbon stock are positive with each other. This shows that peat depth, vegetation diversity, and carbon stock are interdependent and are connected with one another. The deeper the peat, the greater the diversity of vegetation and carbon stock. Deeper peats make peat vegetation grow optimally because those plants have higher adaptation levels. The diverse vegetation as well as carbon stock in peatland forests must be conserved to maximize the environmental services they provide humans in the future. Therefore, protecting this forest from unsustainable use, encroachment, and forest fires is necessary. The connection between vegetation diversity, carbon stock, and peat depth can be applied as indicators of whether to protect or rehabilitate peatland forests. With high diversity, high carbon stock, and deeper peatlands, protection efforts are needed. However, with low diversity, low carbon stock, and shallow peatland, rehabilitation efforts are needed.

AUTHOR CONTRIBUTIONS

R. Garsetiasih performed the conception and design. N.M. Heriyanto performed the analyze and interpreted the data, and drafting of the manuscript literature review. W.C. Adinugroho performed the analyze and interpreted the data, and drafting of the manuscript. H. Gunawan performed the literature review, analyzed and interpreted the data. I.W.S. Dharmawan performed the literature review, analyzed and interpreted the data, and preparation of the manuscript text. R. Sawitri performed analyzed and interpreted the data, and literature review. I. Yeny performed analyzed and interpreted the data, and literature review. N. Mindawati performed literature review and interpreted the data. D. Denny performed the literature review and compiled the data.

ACKNOWLEDGEMENT

The authors would like to thank to the Head of Forest Research and Development Center, Head of Forest the Central Kalimantan Provincial Office and the Communities around the peat land ecosystem block C, Pulang Pisau District.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

ABBREVIATIONS

%	Percent
AGB	Above Ground Biomass
BD	Bulk Density
BGB	Below Ground Biomass
C	Carbon
Ca	Calsium
cm	centimeter
CO_2	Carbondioxide
CWD	Coarse Woody Debris
D	Diameter at breast height
D	Simpson's diversity index
DOM	Dead Organic Matter
e	Pielou's evenness index
eq	equivalent
Fi	frequency of a species
Fig.	Figure
Gi	total base area of a species and *G* is total base area of all species
g	gram
g/cm^3	gram per centimeter cubic
GPS	Global Positioning System
Gt	Giga ton
H'	Shannon's diversity index
H	Height
HPH	Hak Pengusahaan Hutan (Concessionaries)
IVI	Important Value Index
K	Kalium
KHG (PHU)	Kawasan Hidrologi Gambut (Peat Hidrology Unit)
kg	kilogram
km^2	kilometer square
m	meter
Mg	Mega gram
Mg	Magnesium
Mg C/ha	Mega gram Carbon per hectare
N	total number of individuals of all species in the plot
ni	number of individuals of a species

P	Phosporus
pi	number of individuals of a species over total number of individuals
PLG	Proyek Lahan Gambut (Peatland Project)
R	Rarefied species richness
S	Fisher's alpha index
WD	Wood Density
Y	Above-ground/below-ground biomass

REFERENCES

Afrianto, W.F.; Hikmat A.; Widyatmoko, D., (2016). Florist and succession community vegetation after the 2010 eruption at Mount Merapi, Central Java. J. Indonesian Biol., 12(2):265-276 **(12 pages).**

Afzanizam, M.M.; Philip, E.; Shahrul, A.B.; Haniff, H.M., (2019). Biomass and carbon stock assessment of peat swamp forest ecosystem: a case study in permanent forest reserve Pekan Pahang, Malaysia. Int. Res. J. Eng. Technol., 6(1): 21-31 **(11 pages).**

Anshari, G., (2021). Circularity and singularity of tropical peat swamp forest ecosystems, in: Osaki, M., Tsuji, N., Foead, N., Rieley, J. (Eds). Tropical peatland eco-management. Springer, Singapore.

Aravind, J.; Kanmani, P.; Sudha, G.; Balan, R., (2016). Optimization of chromium (VI) biosorption using gooseberry seeds by response surface methodology. Global J. Environ. Sci. Manage., 2 (1); 61-68 **(8 Pages)**.

Astiani, D., (2016). Tropical peat swamp tree-species diversity altered by forest degradation. Biodivers. J., 17(1): 102-109 **(8 pages).**

Dargie, G.C.; Lewis, S.L.; Lawson, I.T.; Mitchard, E.T.A.; Page, S.E.; Bocko, Y.E.; Ifo, S.A., (2017). Age, extent and carbon storage of the Central Congo Basin peat swamp complex. Nature, 542: 86–90 **(5 pages).**

Dohong, A.; Aziz, A.A.; Dargush, P., (2017). A review of the drivers of tropical peat swamp degradation in South - East Asia. Land Use Policy. 69: 349-360 **(12 pages).**

Dommain, R.; Cobb, A.R.; Joosten, H.; Glaser, P.H.; Chua, A.F.L.; Gandois, L.; Kai, F.M.; Noren, A., Salim, K.A.; N. Salihah, H.; Su'ut, N.S.H.; Charles, F.; Harvey, C.F., (2015). Forest dynamics and tip-up pools drive pulses of high carbon accumulation rates in a tropical peat dome in Borneo (Southeast Asia). J. Geophys. Res. Biogeosci., 120: 617–640 **(24 pages).**

Fenner, N.; Freeman, C., (2011). Drought-induced carbon loss in peatlands. Nat. Geosci., 4: 895–900 **(6 pages).**

Graham, L.L.B.; Page, S.E., (2014). Forest restoration in degraded tropical peat swamp forest, in: Bossano, M., Jalonene, R., Boshier, D., Gallo, L., Cavers, S., Bordacs, S., Smith, P., Loo, J. (Eds)., The State of the world's forest genetic resources – thematic study: genetic considerations in ecosystem restoration using native tree species. FAO, Rome.

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.; Hoing, A.; Husson, S. J.; Kulu, I. P.; Soebagio, S. M.; Mang, S.; Mercado, L.; Morrogh-Bernard, H. C.; Page, S. E.; Priyanto, R.; Capilla, B. R.; Rowland, L.; Santos, E. M.; Schreer, V.; Sudyana, I. N.; Taman, S. B. B.; Thorton, S. A.; Upton, C.; Wich, S. A.; van Veen, F. J. F., (2019). Tropical forest and peat swamp conservation in Indonesia: Challenges and directions. People nat., 2(04): 1-25 **(25 pages).**

Haryadi; Sunarto; Sugiyarto., (2019). Vegetation analysis of the secondary forest area in Cangkringan Resort, Mount Merapi National Park. Biodjati, 4(1): 50-57 **(8 pages).**

Hirano, T.; Kusin, K.; Limin, S.; Osaki, M., (2014). Carbon dioxide emissions through oxidative peat decomposition on a burnt tropical peat swamp. Glob. Change Biol., 20(2):555-565 **(11 pages).**

Hooijer, A.; Page, S.; Canadell, J.G.; Silvius, M.; Kwadijk, J.; Wösten, H.; Jauhiainen, J., (2010). Current and future CO2 emissions from drained peat swamps in Southeast Asia. Biogeosciences, 7(5): 1505–1514 **(10 pages).**

Kalima, T.; Suharti, S.; Sumarhani; Trethowan, L.A., (2020). Tree species diversity and ethnobotani of degraded peat swamp forest in Centarl Kalimantan. Reinwardtia, 19(1): 27-54 **(28 pages).**

Kareksela, S.; Haapalehto, T.; Juutinen, R.; Matilainen, R.; Tahvanainen, T.; Kotiaho, J.S., (2015). Fighting carbon loss of degraded peatlands by jump-starting ecosystem functioning with ecological restoration. Sci. Total Environ., 537:268-276 **(9 pages).**

Krisnawati H.; Adinugroho; W.C.; Imanuddin, R.; Suyoko; Weston, C.J.; Volkova, L., (2021). Carbon balance of tropical peat forests at different fire history and implications for carbon emissions, Sci. Total Environ, 779: **(9 pages).**

Kusmana, C.; Hikmat, A., (2015). Diversity of flora in Indonesia. J. Nat. Environ. Manage., 5(2): 187–198 **(12 pages).**

Lähteenoja, O.; Ruokolainen, K.; Schulman, L.; Alvarez, J., (2009a). Amazonian floodplains harbour minerotrophic and ombrotrophic peat- lands. Catena., 79(2):140–145 **(6 pages).**

Lähteenoja, O.; Ruokolainen, K.; Schulman, L.; Oinonen, M., (2009b). Amazonian peatlands: An ignored C sink and potential source, Glob. Change Biol., 15(9):2311–2320 **(10 pages).**

Laumonier, Y.; Edin, A.; Kanninen, M.; Munandar, A.W., (2010). Landscape-scale variation in the structure and biomass of the hill dipterocarp forest of Sumatra: Implications for carbon stock assessments. For. Ecol. Manage., 259(3): 505–513 **(9 pages).**

Lof, M.; Madsen, P.; Metslaid, M.; Witzell, J.; Jacobs, D.F., (2019). Restoring forests : regeneration and ecosystem fungtion for the future. New For., 50(2): 139-151 **(13 pages).**

Lepotin, J.; Kattetenborn, T.; Galleguillos, M.; Perez-QueZada, J.F.; Schmidtlein, S., (2019). Using aboveground vegetation attributes as proxes for mapping peatland belowground carbon stocks. Remote Sens. Environ., 231(111217): 1-26 **(26 pages).**

Mansur, M.; Kartawinata, K., (2017). Phytosociology of a lower montane forest on Mt. Batulanteh, Sumbawa, Indonesia. Reinwardtia, 16(2): 77–92 **(16 pages).**

Manuri, S.; Brack, C.; Rusolono, T.; Noor'an F.; Verchot L.; Maulana, S.I.; Adinugroho, W.C.; Kurniawan, H.; Sukisno, D.W.; Kusuma, G.A.; Budiman, A.; Anggono, R.S.; Siregar, C.A.; Onrizal, Yuniati, D.; Soraya, E., (2017). Effect of species grouping and site variables on aboveground biomass models for lowland tropical forests of the Indo-Malay region. Ann. For. Sci., 74(23): 1-14 **(14 pages).**

Miettinen, J.; Liew, S.C., (2010). Degradation and development of peatlands in Peninsular Malaysia and in the islands of Sumatra and Borneo since 1990. Land Degrad. Dev. 21(3): 285-296 **(12 pages).**

Minayeva, T.; Bragg, O.; Sirin, A., (2017). Toward ecosystem based restoration of peatland biodiversity. Mires Peat., 17(01): 1-36 **(36 pages).**

Morton, P.A.; Heinemeyer, A., (2019). Bog breathing: The extent of peat shrinkage and expansion on blanket bogs in relation to water table, heather management and dominant vegetation and its implications for carbon stock assessments. Wetl. Ecol. Manag., 27(2): 467-482 **(16 pages).**

Mueller-Dombois, D.; Ellenberg, H., (2016). Vegetation ecology: Objectives and methods (translation of aims and methods of vegetation ecology by K. Kartawinata & R. Abdulhadi). LIPI Press and Yayasan Pustaka Obor, Jakarta.

Nelson, K.; Thompson, S.; Hopkinson, C.; Petrone, R.; Chasmer L., (2021). Peatland-fire interactions: A review of wildland fire feedbacks and interactions in Canadian boreal peatlands. Sci. Total Environ., 769(145212): 1-14 **(14 pages).**

Niiyama, K.; Kajimoto, T.; Matsuura, Y.; Yamashita, T.; Matsuo, N.; Yashiro, Y.; Ripin, A.; Kassim, A.R.; Noor, N.S., (2010). Estimation of Root biomass based on excavation of individual root systems in a primary dipterocarp forest in Pasoh Forest Reserve, Peninsular Malaysia. J. Trop. Ecol., 26(3): 271-284 **(14 pages).**

Novita, N.; Kauffman, J.B.; Hergoualc'h, K.; Murdiyarso, D.; Tryanto, D.H.; Jupesta, J., (2020). Carbon stocks from peat swamp forest and oil palm plantation in Central Kalimantan, Indonesia, in: Djalante, R., Jupesta, J., Aldrian E. (Eds.), Climate change research, policy and actions in Indonesia. Springer Climate. Springer, Cham.

Oksanen, J.; Blanchet, F.G.; Friendly, M.; Kindt, R.; Legendre, P.; McGlinn, D.; Minchin, P.R.; O'Hara, R.B.; Simpson, G.L.; Solymos, P.; Stevens, M.H.H.; Szoecs E.; Wagner, H., (2019). Vegan: Community ecology package. R package version 2.5-6.

Osaki, M.; Kato, T.; Takashi, K.; Hidenori, T.; Akira, H.; Kazuo,Y.; Nobuyuki, T.; Satomi, S.; Joeni, S.R.; Tika, D.A.; Ayako, O.; Kayo, M.; Rahmawati, I.W.; Sisva, S., (2021). in: Osaki, M., Tsuji, N., Foead N., Rieley J. (Eds.)., Tropical peat swamp eco-management. Basic information about tropical peat swamp ecosystems. Springer, Singapore.

Page, S.E; Rieley, J.O.; Shotyk, O.W.; Weiss, D., (1999). Interdependence of peat and vegetation in a tropical peat swamp forest. Phil. Trans. R. Soc. Lond. B., 354(1391): 1885-1897 **(13 pages).**

Posa, M.R.C.; Wijedasa, L.S.; Corlett, R.T., (2011). Biodiversity and conservation of tropical peat swamp forests. BioScience, 61(1): 49–57 **(9 pages).**

Qirom, M.A.; Lestari, N.S., (2016). Diversity of plant species at various peat depts in Kalimantan. In National Conference of Wetland. South Kalimantan, Republic of Indonesia. Lembaga Penelitian dan Pengabdian kepada Masyarakat, Universitas Lambung Mangkurat: South Kalimantan.

R Core Team, (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rieley, J.O.; Ahmad-Shah, A.A.; Brady, M.A., (1996). The extent and nature of tropical peat swamps, in: Maltby E., Immirzi, C.P., Safford, R.J. (Eds). Tropical peatlands of Southeast Asia. International Union for Conservation of Nature.

Russell, A.E.; Raich, J.W., (2012). Rapidly growing tropical trees mobilize remarkable amounts of nitrogen, in ways that differ suprisingly among species. Proc. Natl. Acad. Sci USA, 109(26):10398-10402 **(4 pages).**

Schulte, M.L.; McLaughlin, D.L.; Wurster, F.C.; Balentine, K.; Speiran, G.K.; , Aust, W.M.; Stewart, R.D.; Varner, J.M.; Jone, C.N., (2019). Linking ecosystem function and hydrologic regime to inform restoration of a forested peatland. J. Environ. Manage., 233:342-351 **(10 pages).**

Sefidi, K.; Copenheaver, C.A.; Kakavand, M.; Behjou, F.K., (2015). Structural diversity within mature forests in Northern Iran: A case study from a relic population of persian ironwood (Parrotia persica CA Meyer). For. Sci., 61(2): 258-265 **(8 pages).**

Soil Survey Staff, (2014). Keys to soil taxonomy, 12th Edition. USDA Natural Resources Conservation Service: US.

Triadi, L.B., (2020). Restorasi lahan rawa gambut melalui metode pembasahan (sekat kanal) dan paludikultur (Restoration of peat swamp through rewetting (canal blocking) and paludiculture method). J. Sumber Daya Air., 16(2): 103-118 **(6 pages).**

Warren, M.; Hergoualc'h.; Kauffman, J.B.; Murdiyarso, D.; Kolka, R., (2017). An appraisal of Indonesia's immense peat carbon stock using national peat swamp maps: Uncertainties and potential losses from conversasion. Carbon Balance Manage., 12(12): 1-12 **(12 pages).**

Wickham, H., (2016). GGplot2: Elegant graphics for data analysis. Springer-Verlag: New York.

Yuwati, T.W.; Rachmanadi, D.; Pratiwi; Turjaman, M.; Indrajaya, Y.; Nugroho, H.Y.S.H.; Qirom, M.A.; Narendra, B.H.; Winarno, B.; Lestari, S.; *et al.,* (2021). Restoration of degraded tropical peatland in Indonesia: a review. Land. 10(11): 1-31 **(31 pages).**

AUTHOR (S) BIOSKETCHES

Garsetiasih, R., Ph.D., Professor, Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *garsetiasih@yahoo.com*
- ORCID: 0000-0002-5886-0279
- Web of Science ResearcherID: 4807773
- Scopus Author ID: 57209804820
- Academic Homepage: http://puslitbanghut.or.id

Heriyanto, N.M., M.Sc., Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *nurmheriyanto88@yahoo.com*
- ORCID: 0000-0002-1098-7641
- Web of Science ResearcherID: 4809758
- Scopus Author ID: NA
- Academic Homepage: http://puslitbanghut.or.id

Adinugroho, W.C., M.Sc., Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *wahyuk2001@yahoo.com*
- ORCID: 0000-0003-0687-5679
- Web of Science ResearcherID: 59462020
- Scopus Author ID: 57193552889
- Academic Homepage: http://puslitbanghut.or.id

Gunawan, H., Ph.D., Professor, Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *hendragunawan1964@yahoo.com*
- ORCID: 0000-0002-2855-801X
- Web of Science ResearcherID: 4807323
- Scopus Author ID: 57216983705
- Academic Homepage: http://puslitbanghut.or.id

Dharmawan, I.W.S., Ph.D., Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *salifa03@yahoo.co.id*
- ORCID: 0000-0002-7007-393X
- Web of Science ResearcherID: 4807546
- Scopus Author ID: 57267722400
- Academic Homepage: http://puslitbanghut.or.id

Sawitri, R., M.Sc., Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *sawitri_reny@yahoo.com*
- ORCID: 0000-0002-6080-7805
- Web of Science ResearcherID: 4809875
- Scopus Author ID: 57193732162
- Academic Homepage: http://puslitbanghut.or.id

Yeny, I., M.Sc., Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *irmayeny.kemenhut@yahoo.com*
- ORCID: 0000-0002-3450-7913
- Web of Science ResearcherID: 4807972
- Scopus Author ID: 57219414393
- Academic Homepage: http://puslitbanghut.or.id

Mindawati, N., Ph.D., Professor, Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *ninapulp@yahoo.co.id*
- ORCID: 0000-0001-7368-1351
- Web of Science ResearcherID: 75602021
- Scopus Author ID: 104404844009
- Academic Homepage: http://puslitbanghut.or.id

Denny, M.Sc., Forest Research and Development Center, Ministry of Environment and Forestry, Bogor, West Java, Indonesia.
- Email: *dennybppn@gmail.com*
- ORCID: 0000-0003-0800-0956
- Web of Science ResearcherID: 4809845
- Scopus Author ID: NA
- Academic Homepage: http://puslitbanghut.or.id

HOW TO CITE THIS ARTICLE

Garsetiasih, R.; Heriyanto, N.M.; Adinugroho, W.C.; Gunawan, H.; Dharmawan, I.W.S.; Sawitri, R.; Yeny, I.; Mindawati, N.; Denny., (2022). Connectivity of vegetation diversity, carbon stock, and peat depth in peatland ecosystems. Global J. Environ. Sci. Manage., 8(3): 369-388.

DOI: 10.22034/gjesm.2022.03.06

url: https://www.gjesm.net/article_247902.html