Sriwijaya Journal of Environment
Article
ojs.pps.unsri.ac.id

Recovery of Burned Peatland: Revegetation Pattern Planning in Palm Oil Concession, South Sumatra

Supriyadi[1*], Satria Jaya Priatna[2], M. Bambang Prayitno[2], M. Umar Harun[3], M. Yusup Nur Khakim[4], Risfidian Mohadi[5]

[1]*Environmental Management Study Program, Sriwijaya University, Indonesia*
[2]*Soil Science Department, Agricultural Faculty, Sriwijaya University, Indonesia*
[3]*Agronomy Department, Agricultural Faculty, Sriwijaya University, Indonesia*
[4]*Physics Department, Mathematics and Natural Science Faculty, Sriwijaya University, Indonesias*
[5]*Chemistry Department, Mathematics and Natural Science Faculty, Sriwijaya University, Indonesia*
**Corresponding author: supriyadi.sp.1992@gmail.com*

Article history

Received	Received in revised form	Accepted	Available online
22 November 2023	23 December 2023	30 January 2024	31 January 2024

Abstract: Peatland ecosystems can recover from fire disasters through ecological succession, revegetation, or both. In the context of oil palm plantations, revegetation planning for peatlands aims to restore the hydrological and carbon storage functions of peatlands, as well as to continuously increase the diversity of local vegetation by minimizing engineering activities on the land. This study explores the factors that influence revegetation of peatlands and identifies the distribution of water table levels as the main determinant. The water table levels, which vary from approximately 10 cm to 110 cm, correlate with topographic conditions and significantly impact vegetation survivability. The dominant plant species in the study area is Purun (*Eleociharis dulcis*), occupying approximately 44.5% of the total area. Other adaptable vegetation types, such as Gelam (*Melaleiuca* spp.) and Perepat (*Combretocarpus rotundiatus*), are considered suitable for propagation and planting as part of the peatland revegetation program. The study recommends prioritizing revegetation in areas with low vegetation diversity. Planting in areas with deep water table levels (60-80 cm) is recommended during the dry or humid months (June to September) while planting in areas with shallow water table levels (0-40 cm) is better conducted in the rainy season (October to December).
Keywords: burned peatland, revegetation map, palm oil concession.

1. Introduction

Peatland is an invaluable ecosystem in climate change mitigation, serves as a significant carbon reservoir and is essential for global climate stability. Its ecological functions encompass carbon storage, water balance maintenance and biodiversity habitat provision. However, peatlands face a high vulnerability to fire disasters, threatening the ecosystem [1]. Peatland fires result in environmental consequences, including carbon release into the atmosphere, exacerbating climate change [2]. Additionally, social impacts affect local communities relying on peatlands for livelihoods, such as fishermen, weavers, and wood gatherers, deeply intertwining their well-being with ecosystem health [3]. This underscores the urgency of preserving and restoring peatland ecosystems to mitigate climate change, protect biodiversity and sustain local communities and studies are vital.

Due to the urgency of restoring peatland ecosystems, a study focused on plant selection, pattern design and water management strategies within this ecosystem has become imperative [4]. A more profound comprehension of how to tackle the challenges in peatland recovery holds importance not only for preserving the ecosystem but also for taking tangible actions in global climate change mitigation. To achieve the desired peatland recovery targets, comprehensive planning of planting patterns are needed.

The recovery of burned peatland ecosystems can be achieved through ecological succession, revegetation, or a combination of both [5]. These options hinge upon the intricate interplay among plant species, the surrounding environment, and the dynamics of plant populations [6]. Such interactions form the foundational basis for crafting effective planting patterns. In the specific context of oil palm plantations, the planning of peatland revegetation initiatives must meticulously consider implementation patterns that minimize land modification. Furthermore, these plans should maintain a low water table to prevent future land fires, avoid introducing non-native species with invasive potential that could jeopardize local plant diversity, and ensure they do not impose technical or economic burdens on the company [7], [8].

The primary objective of this study is to formulate practical guidelines for the revegetation of post-fire peatlands. It is noteworthy that there is a significant gap in the existing literature regarding the design of revegetation planting patterns, particularly those specifically designed for post-fire peatlands. This study conducts an analysis of both quantitative and qualitative data, encompassing land characteristics and vegetation diversity at the study site. The findings from this analysis are utilized in the creation of a planting pattern map. The outcomes of this study are expected to serve as a valuable reference for stakeholders involved in peatland management and significantly contribute to future restoration project.

2. Material and Methods

2.1. Time, Location and Materials

The research activities were conducted in August 2023, during the dry season, within the Concession Area of "X" Company in Pulau Geronggang, Pedamaran Timur District, Ogan Komering Ilir Regency, South Sumatra, covering an area of 401,82 hectares. The data used in this study included aerial photographs of the research location with a resolution of 3,94 cm/pixel, taken in August 2022 from the archives of "X" Company, which had previously conducted asset management activities in 2022. Land topography data were obtained from DEMNAS, published by the *Badan Informasi Geospasial* (BIG) through their website (tanahair.indonesia.go.id/demnas). Data on peat depth and groundwater depth were acquired through field surveys in August 2023. The monthly rainfall data is derived from CHIRPS (Rainfall Estimates from Rain Gauge and Satellite Observations) data from January 2013 to July 2023.

2.2. Methods

2.2.1. Topography Data Processing

Topography data processing was conducted using QGIS software. The DEMNAS data, once acquired, underwent extraction by cropping it to match the study area coverage. This extraction process yielded raster data representing the elevation of the study area, which was subsequently converted into vector format for overlay with other datasets.

2.2.2. Rainfall Data Processing

Rainfall data processing was carried out by creating an average monthly rainfall distribution table to observe the patterns of annual dry and wet months. The rainfall pattern is then used as a reference for planting timing at the study site.

2.2.3. Peat and Ground Water Level Depth Mapping

The mapping of peat and groundwater depth is conducted through field observations, with the data obtained subsequently processed using spatial interpolation. Peat and groundwater depth at various points are observed and then interpolated using the Inverse Distance Weighting method to predict the distribution of peat thickness [9]. Additionally, the Empirical Bayesian Kriging (EBK) regression prediction method is employed to predict the distribution of the water table [10].

2.2.4. Population density and local plant diversity mapping

The density of vegetation and diversity of local plants are mapped in two stages: first, through manual delineation based on visual interpretation of aerial photographs to categorize areas according to their population density and vegetation diversity. second, through field surveys using 10×10 meter plots to record the quantity and observe the types of local plants present in each area. The results of the field surveys, combined with the visual delineation, provide a distribution of the population density and types of local plants in the study area.

2.3. Data Analysis

The reforestation pattern planning is carried out through an overlay analysis of spatial data on vegetation population density and local plant diversity, with spatial data on land topography, and the distribution of peat and groundwater depths. The overlaid results are then matched with seasonal patterns derived from rainfall data. In areas with lower elevation, inundation, and lower vegetation density and diversity, priority will be given to management during the dry season. Areas with higher elevation, no inundation, and lower vegetation density and diversity will be recommended for management during the wet season. Areas with good vegetation density and diversity will serve as a source of seedlings to be distributed to areas with lower vegetation density and diversity.

3. Results and Discussion

3.1.1. Topography Conditions

The topographic conditions in peatland are crucial to understanding because they affect the water table's elevation on the land. Based on the DEMNAS data extraction results, the topographic conditions in the study area are not flat, as is typically found in peatland. There is an elongated topographic decline in the central part of the study area.

During field surveys, it was observed that the lower-lying areas tend to be inundated, especially during the rainy season. This is consistent with historical accounts from senior employees of Company “X”, who revealed that the study area was previously a riverine area before it became a concession land. The presence of these low-lying areas poses a significant challenge for plantation roads.

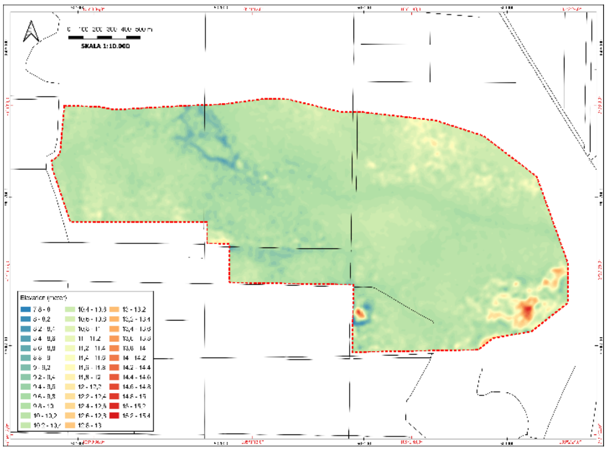

Figure 1. The Topographic Condition.

Based on visual observations during field surveys, the low-lying areas tend to be inundated. According to information from senior company employees, before becoming the concession land of Company "X," the study area used to be a riverine area. The plantation roads in these low-lying areas become submerged during the rainy season, posing a significant obstacle to conducting revegetation activities in the vicinity.

The elevation of the study area ranges from 7,8 to 15,4 meters above sea level, with a relatively flat contour. This range of elevation is typical for peatlands. In addition to the topographic variations in the study area, it's essential to consider the seasonal dynamics of water levels. These wetter conditions might not only impede plantation efforts but also influence the overall success of revegetation. The interaction between topography and seasonal changes in water levels is a vital factor to account.

3.1.2. Wet and Dry Season Pattern

Based on the average monthly precipitation data sourced from CHIRPS from January 2013 to July 2023, it is evident that the monthly rainfall in the study area is relatively high, with an average rainfall of over 100 mm per month. A decrease in rainfall (<200 mm) typically occurs from June to September. During these months, reforestation activities in the study area can be carried out as the groundwater level tends to decrease, facilitating mobility and planting techniques, especially in low-topography areas.

Given the high rainfall conditions, it is advisable to avoid any planting activities in the study area in locations that remain waterlogged from June to September. These locations are better suited for use as water retention areas.

Table 1. Average Monthly Rainfall in 2013-2023

Date	Rainfall (mm/month)	Condition
January	298,17	wet month
February	226,58	wet month
March	297,29	wet month
April	288,51	wet month
May	218,23	wet month
June	161,48	humid
July	149,08	humid
August	137,38	humid
September	157,55	humid
October	225,16	wet month
November	338,84	wet month
December	359,69	wet month

3.1.3. Distribution of Peat Thickness

Based on observations at 18 peat soil boreholes in the study area interpolated with the Inverse Distance Weighting method, it is known that the distribution of peat on the land is currently uneven, with thickness ranging from 0 (no peat) to 250 cm (conservative peat area). The thickness of peat can change naturally or due to human activities [11]. Naturally, peat thickness may decrease through processes like decomposition during seasonal changes or alterations in land features caused by geological events [12].

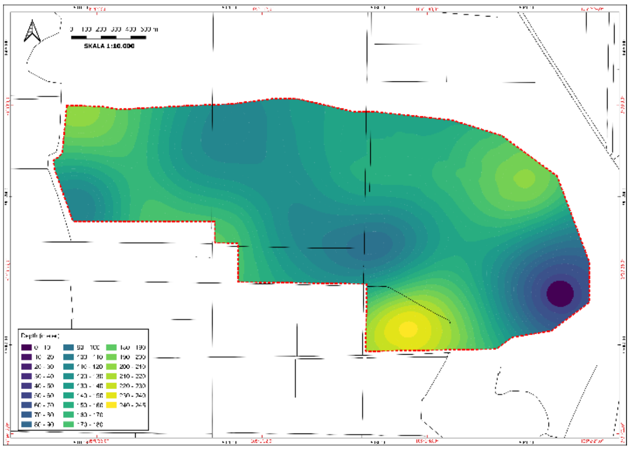

Figure 2. Peat Thickness Distribution.

The type of soil found in the peat substratum in the study area is of the alluvial type. Alluvial soil is a type of soil formed from the process of sedimentation [13]. This type of soil is commonly found on riverbanks or lands that were once part of a river [14]. Peatlands with an alluvial substratum are generally more fertile compared to peatlands with a quartz substratum [15]. The alluvial substratum is composed of clay minerals that have a negative charge capable of attracting and retaining positive nutrient ions such as potassium, calcium, and magnesium. In other words, the clay minerals in the alluvial substratum can function as a nutrient reservoir for plants [16].

The thickness of peat material and the type of substratum (soil layer at the base) on the land can influence the diversity of vegetation that grows on its surface [17]. Human activities on peatlands, such as canal construction or other developments that lower the groundwater table, can trigger unnatural decomposition. In dry conditions, peat not only decomposes but also becomes susceptible to wildfires [11].

3.1.4. Groundwater Level

Concurrent with the peat depth observations, groundwater levels were also monitored at the same 18 peat bore points and interpolated with the EBK regression prediction method, with topographic conditions as the explanatory variables that will be used to build the regression model. EBK regression prediction is a method of interpolating data that combines empirical Bayesian kriging with regression analysis. It uses explanatory variable raster that is known to affect the value of the data that are interpolated [10]. Groundwater levels in the study area varied from approximately 10 cm to 110 cm. The distribution of groundwater depth correlates with the topographic conditions, which become deeper in the middle.

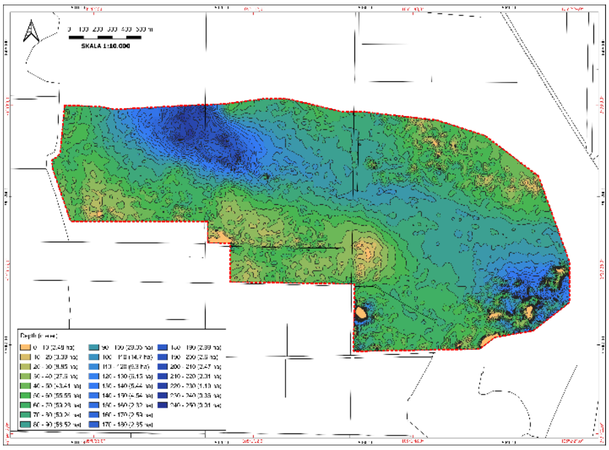

Figure 3. Groundwater Level Distribution.

According to senior employees of Company "X," the low-elevation areas were formerly part of the Burnai River, with water flowing to south-eastward. The depth of the groundwater table is the primary impediment to peatland revegetation activities [18]. Apart from posing technical challenges, the water table's elevation significantly affects the success rate of introduced plant species.

3.1.5. Distribution of Vegetation Population and Diversity

Based on the interpretation of aerial photos taken in August 2022 and verified through field observations, the dominant plant species in the study area is Purun (*Eleocharis dulcis)*. This particular plant species significantly dominates the land cover in the study area, occupying an estimated 44,5% or approximately 178,81 hectares of the total study area. Remarkably, this plant can be found at every observation point. *E. dulcis* exhibits a strong ability to adapt well to areas with high inundation. Intriguingly, during the dry season, the groundwater level in this area will decrease but remain above the ground surface, resulting in conditions of inundation all year round. This unique adaptation allows *E. dulcis* to thrive, outperforming many other plant species in these challenging conditions [19].

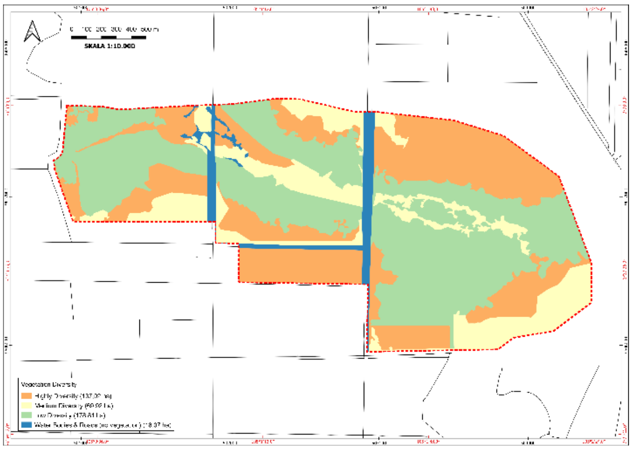

Figure 4. Distribution of Vegetation Diversity.

In addition to *E. dulcis*, other plants that can adapt well to environments with high inundation (>70 cm) are Gelam (*Melaleuca* spp.) and Perepat (*Combretocarpus rotundatus*). *Melaleuca* spp. begins to be found in areas with medium to high diversity. Meanwhile, S. alba) can be found at almost all water levels, but the majority of its population is in areas with medium diversity. Areas with medium diversity cover about 17,4% or approximately 69,92 hectares of the total study area and are dominated by *Melaleuca* spp, *Combretocarpus rotundatus* and *Eleocharis dulcis*.

Areas with high diversity cover 34,1% or approximately 137,02 hectares of the total study area, which includes various species of trees, shrubs, and ferns. Typical swamp plants found in this area include: Purun (*Eleocharis dulcis*), Gelam (*Melaleuca* spp.), Perepat (*Combretocarpus rotundatus*), Jambu-jambuan (*Syzgium* sp), Pakis (*Stenochlaena* sp), Pandan Alas (*Pandanus helicopus*), Beriang (*Ploiarium alternifolium*), Senduduk (*Melastoma malabathricum*), Rumput rija-rija (*Scleria* sp) and Kantong Semar (*Nephentes* sp). In these areas with high diversity, the groundwater level tends to be lower than in other areas.

Based on its distribution pattern, the diversity of vegetation in the study area is more influenced by the height of water accumulation than by the thickness of the peat. This suggests that hydrological conditions, particularly the depth of water, play a significant role in determining the composition and distribution of plant species in the area. The water level can affect the availability of oxygen in the soil, which is crucial for plant root respiration. Higher water levels may lead to anoxic conditions, which can limit the types of plants that can survive in these environments [20]. Conversely, areas with lower water levels may offer more favorable conditions for a wider variety of plant species, resulting in greater biodiversity.

3.1.6. Recommended Plant for Revegetation

With the survey of vegetation diversity resulting from natural succession at the study site, it can be determined what types of local plants can be recommended for planting in revegetation activities. The selected plant species are local plant species that have proven to be able to adapt well to the characteristics of the study site with flooded conditions [21]. Other typical peatland plants that were not found during the observation activity are less recommended because they are feared to be less adaptive to the groundwater level conditions at the study site, and thus may not survive.

In addition to adaptability, the benefits of the chosen plants also become a consideration. These benefits can be economic (forest products, timber, or non-timber) or ecological (being part of key species or rare species). It's important to note that these plants also contribute to carbon sequestration, a key factor in mitigating climate change. From several plants that we found, Gelam (*Melaleuca* spp.) and Perepat (*Combretocarpus rotundatus*) are candidates that are considered suitable to be propagated and planted on the study site in an effort to revegetate the peatlands. These two plants can be found in all groundwater conditions. This indicates that *Melaleuca* spp. and *C. rotundatus* are able to adapt well to soil conditions with various groundwater conditions. Their resilience and adaptability make them ideal for restoration efforts, ensuring the sustainability of the peatland ecosystem in the long term.

Gelam (*Melaleuca* spp.) is a type of wood plant that can naturally grow in swamp forests in Indonesia. The wood from this plant is often utilized in housing construction due to its remarkable strength, being classified as strong II and durable III according to the Indonesian Wood Construction Regulations Standard (PKKI) NI 5-1961 [22]. This wood characteristic is particularly suitable for use as a supporting pole for stilt houses, which are common in swamp areas, or for revetments in watery areas. This plant is relatively easy to cultivate in swamp areas. The propagation of *Melaleuca* spp. is generally carried out through vegetative methods, such as stem cuttings or offshoot separation.

Combretocarpus rotundatus, commonly known as Perepat, is a type of wood plant that is frequently found in tropical swamp forest ecosystems. According to the Indonesian Wood Construction Regulations Standard (PKKI) NI 5-1961, the wood from the Perepat plant is classified as strong class III and durable class IV [23], [24]. The wood of this class is quite suitable for use as building materials for houses, beams, floor and wall boards, door/window frames, and furniture. *C. rotundatus* has superior regeneration capabilities against land fires compared to various other types of typical peatland wood plants. As such, it can regrow from plant residues in the event of a forest fire. *C. rotundatus* are known to be propagated vegetatively using the apical cutting method.

3.1.7. Revegetation Pattern Scheme

The land fire that occurred in the peatland area within "X" company's concession actually took place in 2015. The significant time gap on the burned land has initiated natural succession as a recovery mechanism. The revegetation activities in this area aim to enhance the carbon absorption capacity of the burnt land by increasing the number of growing trees and developing biomass within the peatland.

The overlap of groundwater depth maps and vegetation diversity will indicate which locations need to be prioritized for revegetation. Meanwhile, rainfall patterns are used to compile a planting calendar where areas with deep groundwater levels will be planted in the dry season. It is hoped that technical revegetation activities in these areas can be carried out more easily and increase plant survival due to the declining groundwater levels in the dry season.

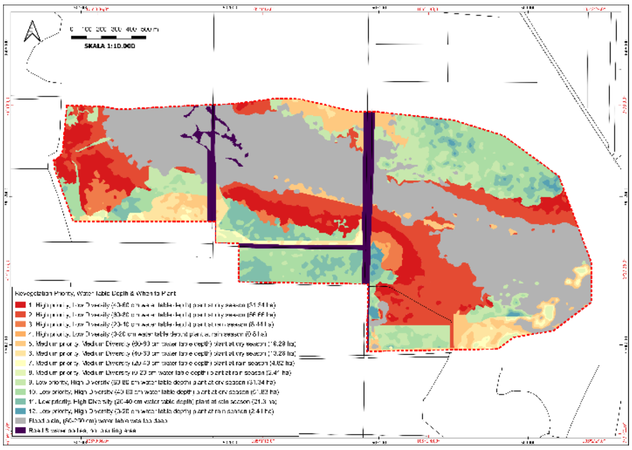

Figure 5. Revegetation Pattern Map

The revegetation of peatlands is a process that requires careful planning and execution. The priority for revegetation is often given to areas with low vegetation diversity and varying water table depths. For instance, areas with a water table depth of 40-60 cm and 60-80 cm, which cover about 7.8% and 14.1% of the total area respectively, are considered high priority for planting during the dry season.

Medium-priority areas, on the other hand, have medium vegetation diversity and cover about 9.9% of the total area. These areas have water table depths ranging from 0-80 cm and are planted in both the dry and rainy seasons depending on the water table depth. The choice of planting season is crucial as it can significantly influence the survival and growth of the planted species.

Low-priority areas are those with high vegetation diversity, covering about 26.6% of the total area. These areas have a water table depth ranging from 0-80 cm and are also planted in both the dry and rainy seasons. Despite being a low priority, these areas are still important for maintaining the overall biodiversity and ecological function of the peatland. In addition to these, there are areas such as flood plains and roads & water bodies, which cover about 39.3% of the total area, where planting is not feasible due to deep water table and non-planting areas respectively.

Rainfall data also plays a crucial role in determining the planting time [25]. Based on the provided data, the months from January to May and October to December are considered wet months, while the months from June to September are considered humid months. Therefore, planting in areas with deep groundwater levels (60-80 cm) is better done in the dry or humid months, while planting in areas with shallow groundwater levels (0-40 cm) is better done in the rainy season. Overall, the proposed revegetation pattern includes various strategies based on revegetation priority, vegetation diversity, water table depth, and planting time. These strategies are designed to maximize the success of revegetation and the recovery of the ecological function of peatlands.

4. Conclusion

Based on the research conducted at the study site, it was found that the water table level is a critical factor affecting peatland revegetation activities. Low-elevation areas present significant technical and ecological challenges. The water table levels in the study area varied from approximately 10 cm to 110 cm, correlating with topographic conditions and becoming deeper in the central area, which was a riverine area in the past. This distribution of water table levels significantly impacts the survivability of vegetation.

The dominant plant species in the study area is Purun (*Eleocharis dulcis*), occupying approximately 44.5% of the total study area. Other vegetation types, such as Gelam (*Melaleuca* spp.) and Perepat (*Combretocarpus rotundatus*), have demonstrated good adaptability to the location. These species are considered suitable candidates for propagation and planting on the study site as part of the peatland revegetation efforts.

Revegetation priorities are given to areas with low vegetation diversity. Rainfall data also plays a crucial role in determining the planting time. Planting in areas with deep groundwater levels (60-80 cm) is recommended during the dry or humid months (June to September), while planting in areas with shallow groundwater levels (0-40 cm) is better done in the rainy season (October to December).

References

[1] M. Taufik, A. A. Veldhuizen, J. H. M. Wösten, and H. A. J. van Lanen, "Exploration of the importance of physical properties of Indonesian peatlands to assess critical groundwater table depths, associated drought and fire hazard," *Geoderma*, vol. 347, 2019, doi: 10.1016/j.geoderma.2019.04.001.

[2] M. S. Omar *et al.*, "Peatlands in Southeast Asia: A comprehensive geological review," *Earth-Science Reviews*, vol. 232. 2022. doi: 10.1016/j.earscirev.2022.104149.

[3] H. Gunawan and D. Afriyanti, "Potential Implementation of Social Forestry in Engaging Community Participation in Restoring Peatlands," *Jurnal Ilmu Kehutanan*, vol. 13, no. 2, pp. 227–236, 2019, doi: 10.22146/jik.52442.

[4] K. Hergoualc'h, R. Carmenta, S. Atmadja, C. Martius, M. Daniel, and H. Purnomo, "Managing Peatlands in Indonesia: Challenges and Opportunities for Local and Global Communities," 2018. doi: 10.17528/cifor/006449.

[5] L. B. Triadi, "Restoration of Peat Swamp Through Rewetting (Canal Blocking) and Paludiculture Method," *Jurnal Sumber Daya Air*, vol. 16, no. 2, pp. 103–118, Nov. 2020, doi: 10.32679/jsda.v16i2.677.

[6] E. M. Goud, C. Watt, and T. R. Moore, "Plant community composition along a peatland margin follows alternate successional pathways after hydrologic disturbance," *Acta Oecologica*, vol. 91, pp. 65–72, 2018, doi: 10.1016/j.actao.2018.06.006.

[7] S. W. Smith *et al.*, "Tree Species That 'Live Slow, Die Older' Enhance Tropical Peat Swamp Restoration: Evidence from a Systematic Review," *Journal of Applied Ecology*, vol. 59, no. 8. 2022. doi: 10.1111/1365-2664.14232.

[8] W. Giesen and E. N. N. Sari, "Tropical Peatland Restoration Report: The Indonesian Case," 2018. doi: 10.13140/RG.2.2.30049.40808.

[9] I. Nengah Surati Jaya, "The interpolation method for estimating the above-ground biomass using terrestrial-based inventory," *Jurnal Manajemen Hutan Tropika*, vol. 20, no. 2, 2014, doi: 10.7226/jtfm.20.2.121.

[10] Y. Li *et al.*, "Empirical Bayesian Kriging method to evaluate inter-annual water-table evolution in the Cuenca Alta del Río Laja aquifer, Guanajuato, México," *J Hydrol (Amst)*, vol. 582, 2020, doi: 10.1016/j.jhydrol.2019.124517.

[11] M. Taufik, B. Minasny, A. B. Mcbratney, J. C. Van Dam, P. D. Jones, and H. A. J. Van Lanen, "Human-induced changes in Indonesian

peatlands increase drought severity," *Environmental Research Letters*, vol. 15, no. 8, 2020, doi: 10.1088/1748-9326/ab96d4.

[12] F. J. Rich, "Peat: Its Origins, Characteristics, and Geological Transformations," *Coal and Peat Fires: A Global Perspective Volume 4: Peat - Geology, Combustion, and Case Studies*, pp. 13–38, Jan. 2015, doi: 10.1016/B978-0-444-59510-2.00002-1.

[13] B. Łabaz and C. Kabala, "Human-induced development of mollic and umbric horizons in drained and farmed swampy alluvial soils," *Catena (Amst)*, vol. 139, pp. 117–126, Apr. 2016, doi: 10.1016/J.CATENA.2015.12.013.

[14] N. Kimiaghalam, M. Goharrokhi, S. P. Clark, and H. Ahmari, "A comprehensive fluvial geomorphology study of riverbank erosion on the Red River in Winnipeg, Manitoba, Canada," *J Hydrol (Amst)*, vol. 529, pp. 1488–1498, Oct. 2015, doi: 10.1016/J.JHYDROL.2015.08.033.

[15] P. Kricella, M. M. Pratamaningsih, and R. E. Subandiono, "Properties of soils from different landform and parent material in Kundur Island, Kepulauan Riau Province," in *IOP Conference Series: Earth and Environmental Science*, 2021. doi: 10.1088/1755-1315/648/1/012017.

[16] P. Samba Assomo, S. Kouayep Lawou, L. C. Okomo Atouba, and B. V. Kamgang Kabeyene, "Evaluation of the fertility of alluvium from nyong valley (Cameroon): Prospection of agricultural areas," *International Journal of Emerging Technology and Advanced Engineering*, vol. 10, no. 7, 2020, doi: 10.46338/ijetae0720_04.

[17] S. E. Page and A. J. Baird, "Peatlands and Global Change: Response and Resilience," *Annu Rev Environ Resour*, vol. 41, pp. 35–57, Oct. 2016, doi: 10.1146/annurev-environ-110615-085520.

[18] C. Lazcano, A. S. Deol, M. E. Brummell, and M. Strack, "Interactive effects of vegetation and water table depth on belowground C and N mobilization and greenhouse gas emissions in a restored peatland," *Plant Soil*, vol. 448, no. 1–2, 2020, doi: 10.1007/s11104-020-04434-2.

[19] G. Tsheboeng, M. C. Bonyongo, and M. Murray-Hudson, "Influence of flood variation on seasonal floodplain vegetation communities in the Okavango Delta, Botswana," *Afr J Aquat Sci*, vol. 39, no. 1, 2014, doi: 10.2989/16085914.2013.878241.

[20] X. Xu, Q. Zhang, Z. Tan, Y. Li, and X. Wang, "Effects of water-table depth and soil moisture on plant biomass, diversity, and distribution at a seasonally flooded wetland of Poyang Lake, China," *Chin Geogr Sci*, vol. 25, no. 6, 2015, doi: 10.1007/s11769-015-0774-x.

[21] W. Giesen, "Tropical Peatland Restoration in Indonesia by Replanting with Useful Indigenous Peat Swamp Species: Paludiculture," in *Tropical Peatland Eco-management*, 2021. doi: 10.1007/978-981-33-4654-3_14.

[22] M. A. Ma'Ruf, Y. F. Arifin, M. Asy'Ari, and Rusdiansyah, "Gelam Wood (Melaleuca cajuputi Powell) as a Substructure Construction Material," in *IOP Conference Series: Earth and Environmental Science*, 2023. doi: 10.1088/1755-1315/1184/1/012004.

[23] G. Luhan, H. Joni, Johansyah, Yanciluk, and A. Mujaffar, "The physical and mechanical Properties of Tumih Wood Based on Section Stem," *HUTAN TROPIKA*, vol. 14, no. 2, 2022, doi: 10.36873/jht.v14i2.1150.

[24] W. Supriyati, G. P. Novelia, M. Yanciluk, and Alpian, "The Effect of Borax Concentration on The Preservation of Tumih Wood (Combretocarpus rotundatus (Miq.) Danser) In Resistance Against Attack of Dry Wood Termite (Cryptotermes Cynocephalus Light.)," *Agrienvi: Jurnal Ilmu Pertanian*, vol. 15, no. 1, pp. 41–51, 2021, doi: 10.36873/aev.2021.15.1.41.

[25] J. Gao, M. Kirkby, and J. Holden, "The effect of interactions between rainfall patterns and land-cover change on flood peaks in upland peatlands," *J Hydrol (Amst)*, vol. 567, 2018, doi: 10.1016/j.jhydrol.2018.10.039.