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Peatlands and Their Relationship with Poverty Levels in Riau Province

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ABSTRACT

The relationship between the existence of peatlands and poverty levels is very important to study. The aim of this study is to identify the area of peatland in Riau Province and its use and its relation to social and economic issues in the community as a basis for compiling long-term peat ecosystem utilization policy scenarios. The data collected for this study consisted of spatial data such as peat hydrological unit determination maps, administrative maps, and other types of maps as well as non-spatial data such as regional development planning documents, strategic environmental studies, and various other scientific publications. The results of the analysis were verified through focus group discussions and multi-party public consultations. The results of the study found that Riau Province has 4.9 million hectares of peatland, but 79.96% of the land has been converted, especially oil palm plantations. The results of the regression analysis showed that the area of peatland in Riau has a positive interaction with poverty levels. However, the increase in the proportion of plantations on peatlands over the past 2 decades has had a negative interaction with poverty levels. This contradiction is very important to note for further management and in line with the sustainable development goals (SDGs), so that the potential trade-off between the economic benefits of plantations on peatlands and sustainable environmental management can be minimized.

1. INTRODUCTION

Peat ecosystems have a very large ecosystem service potential [1]. The wealth of natural resources in peat ecosystems has a variety of environmental functions. These functions include ecological, social, economic, and cultural functions. The ecological function of peat can absorb water in the rainy season to avoid floods and landslides, while in the dry season can provide water reserves [2]. Indonesia has the second largest tropical peatland in the world with an estimated area of 22 million hectares [3]. Indonesian peat is estimated to have the ability to absorb 30% of global CO_2 [4]. The social function of peat is as a source of human livelihood. Some people also live and live in peatlands. It also provides economic functions for the community, both in the form of forestry businesses, as well as agricultural and plantation businesses [5]. The existence of people who have long lived in peatlands also raises the value of local wisdom in the community. This value is a cultural function in peat ecosystems.

Riau Province is a province that has the largest peat hydrological unit in Indonesia. This ecosystem plays an important role in producing natural resources and environmental services for the welfare of the people of Riau Province [6]. However, many studies have stated that the impact of cultivation activities in peat areas hurts the shift in the balance of water and carbon systems that will change the carrying capacity of the peat environment to smaller [7]. Moreover, peat areas in Riau always experience forest and land fires yearly caused by various things, such as efforts to convey land. The limited mineral land in Riau Province causes peatlands to turn into oil palm plantations [8]. Peatland fires are a serious problem that has an important impact on the sustainability of ecosystems and the environment, for example, smoke pollution, decreased quality of environmental health, improvement of GHG emissions, loss of biodiversity, and the impact of loss of economic potential in various productive sectors [9, 10]. Increasing the number and needs of the population in Riau is also one of the causes of changes in the function of peatlands every year [11]. Therefore, peat ecosystems must be managed properly.

Many peat ecosystem management policies have been implemented, both by central and regional governments. Various management efforts have also been carried out, ranging from government programs, private initiatives, non-governmental organizations, and community groups to universities. However, these efforts have yet to be integrated optimally and have even been carried out partially. The efforts have yet to be on target with the main problems faced. Each policy and program must be integrated by developing a long-term plan to protect the peat ecosystem. A long-term plan is needed so that each party has the knowledge to carry out sustainable protection and management efforts. Policy formulation begins by paying attention to the complexity of the problems in protecting peat ecosystems. This research was conducted to collect and identify the main characteristics and problems in protecting and managing peat ecosystems. The results of this identification will be the basis for preparing long-term peat ecosystem utilization policy scenarios.

2. RESEARCH STUDY

2.1 Study area

The research was conducted at the Peat Hydrological Unit (PHU) in Riau Province. Riau Province has 59 peat hydrological units in Riau Province. A peat hydrological unit is an area of peat ecosystem located between two rivers, between a river and the sea, and/or in a swamp. Peat is an organic material formed naturally from incompletely decomposed plant remains with a 50 cm or more thickness and accumulates in swamp areas (Figure 1).

2.2 Procedures

The research used collaborative techniques involving a work team of government representatives from the central government, regional government, private sector, and universities. Data was collected from both primary and secondary. Data collection is carried out to collect various data and information from various parties, followed by verifying conditions through field surveys. The type of data required consists of spatial and non-spatial data. Spatial data includes peat hydrological unit designation maps, administrative maps, peat depth maps, and forest area designation maps. Non-spatial data includes regional statistical documents, regional development plans, peat restoration plan documents, strategic environmental studies, and various scientific publications.

2.3 Data analysis

The data analyzed are data from several districts/cities in Riau. The data is representative of the existence of peat according to the characteristics of the region and social and economic issues such as poverty rates in Riau Province. The data obtained were analyzed statistically, descriptively, and spatially. Some of the data obtained, both secondary data and primary data, were subjected to statistical analysis in the form of regression analysis to see the relationship between the variables analyzed, such as the area of peat land with the percentage of poverty in several areas of Riau. Spatial data analysis was carried out using the overlay technique using the Geographic Information System Mapping application. The results of the data analysis were carried out to obtain information about the characteristics of the peat ecosystem and the main problems in the protection and management of peat ecosystems in Riau Province, as well as the relationship between peat ecosystems and socio-economic problems such as community poverty. Data analysis was then carried out descriptively exploratively based on the data that had been processed and through a series of Focus Group Discussions and Public Consultations involving many parties.

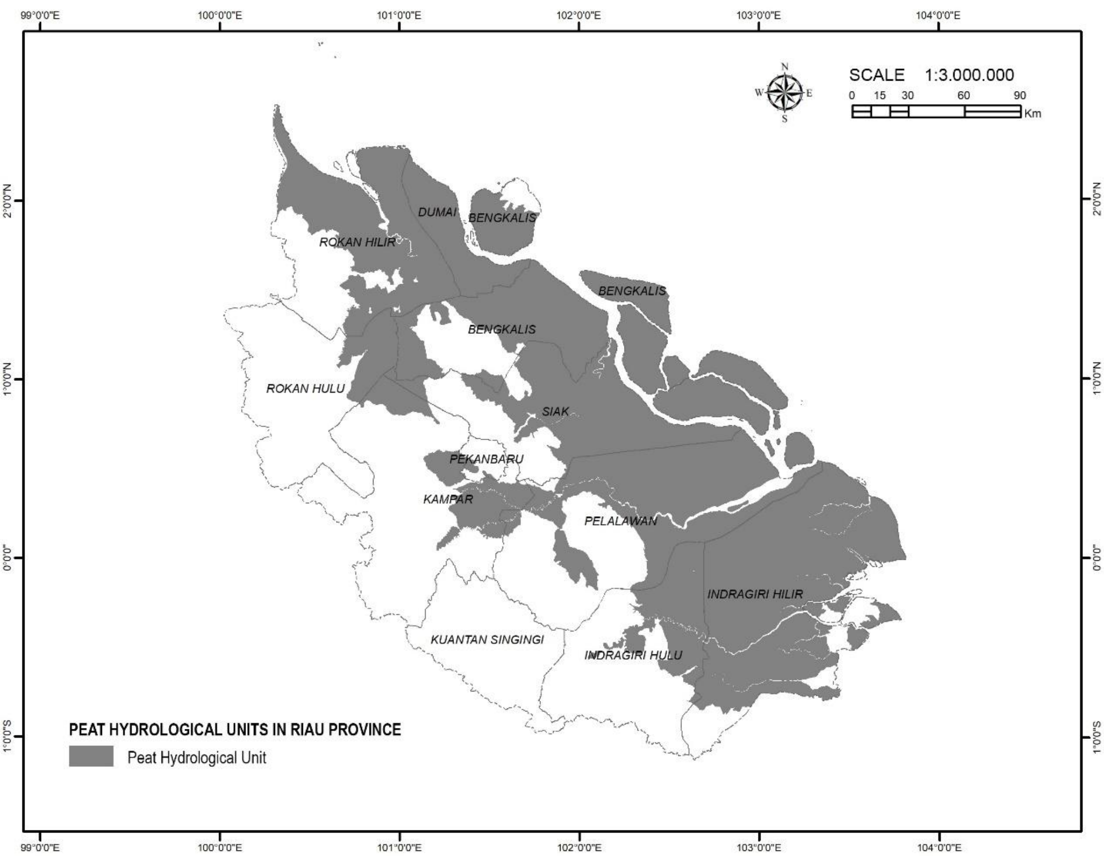

Figure 1. Map of the distribution of peat hydrological units in Riau Province

3. RESULT

3.1 Peatland conditions

Based on the results of the mapping analysis, the PHU area in Riau Province is spread across 11 Regencies/Cities with the PHU area in Riau Province covering 4,972,606.90 ha with the largest PHU being in Indragiri Hilir Regency reaching 1,168,383.56 ha (Table 1). Dumai City is a Regency/City area with the largest proportion of PHU to administrative areas in Riau Province with an area proportion of 99.75% and Kuantan Singigi is the smallest area because this Regency does not have a single PHU area (Figure 2).

Table 1. Distribution of PHU in Riau Province

No.	Regency	PHU	An area Regency/City (ha)	Total Area of PHU (ha)	Percent (%)
1	Bengkalis	8	852,043.63	647,147.86	76.0
2	Dumai	1	217,779.79	217,226.03	99.7
3	Indragiri Hilir	11	**1,346,589.47**	**1,168,383.56**	86.8
4	Indragiri Hulu	8	797,816.84	271,534.31	34.0
5	Kampar	7	1,089,721.66	225,839.90	20.7
6	Kep. Meranti	6	363,679.18	359,856.44	98.9
7	Kuansing	0	527,273.74	0	0.0
8	Pekanbaru	2	63,340.30	8,019.91	12.7
9	Pelalawan	**13**	1,315,503.34	780,234.67	59.3
10	Rokan Hilir	6	915,472.45	623,972.38	68.2
11	Rokan Hulu	4	752,743.28	118,136.46	15.7
12	Siak	12	784,396.97	552,255.38	70.4
	Total	**59**	**9,026,360.64**	**4,972,606.90**	**55.1**

Description: Bold & Background Color = Highest

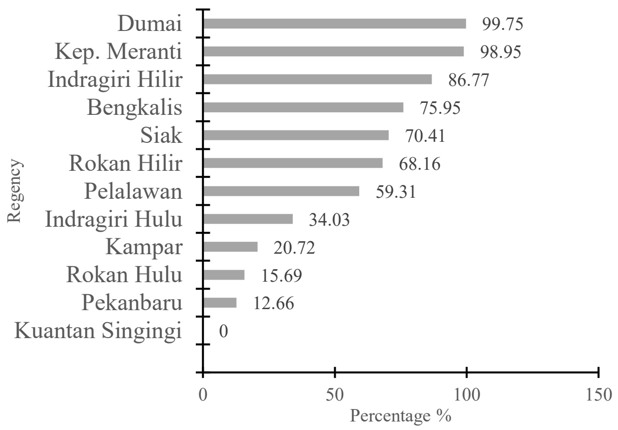

Figure 2. Proportion of PHU to regency area (%)

Table 2. Characteristics of PHU in Riau Province

No.	Parameter	Criteria (cm)	Area (ha)	Percentage (%)
1	Peat depth	<50	1,021,414.30	20.54
		50-100	439,328.36	8.83
		100-200	780,941.35	15.7
		200-300	794,693.30	15.98
		>300	1,936,229.60	38.94
2	Ground Water Level (sampling point)	≤40	74	58.73
		>40	52	70.27

Table 3. Extent of plantations in peatlands in Riau Province

Year	Plantation Area on Peat Land (ha)	Percentage of Plantations on Peat Land (%)
2000	935,348.37	18.81
2005	961,441.25	19.33
2010	1,063,053.25	21.38
2015	1,387,333.22	27.90
2020	1,897,194.42	38.15

Ecologically based peat ecosystem management needs to pay attention to regional conditions. Peat hydrological units have diverse characteristics. Based on the results of the PHU inventory and mapping, it was found that peatlands in the PHU of Riau Province have varying peat depths (Table 2). Most of the PHU in Riau Province are at a depth of >300 cm with an area of 1,936,229.60 ha (38.94%). Peat with a depth of >300 cm is classified as a very deep peat layer.

There has been a change in the function and management of peat in Riau Province. This change in management occurred due to various things, such as housing, annual plantations, seasonal plantations, and various other things. However, changes in peatland management in Riau Province are dominated by plantations. The high demand and need for palm oil commodities have resulted in existing peatlands being converted into oil palm plantations. From 2000 to 2020, there has been an increase in the conversion of peatlands to plantations by more than 10% (Table 3).

3.2 The level of poverty in peatland communities

Poverty is a lack of resources and finances to meet the needs of life and community welfare. Analysis of poverty levels in five districts/cities: Pekanbaru City, Kampar Regency, Indragiri Hulu, Pelalawan, and Kep. Meranti. The analysis results show that the poverty rate ranges from 3.06% to 23.84% (Figure 3). The poverty level is measured using the standard poverty line for Riau Province in 2022, IDR 605,912/capita/month [12]. These five districts/cities represent the entire peat typology in Riau Province. The five districts/cities represent the entire peat typology in Riau Province. The five areas are areas with typical urban peat (Pekanbaru), inland/mainland peat (Kampar and Indragiri Hulu), coastal peat (Pelalawan), and island peat (Meranti). In general, peat in Sumatra is grouped based on the characteristics of the peat area into 3 groups, namely coastal, transitional and inland peat [13]. The five districts/cities represent the 3 peat groups.

The five districts/cities are areas in Riau Province with low poverty percentages (<% Provincial and National poverty), moderate (>% Provincial poverty, and <% national poverty), high (>% Provincial and National poverty). In 2023, the poverty rate in Riau Province was 6.68% and National was 9.03%. Based on data collection in 5 districts/cities in Riau Province, it was found that there was a relationship between the level of poverty and the proportion of peatland distribution. The wider the proportion of peatland in an area, the greater the impact on the community's poverty level. The highest poverty rate occurred in Meranti Islands Regency, reaching 23.84. This value is very high and even exceeds the target for achieving national and global poverty levels. 98.95% of the land in Meranti Regency is peat land and islands. The proportion of peatland area based on regression analysis has a significant positive interaction with the community poverty level with a regression coefficient of 89% (Figure 4). This analysis shows that the larger the peatland area in an area, the higher the poverty level in that area.

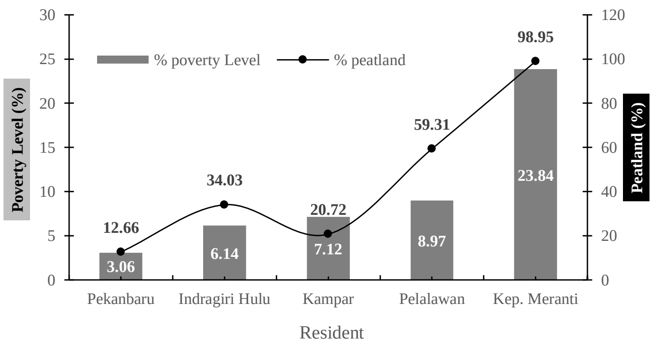

Figure 3. Relationship between poverty level and the proportion of peat area in a region

Note: PKU= Pekanbaru, INHU= Indragiri Hulu, KPR= Kampar, PLW= Pelalawan, Kep. Meranti

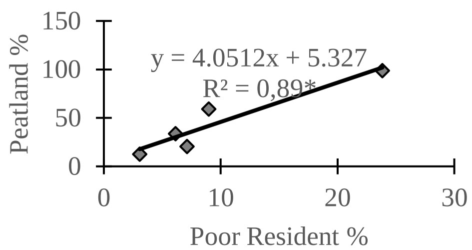

Figure 4. Interaction between peat area and community poverty level

Note: *=Significant <0.05

3.3 Suitability of peatlands for agriculture

Peatlands have a higher level of obstacles to agricultural cultivation than mineral lands. The thicker the peat layer, the higher the level of resistance. The higher the level of obstacles, the lower the level of land suitability for cultivation (Table 4).

Table 4. Level of barriers to agricultural cultivation based on peat thickness

Peat Layer Thickness	Barrier Level	Land Suitability	% Peatland Suitability
<50 cm	Mild	very suitable	20.54
50-100 cm	Moderate	quite suitable	8.83
100-300 cm	Heavy	marginal	3.68
>300 cm	Very Heavy	unsuitable	38.94

3.4 Peat land use conflict

The extent of the peat ecosystem in Riau Province has given rise to problems of land and space use conflicts (Figure 5). Conflicts can occur due to the establishment of spatially based policies or conflicts due to the use of land that has been developed. The dominant peatland utilization sector is for plantation and forestry activities. These activities are spread throughout the depths of the peat. The condition of peat land cover still in the form of secondary forest is only 21.04%. Another type whose utilization is relatively small when compared to the plantation sector. The type of plantation in Riau Province is dominated by oil palm plantations.

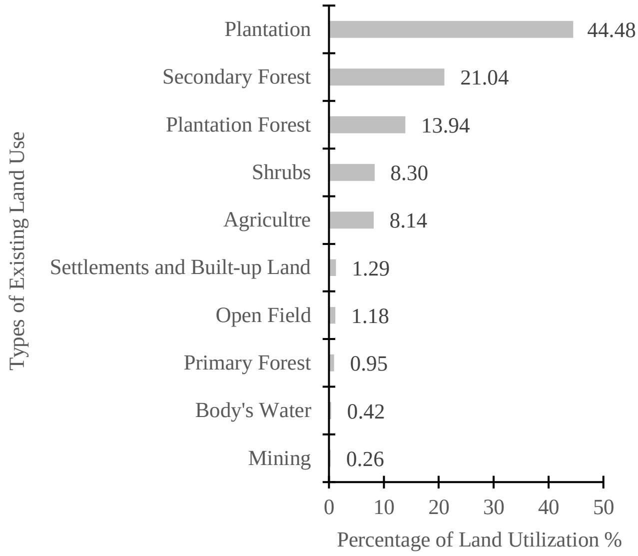

Figure 5. Land use conflicts on peatlands

3.5 The relationship between the increase in plantations on peatlands and the level of poverty

Oil palm plantations have greatly contributed to the community's economic income. The comparative analysis shows a relationship between plantation opening activities on peatlands and poverty levels. Over the last two decades (2000-2020), activities for using oil palm plantations on peatlands have increased while poverty rates have decreased (Table 5). The proportion of plantation area on peatland significantly negatively interacts with the community's poverty level.

Table 5. Relationship between poverty level and the proportion of plantation utilization of peat area 2000-2020

Years	Plantation Area on Peat Land (ha)	Percentage of Plantations on Peat Land (%)	Poverty Level (%)
2000	935,348.37	18.81	13.61
2005	961,441.25	19.33	12.51
2010	1,063,053.25	21.38	10.01
2015	1,387,333.22	27.90	8.42
2020	1,897,194.42	38.15	6.82

Based on the data in Table 5 regarding the area of plantations on peatlands and the level of poverty in Riau Province, it can be seen that there is a significant negative relationship between the area of plantations on peatlands and the level of poverty in Riau Province with a coefficient of determination (R^2) of 83% (Figure 6). The wider the plantation area on peat land, the lower the poverty level. This contradicts the relationship between the peatland area and the community poverty level. Where the wider the peatland in an area, the higher the level of poverty in the community.

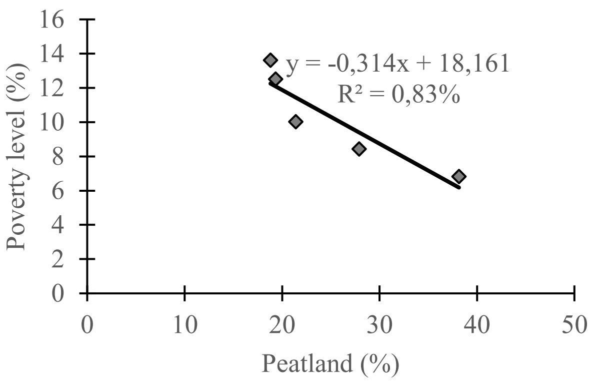

Figure 6. Interaction between the area of oil palm plantation on peatland (%) and the level of community poverty

4. DISCUSSION

4.1 Peatland in Riau Province

The peat hydrological unit is one ecosystem, so there is PHU, which are cross-administrative areas across districts and provinces. The administrative approach is a form of setting planning and development implementation policies by the government based on the distribution of administrative areas [14]. A holistic ecological approach must be carried out through collaboration between local governments. Ecosystem-based environmental management requires socio-ecological transformation [15]. Socio-ecological transformation is carried out using an ecosystem landscape approach through cross-regional collaboration. PHU is a peat ecosystem between 2 rivers or one river or sea. PHU, with a depth of >300 cm, is generally in the middle. Meanwhile, the boundaries of water bodies and their banks tend to have shallower peat depths [16]. Based on peat depth data, it is known that not all areas of the peat hydrological unit in Riau Province are peatlands. Of all PHUs, there are 20.54% that have a depth of <50 cm. KHU areas with peat depths <50 cm has a better potential for cultivation utilization than other peat depths [17].

Utilization of the Peat Ecosystem must be carried out by maintaining the hydrological function of the peat. Water level is an important hydrological parameter for peat [18, 19]. Based on the results of field verification in 126 locations spread across 59 PHU, it is known that 52 points have a TMAT value >40 cm, 2 points have a TMAT value =40 cm, and 72 points have a TMAT value <40 cm. The water level in peatlands is influenced by several factors, including rainfall, biophysical conditions (peat depth, fiber content, and bulk weight), drainage distance, and surrounding surface channels [20]. The deeper the groundwater level in peatlands, the drier the surface layer of peat will be. Groundwater levels can also have a significant influence on soil moisture. Peat moisture will maintain biophysical conditions so that it does not trigger significant degradation and fires [21]. The peat water level must be maintained at less than 40 cm [22]. Peatland fires mainly occur if the water depth in the peatland is >40 cm. The critical groundwater level is 40 cm below the peat surface [22]. Groundwater levels in peatlands must be maintained to prevent peatland fires in dry and degraded peatlands.

During 1990-2020, forested land cover decreased, except for plantation forests and non-forests [23]. Changes in land cover are caused by a complex of various factors that encourage increased land-clearing activities. The causes of land change can be divided into basic causes and direct causes. The direct cause is direct human activity for land use purposes. The basic causes are processes that trigger land clearing, such as increases in human population growth rates or the consequences of development policies [24]. Another peatland problem is forest and land fires. Forest and peatland fires always occur yearly in Riau Province, especially during the dry season. Data shows that the indicative area of peatland fire scars in Riau Province during 2018-2020 ranged from 11.099,61-62,736.31 ha/year [25]. The most widespread fires occurred in 2019, with longer dry seasons than in 2018 and 2020 [26]. Land-clearing activities generally cause fires. This activity triggers disruption of the hydrological balance of the peat [27]. Burned peatlands are usually dry peatlands. Dry peat is caused by the loss of water content in the peat. The water content in peat can be seen based on groundwater level parameters. The deeper the groundwater level in peatlands, the drier the peat surface, so the potential danger of peatland fires is higher [28]. The level of peat decomposition also influences peat fires. Speed of decomposition of the peat layer has a strong relationship with the wetness level of the peat material, the depth of the peat, the type of litter, and the maturity of the peat [29]. The loss of water content in peat will cause the peat to become aerobic, triggering accelerated decomposition and subsidence [30]. Climate change and human activities dominate the long-term trend in triggering peatland fires [31]. Groundwater levels between 30 cm and 50 cm significantly affect soil moisture [32-34]. However, the water level between 50 and 80 cm did not experience significant changes. The peak of peatland fires occurs when the groundwater level is at a critical condition, namely >40 cm [35]. So, the safe water level to prevent fire is 40 cm below the peat surface.

4.2 Challenges of peat ecosystem management

Identifying peat ecosystem management problems is necessary to focus more on dealing with the most pressing problems [36]. Ecosystems are related to a region's poverty level [37]. Good management of an ecosystem will improve the economy of the community around that ecosystem [38]. Several districts in Riau Province dominated by peat land have quite high levels of poverty because it requires greater costs to carry out development activities on this land compared to non-peat land. Soil in drained peatlands contains a large source of nitrogen oxide (N_2O) and carbon dioxide (CO_2) [39]. The suitability of peatlands for agricultural land must take into account the water level in the peatlands. Water levels as high as <30 cm can increase the productivity of horticultural crops while reducing soil CO_2 emissions but without causing the loss of CH_4 to the atmosphere, both in conditions of CO_2 concentrations in the environment and when they are high [40]. Fires often occur in peatlands during the dry season, so the peat becomes very dry, or fires can be caused by human activity in peatland conversion activities [41]. Burning peat releases a lot of carbon into the air, which negatively impacts the environment [42]. Peatlands are also very difficult to extinguish if a fire occurs compared to other ecosystems.

Meanwhile, peat ecosystems are often faced with other problems, such as conflicts over land use. Many tropical peat swamp forests have been converted to increase agricultural, plantation, and industrial production, resulting in large losses of peat carbon, especially in the Asia-Pacific region [43]. Peatlands in various countries, such as Indonesia, are experiencing rapid degradation due to the expansion of oil palm plantations [44]. Potential trade-offs between economic benefits and environmental sustainability are often the underlying issue of conflicts [45]. Peatlands' interests in providing ecosystem services often clash with other interests, such as those of social and economic segments of society, thus causing conflict. This underlies the four problems and makes it a strategic issue for peat ecosystem management.

Peat with a depth of >200 cm requires actual inventory, identification, and mapping of peat depth. To determine the top of the peat dome that needs to be protected. The top of the peat dome is a peat area with a depth of more than 3 m and functions as a source of peat water hydrological reserves. The top of the peat dome has the largest organic volume and functions to store carbon and water. Peatlands are the largest source of soil carbon reserves stored for thousands of years in wet conditions [46]. The availability of water in peat determines its biophysical resilience. Loss of water in the peat will cause the peat to dry out and rot very quickly. So, the peat becomes damaged and easily burns [47] The top of the peat dome can naturally absorb and store more water to supply the water needs below [48]. Peat water content is a key variable in the ecohydrological and biogeochemical cycles that can control greenhouse gas emissions and peatland fire vulnerability [49]. The upper part of the peat dome, which still has forest/natural land cover, is designated as a peat conservation and protection area and can only be used for research and development activities and environmental services. Meanwhile, the area at the top of the peat dome that is no longer forested will become a priority area for peatland rehabilitation [50]. The development of peat environmental services is adapted to the social and cultural characteristics of the region [51]. Peat cultivation can be used on a concession or community basis, but attention must still be paid to the principles of peat hydrological sustainability. The existence of a concession is necessary to ensure that there is someone responsible for managing the concession area [52, 53]. Meanwhile, community-based utilization can be developed through cooperation schemes, social forestry, and community partnerships [54]. The combination of regulations for using peat ecosystems will become the basis for controlling and managing peat ecosystems in the long term. Peat functions ecologically and must support regional social and economic improvement. The community needs a source of livelihood by utilizing peatlands. Peat areas for cultivation are optimized on land with a depth of <3 meters [55]. This is because peat with a depth of >3 meters have a marginal level of suitability for agricultural land and plantations, so economically, it does not have good production value. In addition, peat with a depth of >3 meters are needed for the hydrological protection of the peat so that cultivation activities can maintain its hydrological sustainability.

4.3 Suitability of peatlands for agriculture

Based on depth, naturally, the level of suitability of peatlands for agriculture can be grouped into 4, namely: S1 (very suitable), S2 (quite suitable), S3 (marginal), and N (not suitable). Criterion S1 is because the land has relatively light limiting factors (maximum 4 light limiting factors). S2 criteria because the land has 3-4 light barriers and a maximum of 3 medium barriers. S3 criteria because the land unit has 2-3 light obstacles and a maximum of 1 heavy (heavy) obstacle. Meanwhile, criterion N (not appropriate) because it has a weight limit of >1 (severe). Factors inhibiting cultivation on peatlands are (1) Low fertility of the peat surface, (2) Uneven maturity and thickness of the peat, (3) Problems of degradation and subsidence of the peat surface, (4) Low carrying capacity of hard buildings, (5) The presence of a layer of pyrite and sand at the bottom of the peat, (6) High levels of soil and water acidity because they contain organic compounds, and (7) Water content that is difficult to control, causing saturated water in peatlands (floods in the rainy season and drought in the dry season) [56]. Agricultural development on peat land requires higher input costs than mineral land. Technological innovation is needed to increase agricultural productivity and sustainability on peatlands, including land preparation, water management, soil improvement, fertilization, and pest and plant disease control [57]. The nutrients limiting peat soil fertility are the macronutrients P, K, Ca, and Mg and the micronutrients Cu, Zn, and B. Plants' need for drainage varies, from plants that are flood resistant, such as sago and jelutung, to plants that require drainage 50-70 cm deep, such as oil palm and rubber. There is a close relationship between peat thickness and agricultural production. The results of their research show that rice yields are very low when the peat thickness is >80 cm and highest when the peat thickness is < 50 cm [58]. This needs to be an important consideration, considering that the land conditions in the regencies/cities in Riau are mostly peat land.

The Meranti Islands are an archipelagic country dominated by peatlands. 98.95% of the land in Meranti Regency is peat land and islands. The proportion of peatland area based on regression analysis has a significant positive interaction with the community poverty level with a regression coefficient of 89% (Figure 4). This analysis shows that the larger the peatland area in an area, the higher the poverty level in that area. Peat land is very limited in developing agricultural potential, basic infrastructure, and tourism. So, the poverty level in Meranti Regency is very high because the peatland area in Meranti Regency is the largest in Riau Province. With the vastness of peatlands, communities will be very dependent on capital, both social and economic, as well as family resource management to achieve better welfare [59]. Factors that cause people on peatlands to experience economic poverty include infertile (marginal) and fragile (fragile) land, isolation, low social capital, low human resource competency, and vulnerability [60-62]. People's livelihoods in peat areas are farming, animal husbandry, and farming or fishing. Meanwhile, farming on peat land is no more profitable than farming on mineral land.

Some communities with sufficient economic capital prefer to use peatlands that are not as deep as oil palm plantations by changing the physical form of the peat. Physical changes in peatlands have the potential to release carbon stored in the peat [63]. This will certainly be contradictory to the principle of peat ecosystem sustainability. The distribution of plantation expansion has advantages that often shift the value of environmental sustainability. This requires the application of agroecological and agroeconomic principles to overcome the potential trade-off between economic benefits and environmental sustainability [64, 65]. Planting endemic peat plants such as sago combined with the tumpeng sari principle is one of the conventional solutions that can be carried out by communities on peatlands. Sustainable water management systems, such as closed canals or monitoring wells, are applied to maintain soil moisture without draining the land. This reduces the risk of fires and peatland degradation that can hurt the ecosystem while reducing carbon emissions from dry land [66, 67]. But of course, the presence of the government or capital owners is very much needed to improve the welfare of people living on peatlands. This is because improving the standard of living of people in peat areas is highly dependent on social and economic capital [68]. Dumai with a large peatland area can reduce the poverty rate to a very low level of around 3.21% [69]. This is because Dumai City is an industrial area so its people switch to the industrial and service sectors. Dumai City takes advantage of its geographical position as an export and import gateway so that its infrastructure and investment are better. This also has an impact on economic diversification, many MSMEs and services are developing as a result of the main industrial activities. This can of course be applied in Meranti Regency with government support and strong economic and social capital so that the poverty rate can be reduced even lower.

4.4 Oil palm plantations on peatlands

The expansion of oil palm plantations in Riau is motivated by the increasing demand for planting palm oil commodities, which have higher economic value than other agricultural or plantation commodities [70]. Land clearing activities for oil palm plantations began in the 1990s. This started with a transmigration program, an oil palm plantation development project by the community, and the granting of access permits for forest clearing for plantations by both the Company and the community. Palm oil has positively impacted the people of Riau, improving the economy and social values of the community [71]. The results of the analysis of land cover changes prove that there has been an increase in the area of plantations on peatlands. Increased use of peatlands for oil palm plantations shows a negative interaction pattern with poverty levels (Table 5) with a coefficient of determination of 83%. As the proportion of plantation use on peatlands increases, the poverty level decreases. The reduction in poverty levels was triggered by a source of income from oil palm plantations as an economic value for the community. Oil palm plantation activities have increased community household income locally [72, 73]. Factors that significantly influence the income of oil palm farmers are land area, number of oil palm plants, and oil palm prices [74, 75]. People who reject palm oil generally do not feel the direct economic impact of palm oil, for example, forest community groups or community groups that have economic interests outside of palm oil [76].

When turning peatlands into oil palm plantations, agroeconomic and agroecological concepts must be applied to prevent possible trade-offs between financial gains and environmental sustainability. Oil palm farms should be arranged spatially to avoid disturbing the most delicate peat ecosystem areas, such as peat domes [77], which are crucial for fire protection and water retention. Plantations can boost output in existing areas without extending land into new peat areas by using precision agriculture technologies, such as soil sensors, drone applications, and analytical data. This preserves the ecosystem's potential economic worth. Combining oil palm with other peatland-tolerant plants, including sago or medicinal plants, can provide revenue [78].

4.5 Management related to sustainable development goals (SDGs)

Using agroecology and agroeconomic concepts in peat ecosystem management can help achieve the Sustainable Development Goals (SDGs) through a sustainable agricultural approach that preserves ecological balance and enhances the economic well-being of communities [79, 80]. Agroecology concentrates on farming techniques that preserve environmental sustainability, whereas agroeconomics aims to boost agricultural yields and farmer incomes through sustainable economic practices [81, 82]. The application of agroecology and agroeconomic principles aids in resolving peat ecosystem management concerns by highlighting eco-friendly practices and providing long-term financial benefits to nearby populations. To assist accomplish the SDGs, peat ecosystem management can make use of both of these concepts in the following ways:

4.5.1 SDGs 1 and 2: End hunger and poverty

Agroecology allows for local food production in peatland farming without requiring significant land modification. The agroeconomic approach boosts income and production by diversifying food crops that are appropriate for peatland conditions. One program that can be put into place is the development of a local food system based on agroecology and agroeconomics that promotes the cultivation of food crops like sago, bananas, and cassava. This project aims to give communities food and financial stability so they can safeguard the environment and develop economically.

4.5.2 SDG 6: Sanitation and clean water

The agroecology concept places a strong emphasis on efficient water management in peatlands to preserve water quality and lower the risk of land fires. Agroecology makes sure that farming doesn't interfere with peatlands' natural water cycle. Program example: one sustainable way to manage water in peatlands is to use canals and reservoirs to regulate water levels. Employing irrigation techniques that replicate natural processes, such shallow and meandering canals, to control water flow and preserve soil moisture [83]. This prevents water degradation and fires, which jopardize the ecosystem's water quality, and keeps the soil moist.

4.5.3 SDG 8: Economic growth and decent work

The agro-economy, which includes the manufacture of derivative commodities from non-timber forest products, swamp fish farming, and crafts derived from local flora, can provide alternative, non-destructive revenue sources through peatland ecosystem management activities. By generating quality jobs, this strengthens the local economy. Programs like swamp catfish farming and purun weaving are examples of agro-based local economic development projects in peat areas. These programs boost local incomes and impart skills by creating high-value items [84].

4.5.4 SDG 13: Addressing climate change

Agroecology in peatland ecosystems includes no-burn farming practices and planting species that are appropriate for peatland features. This can lower carbon emissions from peatlands, which are frequently harmed by burning. One example of a program is the growth of agroecology-based paludiculture farming using crops including sago, purun, and gelam (melaleuca). This technique lowers the risk of fire, preserves peat soil moisture, and aids in carbon sequestration [85]. By utilizing precision agriculture technologies, such as soil sensors, drone applications, and analytical data, agricultural and plantation expansion can preserve ecosystems and potential economic value by optimizing yields in current areas without extending land into new peat areas.

4.5.5 SDG 15: Terrestrial ecosystems

Peatland management employs agroecology to preserve biodiversity and stop peatlands from being turned into plantations. Agroeconomics, on the other hand, promotes economic sustainability by producing useful goods without contributing to environmental damage. Programs like the application of agroforestry methods to preserve biodiversity based on agroecology are examples. Through this program, local people are encouraged to plant fruit trees on ecologically supportive peatlands, such as durian and water apples.

4.5.6 SDG 17: Cooperation to reach the objectives

Agroecological and agro-economic management of peatland ecosystems requires cross-sector cooperation, including partnerships between governments, international organizations, research institutes, the commercial sector, and communities [86]. This is essential for sustainable projects in terms of technology, knowledge, and funding. The multi-sector cooperative effort on peatland management is an example of a program. Governments provide incentives, academic institutions finance research, and the private sector makes investments in eco-friendly supply chains for peatland products used in agriculture, plantations, or tourism under this initiative.

5. CONCLUSION

Based on the study results, there are 59 peatlands in Riau Province that require management. Peatlands cover more than half (55.09%) of the administrative area of Riau Province. In Riau Province, peatlands are spread throughout the province, as well as within districts and cities. The depth of peatlands varies from very shallow (less than 50 cm) to very deep (more than 300 cm). Peatlands have three different levels of groundwater levels: safe (less than 40 cm), critical (40 cm), and unsafe (more than 40 cm). Only 21.04% of the land cover is still secondary forest, according to the study results, while 79.96% of the remaining land has been converted to various uses, especially oil palm plantations. High poverty rates correlate with peatland area. With a coefficient of determination (R^2) of 89%, the regression analysis shows a negative interaction between the area of peatland in Riau and the poverty rate in the region. The poverty rate in a region increases along with the area of peatland. With a determination coefficient (R^2) of 83%, the poverty rate is actually greatly influenced by the increasing percentage of peatland used for plantations over the past 20 years. The poverty rate will decrease along with the increasing percentage of plantation land on peatlands. This shows how the economic conditions of the community improve when plantations are used on peatlands. This contradiction needs to be considered to be further managed in line with sustainable development goals such as SDGs 1 (No Poverty), 2 (Zero Hunger), 6 (Clean Water and Sanitation), 8 (Decent Work and Economic Growth), 13 (Addressing Climate Change), 15 (Terrestrial Ecosystems), and 17 (Collaboration to Achieve the Goals).

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REFERENCES

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

[2] Xu, J., Morris, P.J., Liu, J., Holden, J. (2018). PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. Catena, 160: 134-140. https://doi.org/10.1016/j.catena.2017.09.010

[3] Januar, R., Sari, E.N.N., Putra, S. (2023). Economic case for sustainable peatland management: A case study in Kahayan-Sebangau peat hydrological unit, central Kalimantan, Indonesia. Land use Policy, 131: 106749. https://doi.org/10.1016/j.landusepol.2023.106749

[4] Fatimah, Y.A., Prasojo, Z.H., Smith, S.W., Rahman, N.E.B., Wardle, D.A., Chong, K.Y., Saad, A., Lee, J.S. (2023). Multi-level actor-network: Case of Peatland programs in a Riau Village, Indonesia (1974-2020). Geoforum, 145: 103829. https://doi.org/10.1016/j.geoforum.2023.103829

[5] Thariqa, P., Sitanggang, I.S. (2015). Spatial online analytical processing for hotspots distribution based on socio-economic factors in Riau Province Indonesia. Procedia Environmental Sciences, 24: 277-284. https://doi.org/10.1016/j.proenv.2015.03.036

[6] Syahza, A., Bakce, D., Irianti, M., Asmit, B., Nasrul, B. (2021). Development of superior plantation commodities based on sustainable development. International Journal of Sustainable Development & Planning, 16(4): 683-692. https://doi.org/10.18280/ijsdp.160408

[7] Afriyanti, D., Kroeze, C., Saad, A. (2016). Indonesia palm oil production without deforestation and peat conversion by 2050. Science of the Total Environment, 557: 562-570. https://doi.org/10.1016/j.scitotenv.2016.03.032

[8] Wulandari, S., Haryanto, R., Ramdani, I. (2023). Dominance of palm oil plantation utilization on peatlands in Riau Province. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 1230(1): 012001. https://doi.org/10.1088/1755-1315/1230/1/012001

[9] Haapalehto, T., Kotiaho, J.S., Matilainen, R., Tahvanainen, T. (2014). The effects of long-term drainage and subsequent restoration on water table level and pore water chemistry in boreal peatlands. Journal of Hydrology, 519: 1493-1505. https://doi.org/10.1016/j.jhydrol.2014.09.013

[10] Carmenta, R., Zabala, A., Daeli, W., Phelps, J. (2017). Perceptions across scales of governance and the

Indonesian peatland fires. Global Environmental Change, 46: 50-59. https://doi.org/10.1016/j.gloenvcha.2017.08.001

[11] Haryanto, R., Siregar, S. (2023). 30 years trend of peatland utilization in Riau Province. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 1230(1): 012066. https://doi.org/10.1088/1755-1315/1230/1/012066

[12] Riau Province Central Statistics Agency. (2023). Riau in figures for 2022. Badan Pusat Statistik Provinsi Riau. Pekanbaru. Indonesia. https://riau.bps.go.id/id/publication/2022/02/25/85c4ce5fd9662f99e34a5071/provinsi-riau-dalam-angka-2022.html.

[13] Knill, C., Grohs, S. (2015). Administrative styles of EU institutions. In The Palgrave handbook of the European Administrative System. London: Palgrave Macmillan UK., pp. 93-107. https://doi.org/10.1057/9781137339898_6

[14] Suryani, E., Pratamaningsih, M.M., Muslim, R.Q., Hati, D.P., Kricella, P., Nugroho, E.S., Subandiono, R.E., Anda, M. (2022). Variations in peat soil properties at the west coast of Sumatra Island. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 1025(1): 012025. https://doi.org/10.1088/1755-1315/1025/1/012025

[15] Otero, I., Nielsen, J.Ø. (2017). Coexisting with wildfire? Achievements and challenges for a radical social-ecological transformation in Catalonia (Spain). Geoforum, 85: 234-246. https://doi.org/10.1016/j.geoforum.2017.07.020

[16] Bay Y.P., Nina Y., Suparno, Fengky F.A., Zafrullah D., Sustiyah. (2021). Physical properties of inland peat in the sebangau peat forest natural laboratory, central kalimantan. Jurnal Ilmu Lingkungan, 10(2): 216-233. https://doi.org/10.31258/jil.15.2.p.216-233

[17] Veloo, R., Van Ranst, E., Selliah, P. (2015). Peat characteristics and its impact on oil palm yield. NJAS-Wageningen Journal of Life Sciences, 72: 33-40. https://doi.org/10.1016/j.njas.2014.11.001

[18] Katimon, A., Shahid, S., Khairi Abd Wahab, A., Ali, M.H. (2013). Hydrological behaviour of a drained agricultural peat catchment in the tropics. 1: Rainfall, runoff and water table relationships. Hydrological Sciences Journal, 58(6): 1297-1309. https://doi.org/10.1080/02626667.2013.815759

[19] Zhong, Y., Jiang, M., Middleton, B.A. (2020). Effects of water level alteration on carbon cycling in peatlands. Ecosystem Health and Sustainability, 6(1): 1806113. https://doi.org/10.1080/20964129.2020.1806113

[20] Evers, S., Yule, C.M., Padfield, R., O'Reilly, P., Varkkey, H. (2017). Keep wetlands wet: The myth of sustainable development of tropical peatlands-implications for policies and management. Global Change Biology, 23(2): 534-549. https://doi.org/10.1111/gcb.13422

[21] Ohkubo, S., Hirano, T., Kusin, K. (2021). Influence of fire and drainage on evapotranspiration in a degraded peat swamp forest in Central Kalimantan, Indonesia. Journal of Hydrology, 603: 126906. https://doi.org/10.1016/j.jhydrol.2021.126906

[22] Putra, S.S., Holden, J., Baird, A.J. (2021). The effects of ditch dams on water-level dynamics in tropical peatlands. Hydrological Processes, 35(5): e14174. https://doi.org/10.1002/hyp.14174

[23] Juniyanti, L, Prasetyo, L.B., Aprianto, D.P., Purnomo, H., Kartodihardjo, H. (2020). Land-use/Land cover change and its causes in Bengkalis Island, Riau Province (From 1990-2019). Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan (JPSL), 10(3): 419-435. http://doi.org/10.29244/jpsl.10.3.419-435

[24] Hersperger, A.M., Gennaio, M.P., Verburg, P.H., Bürgi, M. (2010). Linking land change with driving forces and actors: Four conceptual models. Ecology and Society, 15(4): 1-17. http://www.jstor.org/stable/26268195

[25] Riau Province Central Statistics Agency. (2023). Riau in figures for 2022. Badan Pusat Statistik Provinsi Riau. Pekanbaru. [Indonesia]. https://riau.bps.go.id/id/publication/2022/02/25/85c4ce5fd9662f99e34a5071/provinsi-riau-dalam-angka-2022.html.

[26] Fatima, I., Singh, S.N., Kandwal, S. (2023). Flame prediction: Using machine learning to tackle forest fires. In 2023 International Conference on Communication, Security and Artificial Intelligence (ICCSAI), pp. 298-304. http://doi.org/10.1109/ICCSAI59793.2023.10421453

[27] Jefferson, U., Carmenta, R., Daeli, W., Phelps, J. (2020). Characterising policy responses to complex socio-ecological problems: 60 fire management interventions in Indonesian peatlands. Global Environmental Change, 60: 102027. https://doi.org/10.1016/j.gloenvcha.2019.102027

[28] Silviana, S., Saharjo, B., Sutikno, S. (2020). Fire risk analysis based on groundwater level in rewetting peatland, Sungaitohor village, kepulauan Meranti district, Riau province. IOP Conference Series: Materials Science and Engineering, 796: 012041. https://doi.org/10.1088/1757-899X/796/1/012041

[29] Broder, T., Blodau, C., Biester, H., Knorr, K.H. (2012). Peat decomposition records in three pristine ombrotrophic bogs in southern Patagonia. Biogeosciences, 9(4): 1479-1491. https://doi.org/10.5194/bg-9-1479-2012

[30] Rodriguez, A.F., Gerber, S., Daroub, S.H. (2020). Modeling soil subsidence in a subtropical drained peatland. The case of the everglades agricultural Area. Ecological Modelling, 415: 108859. https://doi.org/10.1016/j.ecolmodel.2019.108859

[31] Marcisz, K., Tinner, W., Colombaroli, D., Kołaczek, P., Słowiński, M., Fiałkiewicz-Kozieł, B., Łokas, E., Lamentowicz, M. (2015). Long-term hydrological dynamics and fire history over the last 2000 years in CE Europe reconstructed from a high-resolution peat archive. Quaternary Science Reviews, 112: 138-152. https://doi.org/10.1016/J.QUASCIREV.2015.01.019

[32] Chang, C.T., Sabaté, S., Sperlich, D., Poblador, S., Sabater, F., Gracia, C. (2014). Does soil moisture overrule temperature dependence of soil respiration in Mediterranean riparian forests? Biogeosciences, 11(21): 6173-6185. https://doi.org/10.5194/bg-11-6173-2014

[33] McMillan, H.K., Srinivasan, M.S. (2015). Characteristics and controls of variability in soil moisture and groundwater in a headwater catchment. Hydrology and Earth System Sciences, 19(4): 1767-1786. https://doi.org/10.5194/hess-19-1767-2015

[34] Adhi, Y.A., Anwar, S., Tarigan, S.D., Sahari, B. (2020). Relationship between groundwater level and water content in oil palm plantation on drained peatland in Siak,

Riau province, Indonesia. Pertanika Journal of Tropical Agricultural Science, 43(3): 415-427. https://doi.org/10.5194/bgd-11-7991-2014
[35] Imanudin, M.S., Bakri, B., Armanto, M.E., Wildayana, E., Al Rashid, S. (2021). Development of control drainage operation model and utilization planning of post-Fire peatlands. Journal of Wetlands Environmental Management, 9(1): 1-20. https://doi.org/10.20527/jwem.v9i1.243
[36] Rossita, A., Nurrochmat D.R., Hein R.B.L., Riqqi, A. (2021). Assessing the monetary value of ecosystem services provided by Gaung-Batang tuaka peat hydrological unit (PHU), Riau province. Heliyon, 7(10). https://doi.org/10.1016/j.heliyon.2021.e08208
[37] Suich, H., Howe, C., Mace, G. (2015). Ecosystem services and poverty alleviation: A review of the empirical links. Ecosystem Services, 12: 137-147. https://doi.org/10.1016/j.ecoser.2015.02.005
[38] Barrett, C.B., Travis, A.J., Dasgupta, P. (2011). On biodiversity conservation and poverty traps. Proceedings of the National Academy of Sciences, 108(34): 13907-13912. https://doi.org/10.1073/pnas.1011521108
[39] Gerin, S., Vekkuri, H., Liimatainen, M., Tuovinen, J.P., Kekkonen, J., Kulmala, T., Laurila, M., Linkosalmi, J., Liski, E.J., Tokola, A.L. (2023). Two contrasting years of continuous N2O and CO2 fluxes on a shallow-peated drained agricultural boreal peatland. Agricultural and Forest Meteorology, 341: 109630. https://doi.org/10.1016/j.agrformet.2023.109630
[40] Musarika, S., Atherthon, C.E., Gomersail, T., Wells, M.J., Kaduk, J., Cumming, A.M.J., Page, S. E., Oechel, W.C., Zoena, D. (2017). Effect of water table management and elevated CO2 on radish productivity and on CH4 and CO2 fluxes from peatlands converted to agriculture. Science of The Total Environment, 584: 665-672. https://doi.org/10.1016/j.scitotenv.2017.01.094
[41] Ramdzan, K.N.M., Patrick, T.M., Jacobsen, G., Sala, A.G., Charman, D., Harrison, M.E., Susan, P., Mishra, S., Wardle, D.A., Jaya, A., Aswandi, Nasir D., Yulianti, N. (2023). Insights for restoration: Reconstructing the drivers of long-term local fire events and vegetation turnover of a tropical peatland in Central Kalimantan. Palaeogeography, Palaeoclimatology, Palaeoecology, 628: 111772. https://doi.org/10.1016/j.palaeo.2023.111772
[42] Sim, T.G., Swindles, G.T., Morris, P.J., Baird, A.J., Sala, A.V.G., et al. (2023). Regional variability in peatland burning at mid-to high-latitudes during the Holocene. Quaternary Science Reviews, 305. https://doi.org/10.1016/j.quascirev.2023.108020
[43] Comeau, L.P., Hergoualc'h, K., Verchot, L.V. (2021). Dataset on soil carbon dioxide fluxes from an incubation with tropical peat from three different land-uses in Jambi Sumatra Indonesia. Data in Brief, 39: 107597. https://doi.org/10.1016/j.dib.2021.107597
[44] Ramdani, R., Lounela, A.K. (2020). Palm oil expansion in tropical peatland: Distrust between advocacy and service environmental NGOs. Forest Policy and Economics, 118: 102242. https://doi.org/10.1016/j.forpol.2020.102242
[45] Juutinen, A., Tolvanen, A., Saarimaa, M., Ojanen, P., Sarkkola, S., et al. (2020). Cost-effective land-use options of drained peatlands-integrated biophysical-economic modeling approach. Ecological Economics, 175: 106704. https://doi.org/10.1016/j.ecolecon.2020.106704
[46] Poczta, P., Marek, U., Torsten, S., Kamila, M.H., Klarzyńska, A., Juszczak, R., Schüttemeyer, D., Czernecki, B., Kryszak, A., Chojnicki, B.H. (2023). A multi-year study of ecosystem production and its relation to biophysical factors over a temperate peatland. Agricultural and Forest Meteorology, 338: 109529. https://doi.org/10.1016/j.agrformet.2023.109529
[47] Ishikura, K., Hirano, T., Okimoto, Y., Hirata, R., Kiew, F., Melling, L., Aeries, E.B., Lo, K.S., Musin, K.K., Waili, J.W., Wong, G.X., Ishii, Y. (2018). Soil carbon dioxide emissions due to oxidative peat decomposition in an oil palm plantation on tropical peat. Agriculture Ecosystems and Environment, 254: 202-212. https://doi.org/10.1016/j.agee.2017.11.025
[48] Baird, A., Low, R., Young, D., Swindles, G., Lopez, O., Page, S. (2017). High permeability explains the vulnerability of the carbon store in drained tropical peatlands. Geophysical Research Letters, 44: 1333-1339. https://doi.org/10.1002/2016GL072245
[49] Taufik, M, Marliana, T.W., Santikayasa, I.P., Chusnul, A., Budiman M., (2023). Peat moisture dataset of Sumatra peatlands. Data in Brief, 46: 108889. https://doi.org/10.1016/j.dib.2023.108889
[50] Pertiwi, N., Tsusaka, T.W., Nguyen, T.P.L., Abe, I., Sasaki, N. (2022). Nature-based carbon pricing of full ecosystem services for peatland conservation-A case study in Riau province, Indonesia. Nature-Based Solutions, 2: 100023. https://doi.org/10.1016/j.nbsj.2022.100023
[51] Flood, K., Mahon, M., McDonagh, J. (2021). Assigning value to cultural ecosystem services: The significance of memory and imagination in the conservation of Irish peatlands. Ecosystem Services, 50: 101326. https://doi.org/10.1016/j.ecoser.2021.101326
[52] McCay, B.J., Micheli, F., Ponce-Díaz, G., Murray, G., Shester, G., Ramirez-Sanchez, S., Weisman, W. (2014). Cooperatives, concessions, and co-management on the Pacific coast of Mexico. Marine Policy, 44: 49-59. https://doi.org/10.1016/j.marpol.2013.08.001
[53] Fiqa, A.P., Fauziah, F., Lestari, D.A., Budiharta, S. (2019). The importance of in-situ conservation area in mining concession in preserving diversity, threatened and potential floras in East Kalimantan, Indonesia. Biodiversitas Journal of Biological Diversity, 20(1): 198-210. https://doi.org/10.13057/biodiv/d200123
[54] Gunawan, H., Afriyanti, D. (2019). Potential implementation of social forestry in engaging community participation in Restoring Peatlands. Journal of Forest Science, 13: 227-236. https://doi.org/10.22146/jik.52442
[55] Cobb, A.R., Harvey, C.F. (2019). Scalar simulation and parameterization of water table dynamics in tropical peatlands. Water Resources Research, 55(11): 9351-9377. https://doi.org/10.1029/2019WR025411
[56] Fatkhullah, M., Iwed, M., Bambang, I. (2021). Peatland farming community development strategy through corporate social responsibility programs: Analysis of sustainable livelihood approaches. Journal of Social Development Studies, 2(2): 15-29. https://doi.org/10.22146/jsds.2186
[57] Awang, A.H., Rela, I.Z., Abas, A., Johari, M.A., Marzuki, M.E., Mohd Faudzi, M.N.R., Musa, A. (2021). Peat land

oil palm farmers' direct and indirect benefits from good agriculture practices. Sustainability (Switzerland), 13(14): 7843. https://doi.org/10.3390/su13147843

[58] Surahman, A., Soni P., Shivakoti, G.P. (2018). Are peatland farming systems sustainable? Case study on assessing existing farming systems in the peatland of Central Kalimantan, Indonesia. Journal of Integrative Environmental Sciences, 15(1): 1-19. https://doi.org/10.1080/1943815X.2017.1412326

[59] Wahyuni, I. (2021). Poverty alleviation model in communities peatland areas of Jambi Province. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 694(1): 012015. https://doi.org/10.1088/1755-1315/694/1/012015

[60] Wildayana, E., Armanto, M.E. (2018). Formulating popular policies for peat restoration based on livelihoods of local farmers. Journal of Sustainable Development, 11(3): 85-95. https://doi.org/10.5539/jsd.v11n3p85

[61] Sutrisno, A., Wahyuni, E., Sidik, J., Usman, S. (2022). The relation of cultural value orientation to the poverty of communities around mangrove forests and peatlands in Kayan Sembakung Delta. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 1083(1): 012010. https://doi.org/10.1088/1755-1315/1083/1/012010

[62] Yeny, I., Gartesiasih, R., Suharti, S., Gunawan, H., Sawitri, R., Karlina, E., Narendra, B.H.S., Ekawati, S., Djaenudin, D., Rachmanadi, D., Heriyanto, N.M.S., Takandjandji, M. (2022). Examining the Socio-Economic and natural resource risks of food estate development on peatlands: A strategy for economic recovery and natural resource sustainability. Sustainability, 14(7): 3961. https://doi.org/10.3390/su14073961

[63] Miettinen, J., Shi, C., Liew, S. (2016). Land cover distribution in the peatlands of Peninsular Malaysia, Sumatra and Borneo in 2015 with changes since 1990. Global Ecology and Conservation, 6: 67-78. https://doi.org/10.1016/J.GECCO.2016.02.004

[64] Bonaudo, T., Bendahan, A., Sabatier, R., Ryschawy, J., Bellon, S., Léger, F., Magda, D., Tichit, M. (2014). Agroecological principles for the redesign of integrated crop–Livestock systems. European Journal of Agronomy, 57: 43-51. https://doi.org/10.1016/J.EJA.2013.09.010

[65] Prasetyawan, W. (2023). Willingness to pay for environmental conservation of peat and aquatic ecosystems in a Cash-Poor Community: A Riau case study. Local Governance of Peatland Restoration in Riau, Indonesia, 1: 193-209. https://doi.org/10.1007/978-981-99-0902-5_9

[66] Bisht, I.S., Rana, J.C., Yadav, R., Ahlawat, S.P. (2020). Mainstreaming agricultural biodiversity in traditional production landscapes for sustainable development: The Indian scenario. Sustainability, 12(24): 10690. https://doi.org/10.3390/su122410690

[67] Rayment, E., Ridley, M., Stanley, L., Williamson, K., Worrall, J., et al. (2021). Overriding water table control on managed peatland greenhouse gas emissions. Nature, 593(7860): 548-552. https://doi.org/10.1038/s41586-021-03523-1

[68] Zulkarnaini, Z., Sujianto, S., Wawan, W. (2023). Strengthening community social capital in peatland management. Sosiohumaniora, 25(1). https://doi.org/10.24198/sosiohumaniora.v25i1.36963

[69] Badan Pusat Statistik Provinsi Riau. (2024). Jumlah dan persentase penduduk miskin menurut kabupaten/kota di provinsi riau, 2023. Pekanbaru: Badan Pusat Statistik Provinsi Riau.

[70] Apresian, S., Tyson, A., Varkkey, H., Choiruzzad, S., Indraswari, R. (2020). Palm oil development in Riau, Indonesia: Balancing economic growth and environmental protection. Nusantara: An International Journal of Humanities and Social Sciences, 2(1): 1-29. https://doi.org/10.6936/NIJHSS.202006_2(1).0001

[71] Syahza, A., Asmit, B. (2020). Development of palm oil sector and future challenge in Riau Province, Indonesia. Journal of Science and Technology Policy Management, 11(2): 149-170. https://doi.org/10.1108/JSTPM-07-2018-0073

[72] Rist L., Feintrenie L., Levang P. (2010). The livelihood impacts of oil palm: Smallholders in Indonesia. Biodiversity and Conservation, 19(4): 1009-1024. https://doi.org/10.1007/s10531-010-9815-z

[73] Chalil, D., Barus, R., Alamsyah, Z., Jullimursyida, Mawardati, Sadalia, I. (2019). The impacts of oil palm plantations on local and migrant smallholders' incomes. IOP Conference Series: Earth and Environmental Science, 336: 012002. https://doi.org/10.1088/1755-1315/336/1/012002

[74] Alwarritzi W., Nanseki T., Chomei Y. (2015). Analysis of the factors influencing the technical efficiency among oil palm smallholder farmers in Indonesia. Procedia Environmental Sciences, 28: 630-638. https://doi.org/10.1016/j.proenv.2015.07.074

[75] Syahza A. (2019). The potential of environmental impact as a result of the development of palm oil plantation. Management of Environmental Quality, 30(5): 1072-1094. https://doi.org/10.1108/MEQ-11-2018-0190

[76] Yuliani, E.L., De Groot, W.T., Knippenberg, L., Bakara, D.O. (2020). Forest or oil palm plantation? Interpretation of local responses to the oil palm promises in Kalimantan, Indonesia. Land Use Policy, 96: 104616. https://doi.org/10.1016/j.landusepol.2020.104616

[77] Osman, K.T., Osman, K.T. (2018). Peat soils. Management of Soil Problems. Springer, Cham, 145-183. https://doi.org/10.1007/978-3-319-75527-4_7

[78] Dhandapani, S., Girkin, N.T., Evers, S., Ritz, K., Sjögersten, S. (2020). Is intercropping an environmentally-wise alternative to established oil palm monoculture in tropical peatlands? Frontiers in Forests and Global Change, 3: 70. https://doi.org/10.3389/ffgc.2020.00070

[79] Johnson, J., Jones, S., Wood, S., Chaplin-Kramer, R., Hawthorne, P., Mulligan, M., Pennington, D., DeClerck, F. (2019). Mapping ecosystem services to human well-being: A toolkit to support integrated landscape management for the SDGs. Ecological Applications: A Publication of the Ecological Society of America, 29(8): e01985. https://doi.org/10.1002/eap.1985

[80] Akanmu, A.O., Akol, A.M., Ndolo, D.O., Kutu, F.R., Babalola, O.O. (2023). Agroecological techniques: Adoption of safe and sustainable agricultural practices among the smallholder farmers in Africa. Frontiers in Sustainable Food Systems, 7: 1143061. https://doi.org/10.3389/fsufs.2023.1143061

[81] Gliessman, S. (2016). Transforming food systems with agroecology. Agroecology and Sustainable Food

Systems, 40(3): 187-189. https://doi.org/10.1080/21683565.2015.1130765
[82] Manda, J., Alene, A.D., Gardebroek, C., Kassie, M., Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. Journal of Agricultural Economics, 67(1): 130-153. https://doi.org/10.1111/1477-9552.12127
[83] Schulker, B.A., Jackson, B.E., Fonteno, W.C., Heitman, J.L., Albano, J.P. (2021). Exploring substrate water capture in common greenhouse substrates through preconditioning and irrigation pulsing techniques. Agronomy, 11(7): 1355. https://doi.org/10.3390/AGRONOMY11071355
[84] Scheel, C. (2016). Beyond sustainability. Transforming industrial zero-valued residues into increasing economic returns. Journal of Cleaner Production, 131: 376-386. https://doi.org/10.1016/j.jclepro.2016.05.018
[85] Tan, Z.D., Lupascu, M., Wijedasa, L.S. (2021). Paludiculture as a sustainable land use alternative for tropical peatlands: A review. Science of the Total Environment, 753: 142111. https://doi.org/10.1016/j.scitotenv.2020.142111
[86] Rowland, J., Walsh, J., Beitzel, M., Brawata, R., Brown, D., et al. (2023). Setting research priorities for effective management of a threatened ecosystem: Australian alpine and subalpine peatland. Conservation Science and Practice, 5(3): e12891. https://doi.org/10.1111/csp2.12891

NOMENCLATURE

PHU	Peat Hydrological Unit
R^2	Coefficient of Determination
P	Fosfor
K	Kalium
Mg	Magnesium
Cu	Tembaga
Zn	Seng
B	Boron