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Economics of Peatland Ecosystem Services: A Study of Use and Non-Use Values and People Interplays in Sumatra, Indonesia

Mohammad Yunus [1], Adcharaporn Pagdee [2,*] and Himlal Baral [3]

[1] Department of Integrated Science, Faculty of Science, Khon Kaen University, Khon Kaen 40002, Thailand; mohammad.y@kkumail.com
[2] Department of Environmental Science, Faculty of Science, Khon Kaen University, Khon Kaen 40002, Thailand
[3] Center for International Forestry Research (CIFOR), Situ Gede, Sindang Barang, Bogor 16115, Indonesia; h.baral@cifor-icraf.org
* Correspondence: adcpag@kku.ac.th

Abstract: Peatlands play an important role in the global environment and the well-being of humans by providing valuable ecosystem services. Yet, anthropogenic activities pose significant hazards for peatland management, including low levels of community participation due to lack of awareness and financial incentives. Understanding the social–cultural and economic value of these ecosystems will raise awareness to protect these important ecosystems. Here, we estimated a total economic value (TEV) of peatland ecosystem services and examined relationships between the TEV and landscape characteristics in Riau province, Indonesia. A questionnaire was used to investigate household socioeconomics, perception of peatland importance, peatland product collection, and willingness to pay for habitat and biodiversity protection from May to June 2023. A total of 200 household individuals (92% confidence) in five villages across distinct landscapes in the Sungai Kiyap-Sungai Kampar Kiri Peatland Hydrological Unit participated in the survey. The respondents obtained numerous advantages from the peatlands with an estimated TEV of USD 3174 per household per year (about 1.3 times their annual income). Approximately 81% showed a use value, especially food provisioning from fish and soil fertility. To a lesser extent, non-use values included a habitat for endemic and endangered species, biodiversity conservation for future generations, and community bonds with sacred forests. The landscape characteristics, illustrating habitat types, biophysical conditions, and property rights regimes, interplay with the relative benefits derived from the peatlands. Proximity to secondary peat swamp forests and riparian zones, especially within protected areas, enhanced economic value. Protected area co-management is essential to balance peatland conservation with sustainable livelihoods. Primary forests need restrictive protection. Meanwhile, buffer zone designation and agroforestry practices, especially in the peatland–farm interface, reduce land use tensions and promote local stewardship. This study can be used as a reference by planners and policymakers to recognize factors that promote effective peatland management, especially those that balance ecosystem protection and livelihood maintenance.

Keywords: total economic value; peatland ecosystem services; landscape; Indonesia

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Citation: Yunus, M.; Pagdee, A.; Baral, H. Economics of Peatland Ecosystem Services: A Study of Use and Non-Use Values and People Interplays in Sumatra, Indonesia. *Land* **2024**, *13*, 866. https://doi.org/10.3390/land13060866

Academic Editor: Shiliang Liu

Received: 19 April 2024
Revised: 12 June 2024
Accepted: 12 June 2024
Published: 16 June 2024

1. Introduction

Peatlands are distinctive ecosystems that contribute greatly to the global carbon store. They contain over 600 gigatons of carbon (GtC), representing up to 44% of all soil carbon [1], which surpasses the carbon storage capacity of all the world's forests [2]. Peatlands also offer a range of social and economic benefits, such as provisioning, regulating, cultural, and supporting services on which our livelihoods depend [3–5]. Indonesia encompasses 13.43 million hectares of peatlands, with 44% located on Sumatra Island [6], which contains 18.8 GtC or 3% of the global carbon of peatlands [7]. Riau province in Sumatra contains the largest extent in Indonesia, covering approximately 3.57 million hectares or 27% of the total peatlands [6]. The utilization of peatlands in Riau spans a significant historical timeline, evolving from small-scale subsistence farming to extensive commercial-based agriculture [8,9]. This dynamic pattern of management underscores the economic importance of peatland ecosystem services (ESs) for supporting livelihoods and contributing to regional development, though with negative consequences, especially from peatland conversion to oil palm plantations.

Yet, peatlands are imperiled due to several factors. For example, logging, agriculture, extraction, and infrastructure development are among the largest global threats [10,11], leading to soil erosion, degradation [12], and greenhouse gas emissions [13,14]. Peatlands are also encountering substantial pressures from anthropogenic activities and their consequences, including habitat conversion, pollution, overexploitation, and water drainage across Indonesia [15–18]. Peat swamp forests and their ESs are undergoing significant transformation because of oil palm plantations, building projects, and other forms of rural development. Losses were estimated at 2.6% per year in Sumatra and Kalimantan from 2007–2015 [19]. A recent publication also confirmed this trend; Indonesia's forested peatlands were lost at an average rate of approximately 2.2% per year between 2009 and 2019 [20]. In 2015, enormous peat fires occurred throughout the country, damaging over 2.6 million hectares of peatlands [21], emitting 0.884 $GtCO_2$ [22], and causing air pollution across several Southeast Asian countries [23]. Moreover, socioeconomic development—a key underlying driver—accelerated peatland depletion. Increased demands for commercial crops such as oil palm and timber incentivize farmers to expand more hectares. Peatland conversion is inevitable when economic returns are high.

Effective peatland management is needed now more than ever. Several policies and approaches have been implemented to save peatlands, such as landscape-based management, e.g., the establishment of peatland hydrological units [24]; peatland restoration by the Peatland and Mangrove Restoration Agency (BRGM), with target areas of 1.2 million hectares during 2021–2024 [25] and 2 million hectares by 2030 [26]; agroforestry [27]; and paludiculture [28]. Although these initiatives show positive outcomes, some challenges remain, including low community participation for long-term engagement in management activities [29,30]. Villagers tend to prioritize household well-being over peatland protection due to rational, short-term impacts. Without a clear understanding of benefits, decisions to change practices and invest time or effort in management activities are unlikely [30].

Multifaceted landscapes reflect a combination of landforms and topography, land cover and habitat biophysical conditions, land use patterns, and management institutions. Along with dynamic livelihoods, these elements complicate peatland management [31]. Villagers do not perceive ESs in the same way due to different interactions with the local environment. Strict enforcement of rules and regulations in protected areas controls villager access to resources, thus diminishing their benefits and eventually weakening connections between people and nature [32]. Meanwhile, easy access to community forests and oil palm plantations illustrates a strong connection between people–peatland goods and services. Villager perceptions rooted in personal experiences with nature influence their behavior, doing something or doing nothing. Therefore, effective management requires activities that are compatible with local biophysical and socioeconomic contexts [33–36].

Economic value (EV) is an estimate of the willingness to give up one thing to gain something else, usually goods and services [37]. A magnitude of EV depends on users' experiences with nature, their preferences, and the amounts of benefits gained from the ES. The economic value of peatlands illustrates a form of people–peatland interplay. Landforms and topography, land cover and habitat conditions, land use patterns, and management activities determine the availability of ESs to people within a specific landscape [38–40]. For example, pristine peat swamp forests under restrictive protection can enhance carbon sequestration, water regulation, and biodiversity conservation, showing indirect interactions with people. Conversely, secondary peatlands, where people have modified the land for specific uses and gained extensive access, are likely to offer larger amounts of provisioning services such as food, fuelwood, and fiber—direct use benefits from resources to people [41].

In this study, we examined the EV of peatland ESs in Riau province, Indonesia. Although there are many studies on the economic valuation of peatland ESs, the majority have focused on direct use values, e.g., food and water [42–44], and non-timber forest products (NTFPs) [45–47]. This study measured the total economic value (TEV) of peatland ESs, which serves as a monetary metric for gauging comprehensive values and benefits that people have obtained from "use" and "non-use" interactions, respectively. Finally, understanding people–peatland interactions helped us recognize factors that promote effective management, especially those which balance ecosystem protection and livelihood maintenance.

2. Materials and Methods

2.1. Study Area

This study was conducted at the Sungai Kiyap-Sungai Kampar Kiri Peatland Hydrological Unit (SKKI PHU) in the Kampar Regency, Riau Province, Sumatra Island, Indonesia. The SKKI PHU consists of approximately 72,747 hectares, of which 27,161 hectares are classified as peatlands [48]. The area contains farmlands, peat swamp forests, oxbow lakes, and two main riparian zones, i.e., the Kampar Kanan and Kampar Kiri Rivers. Located in a tropical moist climate, the average temperature is 28 °C, with about 78% relative humidity and annual rainfall from 2000 to 3000 mm [49]. Within the SKKI PHU lies the Buluh Cina Nature Recreation Park (BCNRP), spanning about 963 hectares [50]. The BCNRP is a popular tourist destination in Riau, especially for residents of Pekanbaru, the capital city of Riau. Visitation is due to its proximity to the city (approximately 20 km) and excellent accessibility via well-maintained roads. The main attraction is captivating landscape views of the lowland tropical rainforest, complemented by various activities such as river and lake boat tours, fishing, wildlife photography, animal watching, and cultural tourism. Meanwhile, the BCNRP functions as a nature reserve for peatland ecosystems by nourishing biodiversity, including protected wildlife such as rangkong badak (*Buceros rhinoceros*) and belida (*Chitala chitala*). Local villagers residing nearby the BCNRP often collect peatland products, especially fish, fuelwood, medicinal plants, honey, wild animals, rattan, and fruits.

The SKKI PHU reveals several advantages and challenges for effective peatland management, including (1) substantial pressure from fires, water drainage, and peatland degradation, (2) potential development of multi-stakeholder partnerships among government authorities, the private sector, and community entities, and (3) some existing intervention programs introduced by agents such as universities, private companies, and government officials [25,51,52]. Moreover, a total population of 77,064 [25,49] lives inside the SKKI PHU, adding significant pressure to the peatlands due to increasing demands for land and resources, especially water. Approximately 57% of the SKKI PHU is used as farmlands, particularly for oil palm plantations [53]. This land use type is expanding due to the global demand for oil palm, pitting agriculture against conservation. The study was conducted in five villages: Buluh Cina, Gading Permai, Kepau Jaya, Pangkalan Serik, and Sungai Bunga, located from north to south of the SKKI PHU along the Kampar Kanan and Kampar Kiri Rivers (Figure 1).

Peat swamp forests in the SKKI PHU are part of the Sumatran lowland rainforests. The BCNRP represents lush patches of old-growth rainforest, riparian, secondary peat swamp forests, and oxbow lakes (Figure 2A), intermixed with smallholder farmlands, especially oil palm plantations, scattered throughout the park. Secondary forests, mainly from abandoned farmlands and clear-cuts, can be observed inside and outside the BCNRP near water bodies. They create a vegetative landscape mosaic consisting of mature and young trees, shrubs, and vines (Figure 2B). Oil palm plantations are the most extensive and prominent use of land (Figure 2C), consisting of large-scale and smallholder operations. One national cooperative is managing a massive oil palm facility under a long-term concession in Kepau Jaya Village. Its planting areas extend over 4500 hectares, with well-constructed infrastructure such as canals, transporting routes, housing, and a crude palm oil (CPO) mill. Meanwhile, smallholder farmers own and/or lease an average of 1.5 hectares per household for oil palm plantations. Farmers usually sell oil palm fruits at village co-operatives or private collecting sites where the fruits are supplied to CPO production. Moreover, the rivers illustrate a complex wetland ecosystem that includes many tributaries, oxbow lakes, and riparian zones (Figure 2D).

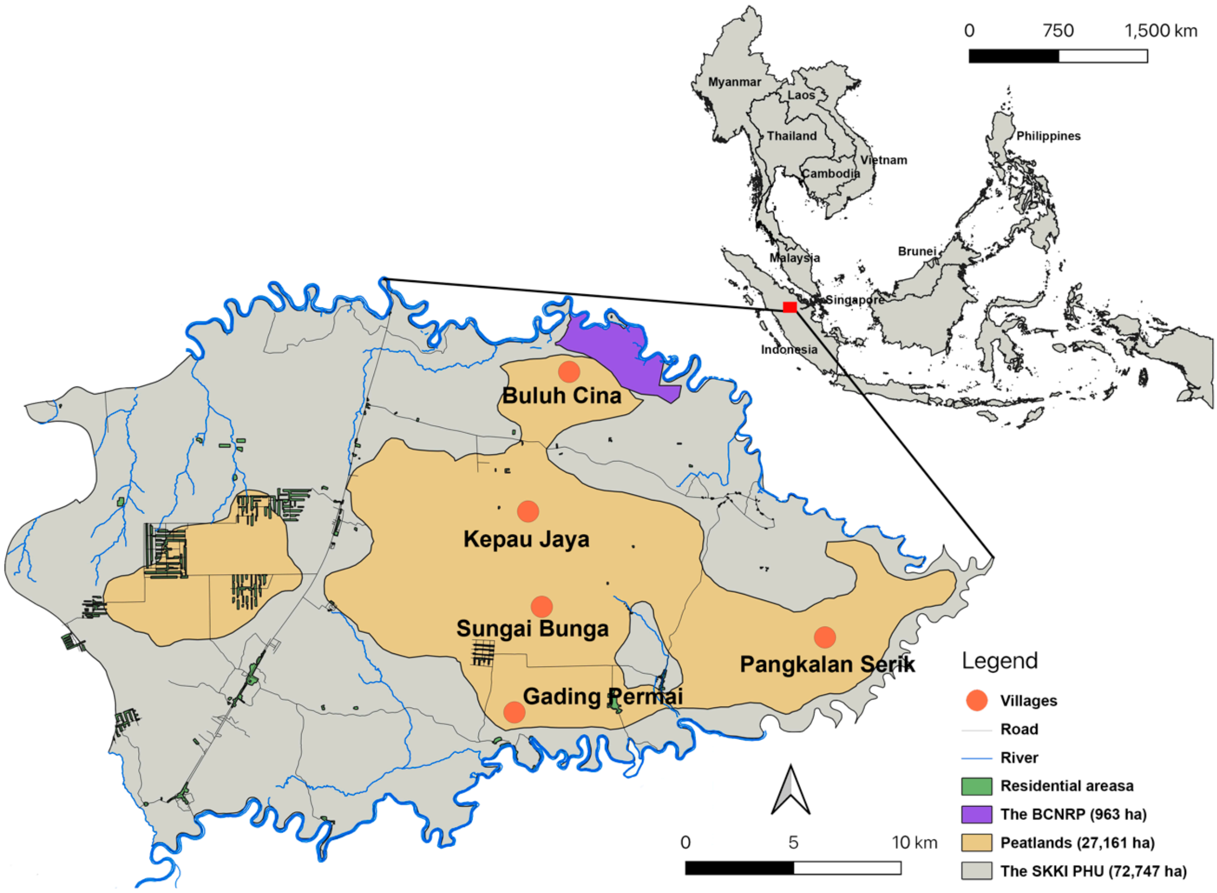

Figure 1. Study area and villages in the SKKI PHU, Riau Province, Indonesia.

2.2. Scope of This Study

Limited engagement from local communities presents a significant barrier to effective peatland management. It likely stems from a low understanding of the intrinsic value of peatlands and the degree to which degradation impacts local livelihoods. Consequently, the need for peatland protection is often overlooked. Economic valuation can be a powerful tool to address this knowledge gap. Quantifying the benefits provides much-needed evidence to show how peatlands contribute to local livelihoods. Moreover, the amounts and quality of ESs are directly influenced by habitat types, ecosystem conditions, and management regimes. These characteristics interplay and form a unique landscape pattern that illustrates locality. Figure 3 depicts the scope of this study, including the research problems, objectives, methodological framework, and expected outcomes. Key peatland ESs were identified following the Millennium Ecosystem Assessment [37]. The TEV consists of the use and non-use values of the peatlands. The use value shows the benefits that people obtain from ecosystem goods and services, including (a) a direct use value representing consumptive and non-consumptive activities; (b) an indirect use value derived from ESs that support or protect economic activities rather than directly providing goods and services to people; and (c) an option value, illustrating a possible use of resources in the future both directly and indirectly. Non-use values also refer to benefits obtained without direct or indirect involvement with the resources, including (a) the bequest value, showing the value that people imagine for future protection of an ecosystem; and (b) the existence value, derived from the presence and importance of a particular ecosystem or species. This study measured the TEV of peatland ESs, capturing both use and non-use values. The estimated TEV allows stakeholders to compare ES value against other commodities and actions. Thus, it will improve public knowledge, awareness, and willingness to participate in active forms of peatland management.

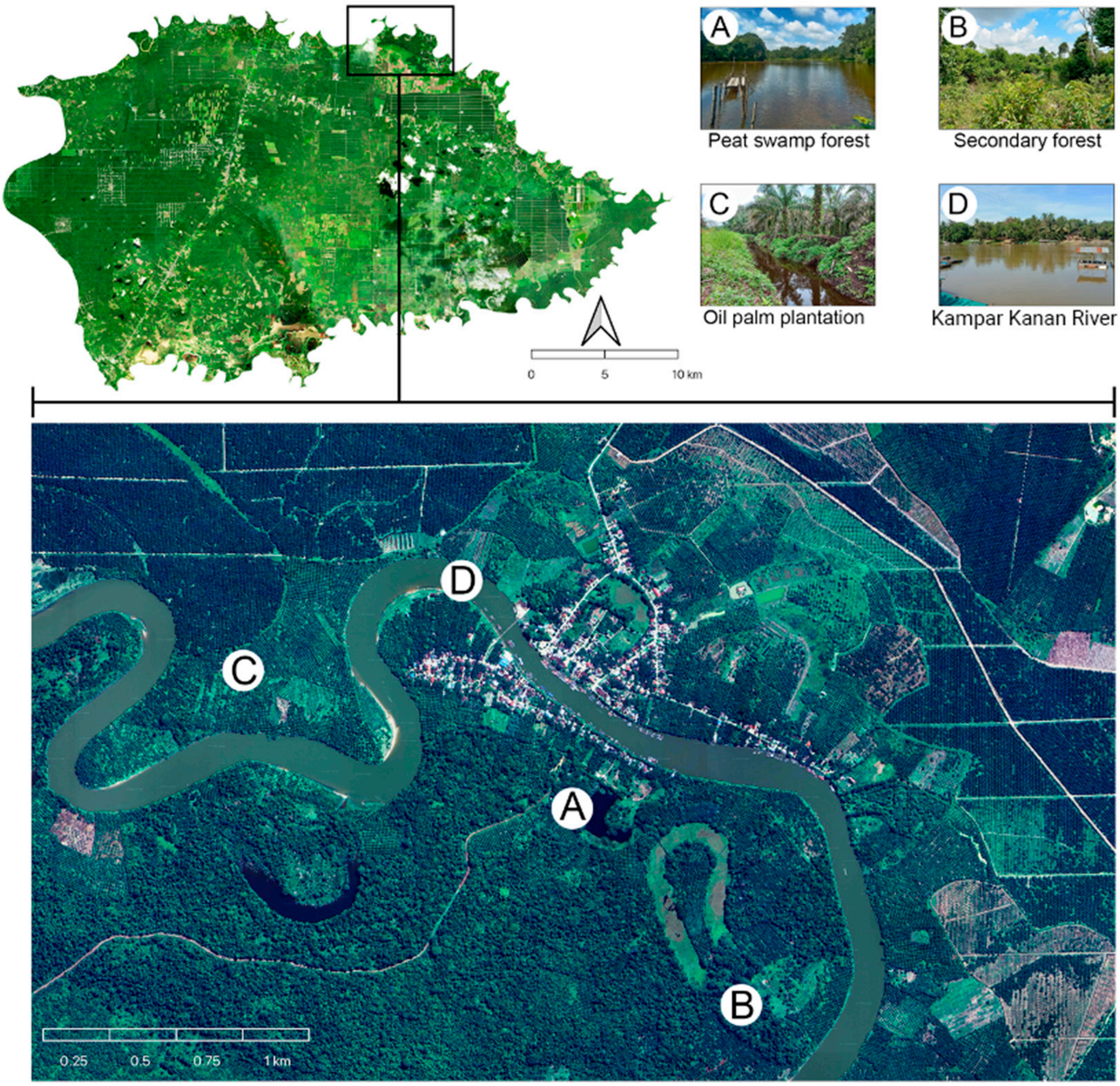

Figure 2. Typical landscapes in the study area: (**A**) the peat swamp forest, (**B**) a patch of secondary forest, (**C**) oil palm plantations, and (**D**) the Kampar Kanan River and a nearby village—Buluh Cina. The satellite image depicts parts of the BCNRP and key land use patterns inside the protected area.

2.3. Data Collection

This study consisted of two main parts: (1) a questionnaire, together with onsite observation and key informant interviews, i.e., village leaders and local administration officers, and (2) secondary data acquisition from relevant authorities and agencies, e.g., the Ministry of Environment and Forestry, Nature Conservation Agency, Indonesia's Central Bureau of Statistics, NGOs, the Kampar Regency Government, village administration offices, and universities. Published and unpublished documents, including organizational reports, maps, research articles, regional statistics, and online databases, were reviewed for data extraction. Simultaneously, the questionnaire and personal interviews were conducted from May to June 2023. With a total of 2755 households in the five villages, a minimum sample size was determined for 96 up to 349 households following Yamane's formula at a 10% to 5% degree of error, respectively. Additionally, an appropriate sample size recommended for the willingness to pay (WTP) measurement ranges between 200 and 2500 [54]. We finalized the minimum sample size of 200 households (92% confidence) according to time, workforce, and budget availability. Subsequently, a number of samples in each village was determined by multiplying 200 with the proportion of the village's number of households over the total number of households from five villages (i.e., 2755). Kepau Jaya village obtained the highest number of households (1254), and the largest number of samples were selected (80 out from 200 households). Meanwhile, the smallest sample size was 20 households from Gading Permai village, with the lowest household number (173). Simple random sampling was employed using two basic criteria to validate household selection. First, the households were situated within or adjacent to peatland habitats. Secondly, household members actively engaged in activities such as peatland product harvesting and management where their actions could determine and/or be affected by peatland conditions. The head of the household, his/her spouse, and/or active members were asked for consent to participate in the questionnaire.

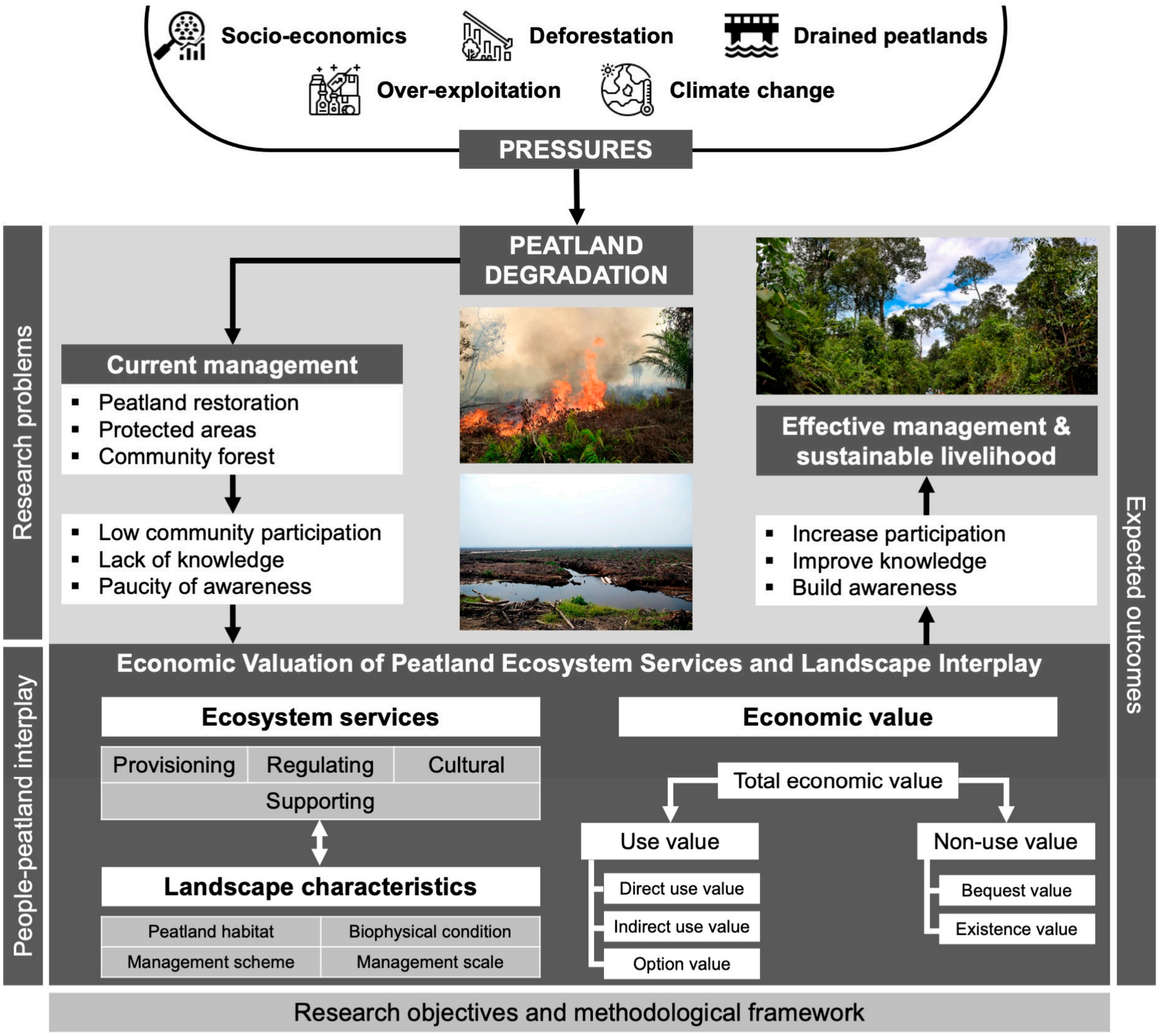

Figure 3. Scope of this study—the research problems, objectives, methodological framework, and expected outcomes.

The economic valuation portion of the questionnaire consisted of five parts: (1) the respondent's household socioeconomic conditions, including their personal information and household profile; (2) the landscape characteristics in/around the respondents' premises, including land use types and distances to frequently accessed peatland locations; (3) the respondent's perception toward peatland importance by asking them to rate the peatland ES contributing to their household livelihoods on a Likert scale from 1 (slightly important) to 5 (very important); (4) peatland product collection, including access frequency, amounts of harvest, and price of peatland products, and (5) the household's WTP for habitat conservation and biodiversity protection. The household representatives, especially the heads of families, were asked for their consent to participate in the study. Personal interviews with village leaders and local officers were used to gather sufficient baseline data to validate the questionnaire.

2.4. Measurement of the Total Economic Value of Peatland Ecosystem Services

Table 1 summarizes 14 peatland ESs with monetary valuation methods, including market price, avoided cost, benefit transfer, and contingent valuation. The market price method was employed to measure a direct use value of peatland goods and services including fish, wild plants and animals, fiber, medicines, soil fertility, and water usage. The amounts of the ESs utilized were multiplied by the prevailing market prices. The water price for household use was acquired from provincial regulations, and the amount of water required per person was calculated following the National Standardization Agency of Indonesia (m^3/person/year). Meanwhile, water for agriculture was estimated based on an irrigation price in Petapahan Village, where a provincial irrigation project is located. We focused on water use for oil palm, coconut, rubber, and rice plantations, since they were the most important agricultural products in the Kampar Regency [49]. The avoided cost method was used to measure an indirect use value of fire prevention and the existence value of the peatlands as spiritual and sacred forests. The amounts of financial aid provided to the households that experienced fire damage during 2022–2023 were used for a price estimate of fire prevention. Meanwhile, the price approximation for the existence value was based on a hypothetical condition if the peatlands were converted to an oil palm plantation. The selling price of the land was derived from household residents, averaged at USD 8644 per ha. Multiplying this number with the quantity of primary peatland forests in the BCNRP created a spiritual and sacred value.

Carbon sequestration was quantified using the benefit transfer method based on the available data, i.e., carbon credit price, amounts of peatlands, and reference carbon stocks for selected crop types (i.e., oil palm, rubber, and coconut) to set up proximate values. The amounts of carbon stock from each of the land use types were converted to tCO_2 by multiplying them by a factor of 44/12 [55]. Table 2 presents information on prices, quantities, assumptions, and data sources needed to estimate the economic value of water usage, carbon sequestration, and sacred forest protection. Lastly, the contingent valuation method was used to measure the non-use value by asking the respondents' amounts of WTP for peatland habitat protection and biodiversity conservation. Household members were provided with information on the status of the peatlands and ESs, including threats, management challenges, and hypothetical conditions if the peatlands were converted to other land use types so habitat protection and biodiversity conservation were needed. The respondents expressed their WTP to support these programs from a list of offers, starting from USD 0.5 up to USD 5 per month, and a blank if they wanted to specify their own WTP amounts.

Table 1. Peatland ecosystem services and calculation formulas for economic valuation.

No.	Ecosystem Services	Calculation Formula	Description
A	*Use value*		
	i. Direct use value		
	Fishery	$V_{pr} = \sum_{j=1}^{n}\left(\sum_{i=1}^{n} P_i \times Q_i\right)$	P_i is the market price of a product (USD/kg), Q_i is the quantity of a product (kg/year), and j is the household
	Wild plants and their outputs as a food source		
	Wild animals and their outputs as a food source		
	Ornamental animals and plants		
	Fibers and other materials		
	Medicines and other materials from wild animals and plants		
	Water for households	$Q_i = Fm_i \times Wt_i$ $V_{wh} = \sum_{j=1}^{n}\left(\sum_{i=1}^{n} P_i \times Q_i\right)$	Fm_i is the number of family members, Wt_i is the water needed per person (m^3/year), P_i is the price of water, and Q_i is the quantity of water
	Water for agriculture	$Q_i = Ar_i \times Wt_i \times Pl_i$ $V_{wa} = \sum_{j=1}^{n}\left(\sum_{i=1}^{n} P_i \times Q_i\right)$	Ar_i is the area of land for production (ha), Wt_i is the water needed per year (m^3/ha), Pl_i is the plant's intensity day per year, P_i is the price of water, and Q_i is the quantity of water
	Soil fertility	$V_{sf} = \sum_{j=1}^{n}\left(\sum_{i=1}^{n} P_i \times Q_i\right)$	P_i is the market price of the tproduct (USD/kg), Q_i is the quantity of he product (kg/year), and j is the household
	ii. Indirect use value		
	Fire prevention	$V_{fr} = \sum_{i=1}^{n} Ec_i \times Fr_i$	Ec_i is the estimated cost of fire prevention (USD/incident), and Fr_i is the fire frequency.
	Carbon sequestration	$V_{cs} = Pr_i \times Cr_i \times Ar_i \times Fc_i$	Pr_i is the carbon prices, Cr_i is the number of carbon stocks, Ar_i is the total area of peatlands, and Fc_i is the conversion factor.
	iii. Option value		
	Habitats for endemic/endangered species	$WTP = (\sum_{i=1}^{n} WTP_i)/n$	WTP is the maximum willingness to pay expressed by a household, and n is the number of observations.
B	*Non-use value*		
	i. Bequest value		
	Biodiversity for future generations	$WTP = (\sum_{i=1}^{n} WTP_i)/n$	WTP is the maximum willingness to pay expressed by a household, and n is the number of observations.
	ii. Existence value		
	Spiritual, sacred, and religious values	$V_{sf} = \sum_{i=1}^{n} \frac{Ar_i \times Pr_i}{n}$	Ar_i is the total area of sacred forests, Pr_i is the land price (i.e., oil palm plantation, USD/ha), and n is the total number of households.

Table 2. Prices, quantities, assumptions, and data sources used for economic value measurement.

Ecosystem Services	Price	Quantity	Assumption	Data Sources
Water for household	0.80 USD/m^3	21.90 m^3/people/year	Average annual water use per person	[56,57]
Water for agriculture	0.0019 USD/m^3	Oil palm: 21,296 m^3/ha/year Coconut: 17,520 m^3/ha/year Rubber: 14,221 m^3/ha/year Rice: 391,495 m^3/ha/year	Annual water use for specific crops per hectare	[58–62]
Carbon sequestration	2 USD/tCO_2	Oil palm: 40 tC/ha Rubber: 75.71 tC/ha Coconut: 100 tC/ha	Carbon sequestration rate per hectare for specific crops	[63–66]
Sacred forest	8643.61 USD/ha/year	963 ha	Value of the primary peatland forest if it were converted into an oil palm plantation	Questionnaire data/this study

2.5. Statistical Data Analysis

Descriptive statistics were calculated to summarize household socioeconomic conditions, peatland product collection, and landscape characteristics. A landscape matrix was created to depict people–peatland interactions. The key criteria used to demonstrate landscape characteristics included: (1) habitat types, (2) biophysical conditions, (3) land use patterns, and (4) management schemes in/around households and frequently accessed peatland locations. Accessibility to peatlands was categorized by estimated distances from households to key locations. One-way analyses of variance (ANOVA) were used to test the amounts of economic value among households within different landscape matrixes and accessibility classes. All the statistical analyses were performed using SPSS version 28; KKU license.

3. Results

3.1. Household Socio-Economic Conditions and Livelihoods

A total of 200 households yielded a diverse socio-economic profile. The respondents' average age was 41.71 years old, suggesting that the sample was part of the workforce and was actively contributing to economic activities. The gender distribution reflected traditional societal roles, where men dominated certain household activities such as agriculture, labor-intensive work, and household voice representation, making up 75% of the participants. In contrast, women spent more time on housekeeping and childcare, with less expression outside their homes. Most of the respondents had resided in this area for generations. Over three-fourths (81%) of them identified as locals, specifically from the Malay tribe. Some individuals moved in from nearby villages and provinces, including migrant workers in oil palm production.

The education level of the respondents included high school (39%), followed by middle school (33%), and primary school (26%). Post-secondary education is not common in the area since young people who have college degrees have migrated to urban areas such as Bangkinang and Pekanbaru to find stable and higher-paying jobs (beyond agriculture), leaving behind their family on the farm. The average number of household members was 3.89, of which one to two were considered active laborers responsible for income generation. This illustrates a single or nuclear family, rather than an extended one, as was common in the past. The primary occupation was agriculture-based (67% of the respondents), especially on oil palm and rubber plantations. Agriculture holds a high prominence due to well-established social networks and communal support systems such as farmer co-operatives and labor-sharing traditions, molding local farming livelihoods and practices. Yet, subsistence agriculture has evolved toward commercial-based farming and agroindustry, especially oil palm and rubber production, creating new job opportunities for many, including migrant workers.

The average household income was USD 2816 per year, falling far below provincial and national averages, i.e., USD 5283 per year [67] and USD 4798 per year [68], respectively. This income disparity suggests economic challenges, including low crop productivity, market price fluctuation, and high production costs, borne by villagers, especially farmers. In general, the respondents were ordinary people, although a small number served as village heads, religious leaders, local politicians, village health volunteers, and/or members of community initiatives such as farmer groups. These people have better access to information, knowledge, and funding sources from outside agencies. Table 3 summarizes the socio-economic profiles of the respondents.

Table 3. Socio-economic conditions and livelihoods of the surveyed households.

No.	Variable	Percent	Mean	No.	Variable	Percent	Mean
	Age				*Gender*		
1	20–40	48	41.71	1	Female	25	
2	41–55	42.5		2	Male	75	
3	>55	9.5					
	Level of education				*Ethnicity*		
1	No education	1		1	Malay	81	
2	Elementary school	26	9.37	2	Bataknese	7	
3	Junior high school	33		3	Javanese	7	
4	High school	39		4	Others	5	
5	Bachelor's degree	1					
	Household members				*Role in community*		
1	<3	34		1	No role	89	
2	3–7	65	3.89	2	Religious leader	5	
3	>7	1		3	Government representative	3	
				4	Member of the organization	2	
				5	Leader of the organization	1	
	Number of active laborers				*Occupation*		
1	<2	95		1	Farming	67	
2	2–4	4	1.29	2	Fishing	10	
3	>4	1		3	Wage laborer	20	
				4	Business	3	
	Length of residence (years)				*Annual income*		
1	<20	24		1	<2000	22	
2	20–50	65	32.52	2	2001–4000	72	2816
3	>50	11		3	4001–6000	4	
				4	>6001	2	

3.2. Residence Locations and Access to the Peatlands for Product Collection

Residence locations, such as the village center, local market, rivers, protected area, oil palm plantations, and secondary riparian zones, were classified into distance and proximity classes. Sixteen percent of the respondents came from the Buluh Cina Village—a settlement inside the protected area prior its establishment. Their households were within a 2 km proximity of the peat swamp forests where the villagers harvest products. The distances from other villages to the peatland locations varied considerably (Table 4).

The collection of peatland products constitutes an integral part of community livelihoods in villages across the SKKI PHU, including the five studied villages. Many of the respondents (43%) reported gathering peatland products for household consumption; 38% said for income generation, while 19% collected these products for household consumption and income generation. Resource availability and accessibility, i.e., distance and control, determined their harvesting attempts. Individuals normally go to several places to search for enough products. With a similar abundance of resources, villagers usually enter nearby locations to minimize travel time and costs. Figure 4 depicts the common access points for peatland product collection. The two most frequently accessed sites are secondary riparian zones and oil palm plantations, either from their farmlands or their neighbors. Nearby riparian forests (~2.37 km from households) provide varieties of products all year round, including seasonal fruits, fuelwood, medicinal plants, honey, and rattan. Oil palm plantations may not have as many products as the riparian zones due to monoculture, but farmers can gather available products easily while at work or after hours. On the other hand, peat swamp forests offered plentiful products, but with limited access and at a farther distance (~4.47 km) from the protected areas, making it inconvenient for villagers. Only those living inside the park accessed peat swamp forests and oxbow lakes, mainly for fishing. Lastly, the villagers went to the rivers for fishing and extracting water for household consumption, especially those without a running water service.

Table 4. Household proximities to key locations.

No.	Household Proximity to Key Locations	% Respondents	Overall Average Distance (km)
1	The BCNRP protected area		8.34
	1.1 Inside the BCNRP	16	
	1.2 Adjacent to the park within 10 km	54	
	1.3 Farther (>10 km)	30	
2	Peat swamp forests		4.47
	2.1 Inside the BCNRP (within 2 km to the swamp)	16	
	2.2 Adjacent to the park within 4 km	27	
	2.3 Farther (>4 km)	57	
3	Riparian		2.37
	3.1 Near the park within 2 km	62	
	3.2 Intermediate within 6 km	31	
	3.3 Farther (>6 km)	7	
4	The rivers		2.30
	4.1 Near the park within 4 km	91	
	4.2 Intermediate within 8 km	3	
	4.3 Farther (>8 km)	6	
5	Oil palm plantations		1.76
	5.1 Near the park within 2 km	75	
	5.2 Intermediate within 4 km	14	
	5.3 Farther (>4 km)	11	
6	A village center		2.15
	6.1 Near the park within 2 km	73	
	6.2 Intermediate within 4 km	10	
	6.3 Farther (>4 km)	17	
7	Local markets		2.31
	7.1 Near the park within 2 km	59	
	7.2 Intermediate within 4 km	33	
	7.3 Farther (>4 km)	8	

3.3. Total Economic Value of Peatland Ecosystem Services

Table 5 shows a list of peatland ESs and economic values. Approximately 81% of the TEV illustrated a use value, especially direct and indirect use benefits obtained by the households. This finding is similar to prior research studies conducted in Indonesian peatlands, i.e., the importance of peatlands as a main source of basic life necessities, especially for local people [69,70]. The amount of fish captured was the highest proportion of use value and TEV, with an average of USD 808 per household per year, or nearly 30% of the annual household income. Fishing activities usually occurred at riverside villages i.e., Buluh Cina, Kepau Jaya, and Sungai Bunga, with the majority being Malay descendants, deeply rooted in the fishing culture. Each year, nearly 50 tons of fish are traded in the villages. Fish trade generates substantial amounts of cash income for households through direct sales or fish processing (e.g., dried fish, fish crackers, and shredded fish), thus saving household spending from fish consumption. Common fish species included baung (*Mystus nemurus*), baung pisang (*Mystus micracanthus*), ingir-ingir (*Mystus nigriceps*), baung geso (*Mystus wyckii*), sengarat (*Belodontichthys dinema*), selais (*Krytopterus palembangensis*), selais budak/Lais padi (*Krytopterus schilbeides*), and tapah (*Wallago leeri*).

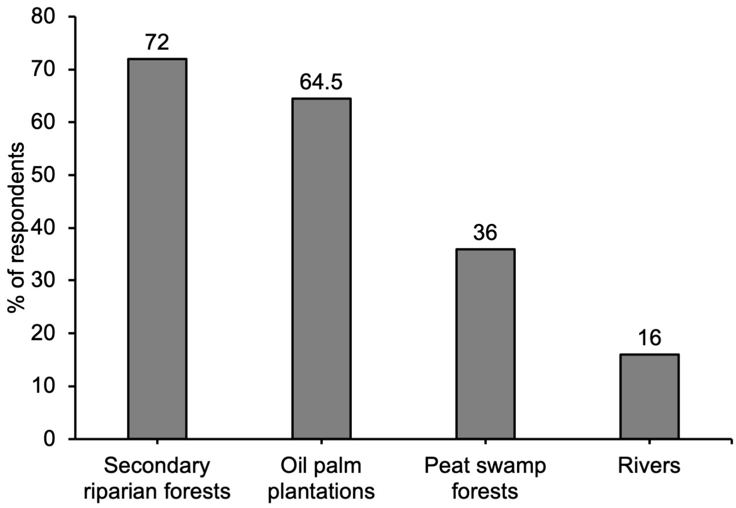

Figure 4. Frequently accessed locations for peatland product collection.

Table 5. Total economic value of peatland ecosystem services.

No.	Peatland Ecosystem Services	Value (USD/hh/Year)	Percent
Use value		2566	81
i	*Direct use value*	1984	77
	1. Fishery	808	41
	2. Wild plants and their outputs as a food source	104	5
	3. Wild animals and their outputs as a food source	154	8
	4. Ornamental animals and plants	36	2
	5. Fibers and other materials	23	1
	6. Medicines and other materials from wild animals and wild plants	28	1
	7. Water for households	58	3
	8. Water for agriculture	64	3
	9. Soil fertility	709	36
ii	*Indirect use value*	579	29
	1. Fire prevention	70	12
	2. Carbon sequestration	509	88
iii	*Option value* (habitats for endemic/endangered species)	3	0.13
Non-use value		608	19
i	*Bequest value* (biodiversity for future generation)	3	1
ii	*Existence value* (spiritual, sacred, and religious values)	604	99
	Total economic value	**3174**	**100**

Soil fertility, specifically for oil palm, rubber, coconut, and rice cultivations, was estimated with average USD 709 per household per year, or approximately 36% of the total use value. Oil palm plantations occupied about 41,414 hectares, of which 30,332 hectares were considered large-scale and 11,082 hectares were managed by small landholders [53]. They covered the largest proportion of farmlands compared to other crop types in the

SKKI PHU area. Growing global demands for oil palm products drive farmers to increase their productivity. Expansion into nearby peatlands is inevitable. Conversely, the collection of mushrooms and wild plants (e.g., fiddlehead ferns, cassava leaves, and taro) for food, ornamental, and medicinal purposes, as well as fibers and other products, contributed minor proportions of the TEV. A similar pattern was observed for hunting birds, wild boar, jungle fowl, and honey. Decreases in wild game hunting may result from habitat conversion and deforestation. Meanwhile, water provisions for agriculture and household use were estimated at USD 64 and USD 58 per household per year, respectively.

The indirect use value of peatlands involves fire prevention and carbon sequestration. Fire prevention exhibits a natural mechanism for curbing outbreaks and fire escalation, safeguarding not only peatlands but also the surrounding areas. The waterlogged condition of peatlands forms a natural barrier against fires [71]. Government allocation for peatland protection and fire damage compensation is one measure of their economic value. Averaged amounts of USD 70 per household per year (12% of the indirect use value) imply a financial commitment to averting fire-related crises and consequential losses to households. Moreover, carbon sequestration from peatlands was estimated at USD 509 per household per year, accounting for 88% of the indirect use value. This underlies peatland importance to climate change mitigation.

Finally, non-use value accounted for 19% of the TEV. All the respondents recognized the peatlands, especially the pristine peat swamp and tropical rainforests inside the protected area, for their existence associated with spiritual, sacred, and religious significance. The existence value was measured at USD 604 per household per year, or nearly 100% of the non-use value. It demonstrated cultural and emotional connections between people and the peatland resource. Meanwhile, the bequest value, estimated by measuring amounts of WTP for biodiversity conservation for future generations, accounted for less than 1% (averaged USD 3 per household per year). Only 20% of the sampled households expressed their WTP for the proposed conservation programs, including habitat restoration, wildlife management, and public education, with 85% confidence of actual payment. The amounts of WTP depend on household preferences and socioeconomic backgrounds [72]. Although the villagers may have thought of peatland importance as biodiversity reserves for future generations, when it came to actual payment, they made decisions based on their income constraints. In other words, the short-term benefits outweighed the uncertainty of long-term gain.

3.4. People–Peatland Interplay: Landscape Characteristics Relating to the Economic Value of Peatland Ecosystem Services

Peatlands provide a variety of ES with substantial amounts of economic value. The estimated TEV of USD 3174 per household per year is nearly 1.3 times the average annual income (USD 2816 per household per year). Direct use value alone generated 70% of the household income and resulted in 12% savings in household expenditures. However, these collective benefits are likely overlooked, making peatland protection a second priority after other land use activities such as agriculture, building construction, and land development. If deforestation and peatland degradation occur, peatland ES provisions will decrease, and local livelihoods will suffer. In this section, we demonstrate a people–peatland interplay by examining the relationships between landscape characteristics and the amounts of economic value accrued from the ESs.

Everyone interacts with land, either directly or indirectly. Local environments are the foundation of culture, determining our ways of thinking within a given landscape. Figure 5 displays four distinct groups of landscape characteristics in/around the respondent households and access locations for peatland product collection. Group 1 represents an intermixed landscape of secondary peat swamp forests and riparian zones, community forests, and residential areas with homestead gardens inside the BCNRP protected area. Group 2 illustrates primary forests and peat domes inside the park, with strict enforcement of rules and regulations regarding access, especially for direct use activities such as logging, farming, and product collection. Group 3 depicts small-scale agriculture, especially oil palm and rubber plantations, community infrastructure (e.g., roads, residential areas, village centers, and local markets), and patches of secondary vegetation in diverse habitats, including rivers and oxbow lakes. Group 4 describes mainly large-scale farmlands extending over 4500 hectares of oil palm plantations, with production facilities such as canals, sorting areas, and a CPO milling plant. Designated forest areas with special purposes or Kepau Jaya (KHDTK) occurred in Group 1, aiming for sustainable resource utilization and participatory-based forest conservation. Peatland restoration sites with prohibited access were also found in Group 1.

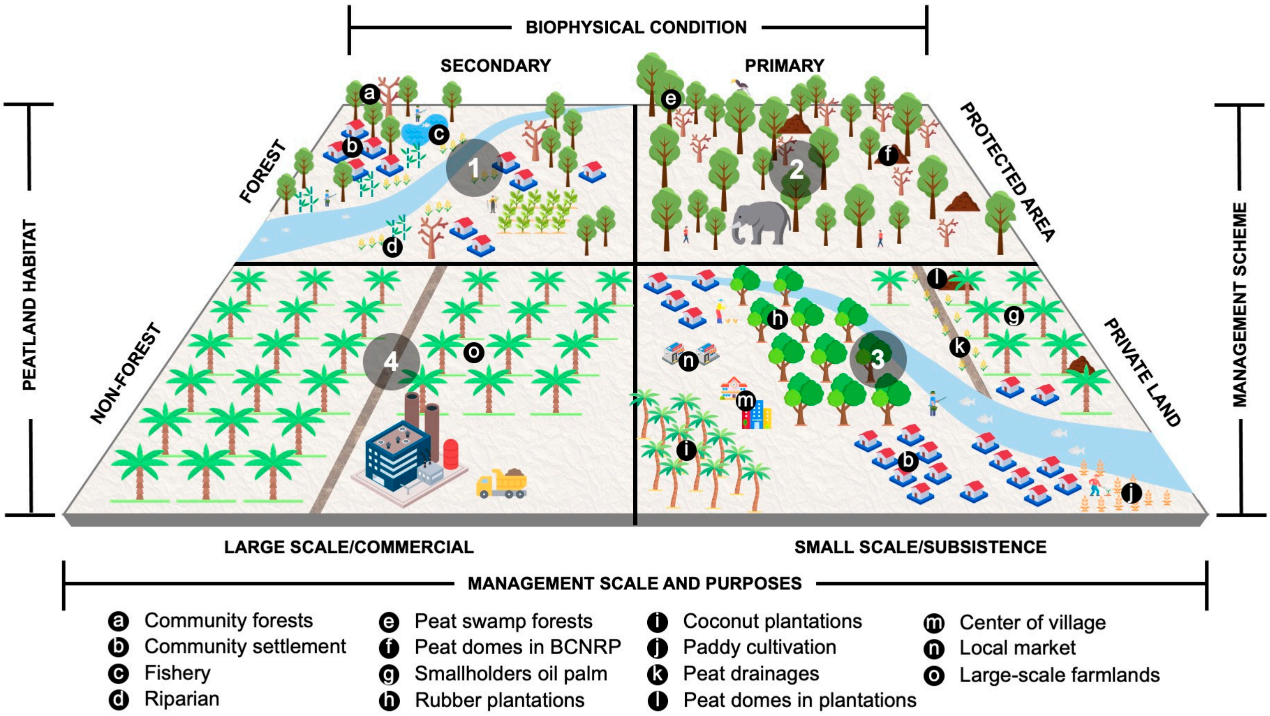

Figure 5. Landscape characteristics grouped by habitat types, biophysical conditions, land use patterns, and management schemes in/around households and frequently accessed peatland locations.

Most of the respondents (58%) interacted with peatlands in Group 3 of the landscape matrix. Smallholder plantations served as the primary sources of household income. A drainage system, including canals and ditches, was designed to store water and distribute it throughout the farmlands. An average farm size was 1.5 hectares per household, and they were located mostly in the peripheral areas of residential zones. The respondents in this group usually harvested peatland products on their farmlands or adjacent areas due to convenient access and readily available resources. Meanwhile, 26% of the respondents, including those from Buluh Cina and Kepau Jaya Village, were categorized in Group 1. Secondary peat swamp forests and riparian zones dominated the landscape within the co-managed BCNRP protected area. The Buluh Cina Village established before park designation remains inside, but villagers must comply with certain rules and regulations, such as the Conservation Act No. 5 of 1990 and Forestry Act No. 41 of 1999. These policies prohibit inhabitants from exploiting resources inside the park (e.g., logging, hunting, and gathering). Subsequently, a peatland restoration project was introduced by the Ministry of Environment and Forestry through the Natural Resource Conservation Agency (BBKSDA)—the main governmental authority responsible for BCNRP management, in collaboration with several agencies and community groups. The project aimed to restore fire-damaged peat swamp forests by planting multiple native trees such as balangeran (*Shorea balangeran*), geronggang (*Cratoxylum arborescens*), and gelam (*Melaleuca cajuputi*).

The remaining respondents (16%) were categorized into Group 4, depicting those who lived in/around large-scale oil palm plantations. Different stages of plantations, including newly planted areas (within 1–4 years), mature and productive palms (>4 years), and abandoned unproductive patches (>25 years), created a mosaic. The local communities actively engaged in various components of oil palm production including planting, harvesting fruits, processing, transporting oil palm products, and replanting the palms. None of the respondents directly interacted with those in Group 2, which is covered by pristine peatland vegetation and peat domes inside the BCNRP. Accessibility to these areas is prohibited. However, local villagers perceived the intrinsic value of pristine peatlands and respected them as a sacred place.

One-way ANOVA and Games–Howell post hoc tests were conducted to examine the amounts of direct use benefits and TEV among different household proximities to key locations and landscape matrix groups (Table 6). The households inside the protected area and closer to the secondary peat swamps and riparian forests obtained higher direct use benefits (p = 0.006) than those living farther away. Although direct access to the primary forests inside the protected park was limited, the villagers could travel to nearby secondary forests and oxbow lakes for fishing and collecting peatland products. Riparian zones provide access to valuable plants, such as bamboo (*Bambusa* sp.), rattan (*Calamus* sp.), pandan (*Pandanus* sp.), and rengas (*Gluta* sp.). These plants served as essential sources of food, fiber, medicine, and construction materials for local communities. Using traditional knowledge, villagers were able to harvest these products extensively.

Table 6. Amounts of direct use value and TEV of peatland ES among different household proximities to key locations and landscape matrix groups.

No.	Variable	Economic Value	*p*-Value
1	Protected area		
	Inside the PA	3423.29 ^{a}	
	Adjacent to the PA (≤10 km to the border)	2634.39 ^{b}	0.006
	Far (>10 km)	1729.28 ^{c}	
2	Peat swamp forests		
	Inside the PA (0–2 km from the household)	3423.29 ^{a}	
	Adjacent to the PA (≤4 km)	2663.81 ^{b}	0.033
	Far (>4 km)	2144.08 ^{c}	
3	Oil palm plantations		
	Near (0–2 km)	2650.10	
	Intermediate (≤4 km)	2584.37	0.055
	Far (>4 km)	1269.95	
4	Secondary riparian forests		
	Near (0–2 km)	2965.71 ^{a}	
	Intermediate (≤6 km)	1828.62 ^{b}	0.002
	Far (>6 km)	1192.40 ^{c}	
5	Landscape matrix group		
	Group 1	6353.00 ^{a}	<0.001
	Group 3	2315.27 ^{b}	
	Group 4	1122.97 ^{b}	

Note: Different superscripts ($^{a,\ b\ \text{and}\ c}$) represent significant variations among groups at the 0.05 level based on Games–Howell post hoc paired comparisons. Economic values tested for Variables 1 to 4 represented amounts of the direct use value, while Variable 5 was the amount of TEV.

The amounts of TEV among the landscape matrix groups were different (p = <0.001). The households in Group 1 obtained the highest benefit. Although it is part of the BCNRP with limited access, the villagers went to nearby oxbow lakes and secondary riparian forests for fishing and collecting peatland products. The villagers went fishing on a daily basis and sold fish directly to traders in Buluh Cina Village, who later traded the fish at a local market. The villagers also collected peatland products during their fishing trips and sold them for additional income. High market demand elevated the fish price, especially for tapah (*Wallago attu*) and selais (*Ompok hypophthalmus*), since they were used as key ingredients in several traditional Malay dishes such as *asam pedas* (sour spicy soup) and *gulai ikan* (fish curry).

The households in Groups 3 and 4 obtained smaller amounts of TEV, illustrating the benefits of the peatland–farm interface in smallholder and large-scale agriculture, respectively. Farm settings, such as monoculture plantations, irrigation structures, and intervention activities (e.g., weeding and crop harvesting), alter ecosystem conditions and affect ES provisioning. Moreover, farmers rely on oil palm, rubber, and/or coconut production as their primary sources of income. These commodities are subject to market price fluctuations. For example, in mid-2022, the price of oil palm plummeted to its lowest point (USD 0.033/kg) from an average normal price of USD 0.2/kg due to export sanctions. Many factories stopped purchasing palm fruits, resulting in drastic losses for farmers. An interceding supply chain in which a middleman hinders direct negotiation between farmers and sellers increased transaction costs, resulting in profit reductions for farmers. Furthermore, land tenure insecurity, especially in Group 4 where the majority of the respondents were migrant workers in large-scale oil palm plantations, violated their access and benefits.

4. Discussion

This study provides compelling evidence of peatland contributions to local livelihoods as well as benefits to the global community. These findings align with previous research in various provinces in Indonesia, especially provisioning and regulating services, i.e., food, freshwater, raw materials, timber, and carbon sequestration [44,46,47,69]. Provisioning services offer basic life necessities. Meanwhile, regulating services provide checks and balances for the entire ecosystem, creating a good life, security, and health [37,73,74]. Peatlands are one of the major carbon sequestering ecosystems, estimated at about 0.37 $GtCO_2$ yearly, that regulate global climate [1]. Degradation of peatlands damages ecosystem services, especially those having direct impacts on well-being.

Landscape characteristics and accessibility to key locations influenced the amount of benefits gained from the peatlands. Secondary peat swamp forests, riparian, and oxbow lakes under the BCNRP protected area co-management enhances economic value. Diverse habitats inside the BCNRP provide villagers with abundant resources, with flexible management granting a usufruct right and access to available resources. This finding aligns with studies documenting a link between accessibility and amounts of benefits. A study in Indonesia's Giam Siak Kecil-Bukit Batu Biosphere Reserve revealed different economic values between forest-dwelling communities in the core area and buffer zones. Smaller amounts of benefits generated from the core zone were based on valuable NTFPs, whereas benefits from the buffer zone came from various activities, e.g., fisheries and logging. Communities near the Merang Kepayang peat swamp in South Sumatra obtained higher benefits from water resources for household consumption and transportation than villages located farther away [75].

Nonetheless, we observed evidence of illegal logging, land encroachment, and agricultural expansion, specifically oil palm plantations inside the protected area. Clear demarcation, land-use zoning, and robust enforcement measures to safeguard the peatlands are needed. Pristine habitats require rigorous protection and thus need to be designated as a core zone with limited access, especially for direct use such as farming, grazing, and harvesting of peatland products. Meanwhile, adjacent areas can be used as the buffer, where community activities are allowed but with sustainable agriculture and agroforestry. Flexible management schemes help prevent land use conflicts while balancing ecosystem protection and livelihood maintenance.

Active engagement of local communities in peatland protection, especially for climate change mitigation and adaptation, is also of paramount importance. For example, lessons learned from Jambi Province illustrated that transnational networks play a crucial role in Sumatra's coastal peatland governance, including the development of laws, policies, and land use agreements [76]. However, many projects have ignored local perspectives on development and implementation and could not deliver the promised benefits. Moreover, a rearrangement of local land use rights, usually following the Global North system, have lessened the local capacities to benefit from the land, specifically for smallholder farmers. The projects failed to protect the peatlands while placing the climate change mitigation burden onto local communities, including forest protection, fire prevention, and peatland restoration [76]. Thus, local communities are expected to work with local and national governments as well as international agencies to ensure better management and sustainable use of natural resources, since they are familiar with the area and know what is needed based on local knowledge. Participatory-based management empowers local residents in decision-making for land use management, as evidenced in several community forestry programs [77]. However, adequate support from relevant authorities is needed, especially capacity-building and benefit-sharing arrangements such as livelihood development workshops, outreach programs, and traditional ecological knowledge transfer, to improve community participation in peatland stewardship [30,78]. Peatlands demonstrate economic potential, especially for livelihood alternatives, including ecotourism, aquaculture, and agroforestry. They also reduce household dependence on peatland products and in return offer protection for peatlands.

Lastly, the economic value of carbon sequestration emphasizes the major role of peatlands in climate change mitigation and adaptation. Effective peatland protection helps to reduce enormous amounts of greenhouse gas emissions. The quantified TEV of peatland ESs can inform policy makers to make a long-term commitment to peatland protection against short-term benefits from land developers [79,80]. Knowledge exchange through dissemination of research findings and capacity-building programs are key to empowering local communities and stakeholders to make decisions that support peatland conservation. Integrating scientific findings with indigenous knowledge and practices through participatory approaches fosters sustainable peatland management [81]. By elucidating the long-term benefits provided by peatlands, villagers might not take them for granted. Urgent efforts are needed from all stakeholders to ensure sustainable ecosystem services amidst a host of growing pressures.

5. Conclusions

Our study revealed substantial economic benefits provided by peatlands in Riau, Sumatra, Indonesia. The total economic value was estimated at USD 3174 per household per year; approximately 1.3 times the average household income. Provisioning services, especially fishery resources, constituted the largest proportion of use value, greatly contributing to local livelihoods. This quantifiable reliance suggests vital connections between people and peatlands. Landscape characteristics, illustrating habitat types, biophysical conditions, and property rights regimes, determined the amounts of benefits derived from the peatlands. Proximity to secondary peat swamp forests and riparian zones, especially within the protected area, enhanced economic value. However, degradation can disrupt this relationship and the flow of benefits. Protected area co-management of peatlands is key to success. Primary forests need restrictive protection. Meanwhile, buffer zone designation and agroforestry practices, e.g., planting trees on farms and alley cropping, especially in a peatland–farm interface, reduce land use tension and promote local stewardship.

With high economic value at stake, this study underscores the need to protect important peatland ecosystems before their services are jeopardized. To better understand the full range of economic value of peatland ESs, further research studies are recommended, including economic valuation of regulating services such as flood mitigation, pollination, erosion protection, and water purification. These ecosystem services are poorly understood and are treated as non-market services. Quantifying their value can provide a comprehensive outlook. It is also important to integrate cultural, spiritual, and aesthetic values into economic valuations of peatlands. Capturing these intangible values can foster a stronger sense of community stewardship because they encourage belonging and responsibility. Moreover, long-term monitoring of ecosystem services and economic value is important for discerning drivers of change, assessing resilience, and evaluating policy effectiveness for optimized management. Comparative analyses across diverse peatlands such as coastal, brackish, and freshwater peatlands can reveal distinct ecological and socio-economic factors that determine economic value.

Author Contributions: Conceptualization, M.Y. and A.P.; methodology, M.Y. and A.P.; software, M.Y.; validation, M.Y. and A.P.; formal analysis, M.Y.; investigation, M.Y.; resources, M.Y.; data curation, M.Y.; writing—original draft preparation, M.Y.; writing—review and editing, A.P. and H.B.; visualization, M.Y.; supervision, A.P. and H.B.; project administration, M.Y.; funding acquisition, M.Y., A.P., and H.B. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by Khon Kaen University (KKU) through the KKU Scholarship for ASEAN and GMS Countries' Personnel for the Academic Year 2022 (No. 879/2022), and the APC was funded by the International Tropical Timber Organization (ITTO) through ITTO Fellowship 2023 (Ref 064/23A).

Institutional Review Board Statement: This research was approved by the Center for Ethics in Human Research, Khon Kaen University, with the Record No.4.3.03:24/2566 and Reference No. HE663206. Approved date: 19 August 2023.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: This paper is part of a thesis. We extend our appreciation to all the individuals who participated in our study, especially to the village leaders and villagers at Buluh Cina, Gading Permai, Kepau Jaya, Pangkalan Serik, and Sungai Bunga. Their willingness to share their experiences and insights was essential for our data collection and analysis. We also thank our colleagues and collaborators, including the Integrated Land and Water Resource Management Research and Development Center in Northeast Thailand, Khon Kaen University, for their constructive discussions, critical reviews, and collaborative efforts, all of which significantly contributed to the development of our research. Finally, we acknowledge Mark Morgan, School of Natural Resources at the University of Missouri, who helped edit and improve the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

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