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Economic Depreciation Of Forest Resources Due To Plantation Land Conversion And Its Impact On The Value Of Ecosystem Services

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Abstract

This study aims to identify changes in forest cover in Riau Province, compare the value of forest ecosystem services and oil palm plantations, and estimate economic depreciation due to reduced forest cover. The study uses a quantitative descriptive approach with secondary data from 2022 and the 2014–2023 forest cover series. The value of ecosystem services is estimated using the benefit transfer method, referring to the average value of tropical forest ecosystem services from de Groot et al. (2012), while the value of oil palm plantation landscapes refers to Aulia et al. (2020). The results show that in 2022, Riau's forest cover reached 2,577 thousand hectares, or approximately 29.15% of the land area. The decrease from 2021 was recorded at 3,900 hectares. With a reference value of 5,264 international dollars per hectare per year, the depreciation of ecosystem services in 2022 is estimated at 20.53 million international dollars per year. A comparison of TEVs shows that the value per hectare of oil palm landscapes is higher, primarily due to the contribution of provisioning services that have market value, while forests account for a larger share of non-provisioning benefits. This estimate is indicative because it uses transfer values from previous research and is not yet based on data on forest conversion to oil palm in the same location. Therefore, sustainable oil palm management needs to focus on intensifying existing plantations, protecting forests and peatlands, and integrating ecosystem service values into regional policies.

Keywords: Economic depreciation; ecosystem services; forest cover; oil palm; Riau.

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INTRODUCTION

Tropical forests provide a variety of ecosystem services that underpin life, from providing food and raw materials, to regulating climate and water management, to maintaining biodiversity and cultural values (de Groot et al., 2012). Almost all of these services are not traded in the market and therefore have no price, even though their benefits are widely felt by the community. This situation has led to the perception that the value of forests is lower than its true value when compared to land uses that generate direct income. For example, the increasing global demand for agricultural commodities and vegetable oils has contributed to the rate of deforestation, which is one of the largest sources of greenhouse gas (GHG) emissions and environmental degradation in Indonesia.

One region in Indonesia experiencing significant land cover changes due to the development of oil palm plantations is Riau Province. Based on data from the Riau Provincial Plantation Office collected through Rumah Data Riau, the area of oil palm plantations in Riau Province in 2022 was recorded at approximately 1,732,748 hectares. This area demonstrates the significant role of oil palm plantations in the land use structure in Riau Province. However, plantation development also requires environmental considerations, particularly when land use changes involve forest areas. According to the Regional Environmental Issues Analysis document published by the Ministry of Environment and Forestry of Riau Province, forest cover in Riau was 2,577,000 hectares in 2022.

This situation demonstrates the importance of addressing land-use change in Riau, particularly in relation to the development of oil palm plantations and the sustainability of forest ecosystem functions. The significantly reduced functions and value of forest ecosystem services are often overlooked when development occurs through land clearing. Considerations based solely on short-term financial perspectives lead to a misinterpretation of the true value of natural resources. The benefits of conversion are enjoyed by plantation owners, while the environmental losses, such as the loss of carbon sequestration, reduced water regulation, and destruction of wildlife habitats, are borne by the wider community and future generations. Therefore, a natural resource economics approach is needed to quantify these losses in rupiah terms, or what this study calls economic depreciation.

Several studies have assessed ecosystem services in similar contexts. Aulia et al. (2020) calculated the economic value of ecosystem services in a landscape dominated by oil palm plantations in Riau Province, while research on forest conversion to oil palm plantations has been conducted in West Kalimantan, such as a feasibility study of conversion in Melawi Regency (Yani, 2020) and oil palm expansion scenarios in West Kalimantan (Sharma et al., 2019). Therefore, this study estimates the economic

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depreciation of ecosystem services due to land conversion in Riau Province by combining official land area and benefit transfer data and linking these data to implications for regional fiscal policy. This study fills this gap by calculating the difference in value of forest and oil palm ecosystem services, linking this to the concept of natural resource depreciation, and distinguishing private from public value.

Based on the description, this study aims to answer four questions: (1) what are the dynamics of changes in forest land cover to oil palm plantations in Riau; (2) what forest ecosystem services are impacted and can be economically valued; (3) what is the estimated change in the economic value of ecosystem services (depreciation) after conversion; and (4) what are the implications of the valuation results for sustainable oil palm plantation management. The results of the study are expected to provide academic benefits in the form of a depreciation estimation framework based on secondary data, and practical benefits in the form of a basis for consideration for local governments in formulating land use policies.

METHOD

This research is a descriptive quantitative study with a natural resource economics approach. The methods used are secondary data analysis and benefit transfer, adapting the economic value of ecosystem services from previous studies to estimate the value of forest and oil palm plantation ecosystem services in Riau Province. This study also uses a Total Economic Value (TEV) approach to identify direct use value, indirect use value, option value, and ecosystem existence value (Aulia et al., 2020; de Groot et al., 2012).

The research instrument consisted of secondary data documentation sourced from the Ministry of Environment and Forestry, the Riau Provincial Environment and Forestry Service, the Riau Provincial Plantation Service, and previous scientific publications. Data were analyzed using descriptive analysis, TEV value comparison, economic value conversion based on the 2022 rupiah exchange rate, and ecosystem service depreciation calculations. Depreciation estimation was carried out by multiplying the decrease in forest cover area by the economic value of ecosystem services per hectare per year based on de Groot et al. (2012), and using the value of Costanza et al. (2014) for sensitivity analysis. The results of the analysis were then used to identify the economic and environmental implications of sustainable oil palm plantation management.

The study population encompassed all forest cover and oil palm plantation areas in Riau Province. The sample was determined using a purposive sampling technique, selecting data on forest cover, oil palm plantation area, and forest area by function for the relevant period, specifically 2022. Forest cover change data for the 2014–2023 period was also used as a comparison to observe the dynamics of ecosystem service

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depreciation. Data selection was based on the availability, relevance, and suitability of the information to the research objectives.

The research was conducted in four stages. First, secondary data was collected on forest cover, oil palm plantations, and forest areas in Riau Province. Second, the study identified and compared forest and oil palm plantation ecosystem services based on the categories of provisioning, regulating, supporting, and cultural services. Third, the total economic value and estimated depreciation of ecosystem services were calculated using a benefit transfer approach and data on changes in forest cover area. Fourth, the results were interpreted to formulate implications for plantation intensification, forest and peatland protection, and the integration of ecosystem service valuation into regional fiscal policies (Sharma et al., 2019; United Nations et al., 2021; Yani, 2020).

RESULTS AND DISCUSSION

Changes in Forest Land Use to Oil Palm Plantations in Riau Province

Riau Province has experienced a landscape transformation due to the conversion of forests to oil palm plantations and other land uses over more than three decades (Wicke et al., 2011). According to 2022 data from the Ministry of Environment and Forestry, approximately 70.85% of Riau's land area, or 6,264,400 hectares, has become non-forested. Conversely, natural forest cover has continued to decline, from approximately 63% in the 1990s to only 29.15%, or 2,577,000 hectares, in 2020 (Aulia et al., 2020). This condition indicates that Riau's forest cover has fallen below the minimum ecological threshold of 30%, indicating an ecological deficit (Fauzi, 2021).

1. Distribution of Spatial Allocation and Land Change Structure

To understand in detail the magnitude of changes in land cover in Riau Province until 2022.

Table 1. Land Cover Distribution in Riau Province in 2022

Land Cover Categories	Area (Thousand Hectares)	Percentage(%)	Description of Vegetation Dominance / Use
Non-Forest Areas	6,264.4	70.85%	Monoculture oil palm plantations, industrial crops, settlements, & APL

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Land Cover Categories	Area (Thousand Hectares)	Percentage(%)	Description of Vegetation Dominance / Use
Remaining Natural Forest Cover	2,577.0	29.15%	Primary forest, secondary forest, and remaining in conservation/protected areas
Total Land Area	**8,841.4**	**100.00%**	**Total Land Area of Riau Province**

Source: Secondary data processing of land cover 2022 (Directorate General of PKTL KLHK, 2022).

FromThe table above shows that Riau Province is completely dominated by non-forest landscapes, covering more than two-thirds of its total area. This land conversion has occurred gradually but shows an exponential trend. In the initial phase, from 1990 to 2000, land clearing focused on relatively accessible lowland forests. However, as the allocation of forested dryland dwindled, land clearing shifted sporadically to more ecologically vulnerable areas, such as peat swamp forests.

2. Main Driving Factors for Forest Land Conversion

The rapid process of forest land use change in Riau Province did not occur by chance, but rather was the result of a complex interaction between global economic dynamics, regional financial incentives, and spatial planning policies.

a. Financial Incentives and Global Commodity Demand

The high profit margins from oil palm compared to conventional agricultural crops are the main driving force behind massive land expansion.This market push is fueled by the soaring global demand for crude palm oil (CPO) for the food and biofuel industries. This highly promising economic potential has not only attracted large corporations with significant capital but has also fueled a wave of independent smallholders converting private land and open forest areas into large-scale monoculture plantations (Hasnati et al., 2021).

b. Resource-Based Development Policy

For decades, the Riau Provincial Government has made the plantation sector a main pillar in boosting Gross Regional Domestic Product (GRDP).In the past, regulatory laxity regarding the granting of permits for the release of forest areas and the ease of issuing Plantation Business Permits acted as a red carpet that legalized large-scale conversion of forest land in pursuit of regional economic growth.

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c. Weaknesses in Law Enforcement and Spatial Governance

The gap between the Regional Spatial Planning Plan and the facts on the ground has triggered widespread forest encroachment.This problem is exacerbated by minimal oversight in forest border areas and unresolved land tenure conflicts. As a result, the conversion of natural forests, both primary and secondary, into monoculture plantations is accelerating and becoming increasingly difficult to control (Muammar & Amrullah, 2023).

3. Ecological Implications and Impacts on Peat Swamp Forests

Massive land conversion in Riau Province has had the most devastating impact on peat swamp forest areas. Riau's peat ecosystems are among the world's largest terrestrial carbon pools. When peat swamp forest areas are converted into monoculture oil palm plantations, several fundamental ecological cycles are permanently disrupted:

a. Peat Drainage and Carbon Emission Release

Preparing oil palm land in peatlands requires the construction of a network of drainage canals to lower the groundwater level. This drainage process triggers aerobic decomposition and oxidation of peat organic matter, which directly releases gigatons of greenhouse gas (GHG) emissions into the atmosphere, including carbon dioxide (CO2) and methane (CH4).

b. Land Subsidence and the Threat of Disaster Vulnerability

Peat drainage triggers subsidence, or the gradual lowering of the peat soil surface. This damages the landscape's hydrological regime, making inland areas highly vulnerable to flooding during the rainy season and highly flammable during the dry season. Seasonal forest and land fires in Riau are a direct consequence of this disruption to the peat's hydrological balance.

c. Biodiversity Degradation and Habitat Fragmentation

Large-scale clearing of natural forests has fragmented previously intact forest cover into small, isolated fragments (habitat fragmentation). This loss of natural canopy vegetation has destroyed movement corridors for endemic Sumatran wildlife (such as the Sumatran tiger and the Sumatran elephant), triggered detrimental human-wildlife conflicts, and triggered irreversible population declines for these species.

4. Synthesis Perspective of Sustainable Spatial Planning Dilemmas

The Riau landscape in 2022, dominated by 70.85% non-forest areas and remaining 29.15% forest cover, confirms the highly dependent economy on land-based expansion. While this expansion increases short-term regional economic revenues, the resulting negative externalities, such as economic losses from forest and land fires, the

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loss of clean water services, and ecosystem restoration, often outweigh the resulting economic value.

Therefore, these findings underscore the need for a complete paradigm shift in spatial planning management in Riau Province. The government and stakeholders can no longer rely on an extensification approach (clearing new land). The moratorium on forest area release policy must be coupled with law enforcement against illegal plantations within forest areas. Furthermore, the agricultural sector development strategy in Riau must focus on increasing existing land productivity (intensification) through technological partnerships, replanting smallholder oil palm plantations, and landscape-based peat ecosystem restoration to prevent further degradation of natural forests in the future.

Identification and Valuation of Forest Ecosystem Services Compared to Oil Palm Plantations in Riau Province

Natural forests and oil palm plantations have distinct economic and ecological benefits. Forests provide ecosystem services, such as carbon storage, water regulation, soil protection, and habitat maintenance, while oil palm plantations primarily generate commodities, create jobs, and generate regional economic activity. This distinction is important to examine in Riau Province, which boasts extensive oil palm plantations, forest and peatland areas (Aulia et al., 2020).

Therefore, this study uses a Total Economic Value (TEV) approach to identify the direct, indirect, optional, and existing use values of both land uses. The assessment was conducted using the benefit transfer method, adapting the results of previous studies based on land area and the 2022 exchange rate.

1. Identification of Forest Ecosystem Services and Oil Palm Plantations

Ecosystem services are grouped into four categories: provisioning services, regulating services, supporting services or habitats, and cultural services (de Groot et al., 2012). This grouping is used to explain the benefits of forests and oil palms and to examine the differences in their functions. A summary is presented in Table 1, then broken down by category.

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Table 2. Comparison of forest ecosystem services and oil palm plantations

Service categories	Forest	Oil palm plantation
Provision	Timber and non-timber forest products (honey, rattan, fruit, medicinal plants), genetic resources, water supply	Fresh fruit bunches (FFB) are processed into crude palm oil (CPO) and its derivatives
Arrangement	Carbon storage, water flow regulation, erosion control, flood risk reduction	Vegetation still absorbs carbon, but its regulatory function is not automatically equivalent to that of forests.
Habitat/support	Layered vegetation as a living space for flora and fauna, including Sumatran elephants and tigers.	Simple habitat structure; fragmentation can trigger human–animal conflict
Cultural	Landscape beauty, education and research, recreation, local knowledge	Employment, business opportunities and household income

Source: Author's synthesis based on Aulia et al. (2020) and de Groot et al. (2012).

a. Provisioning Services

Provisioning services include goods that humans can harvest from ecosystems. Riau's forests produce timber and non-timber products such as honey, rattan, fruit, medicinal plants, and genetic resources, and contribute to maintaining water availability for communities and economic activities. These benefits support the daily needs and livelihoods of residents living near forest areas.

Oil palm plantations produce fresh fruit bunches (FFB) that are processed into crude palm oil (CPO) and derivative products, which serve as raw materials for many industries. According to data from the Plantation Service, Riau's oil palm area in 2022 reached 1,732,748 hectares, or 19.6% of the province's total area. Palm oil excels in this service category because its results are directly reflected in commodity prices, while most forest services are not traded.

b. Regulatory Services

Regulating services relate to an ecosystem's ability to maintain natural processes and maintain environmental balance. Forests absorb and store carbon, regulate water flow, retain soil moisture, reduce erosion, and mitigate flooding risks. This function is

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crucial for Riau because its tropical forest and peatland ecosystems are highly sensitive to changes in land use.

Relatively natural vegetation and soil cover help rainwater infiltrate and store it. When forests are cleared, especially when accompanied by peat drainage or changes in soil structure, this regulating capacity can be reduced, potentially increasing carbon emissions, surface runoff, erosion, and water management disruptions. Oil palm plantations continue to cover the land and sequester carbon as they grow. However, a uniform stand differs from the diverse structure of natural forests, so their carbon storage, water regulation, and soil protection capabilities cannot be readily assumed. Aulia et al. (2020) note that oil palm plantations can retain some of these functions when planted on previously non-forest or peatland, so previous land use determines the extent of loss.

c. Supporting Services or Habitat

Supporting services include ecological processes that maintain ecosystem function, such as soil formation, nutrient cycling, plant regeneration, and habitat provision. Riau's natural forests boast layered vegetation that is home to a diverse range of flora and fauna, including protected species like elephants and Sumatran tigers.

The diversity of forest structures provides shelter, food, and breeding space. In contrast, oil palm plantations dominated by a single plant species tend to have simpler habitats, limiting wildlife's food choices and living space. When plantation clearing disrupts connected forest areas, habitat fragmentation increases and human-wildlife conflict can escalate.

d. Cultural Services

Cultural services are the non-material benefits that communities receive from an ecosystem. Forests can be valuable as beautiful landscapes, educational and research sites, recreational spaces, sources of local traditions and knowledge, and even as part of a community's social identity.

Oil palm plantations also provide social benefits in the form of employment, business opportunities, and additional household income. The nature of these benefits differs from the cultural services provided by forests. Uniform plantation landscapes generally do not offer the diversity of natural experiences and habitats that forests offer.

2. Condition of Forest Cover and Oil Palm Plantations in Riau Province

A land use overview is necessary to ground discussions of ecosystem services in regional contexts. A land cover summary shows that in 2022, Riau's forest cover was 2,577,000 hectares, and non-forest cover was 6,264,400 hectares, out of a total area of 8,841,400 hectares. Thus, forest cover comprised approximately 29.1% of the total area, and non-forest cover approximately 70.9% (Table 3).

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Table 3. Land closure in Riau Province, 2022

Category	Area (thousand ha)	Percentage
Forest cover	2,577.0	29.1
Non-forest cover	6,264.4	70.9
Amount	**8,841.4**	**100.0**

Source: Processed from the 2023 Indonesian Land Cover Recalculation Book, Ministry of Environment and Forestry.

In terms of forestry status, Riau's forest area in 2022 was 5,352,503 hectares, approximately 60.5% of the province's total area. The breakdown is as follows: 229,776 hectares of protected forest, 630,623 hectares of nature reserves and conservation areas, 1,013,165 hectares of limited production forest, 2,329,904 hectares of permanent production forest, and 1,149,035 hectares of convertible production forest (Table 4). Protected and conservation areas account for only 16.1% of the total, while production forests account for 83.9%.

Table 4. Forest areas of Riau Province by function, 2022

Area function	Area (ha)	Percentage
Protected forest	229,776	4.3
Nature reserves and nature conservation	630,623	11.8
Limited production forest	1,013,165	18.9
Permanent production forest	2,329,904	43.5
Convertible production forest	1,149,035	21.5
Amount	**5,352,503**	**100.0**

Source: Processed from data from the Riau Province Environment and Forestry Service.

Forest area data based on forestry function must be distinguished from forest cover data, which indicates the physical condition of the land. In 2022, Riau's forest cover reached 2.58 million hectares, equivalent to 48.1% of the total forest area of 5.35 million hectares. Meanwhile, convertible production forests covered 21.5% of the forest area and are one of the areas subject to land conversion pressure. Oil palm plantations covered

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1,732,748 hectares, but this area does not necessarily reflect the extent of converted forest.

Land use pressures also vary between regions. Pelalawan has the largest forest area, while Kampar has the largest oil palm area. The highest ratio of oil palm area to forest area is found in Kuantan Singingi (69.3%) and Rokan Hulu (68.8%). Meanwhile, Indragiri Hilir and Rokan Hilir have a low proportion of protected and conservation areas and relatively large areas of converted production forest, making them more vulnerable to land conversion pressures.

Table 5. Forest areas and oil palm areas by district/city, 2022

Regency/city	Forest area (ha)	Protect + conservation (%)	Conversion production forest (%)	Oil palm (ha)	Oil palm/forest area (%)
Kuantan Singingi	319,575	29.8	23.7	221,520	69.3
Indragiri Hulu	532,814	32.5	29.6	69,292	13.0
Indragiri Hilir	693,380	5.7	39.6	109,839	15.8
Pelalawan	872,641	15.4	7.9	188,194	21.6
Siak	415,800	17.7	2.7	208,075	50.0
Kampar	548,201	28.8	23.2	279,720	51.0
Rokan Hulu	393,646	18.5	35.0	270,886	68.8
Bengkalis	604,770	13.7	11.3	133,798	22.1
Rokan Hilir	552,279	3.5	26.8	195,204	35.3
Meranti Islands	259,756	3.0	22.9	0	0.0
Pekanbaru	4,196	17.3	38.5	17,418	—*
Dumai	155,445	2.3	12.1	38,804	25.0
Riau Province	**5,352,503**	**16.1**	**21.5**	**1,732,748**	**32.4**

Source: Processed from data from the Environment and Forestry Service and the Plantation Service of Riau Province.

Two data points need to be addressed. The Meranti Islands are listed as having no oil palm areas in all years on file, and Kuantan Singingi's oil palm area increased from 94,116 hectares (2021) to 221,520 hectares (2022); both need to be verified with the source agency. The provincial oil palm area series for other years also do not align with

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the district/city figures (e.g., 2021: 2.71 million hectares versus 1.61 million hectares), so the discussion is limited to 2022, the year when the provincial figures (1,732,748 hectares) and the district/city figures (1,732,750 hectares) align.

Overall, Riau needs to manage plantation activities and maintain the function of forest areas simultaneously. Land use policies must consider both the economic contribution of plantations and the ecological benefits of forests for environmental quality and community life.

3. Economic Valuation of Forest Ecosystem Services and Oil Palm Plantations

Economic valuation is used to estimate the utility value of an ecosystem. The TEV framework encompasses direct use value, indirect use value, option value, and existence value, so ecosystem value extends beyond traded goods to include the benefits received by communities through ecological processes.

For comparison, de Groot et al. (2012) reported an average TEV of USD 5,264 per hectare per year for tropical forests. Aulia et al. (2020), who studied oil palm-dominated landscapes in four smallholder villages in Riau, involving 62 households, obtained a TEV of USD 6,520 per hectare per year. Both figures come from studies with different scopes and methods, and are therefore used as indicative comparisons, not paired measurements at the same location. To express the value in rupiah, the 2022 average middle exchange rate of IDR 14,849.85 per USD was used; this exchange rate should be cited along with its official source in the bibliography.

a. Estimation of the Total Economic Value of Tropical Forests
TEV of tropical forests = USD 5,264 × Rp14,849.85
= Rp. 78,169,610.40 per hectare per year
Thus, the TEV of tropical forests is around IDR 78.17 million per hectare per year.

b. Estimation of the Total Economic Value of the Oil Palm Plantation Landscape
TEV of oil palm landscape = USD 6,520 × Rp14,849.85
= Rp96,821,022.00 per hectare per year

Thus, the TEV of oil palm landscapes is approximately IDR 96.82 million per hectare per year, or IDR 18.65 million higher than that of tropical forests. This difference does not necessarily mean that oil palm is ecologically superior. TEV is influenced by the calculated components, location characteristics, valuation methods, and socio-economic conditions of the study area. Therefore, interpretation must consider the composition of the value, not just the total.

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Table 6. Economic value per hectare per year

Component	Forest (USD)	Forest (Rp million)	Palm Oil (USD)	Palm oil (Rp million)
Total economic value (TEV)	5.264	78,17	6.520	96,82
Provision services	1.828	27,15	4.331	64,31
Difference between TEV and provision services	3.436	51,02	2.189	32,51

Source: Calculations by the author based on Aulia et al. (2020), de Groot et al. (2012), and the 2022 average exchange rate (Rp14,849.85 per USD).

The value of tropical forest provision services reaches around Rp27.15 million per hectare, lower than the oil palm landscape at Rp64.31 million due to the dominance of market commodity yields. However, the non-provision benefits of the forest reach Rp51.02 million, while for oil palm it's Rp32.51 million. Thus, 65.3% of the forest's economic value comes from non-provision services, whereas for oil palm it's only 33.6%. This shows that most of the forest's benefits are not reflected in market transactions, so they risk being overlooked in decision-making. To estimate the value on a provincial scale, the per-hectare value is multiplied by the land area in 2022, assuming the average value applies uniformly across the entire region.

Table 7. Estimated annual aggregate value, 2022 (Rp trillion)

Land type	Area (ha)	TEV	Provisioning	Non-provisioning
Forest cover	2.577.000	201,44	69,95	131,49
Oil palm area	1.732.748	167,77	111,44	56,33

Source: Author's calculations. The two areas do not exclude other uses and are not summed to a provincial total.

Even though the TEV per hectare of oil palm is higher, the aggregate TEV of forest cover (Rp201.44 trillion per year) is bigger than that of oil palm (Rp167.77 trillion) because of the larger forest area. For the non-provisioning components, the gap is even wider: Rp131.49 trillion for forests compared to Rp56.33 trillion for oil palm.

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4. Economic Depreciation of Ecosystem Services Due to Land Use Change

Economic depreciation occurs when forest conversion reduces the value of natural assets and the ecological benefits they can provide in the future. Based on estimates from 2022, the difference in non-provisioning benefits between tropical forests and palm oil landscapes reaches IDR 18.52 million per hectare per year. Although palm oil provisioning services increased by IDR 37.17 million, this increase does not fully offset the loss of non-provisioning benefits. This depreciation value is based on differences in study estimates, not the actual definite loss due to forest conversion in Riau. The calculation scenario based on various land conversion areas is used only to illustrate potential scale, not as a precise forecast.

Table 8. Hypothetical scenarios of forest conversion to palm oil landscapes (IDR trillion per year)

	Additional provisioning	Loss of non-provisioning	Net change
10.000	+0,37	−0,19	+0,19
100.000	+3,72	−1,85	+1,87
500.000	+18,58	−9,26	+9,33

Source: Author's calculations. The positive net change is a consequence of the nature of the source TEV data, not a recommendation for land-use change.

Forest conversion has the potential to reduce ecological benefits, such as carbon storage, water regulation, erosion control, and habitat provision. On peatlands, hydrological changes also increase the risk of fire and carbon emissions, which can incur environmental costs and socioeconomic losses. Although oil palm plantations generate higher provisioning values, these values represent production values, not net profit after costs. Meanwhile, the loss of environmental services has long-term impacts and can be borne by the wider community. Therefore, the difference in non-provisioning values only indicates the potential reduction in ecological benefits, not the final loss figure. More accurate estimates require data on land-use change at the same location and consistent valuation methods.

5. Implications for Sustainable Palm Oil Plantation Management in Riau

Natural resource management in Riau requires balancing the economic interests of oil palm plantations with environmental protection. Production increases should be achieved through intensification of existing plantations, without expanding plantations

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into forest areas (Sharma et al., 2019). Furthermore, forest and peatland protection, spatial planning oversight, and restoration of damaged ecosystems need to be strengthened, particularly in areas with limited protected areas. Local governments also need to integrate the value of ecosystem services and the costs of externalities into development planning. Implementing sustainable plantation practices, such as erosion control, riparian protection, waste management, and fire prevention, is crucial to maintaining oil palm productivity without compromising environmental carrying capacity.

Estimation of Economic Depreciation of Ecosystem Services Post-Land Conversion

1. Conceptual basis

This subsection treats forests as natural assets whose value depreciates as their land is converted to other uses, much like man-made capital goods that depreciate in the national accounts. This idea stems from a study by Repetto et al. (1989), which showed that national income is over-represented if the depletion of natural resources is not recorded as a deduction. The SEEA Ecosystem Accounting Framework (United Nations et al., 2021) subsequently provides standard guidelines for recording the extent, condition, and services of ecosystems as a basis for monetary valuation. In this study, depreciation is defined as the value of the annual flow of ecosystem services lost due to reduced forest cover.

2. Estimation method

The assessment used value transfer, borrowing per-hectare values from global syntheses. De Groot et al. (2012) compiled 96 estimates for tropical forests and obtained an average value of the ecosystem services package of US$5,264 per hectare per year at 2007 prices. Costanza et al. (2014) updated the global estimates and found that the value of tropical forests increased from US$2,769 (1997 estimate) to US$5,382 per hectare per year (2007 prices). The de Groot et al. value was used as the main scenario, while the two Costanza et al. values served as sensitivities. Riau's forest area was taken from the 2023 Indonesian Land Cover Recalculation (Ministry of Environment and Forestry [KLHK], 2023). The status of forest areas by function and the area of oil palm plantations in Riau were sourced from the Riau Provincial Environment and Forestry Service (2026) and the Riau Provincial Plantation Service (2026). Depreciation in year t is calculated using the following equation.

$$D_t = \max(0, F_{t-1} - F_t) \times V \quad (3.1)$$

Where D is depreciation (in international dollars per year), F is forest cover area (ha), and V is the value of tropical forest ecosystem services per hectare per year. Only

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decreases in area are counted as depreciation. Increases in area are not credited as appreciation, because regeneration or changes in classification do not necessarily restore ecosystem services equivalent to those of natural forests.

3. Estimated results of Riau's depreciation in 2022

According to Ministry of Environment and Forestry data, Riau's forest cover decreased from 2,580.9 thousand hectares in 2021 to 2,577.0 thousand hectares in 2022, a decrease of 3.9 thousand hectares (3,900 hectares). Using Equation 3.1 and V = 5.264, the depreciation of Riau's ecosystem services in 2022 is 3,900 × 5,264 = 20,529,600 international dollars, or approximately 20.5 million rupiah per year. This value is current: as long as the land is not restored, the same losses will recur annually.

Table 9. Calculation of depreciation of Riau ecosystem services, 2022

Component	Mark
Forest cover area 2021 (thousand ha)	2,580.9
Forest cover area 2022 (thousand ha)	2,577.0
2022 Depreciation (thousand ha)	3.9 (= 3,900 ha)
Main scenario: 3,900 × 5,264 international dollars	20,529,600 (≈ 20.5 million)
Sensitivity: 3,900 × 5,382 US dollars	20,989,800 (≈ 21.0 million)
Sensitivity: 3,900 × 2,769 US dollars	10,799,100 (≈ 10.8 million)

Area data source: KLHK (2023); value per hectare: de Groot et al. (2012) and Costanza et al. (2014), 2007 prices. Calculation: author.

Forest area data provides a more complete picture. Riau's forest area remained virtually unchanged from 2021 to 2022 (from 5,352,502 to 5,352,503 hectares, a difference of 1 hectare), and there were no changes in the functions of protected forests, limited production forests, permanent production forests, or convertible production forests (Table 10). This means that the 2022 depreciation did not stem from the relinquishment of forest status, but rather from the physical loss of forest cover.

Table 10. Riau forest area by function, 2021–2022 (ha)

Area function	2021	2022	Difference
Protected forest	229,776	229,776	0

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Area function	2021	2022	Difference
Nature Reserves and Conservation	630,622	630,623	+1
Limited Production Forest	1,013,165	1,013,165	0
Permanent Production Forest	2,329,904	2,329,904	0
Convertible Production Forest	1,149,035	1,149,035	0
Amount	**5,352,502**	**5,352,503**	**+1**

Source: Riau Province Environment and Forestry Service (2026).

There are two important issues related to data validity and the risk of land conversion in Riau. First, forest cover in 2022, at 2,577,000 hectares, represents only 48.1% of the total forest area of 5,352,500 hectares. Meanwhile, convertible production forests cover 1,149,035 hectares, or 21.5% of the forest area, and are potentially subject to land conversion.

Second, data on oil palm plantation area from 2018–2022 shows inconsistencies, including a 36.1% decrease in 2022, which does not necessarily reflect a real reduction in plantations. Therefore, this data was not used to calculate conversion and needs to be verified through the Plantation Service or the Statistics Indonesia (BPS). Forest area data from 2020 was also not used because the recorded area did not correspond to the total area of Riau Province.

4. Dynamics 2014–2023 as a comparison

To put the 2022 figures into context, the equation in Table 9 is applied to the entire period 2014–2023 (Table 11). Riau's forest area was recorded at 2,562.3 thousand hectares in 2014 (28.85% of the 8,882.8 thousand hectares) and 2,561.9 thousand hectares in 2023 (28.94% of the 8,851.8 thousand hectares). The net difference is only -0.4 thousand hectares, equivalent to a loss of approximately 2.11 million international dollars per year. In gross terms, six of the nine annual changes were negative, totaling 673.2 thousand hectares, or 673,200 × 5,264 = 3,543.7 million international dollars (approximately 3.54 billion); the average is 74.8 thousand hectares or 393.7 million per year. With a value of 5,382 the total gross becomes 3,623.2 million US dollars, and with 2,769 it becomes 1,864.1 million US dollars.

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Table 11. Riau forest area and ecosystem service depreciation, 2014–2023

Year	Forest area (thousand ha)	Change (thousand ha)	Gross depreciation (thousand ha)	Depreciation (millions of international dollars)
2014	2,562.3	–	–	–
2015	2,350.0	−212.3	212.3	1,117.5
2016	2,617.6	+267.6	0	0
2017	2,304.3	−313.3	313.3	1,649.2
2018	2,260.5	−43.8	43.8	230.6
2019	2,459.2	+198.7	0	0
2020	2,665.7	+206.5	0	0
2021	2,580.9	−84.8	84.8	446.4
2022	2,577.0	−3.9	3.9	20.5
2023	2,561.9	−15.1	15.1	79.5
Total	**−0.4 (net)**	**−0.4**	**673.2**	**3,543.7**

Source: KLHK (2023); author's calculation with V = 5,264 international dollars per ha per year.

Compared to other years, depreciation in 2022 was relatively small. The largest depreciation occurred in 2017 (-313.3 thousand ha; 1,649.2 million hectares) and 2015 (-212.3 thousand ha; 1,117.5 million hectares), which together accounted for 78% of the total gross depreciation, while the 2022 figure was only about 0.6% of that total.

5. Interpretation and limitations

The three increases in area (2016, 2019, and 2020) totaled 672.8 thousand hectares and almost exactly offset the total decline, which is why the net figure is close to zero. This increase should be read with caution. Adrianto et al. (2020) noted that secondary forests constitute approximately 87% of the remaining natural forest in Riau (primary forests less than 13%), and the dominant conversion pathway is from secondary peat swamp forest to shrubland and then plantations. Therefore, recovery of cover does not necessarily translate into a recovery of ecosystem services. Therefore, the gross figure is more appropriate as a reflection of conversion pressure, and the net figure serves as a lower limit. For studies of DBH SDA and IKLH in Riau, this depreciation value can

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serve as a monetary benchmark for ecological losses when compared to revenue sharing funds.

Limitations of the estimates include: (1) the value per hectare is a global average, not the result of a field study in Riau; (2) prices are still from 2007 and have not been adjusted for inflation until 2022, while conversion to rupiah must use purchasing power parity factors, not market exchange rates (de Groot et al., 2012); (3) the economic benefits of new land, such as plantation yields, have not been deducted; and (4) fluctuations in forest area between years in the KLHK data may partly stem from differences in image interpretation.

Implications for Sustainable Palm Oil Plantation Management

1. Implications for Sustainable Palm Oil Plantation Management

The estimates in the previous sub-chapter demonstrate two points that must be read together. First, the value of provisioning services in oil palm landscapes exceeds the value of forest provisioning, making the total economic value of oil palm landscapes appear higher. Second, the value of regulating, habitat, and cultural services not traded in the market is lower after conversion. This difference represents a loss borne by the wider community, not the plantation owners. Aulia et al. (2020) themselves note that the provisioning value in their study did not deduct input and variable costs, so the superior value of oil palm tends to be overestimated. The policy issue, therefore, lies not in the existence or absence of value generated by oil palm, but rather in how to achieve that value without increasing the loss of ecosystem services.

The following three implications are drawn from this logic: increasing yields per hectare without increasing conversion area, maintaining remaining forests and peat as sources of non-market services, and changing regional fiscal incentives so that losses of ecosystem services are included in decisions.

2. Sustainable Intensification

Clearing new land benefits the perpetrator because the full value of the provision of the land is received by the owner, while the loss of regulating services and habitat is not included in the calculation of profits. In the framework of Tietenberg and Lewis (2012, pp. 25–26), this situation is a negative externality: the social costs are greater than the costs borne by the producer, so that decisions that follow only private costs result in expansion beyond the socially efficient level. In forestry, a similar pattern is seen when the value of the remaining forest is outside the consideration of the perpetrator of logging (Tietenberg & Lewis, 2012, pp. 301–303).

Sharma et al. (2019) compared three oil palm expansion scenarios in West Kalimantan for the period 2017–2035: business as usual (BAU), conservation, and

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sustainable intensification. In the intensification scenario, expansion occurs only on land deemed suitable, with superior cultivars and intensive management increasing yields from an average of 3.8 to 5.1 tons of crude palm oil (CPO) per hectare per year, or approximately 34%. Compared to current land use, the total present value of the economic value of ecosystem services at a 3.5% discount rate decreases by US$317 billion in the BAU scenario, US$31 billion in the intensification scenario, and US$15 billion in the conservation scenario (Table 12). Losses in the intensification scenario are only about one-tenth of the losses in the BAU scenario, and this comparison holds at discount rates of 5%, 10%, and 15%.

Table 12. Present Value of Total Economic Value of Ecosystem Services by Scenario, 2017–2035

Discount rate	Current land use	SMELL	Conservation	Sustainable intensification
3.5%	2,223	1,906 (−317)	2.208 (−15)	2.192 (−31)
5%	1,960	1,680 (−280)	1,946 (−13)	1,932 (−27)
10%	1,356	1.163 (−194)	1,347 (−9)	1,337 (−19)
15%	1,005	862 (−143)	998 (−7)	991 (−14)

Note. Values are in billions of US dollars. Figures in parentheses are the difference from current land use. BAU = business as usual. Study area: West Kalimantan. Adapted from Sharma et al. (2019, Table 7).

Sharma et al. (2019) showed that conservation provides the highest ecosystem service value, while intensification is a compromise because it still allows expansion on appropriate land at the expense of habitat degradation. However, these results are from West Kalimantan and have not been validated, so they are only used as a conceptual reference, not as figures for Riau.

In Riau, intensification through rejuvenation of old plantations, use of high-quality seeds, and improved maintenance can increase productivity without increasing pressure on forests and peatlands. The feasibility of this approach depends on the age and productivity of existing plantations, data for which needs to be verified through the latest plantation statistics. This approach does not imply that oil palm always has a lower economic value than forests, but rather emphasizes that intensification can increase production benefits without further depreciating ecosystem services, unlike extensification through forest and peat clearing.

Yani (2020) strengthens this argument through the concept of forest insurance value. In a 25-year analysis in Melawi Regency, a feasibility index (Ky) of -6.4401 indicates that the damage from converting 10,000 hectares of forest is valued at 6.4401

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times greater than the benefits of maintaining the forest. While not directly applicable to Riau, this finding demonstrates the importance of considering the long-term benefits of ecosystem protection. If plantation expansion remains necessary, priority can be given to cleared non-forest lands, such as areas for other uses (APL), agricultural land, and shrubland.

3. Protection of High Carbon Value (HCS) and High Conservation Value (HCV) Areas

Oil palm plantation intensification must be accompanied by protection of remaining forests and peatlands by designating areas that cannot be converted. Sharma et al. (2019) showed that a conservation scenario that protects forests, peatlands, and high conservation value (HCV) and high carbon stock (HCS) areas resulted in the smallest decrease in ecosystem service value, at US$15 billion, compared to US$317 billion in the BAU scenario. The importance of this protection is also evident in the dominance of regulating services in the economic value of tropical forests, which account for approximately 48% of the total economic value, primarily through their climate regulation function (de Groot et al., 2012). Meanwhile, Aulia et al. (2020) showed that the carbon storage value of oil palm landscapes in Riau is much lower. The findings of Sari et al. (2022) further reinforce the importance of forest ecological functions, which contribute 58.96% of the total economic value of the studied forest areas.

Forest protection is also crucial because climate and habitat services have limited capacity to be replaced by artificial capital. According to Hartwick's sustainability concept, the decline in natural capital cannot always be offset by investment in artificial capital (Tietenberg & Lewis, 2012). Furthermore, forest conversion eliminates option value, the potential benefits from future resource utilization. In Riau, forest cover in 2022 will only be 2,577,000 hectares, or 29.15% of the land area. Therefore, protection needs to be achieved through three steps: using HCV and HCS maps as the basis for land planning and permitting, considering compensation mechanisms for land rights holders who bear conservation costs, and conducting regular land cover monitoring. Therefore, oil palm intensification should be directed towards increasing the productivity of existing land, not as an excuse to expand forest and peatland conversion.

4. Integration of Environmental Valuation in Regional Fiscal Policy

Forest protection and palm oil intensification require fiscal policy support to ensure that the costs of environmental damage are factored into regional development. Tietenberg and Lewis (2012) explain that fiscal policies that ignore the depreciation of natural capital can encourage socially inefficient forest conversion. Therefore, estimates of ecosystem service depreciation can be used as shadow prices to compare policy

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alternatives, rather than as fixed rates, given differences in ecological conditions and the limitations of benefit transfer methods.

One instrument that can be utilized is the Palm Oil Plantation Revenue Sharing Fund (DBH) based on Minister of Finance Regulation Number 91 of 2023. This study proposes three uses: allocating a portion of the funds for peat restoration and protection of HCV/HCS areas, including ecological performance as an indicator for inter-district fund distribution, and including ecosystem service depreciation in regional planning and budgeting documents. Carbon credit and REDD schemes can also be complementary instruments by assigning a financial value to retained carbon, with adequate baseline, monitoring, and verification requirements.

Overall, the sustainability of oil palm plantations in Riau requires integrated intensification, protection of high-ecological-value areas, and reform of fiscal incentives. All three aim to reduce pressure on forests while maintaining natural capital stocks. However, policy implementation must consider the limitations of estimates, particularly the use of benefit transfers, differences in price units and years, and the lack of provincial-level palm oil value-added data to measure the balance between economic income and ecosystem service depreciation. Therefore, research findings are more appropriate as a basis for policy direction than for determining definitive compensation values.

Table 13. Summary of Implications for Sustainable Oil Palm Plantation Management

Implications	The basis of this research	Proposed instrument
Sustainable intensification	The value loss in the intensification scenario is about one-tenth of the BAU scenario (Sharma et al., 2019); Ky = −6.4401 for a 10,000 ha conversion in Melawi (Yani, 2020)	Rejuvenation with superior seeds; improved maintenance; expansion, if necessary, only on non-forest land
Protection of HCS and HCV areas	Regulating services account for approximately 48% of the value of tropical forests (de Groot et al., 2012); carbon storage in oil palm landscapes is USD 147/ha/year (Aulia et al., 2020); conservation scenario -US$15 billion vs -US$317 billion in BAU (Sharma et al., 2019)	HCV and HCS maps as planning references; restrictions on forest and peat conversion; cost sharing for land rights holders
Integration of valuation in	Externalities and perverse incentives (Tietenberg & Lewis, 2012); DBH Palm Oil Plantations as transfers to regions	A portion of DBH for ecosystem services; ecological performance

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regional fiscal policy	(Ministry of Finance of the Republic of Indonesia, 2023)	indicators in fund distribution; depreciation reporting in planning documents

CONCLUSION

This research shows that land cover change is a critical issue in natural resource management in Riau Province. In 2022, forest cover was recorded at 2,577,000 hectares, or approximately 29.15% of the land area, while non-forest cover reached 70.85%. The area of oil palm plantations in the same year was recorded at 1,732,748 hectares. While these figures demonstrate the significant role of oil palm in Riau's land use, the area of oil palm conversion cannot be directly equated with the area of converted forest because the origin and history of land use cannot be ascertained from available aggregate data.

A comparison of total economic values shows that the estimated TEV per hectare of oil palm plantation landscapes (approximately IDR 96.82 million per hectare per year) is higher than that of tropical forests (approximately IDR 78.17 million per hectare per year). However, this difference is primarily influenced by the substantial value of oil palm provisioning services reflected in commodity yields. In contrast, forests have a greater proportion of non-provisioning benefits, such as regulating services, habitat, and cultural benefits. Because both values are derived from studies with different locations, scopes, and methods, the results of this comparison are indicative and should not be interpreted as evidence that oil palm is ecologically superior.

Depreciation estimates based on changes in forest cover indicate a decrease of 3,900 hectares in 2022, from 2,580.9 thousand hectares in 2021 to 2,577.0 thousand hectares in 2022. With a reference value of 5,264 international dollars per hectare per year, the depreciation of ecosystem services is estimated to reach 20.53 million international dollars per year. In the 2014–2023 period, the accumulated gross depreciation of forest cover was recorded at 673.2 thousand hectares. This figure reflects the pressure of forest cover loss, but not all of it can be attributed to conversion to oil palm plantations. Annual area changes also need to be interpreted cautiously as they can be influenced by differences in image interpretation and land cover classification.

Based on these results, oil palm plantation management in Riau needs to be directed at increasing the productivity of existing plantations, protecting forest areas and peat ecosystems, and utilizing ecosystem service valuation in regional planning and fiscal policy. This way, the economic benefits of the palm oil sector can be achieved without ignoring the environmental costs borne by the community. The estimates in this study are still indicative because they use the benefit transfer method and are not supported by paired spatial data on forest conversion to oil palm. Future research should use land

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cover change data at the same location and time period, as well as ecosystem service values that are more appropriate to Riau's local conditions.

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