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Valuing mangrove ecosystem services in Dumai, Indonesia, for conservation and policy

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Abstract. *Insusanty E, Mulyadi A, Efriyeldi, Warningsih T. 2025. Valuing mangrove ecosystem services in Dumai, Indonesia, for conservation and policy. Asian J For 9: 428-439.* Mangrove ecosystems deliver diverse services that are vital for ecological stability and human well-being, encompassing provisioning, regulating, supporting, and cultural functions. Despite their importance, the economic value of these ecosystems is often undervalued, leading to inadequate conservation efforts. This study estimates the Total Economic Value (TEV) of mangrove ecosystem services in Dumai City, Indonesia, by applying a combination of valuation approaches: market price (effect on production), benefit transfer, individual travel cost, and contingent valuation methods. The estimated TEV of mangrove ecosystem services is approximately Rp 110.95 billion annually. Regulating services contribute the largest share (49.25%), primarily from carbon sequestration, coastal protection, and seawater intrusion control. Provisioning services account for 40.19%, mainly from fisheries and firewood, while supporting services (3.15%) and cultural services (7.41%) provide additional ecological and socio-cultural benefits. These results demonstrate that mangroves play a critical role in sustaining livelihoods and maintaining ecological balance in Dumai. Recognizing their substantial economic value can strengthen evidence-based coastal management, promote the implementation of Payment for Ecosystem Services (PES), and support long-term conservation policies that balance ecological integrity with socio-economic development.

Keywords: Dumai City, economic valuation, ecosystem services, mangrove ecosystem

INTRODUCTION

Indonesia, the world's largest archipelagic nation, possesses one of the most extensive mangrove ecosystems globally, distributed along its vast coastlines (Marlianingrum et al. 2019). Among its provinces, Riau hosts significant mangrove coverage, with dense stands covering 97.21% of the total 226,109 hectares recorded in 2021 (Direktorat Konservasi Tanah dan Air 2021). Mangroves provide vital ecological benefits by storing substantial amounts of carbon, stabilizing coastlines, preventing seawater intrusion, and serving as natural barriers that can reduce tsunami wave energy by up to 60%. They also function as critical habitats for breeding and nursery grounds of various marine organisms and support planktonic food webs that sustain coastal fisheries (Eddy et al. 2021).

Despite their high ecological value, public understanding and appreciation of mangrove benefits remain limited (Marlianingrum et al. 2021). Low awareness has contributed to excessive exploitation and land conversion for unsustainable activities, reducing mangrove cover and degrading ecosystem functions. This situation underscores the urgent need for approaches that can make the ecological and economic contributions of mangroves more visible and quantifiable.

Economic valuation of ecosystem services offers a systematic approach to quantify the direct and indirect benefits provided by natural ecosystems. By translating ecological functions into measurable economic terms, valuation provides critical evidence to support policy formulation, sustainable management strategies, and conservation investment (Agustriani et al. 2023). According to established frameworks such as the Millennium Ecosystem Assessment (MEA 2005) and The Economics of Ecosystems and Biodiversity (TEEB 2010), ecosystem services are classified into four categories: provisioning, regulating, cultural, and supporting services (De Groot et al. 2002; Costanza et al. 2011). However, many mangrove ecosystem services remain unpriced because they lack formal market mechanisms, leading to their underrepresentation in policy and development decisions (Hernández et al. 2021; Bimrah et al. 2022). Assigning economic value to these services is therefore essential to highlight their true contribution to human welfare and to strengthen arguments for conservation (Sofian et al. 2019).

Dumai City, located on the eastern coast of Sumatra within Riau Province, Indonesia, has a mangrove forest distributed across three sub-districts: Sungai Sembilan, Dumai Barat, and Medang Kampai. The city's mangrove ecosystems face significant threats from land conversion, industrial and port development, aquaculture expansion, and oil palm plantations. Between 2000 and 2019, Dumai experienced an estimated loss of 4,131.4 hectares of mangroves due to these pressures (Ilman et al. 2011; Ilman et al. 2016; Richards and Friess 2016; Oktorini et al. 2022). In Dumai Barat and Medang Kampai, industrial activities and infrastructure development are major drivers of mangrove degradation, whereas in Sungai Sembilan, conversion to oil palm plantations and aquaculture are dominant. The extraction of mangrove wood for domestic use and the accumulation of solid waste further exacerbate degradation (Mulyadi and Amin 2016). These land-use changes have led to soil fertility decline, erosion, biodiversity loss, and increased vulnerability to flooding and salinization. The major causes of deforestation include: (i) land-use conversion (e.g., agriculture, shrimp farming, development, and human settlements), (ii) overexploitation (such as grazing, logging, and fishing), (iii) pollution, (iv) decline in freshwater availability, (v) flooding, (vi) reduction in silt deposition, (vii) abrasion, and (viii) disturbances caused by tropical cyclones and tsunamis (Giri et al. 2011).

Although several studies have examined mangrove valuation in nearby regions such as Rokan Hilir (Warningsih et al. 2020) and Bengkalis (Novizantara et al. 2022), no comprehensive economic valuation has been conducted in Dumai City. Considering Dumai's rapid urbanization and industrial development, such research is crucial to assess how mangrove ecosystems contribute to local livelihoods, ecological stability, and coastal protection.

Therefore, this study aims to estimate the Total Economic Value (TEV) of mangrove ecosystem services in Dumai City using multiple valuation approaches, including market price, benefit transfer, travel cost, and contingent valuation methods. By quantifying the economic benefits of mangroves, this study provides a scientific foundation for evidence-based conservation policies, promotes the integration of ecosystem valuation in local development planning, and supports the establishment of Payment for Ecosystem Services (PES) schemes to ensure the long-term sustainability of mangrove ecosystems in Dumai. We hypothesized that regulating services would contribute the largest share to the Total Economic Value (TEV) of mangrove ecosystems in Dumai City due to the high carbon storage potential, coastal protection functions, and freshwater intrusion prevention provided by its remaining mangrove stands, while provisioning services would remain significant because of strong local dependence on fisheries.

MATERIALS AND METHODS

Study area

This research was conducted on the coastal area of Dumai City, Riau Province, Indonesia, covering three sub-districts: Sungai Sembilan, West Dumai, and Medang Kampai (Figure 1). The study area was selected purposively due to its extensive mangrove coverage and increasing anthropogenic pressure from industrial development, aquaculture, and oil palm expansion. Data collection was carried out over eight months, from March to October 2024.

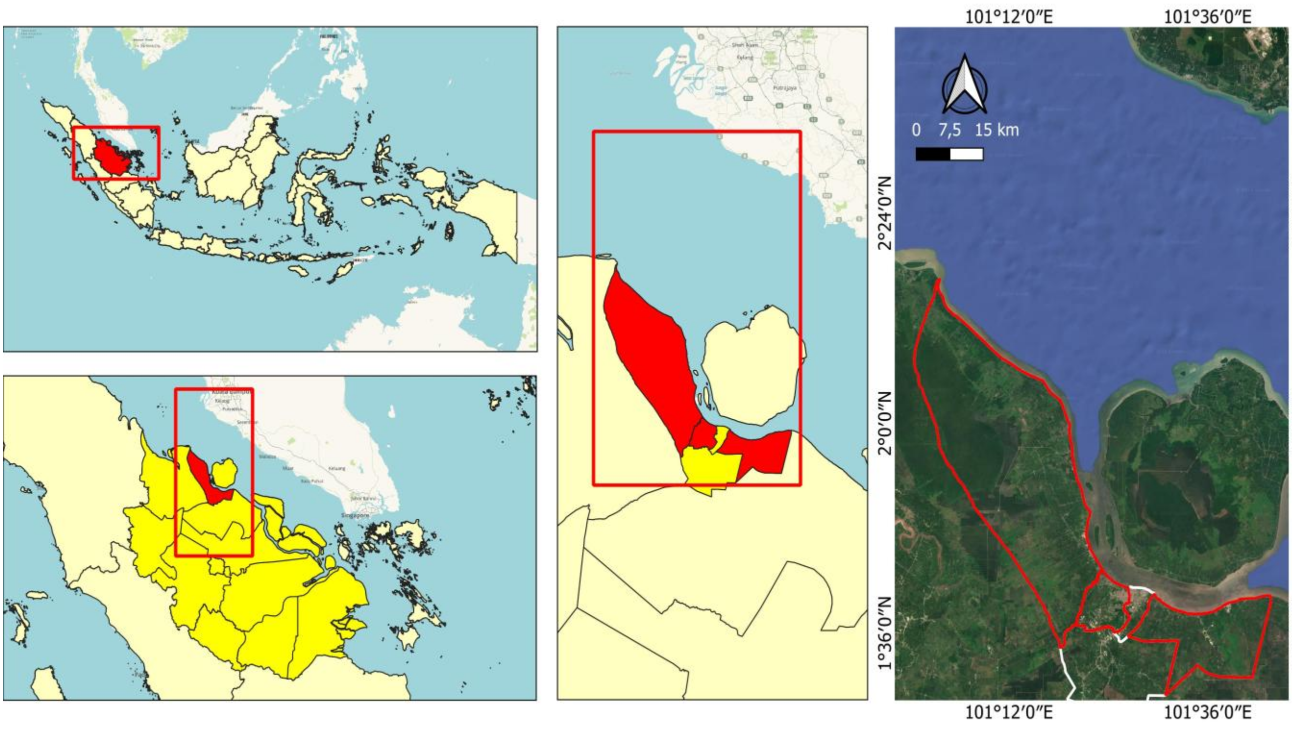

Figure 1. Research location in Dumai City, Riau Province, Indonesia

Sampling method

Primary data were collected through field surveys using structured questionnaires and direct interviews. Respondent selection was adjusted to the type of mangrove ecosystem service being assessed. For provisioning services, a total of 126 fishers (71 fish, 28 shrimp, 10 crabs, 7 langkitang, and 10 firewood collectors) were selected through purposive sampling, as they are directly dependent on mangrove-based fisheries resources. The sample distribution consisted of 49 fishers in Basilam Baru, 41 fishers in Pangkalan Sesai, and 36 fishers in Pelintung.

To estimate recreational and educational values, tourists were selected using accidental sampling by approaching visitors present at the Bandar Bakau eco-edutourism site (Hair et al. 2004). The sample consisted of 68 tourists (40 for recreation and 28 for education), determined using the formula for large populations with a 10% margin of error (Sugiyono 2013). Meanwhile, to assess the existence value through the Willingness to Pay (WTP) approach, random sampling was applied to 99 households in the vicinity of the study area, calculated using the Slovin formula with a 10% error level.

$$n = (Z_{\alpha/2})^{2}(P.Q)/e^{2} = (1.64)^{2}(0.5x0.5)/(0.1)^{2} = (2.6896)(0.25)/(0.01) = \frac{6724}{0.01} = 67.24 \approx 68 \text{ tourism}$$

Where:
n: Sample
Z: Value for a 90% confidence level
P: Estimation of population proportion
Q: Proportion of the population that is not targeted for sampling
e: Margin error

$$n = \frac{N}{1+N\,(e)^{2}} = \frac{7944}{1+7944(0.10)^{2}} = \frac{7.944}{80.44} = 98.75 \approx 99 \text{ head of household}$$

Where:
n: Sample
N: Population
e: Margin error

Thus, respondent selection in each category was tailored to ensure relevance and representativeness based on the specific ecosystem services being analyzed. This mixed sampling design was adopted to ensure that each group of respondents represented the stakeholders most closely linked to specific mangrove ecosystem services.

Tree sampling followed standard forest inventory procedures using nested plots. For each plot, all trees were measured. Biomass was estimated through non-destructive measurements in main plots 10 × 10 m following Kiruba-Sankar et al. (2018). Carbon measurement in mangrove stands was conducted using main plots to record tree diameters (DBH ≥ 5 cm), which served as the basis for estimating above-ground biomass using species-specific allometric equations. To assess the contribution of younger vegetation, side plots were established in the form of 5 m × 5 m sub-plots for saplings (diameter < 5 cm) and 1 m × 1 m sub-plots for seedlings. The combination of main plots and sub-plots provides a more comprehensive and representative estimate of mangrove carbon stocks.

Data analysis

Economic valuation was conducted using the Total Economic Value (TEV) framework (MEA, 2005), which integrates four major categories of ecosystem services:

TEV=PS+RS+SS+CS

Where:
PS: Provisioning services (Rp annually)
RS: Regulating services (Rp annually)
SS: Supporting services (Rp annually)
CS: Cultural services (Rp annually)

Provisioning services

Provisioning services were evaluated using the Effect on Production (EoP) approach (Adrianto 2006), which measures the contribution of mangrove ecosystems to fishery production and household use (fish, crabs, shrimp, snails, and firewood). The annual economic value was estimated by aggregating the net revenue of each commodity. Furthermore, regression analysis was employed to examine the relationship between fishing effort, catch levels, and the proximity of fishing grounds to mangrove areas. Consumer surplus was also calculated to capture the additional welfare benefits received by fishers beyond their actual expenditures.

The stages in carrying out the EOP (Adrianto 2006):

Identification of the utilization function of mangrove ecosystem resources is conducted using the Cobb-Douglas production function, as outlined below

$$Q = \beta_0 + X_1\beta_1 + X_2\beta_2 + X_3\beta_3 \ldots X_n\beta_n$$

Where:
Q: Amount resources requested,
X_1: Price
X_2, X_3, X_n: Social economy consumer characteristics/ household

Transforming the utilization function into its linear form:

$$\ln Q = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \ldots\ldots + \beta n \ln X_n$$

$$\ln Q = (\beta_0 + \beta_2 \ln \bar{X}_2 + \beta_3 \ln \bar{X}_3 + \ldots\ldots + \beta n \ln \bar{X}_n) + \beta_1 \ln X_1$$

$$\ln Q = \beta_1 \ln X_1 + \beta' \text{ or } \ln Q = \beta' + \beta_1 \ln X_1$$

Transform the demand function into the original demand function.

$$Q = \alpha X_1 \beta$$

Estimating total willingness to pay (Economic value of resources)

$$U = \int_0^a f(Q)dQ$$

Where:
U: Utility to resources
a: Limit on the average amount of resources consumed/demanded
f(Q): Demand function

Estimating Consumer Surplus (CS)

CS = U-PQ

$Pt = X_1 \times Q$

Where:
CS: Consumer Surplus (IDR/person/year)
Pt: Price paid
Q: Average amount of resources consumed/demanded
X_1: Price per unit of resource consumed/demanded

Regulating services

Regulating services include carbon sequestration, coastal protection, and seawater intrusion prevention.

Carbon sequestration: The carbon stock was calculated as 47% of total biomass, followed the Indonesian National Standard for mangrove carbon stock assessment (SNI 2011) and converted to CO_2-equivalents using a factor of 3.67 (IPCC 2014). The economic value was obtained by multiplying total carbon storage by the carbon market price of US$5.36 per ton (Carbon Exchange Indonesia 2024).

Tree biomass is calculated using the allometric coefficient values (a and b) for estimating above-ground stand biomass based on tree species, using the following formula:

$B = a \times D^b$

Where:

B: Biomass content

D: Diameter at breast height

a and b: Constants

Coastal Protection: The replacement cost method was used to estimate the cost of constructing man-made structures (e.g., seawalls) equivalent to the protective function of mangroves (Mandela et al. 2020).

$$CAR = \frac{TC-(rxTC)}{EL}$$

Where:

CAR: Construction of Abrasion-Resistant structures (Rp annually)

TC: Total Cost for the construction of abrasion-resistant structures (Rp)

r: Interest rate (%)

EL: Economic Life (years)

Seawater intrusion prevention: The economic value of freshwater maintained by mangroves was calculated using the avoided cost approach, based on the number of households, average freshwater use, and local water prices (Mandela et al. 2020).

$FWV = NH \times TW \times P$

Where:

FWV: Value of fresh water supply (Rp annually)

NH: Number of households

TW: Total water requirement (m^3 annually)

P: Price (Rp/m^3)

Supporting services

Supporting services were represented by biodiversity and habitat value, nutrient providers, and spawning grounds.

Biodiversity and habitat value: Biodiversity and habitat value were estimated using the benefit transfer method. The valuation adopted an average biodiversity and habitat benefit of US$30 per hectare annually, following Johari (2009) and Johari and Sukuryadi (2023). This approach assumes ecological similarity with reference sites in Indonesia, a common practice when direct field-based valuation is not feasible (Suharti et al. 2016; Widiastuti et al. 2016).

$BV = B \times M$

Where:

BV: Biodiversity value (Rp/annually)

B: Estimated value of mangrove ecosystem biodiversity (Rp/ha/annually)

M: Area of mangrove ecosystem (ha)

Nutrient provider value: The nutrient provider value was also assessed using the benefit transfer method, based on estimates reported by Novizantara et al. (2022). This approach assumes that mangrove nutrient cycling functions in the study area exhibit ecological comparability to reference sites in Riau Province, Indonesia, thereby enabling the transfer of unit value estimates.

$NV = NP \times M$

Where:

NV: Nutrient Provider value (Rp/annually)

NP: Estimated value of mangrove ecosystem nutrient provider (Rp/ha/ annually)

M: Area of mangrove ecosystem (ha)

Spawning grounds: The value of mangrove ecosystem services as spawning grounds was estimated using the production function approach. The calculation employed a regression-based model developed by Marlianingrum (2007), which relates mangrove area, fishing effort, and shrimp production:

$h=0.0268EM +1.141E-0.5 E^2$

Where:

H: Production

E: Effort

M: Mangrove forest area (ha)

Cultural services

The cultural services of the mangrove ecosystem consist of recreational, education, and existence values. The recreational value was estimated using the Travel Cost Method (TCM), in which the visitation rate was modeled as a function of travel costs and visitors' socio-economic characteristics. The total recreational value was then calculated by multiplying the consumer surplus per visit by the annual number of visits. Estimating the recreational value use, the Travel Cost Method (TCM).

$V = f(TC, X)$

Where:

V: Number of visits (time/ annually)

X: Socio economic variables of visitors

TC: Total Cost of individual (Rp)

The education value was evaluated as a cultural benefit, reflecting the frequent use of mangrove areas for research and learning activities. The Mangrove Education Value Index (MEVI) was applied to determine the proportion of visits specifically intended for educational purposes by incorporating ecological significance. The integration of TCM and MEVI enabled a more accurate estimation of the mangrove's educational value. The formula applied is as follows:

$$\text{MEVI} = \frac{\sum_{i=1}^{n} S}{n}$$

Where:
MEVI: Education Value Index
S: Respondent's score indicator

The existence values: The existence value of the mangrove ecosystem was assessed using the utilizing the concept of Willingness to Pay (WTP). The formula applied is as follows:

Average WTP = $\sum WTP$/n
Total WTP = Mean WTP x N
Where:
N: Population
n: Sample

Study limitations

Several limitations should be noted. The assumption of ecological homogeneity may overlook spatial variation in mangrove condition and productivity. Constant market prices do not capture temporal and seasonal fluctuations. Despite efforts to avoid double counting, overlaps among ecosystem services may persist. Benefit transfer relies on the assumption of comparable ecological and socio-economic conditions, and fisheries benefits may be overestimated due to variable utilization by local communities. Acknowledging these limitations is essential for transparent interpretation of the valuation results.

RESULTS AND DISCUSSION

Provisioning services

Mangroves provide essential services that have both direct and indirect impacts on local communities. However, the indirect benefits of mangrove ecosystems are often underestimated by the public. Although mangroves provide multiple benefits, many of these do not directly translate into economic gains. Natural ecosystems contribute to human well-being by supplying vital goods and services that sustain quality of life (Wang et al. 2021). The economic value of these benefits can be identified and measured through economic valuation studies. Such valuation is crucial for informing policy decisions related to the management and conservation of natural resources (Martino and Kenter 2023).

Mangrove provisioning services represent the direct benefits that can be utilized by local communities. In the context of the mangrove ecosystem in Dumai City, these services include various non-timber forest products and economically valuable fishery resources. Ecologically, mangrove areas function as habitats and nursery grounds for various species of fish, shrimp, crabs, and snails that serve as the main sources of livelihood for local fishermen. In addition, mangrove vegetation such as *Rhizophora apiculata* and *Avicennia marina* is also utilized as firewood by communities living around the mangrove forests.

Mangrove ecosystems in Dumai City provide essential provisioning services, directly supporting food security and income generation for coastal communities. The main commodities derived from these ecosystems include fish, shrimp, crabs, snails, and firewood (Table 1).

Fish and shrimp dominate the total provisioning value, contributing Rp 17.26 billion and Rp 15.17 billion respectively, or over 73% of the total. The dominance of these commodities is ecologically linked to the extensive mangrove-lined coast of Dumai, which provides ideal nursery and feeding habitats for fish and shrimp species. Rhizophora sp. and Avicennia sp. stands create a complex root structure that shelters juvenile fish and crustaceans, increasing survival and catch potential (Vo et al. 2012; Honda 2013).

The high economic value of shrimp reflects both strong market demand and the species' ecological dependence on mangroves for larval development and detritus-based food chains. In contrast, although fish have lower individual utility and consumer surplus values, their widespread availability and cultural importance make them a staple resource for local fishers.

Compared to nearby regions, Dumai's total provisioning value (Rp 44.59 billion annually) is significantly higher than Sungai Apit, Siak District, Riau (Rp 24.75 billion annually; Warningsih et al. 2021), reflecting both greater mangrove extent and stronger local dependence on fishery-based livelihoods. However, degradation and overexploitation threaten these values. Observations indicate depletion of firewood and pole resources, primarily due to unsustainable harvesting (Nyangoko et al. 2021), suggesting that without effective management, provisioning benefits will decline sharply.

Firewood provides the smallest economic contribution (Rp 3.49 billion), yet it remains vital for household energy security. Although most homes now use gas stoves, firewood collection continues as a complementary activity, especially among lower-income households near mangrove areas. Women play a central role in this activity, collecting fallen branches weekly for domestic use, a reflection of mangrove resources' social as well as economic relevance.

Table 1. Provisioning services of the mangrove ecosystem in Dumai City, Riau Province, Indonesia

Type of benefit	Utility value (Rp)	Consumer surplus (Rp)	TEV (Rp)
Fish	39,042,008	26,028,005	17,256,567,325
Shrimp	148,758,130	109,233,198	15,173,329,272
Crab	91,013,307	55,578,854	5,460,798,417
Snail	107,097,163	87,615,950	3,212,914,898
Firewood	69,728,048	54,654,718	3,486,402,416
Total			44,590,012,328

The dominance of fish and shrimp within Dumai's mangrove provisioning services is primarily influenced by ecological, market, and socio-economic factors. Ecologically, the dense and productive mangrove stands generate rich detritus-based food webs that support high biomass of commercially valuable aquatic species. From a market perspective, the strong and consistent demand for seafood products, coupled with well-established local and regional supply chains, enhances the economic value of these resources. Socioeconomically, coastal communities in Dumai are highly dependent on fishing activities as their main source of income and livelihood security. The interaction of these factors underscores the central role of mangrove ecosystems in sustaining both biodiversity and the local economy.

These findings underscore the critical need to maintain mangrove health as the ecological foundation for local fisheries. The degradation of mangrove areas would directly reduce fishery productivity, undermining both household welfare and local revenue. Policy interventions in Dumai should therefore prioritize ecosystem-based fishery management, including replanting of degraded zones, sustainable harvest practices, and integration of mangrove conservation with community livelihood programs.

Regulating services

Regulating services are the key ecological functions of mangrove ecosystems that indirectly support human welfare by maintaining environmental stability. In Dumai City, these services include carbon sequestration, coastal protection, and seawater intrusion prevention. The total regulating value of the mangrove ecosystem is estimated at Rp 54.64 billion annually (Table 2).

Carbon sequestration contributes the highest share (46.7%) of total regulating services. This reflects the high biomass density of Dumai's mangrove stands dominated by *R. apiculata* and *R. mucronanta*, which have strong carbon storage capacity in both above-and below-ground biomass. The carbon stock values observed are consistent with studies (Alongi 2014), confirming that well-conserved mangrove forests serve as major blue carbon sinks.

The coastal protection values and seawater intrusion prevention highlight the physical barrier function of mangroves against coastal hazards. Dumai's coastal morphology, shaped by tidal flats and shallow estuaries, makes it vulnerable to abrasion and saline intrusion. Mangrove roots effectively dissipate wave energy, reducing erosion rates and stabilizing sediment deposition. The economic valuation, based on avoided damage and replacement cost methods, demonstrates that the cost of restoring eroded coastlines or constructing seawalls would far exceed the natural protection provided by intact mangrove belts.

When compared to other sites, Dumai's regulating value (Rp 54.64 billion annually) is relatively moderate. For instance, mangrove in Area Fahiluka-Lakun Pound in Malaka District, Rp 31.78 billion annually (Bessie et al. 2022), while the Sari Ringgung area, Pesawaran District, reached Rp 109.95 billion annually (Efendi et al. 2024). Mangrove in Sembilang National Park of South Sumatra, Indonesia, were valued at Rp 78.60 billion annually (Agustriani et al. 2023). The slightly lower value in Dumai may result from partial degradation of mangrove stands, especially in industrial and port-adjacent areas where land conversion reduces ecological efficiency. However, Dumai's remaining mangrove area still delivers substantial regulating benefits, especially carbon storage, which could be enhanced through blue carbon programs or Payment for Ecosystem Services (PES) schemes.

From a policy standpoint, maintaining and restoring mangrove health should be a strategic priority for Dumai's climate mitigation and disaster risk reduction agendas. The integration of mangrove conservation into spatial planning and corporate environmental responsibility programs would generate long-term economic and ecological co-benefits.

Mangrove ecosystems play a crucial role in mitigating climate change by capturing and storing carbon (Manan et al. 2025). Carbon sequestration data were collected from each transect using the quadrat transect method. The carbon content at each observation site is presented in Figure 2, which provides a visual representation of the variation in carbon storage capacity across the entire study area.

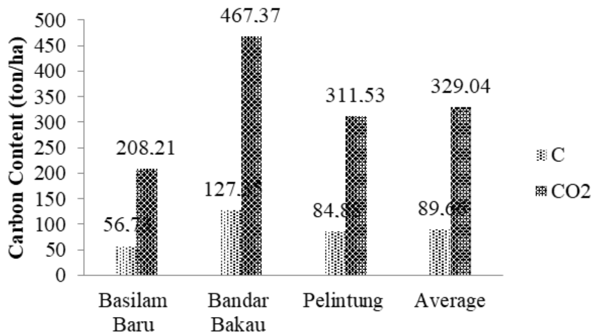

Figure 2. Carbon content

Table 2. Economic value of regulating services of the mangrove ecosystem in Dumai City, Riau Province, Indonesia

Type of service	Estimated value (Rp annually)	Method used
Carbon sequestration	24,831,996,931	Voluntary carbon market
Coastal protection	20,178,294,840	Replacement cost
Seawater intrusion prevention	9,629,438,760	Avoided damage cost
Total	54,639,730,531	

The graph illustrates carbon (C) and carbon dioxide absorption (CO_2) content in mangrove ecosystems across three locations in Dumai City: Basilam Baru, Bandar Bakau, and Pelintung, along with their average values. On average, the carbon content across the three locations is 89.66 tons/ha, or CO_2 absorption of 392.04 tons/ha. For comparison, a study in the Musi River estuary, South Sumatra, reported that mangrove carbon stocks amounted to 107.34 tons C/ha, with carbon dioxide (CO_2) sequestration reaching 393.59 tCO_2/ha (Farahisah et al. 2021).

Regulating services are essential for maintaining ecological balance and strengthening the resilience of coastal communities. Carbon sequestration was assessed by estimating the biomass of mangroves, focusing on above-ground components. The carbon content across the three study locations showed Dumai City's significant potential for carbon storage and its important role in climate change mitigation. Biomass potential varies across mangrove ecosystems due to factors like soil fertility and tree density. Stand biomass, carbon stock, and sequestration are strongly influenced by the density of trees with higher DBH (diameter at breast height), which correlates with greater carbon storage capacity (Syafruddin and Yurike 2020; Fatonah et al. 2023)

The dominance of carbon storage in the Dumai mangrove ecosystem is primarily attributed to the density and species composition of the mangroves. *Rhizophora apiculata* and *Rhizophora mucronata*, which dominate the mid-zone, possess large biomass and store substantial amounts of carbon. High tree density increases total biomass per hectare, thereby enhancing carbon accumulation and CO_2 sequestration. Furthermore, the homogeneous stand structure and muddy substrates support optimal growth of *Rhizophora* spp., reinforcing their contribution to carbon stock compared to other species found in the seaward or landward zones.

Rhizophora apiculata, abundant at all sites, has large biomass, enabling greater carbon storage. In addition, high tree density maximizes CO_2 absorption through photosynthesis, thereby increasing carbon stocks per unit area. The combination of dominant species with high biomass and dense forest structure makes carbon storage the most prominent regulation service in this ecosystem. According to Efriyeldi et al. (2023) and Efriyeldi et al. (2025), the potential for mangrove biomass and carbon storage increases with tree diameter and age, while carbon stock and sequestration at the stand level are primarily influenced by tree density. Stands with larger dbh and higher density exhibit greater biomass, leading to higher carbon stock and enhanced carbon sequestration.

Supporting services

Supporting services form the ecological foundation of all other ecosystem functions, ensuring the productivity and stability of coastal environments. In the mangrove ecosystem of Dumai City, these use the biodiversity value. The total economic value of supporting services is estimated at Rp 3.49 billion annually (Table 3).

The nutrient providers represent the largest share (76.3%) of the total supporting value. Dumai's mangrove areas, particularly in Sungai Sembilan and Medang Kampai sub-districts, serve as critical breeding and nursery grounds for fish, shrimp, and crabs. This biological role underpins the productivity of adjacent fisheries, making it directly linked to provisioning services. The dominance of fish and shrimp commodities in local livelihoods aligns with the high nursery function value, confirming that ecological health strongly influences economic output. Similar findings were reported in Mahakam Delta (Wahyuni et al. 2014) and in Rokan Hilir (Warningsih et al. 2020), where fish nursery functions significantly supported household incomes of coastal communities.

Compared with other regions, Dumai's supporting service value (Rp 3.50 billion annually) is higher than Bintan Island (2.56 billion annually: Arkham et al. 2023). The value reflects Dumai's transitional ecological condition, in which some mangrove zones remain productive and ecologically intact, while others have been degraded due to industrial expansion and domestic waste inputs.

Intertidal mangroves play a crucial role in supporting marine, freshwater, and terrestrial biodiversity. Therefore, mangrove biodiversity should be assessed at three levels: genetic, species, and ecosystem. Species diversity of mangroves is relatively well documented for large flora and fauna, but remains poorly studied for microorganisms and insects. Many species, such as fish, birds, and crustaceans, only utilize mangroves seasonally; thus, the ecosystem's supporting functions must be considered in conservation strategies (Macintosh and Ashton 2002).

In Indonesia, 240 mangrove species have been recorded (48 true and 192 associated), including various vegetation forms such as 74 trees, 36 shrubs, 52 herbs, 6 palms, 43 epiphytes, 23 lianas, 3 ferns, and 3 parasites. Mangrove areas also hosted 125 fish species (47 families), 169 macrozoobenthos species (52 families), and 161 terrestrial fauna species (80 birds, 38 squamates, 4 crocodiles, 6 amphibians, 11 testudinates, and 21 mammals) (Rahman et al. 2024). In the context of Dumai, these national initiatives are particularly relevant, as the city's mangrove ecosystems serve as critical habitats that support diverse species and contribute significantly to regional ecological stability and coastal resilience.

Table 3. Economic value of supporting services of the mangrove ecosystem in Dumai City, Riau Province, Indonesia

Type of service	Estimated value (Rp annually)	Method used
Biodiversity and Habitat	430,320,000	Benefit transfer
Nutrient providers	2,666,549,600	Benefit transfer
Spawning grounds	398,198,556	Production function approach
Total	3,495,068,156	

The degradation of supporting functions poses long-term threats to biodiversity, fishery sustainability, and carbon dynamics. Thus, the protection of nursery habitats and sediment stabilization zones should be prioritized in Dumai's coastal spatial planning. Restoration programs that combine ecological rehabilitation (replanting native species) and community-based management (eco-fishing, mangrove ecotourism) can enhance both ecological functions and economic benefits.

Cultural services

Cultural services represent the non-material benefits provided by the mangrove ecosystem, including recreation, education, aesthetic appreciation, and the sense of place that enhances community well-being. In Dumai City, cultural services are primarily linked to ecotourism and education activities, public awareness programs centered around the *Bandar Bakau Ecoedutourism Area*, a community-managed mangrove conservation site. The total estimated economic value of cultural services is Rp 8.22 billion annually, comprising recreational and existence values (Table 4).

The recreational value dominates the cultural component (69.88%), reflecting the growing interest in mangrove-based tourism and outdoor activities. The Bandar Bakau Ecotourism Area attracts local and regional visitors, particularly school groups and environmental organizations. Based on travel cost data, visitor expenditure and travel frequency were influenced by distance, income level, and environmental awareness, similar to findings in Karimunjawa (Suprapto et al. 2015) and Langkawi (Patwary et al. 2022). Visitors with higher environmental awareness tend to visit more frequently and spend more, suggesting that ecotourism development could strengthen conservation funding mechanisms.

The existence, though smaller in magnitude, represents a profound social dimension. Most respondents expressed a Willingness to Pay (WTP) between Rp 10,000-Rp 25,000 annually for mangrove conservation, indicating a tangible sense of environmental stewardship. This aligns with the concept of passive use value benefits derived from knowing that mangrove ecosystems exist and are protected for future generations. Similar WTP levels have been observed in East Lombok District, West Nusa Tenggara (Furqon and Hak 2025) and Sembilang National Park, South Sumatra, Indonesia (Fauziyah et al. 2023), reinforcing the role of cultural attachment and awareness in driving conservation support.

When compared with other mangrove areas, Dumai's total cultural service value (Rp 8.22 billion annually) is higher than that of Tangerang (Rp 2.73 billion annually; Marlianingrum et al. 2021). This difference can be attributed to variations in tourism infrastructure, accessibility, and institutional management. Dumai's limited supporting facilities (visitor centers, signage, and guided trails) constrain visitor satisfaction and frequency. However, its advantage lies in strong community-based management, which has fostered long-term commitment to mangrove protection and environmental education.

The degradation of mangrove areas, particularly due to industrial expansion and waste discharge, poses risks to the sustainability of cultural services. If degradation persists, the aesthetic and recreational appeal of these landscapes may decline, leading to reduced tourism income and public engagement. Conversely, investing in eco-education programs, visitor infrastructure, and digital promotion can substantially increase both visitor numbers and WTP levels.

Total Economic Value (TEV) of mangrove ecosystem services

TEV is the aggregate of several service categories previously outlined, including provisioning services, regulating services, supporting services, and cultural services, presented in Table 5. The results indicate that mangroves provide significant economic contributions through four categories of ecosystem services. Provisioning services (fish, shrimp, crab, snail, firewood) amount to Rp 44.59 billion annually, highlighting mangroves as a vital source of livelihood for coastal communities. Regulating services (coastal protection, carbon sequestration, intrusion prevention) were valued at Rp 54.64 billion annually, emphasizing their role in climate change mitigation and shoreline protection. Supporting services (biodiversity and habitat, nutrient providers, spawning grounds) have an economic value of Rp 3.49 billion annually, demonstrating their critical ecological importance. Cultural services (ecotourism, education, and existence value) contribute Rp 8.22 billion annually, supporting awareness and community income.

The sensitivity analysis indicates that the economic value of mangrove ecosystem services is responsive to ±10% variations in key parameters (Table 6). Provisioning services, including fish, shrimp, crab, snail, and firewood, exhibit significant changes in TEV, such as fish production contributing between Rp 12.53-18.98 billion annually. Regulating services, including carbon sequestration, coastal protection, and intrusion prevention, also show notable variations. Carbon sequestration, for instance, contributes between Rp 22.35-27.31 billion annually with ±10% change in biomass.

Table 4. Economic value of cultural services of the mangrove ecosystem in Dumai City, Riau Province, Indonesia

Type of service	Estimated value (Rp annually)	Method used
Ecotourism (recreation) value	5,745,415,225	Travel Cost Method (TCM)
Education value	1,436,353,806	Integration TCM-MEVI (Mangrove Education Value Index)
Existence value	1,039,941,818	Contingent Valuation Method (CVM)
Total	8,221,710,849	

Table 5. Economic valuation of mangrove ecosystem services

Ecosystem service	Parameter	Value	Unit	Formula	Economic value (Rp/yr)
Provisioning services					
Fish	Fish production (FP)	422	HoH	EV = FP x CS	17.26 billion
Shrimp	Shrimp production (SP)	102	HoH	EV = SP x CS	15.17 billion
Crab	Crab production (CP)	60	HoH	EV = CP × CS	5.46 billion
Snail	Snail production (SP)	30	HoH	EV = SP × CS	3.21 billion
Firewood	Firewood production (FWP)	50	HoH	EV = FWP × CS	3.49 billion
Regulating services					
Carbon sequestration	Biomass (B)	89.66	ton CO_2/ha	EV = M x B × Carbon price	24.83 billion
Coastal protection	Coastline length protected (L)	27.75	Km	EV = Replacement Cost/m×L	20.18 billion
Intrusion prevention	Water needs (WN)	219	m^3/yr	EV = WN x Water price x N	9.63 billion
Supporting services					
Biodiversity and habitat	Biodiversity Value (BV)	880	Ha	EV = BV x M	0,43 billion
Nutrient providers	Nutrient providers Value (NP)	880	Ha	EV = NP x M	2,67 billion
Spawning grounds	Spawning ground Value (SV)	46,607	Rp/kg	EV = H x P	0,40 billion
Cultural services					
Ecotourism	Number of Tourism (NT)	6,650	person/yr	EV = NT x CS	5.74 billion
Education	Number of Education Value (NE)	1,662	person/yr	EV = TCM x MEVI X NE	1.44 billion
Existence	Willingness to Pay (WTP)	130,909	Rp/HoH	EV = N x WTP	1.04 billion
Total Economic Value					110.95 billion

Note: CS: Consumer Surplus; N: Population; M: Mangrove Area; Carbon Price: US$ 5.36; Water Price: Rp5,535; NP: US$ 185.9; H: Production shrimp: 8,548 kg annually

Table 6. Sensitivity analysis

Parameter	Base value	Unit	± 10%	Impact on TEV (Rp/yr)
Fish production	422	HoH	380-464	12.53-18.98 billion
Shrimp production	102	HoH	92-112	15.65-16.69 billion
Crab production	60	HoH	54-66	4.91-6.00 billion
Snail production	30	HoH	27-33	2.89-3.53 billion
Firewood production	50	HoH	45-55	3.31-3.83 billion
Carbon Sequestration	89.66	ton CO_2/ha	80.69-98.65	22.35-27.31 billion
Coastal Protection	27.75	Km	24.98-30.53	18.16-22.20 billion
Intrusion prevention	219	m^3	197-241	8.66-10.59 billion
Biodiversity	880	Ha	792-968	2.39-2.92 billion
Nutrient providers	880	Ha	792-968	2.40-2.84 billion
Spawning grounds	46,607	Rp/kg	51,267-41,946	0.36-0.44 billion
Ecotourism	6,550	persons/yr	5,895-7,205	5.17-6.31 billion
Education	1,662	persons/yr	1,496-1,828	1.58-1.29 billion
Existence	130,909	Rp/HoH	117,818-143,000	0.94-1.14 billion

Supporting services, particularly spawning grounds, contribute the least to the TEV, amounting to Rp 0.36-0.44 billion annually. This relatively low value is due to their indirect and non-market nature, which makes monetary valuation challenging. Despite this, they play a fundamental ecological role by sustaining ecosystem functions and supporting other services. Cultural services, such as ecotourism, education, and existence value, are relatively stable with smaller impacts on TEV compared to other categories, yet they still play a role in raising community awareness and generating local income. Sensitivity analysis confirms that despite minor fluctuations in key parameters, mangroves maintain significant economic value, especially through provisioning and regulating services.

The TEV of mangrove ecosystem services, such as provisioning services, supporting services, regulating services, and cultural services. The percentage graph of the economic services is presented in Figure 3.

The highest proportion of mangrove ecosystem services was in regulating services (49.25%), followed by provisioning services (40.19%), which include direct benefits like fisheries and firewood. Although cultural and supporting services are less visible, they provide substantial benefits. These findings are consistent with studies that show mangroves offer a wide range of ecosystem services that contribute to human well-being (Costanza et al. 2011).

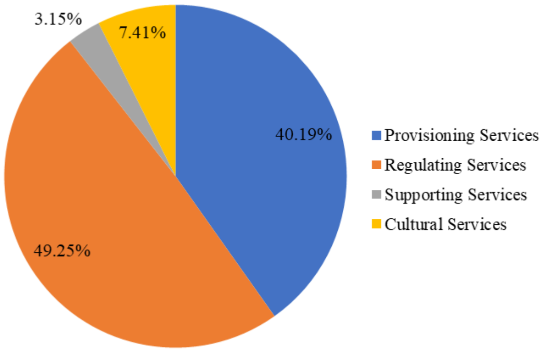

Figure 3. Percentage of the economic value of mangrove ecosystem services in Dumai City, Riau Province, Indonesia

TEV of mangrove ecosystem services in Dumai City was estimated at Rp 110.95 billion annually. This is consistent with other studies in the Riau region, such as Rokan Hilir District, Rp 98.70 billion annually (Warningsih et al. 2020), and Bengkalis District, estimated at USD 5.8 million annually (Novizantara et al. 2022). The TEV of the mangrove ecosystem in Dumai City is dominated by regulating services (Rp 54.64 billion annually or 49.25%), followed by provisioning services (Rp 44.59 billion annually or 40.19%), supporting services (Rp 3.49 billion annually or 3.15%), and cultural services (Rp 8.22 billion annually or 7.41%). Furthermore, Arkham et al. (2023) stated that the economic value of mangrove ecosystem services reaches Rp 135.66 billion annually from an area of 4,354.11 ha, with provisioning services contributing 61%, regulating services 21%, supporting services 2%, and cultural services 16%, underscoring the strategic role of mangroves in conservation, social welfare, and environmental policy in Bintan District, Riau Islands, Indonesia.

These findings highlight the importance of an integrative approach that balances economic development with ecological sustainability, particularly in mangrove management. Mangroves play a strategic role in supporting coastal economies and conserving marine biodiversity. Therefore, their preservation is essential for maintaining environmental stability and securing livelihoods, especially for fishing communities. As a policy implication, coastal zoning plans should involve local governments and communities. The designation of conservation and utilization zones can support sustainable mangrove management. Additionally, cross-sector collaboration in conservation and management should be enhanced, emphasizing community participation and sustainable resource use, possibly through Payment for Ecosystem Services (PES) schemes. According to Manan et al. (2025), the ecological and economic importance of mangroves serves as the foundation for conservation and sustainable management strategies aimed at enhancing resilience.

Mangrove management requires an integrated approach that balances ecosystem conservation with economic utilization. Mangroves play a strategic role in supporting coastal economies by providing fish, shrimp, crabs, timber, firewood, and charcoal, while also maintaining biodiversity and offering coastal protection against erosion and flooding. With proper management, environmental stability is maintained, and the livelihoods of coastal communities, especially fishers, are safeguarded from the impacts of ecosystem degradation. According to Rahman et al. (2024), mangrove ecosystem management through conservation efforts will influence the high level of biodiversity. These efforts are carried out to preserve and enhance ecosystem services, such as mangrove biodiversity, carbon stock potential, coastal protection, and the unique biodiversity of both marine and terrestrial fauna.

The dominance of provisioning services indicates that local communities are still heavily dependent on tangible resources such as fish, shrimp, and firewood. Among these, fish and shrimp production accounted for over 70% of the provisioning value. This pattern can be attributed to Dumai's extensive estuaries and tidal flats, which provide ideal habitats for fish and crustacean spawning (Ilman et al. 2016). Fishers' reliance on these resources highlights both the economic importance of mangroves and their vulnerability to ecosystem degradation. As mangrove cover declines, the nursery function that sustains these fisheries diminishes, leading to reduced catch and income, that a trend already observed in coastal zones of Bengkalis and Rokan Hilir (Warningsih et al. 2020; Novizantara et al. 2022).

The relatively strong regulating service value (28.5%) demonstrates the significant contribution of mangroves to carbon sequestration and coastal protection. Dumai's coastal morphology and high sedimentation rate make mangroves effective carbon sinks, with an estimated carbon storage of 320-350 tons CO_2-e per hectare, comparable to global averages (Donato et al. 2011). However, conversion and pollution could diminish this potential by reducing mangrove biomass and soil carbon pools.

In conclusion, this study estimates the Total Economic Value (TEV) of mangrove ecosystem services in Dumai City at approximately Rp 110.95 billion per year. Regulating services contribute the largest share (49.25%), followed by provisioning (40.19%), cultural (7.41%), and supporting services (3.15%). This composition indicates strong community dependence on direct-use resources such as fisheries and firewood, while also underscoring the critical role of mangroves in providing regulating functions, including carbon sequestration, coastal protection, and prevention of seawater intrusion. Mangroves in Dumai, therefore, function both as a livelihood base and as natural infrastructure supporting coastal resilience. Despite their high economic value, mangrove ecosystems in Dumai continue to face pressure from land conversion for industry, settlements, and oil palm plantations. Continued degradation may result in substantial economic losses due to declining fishery productivity, reduced carbon storage, and increased coastal vulnerability. Compared with other Indonesian coastal regions, Dumai's TEV is relatively moderate, reflecting intensive resource use alongside degraded ecological conditions. These findings demonstrate that the economic contribution of mangroves is often underestimated in policy and spatial planning. Integrating economic valuation into management frameworks is essential to support long-term sustainability, climate mitigation, and livelihood security. Further research should focus on improved ecological resolution, long-term monitoring, and integration of remote sensing and blue-carbon accounting to strengthen policy relevance.

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