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Economic valuation of ecosystem services in the Luppung Mangrove Forest, South Sulawesi, Indonesia

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Abstract. *Sribianti I, Muthmainnah, Hikmah, Nirwana, Hasanuddin, Khair M. 2025. Economic valuation of ecosystem services in the Luppung Mangrove Forest, South Sulawesi, Indonesia. Asian J For 9: 322-331.* Mangrove ecosystems are globally recognized for their critical ecological and economic functions, but remain vulnerable to degradation. This study quantifies the Total Economic Value (TEV) of provisioning, regulating, and supporting ecosystem services provided by the Luppung Mangrove Forest in Bulukumba District, South Sulawesi, Indonesia, using benefit transfer, market price, and replacement cost methods. Using a structured TEV framework, we gathered data through field surveys, structured interviews, and secondary sources. To figure out the value of these services, we looked at several approaches like market prices, replacement costs, and benefit transfers, while being mindful of some limitations and possible overlaps in our methods. According to our research, the Luppung ecosystem in the mangrove area has an estimated annual economic value of approximately USD 10,899.40 ha^{-1} year^{-1}. Provisioning services, which consist of timber, firewood, seeds, and some medicinal bark, contributed USD 2,656.63 ha^{-1} year^{-1}. Regulating services, which include shoreline protection, prevention of seawater intrusion, and carbon sequestration, contributed USD 2,033.82 ha^{-1} year^{-1}. These findings underscore the substantial economic contribution of mangrove resources to local livelihoods and coastal protection. Integrating these values into local development and conservation planning could support more sustainable management through Payment for Ecosystem Services (PES), establish protected areas for conservation, and Ecosystem-based Adaptation (EbA) strategies.

Keywords: Biodiversity, benefit transfer method, mangrove conservation economics, Payment for Ecosystem Services (PES)

Abbreviations: PES: Payment for Ecosystem Services, TEV: Total Economic Value

INTRODUCTION

Mangrove ecosystems are gaining recognition as critical ecological assets in coastal regions located in the tropics and subtropics. These areas also serve multipurpose roles as social and economic assets. Along with preventing erosion and capturing carbon, these types of mangroves enhance the livelihoods of coastal communities (Alongi 2015; Gandaseca et al. 2024). Sippo et al. (2018) underscore the importance of these elements in sustaining biodiversity and perpetuating the nutrient cycle. The importance of sustainability, strong adaptive practices for climate change, and conservation with respect to mangrove ecosystems must be underscored.

Covering approximately 3.36 million hectares, Indonesia holds the top position globally for the most continuous stretch of mangrove forests, accounting for almost 23% of the world's mangrove ecosystems (Directorate of Soil and Water Conservation 2021). Despite this, the country also suffered the loss of 600,000 hectares of mangrove forests between the years 2000-2016, as a consequence of fragmented and badly degraded mangrove ecosystems (Thomas et al. 2017). These worrying patterns underscore the necessity of better conservation planning. Indonesia's mangrove harbors more than 202 species with 43 endemics, demonstrating the extraordinary fusion of different habitat combinations (Khairunnisa et al. 2020). Furthermore, Indonesia's mangrove areas hold global strategic importance, particularly for biodiversity preservation and climate regulation. Plants play a vital role in sequestering carbon, thereby reducing greenhouse gas concentrations. Their ability to absorb atmospheric carbon dioxide, mangroves contribute to mitigating climate change and maintaining environmental health (Arifanti et al. 2022).

Mangrove forests are currently confronting unprecedented pressures from both natural dynamics and human interventions (Worthington et al. 2020; Askar et al. 2021). Sulawesi and Kalimantan have insightfully documented degradation, particularly triggered by aquaculture and agriculture expansion, unsustainable deforestation at high rates, and land conversion at high rates (Malik et al. 2016). Climate change impacts, such as the amplification of extreme events, the disruption of salinity balance in estuaries, and the acceleration of sea level rise, compound these human impacts (Ward et al. 2016; Hakim et al. 2017). Confronting this multifaceted problem demands integrated restoration efforts and the formulation of long-term management frameworks aimed at preventing further ecological deterioration. The loss of mangroves has led to a significant reduction in ecosystem services, which often remains unnoticed. As vital ecosystems, mangroves provide essential benefits, including supporting fisheries, offering habitat near human settlements, preserving cultural heritage, and maintaining environmental balance, making them irreplaceable yet frequently overlooked natural resources (Vo et al. 2012). Developing standardized economic studies that value ecosystems is invaluable, as Indonesia lacks them despite the existence of numerous research studies around the world. Most evaluations tend to focus on individual aspects like fisheries or carbon capture, missing out on a comprehensive view of the services mangroves offer. This limited perspective reduces the effectiveness of their findings for policy-making (Getzner 2020; Su et al. 2021). Recent studies highlight the need for integrated valuation techniques, like Total Economic Value (TEV), which take into account both market and non-market benefits, bridging important gaps in current valuation research in Indonesia (Barbier et al. 2011).

The global recognition of the economic value that mangrove ecosystems provide is becoming increasingly clear (Akanni et al. 2018; Gargaran et al. 2024). However, the absence of methodological uniformity poses a fundamental problem concerning the consistency and trustworthiness of valuation frameworks adapted to Indonesia's socio-ecological systems. This inconsistency gives rise to the risk of undervaluation or overvaluation, which impedes effective conservation and management.

The Luppung Mangrove Ecosystem, located in Bulukumba District, South Sulawesi, Indonesia, serves as a classic example of an ecosystem that remains obscure yet immensely significant. The ecosystem is valuable for its shoreline stabilization, carbon storage, timber, and medicine, along with ecotourism and other potential benefits yet to be explored. At the same time, increasing human activity in these areas poses the greatest threat (Feka and Ajonina 2011; Alongi et al. 2016). This underscores the urgent need for case-specific valuation studies that support the management of mangrove forests. The study aims to assess the Total Economic Value (TEV) of the Luppung Mangrove Forest. We're using a method called benefit transfer, and our focus is on the various services that these forests provide, including provisioning, regulating, and supporting services. Additionally, we want to see how this information can be useful for planning and policy-making in Indonesia.

MATERIALS AND METHODS

Study area

This study applied the TEV framework to assess the ecosystem services of the Luppung Mangrove Forest in Bulukumba District, South Sulawesi, Indonesia (Figure 1). The methodology incorporates area selection, the collection of relevant data, and systematic evaluation, all according to the principles of environmental economics at multidisciplinary levels. To capture all ecosystem services, we integrate the community's qualitative input with quantitative economic techniques, as other scholars also do (Barbier et al. 2011; Getzner 2020). Baseline biophysical parameters such as stand density, plot-based inventories, shoreline length, and wave exposure were also recorded to support the calculation of ecosystem services. Specifically, benefit transfer, adjusted for purchasing power parity and local wage indices, was appropriately implemented for local valuation.

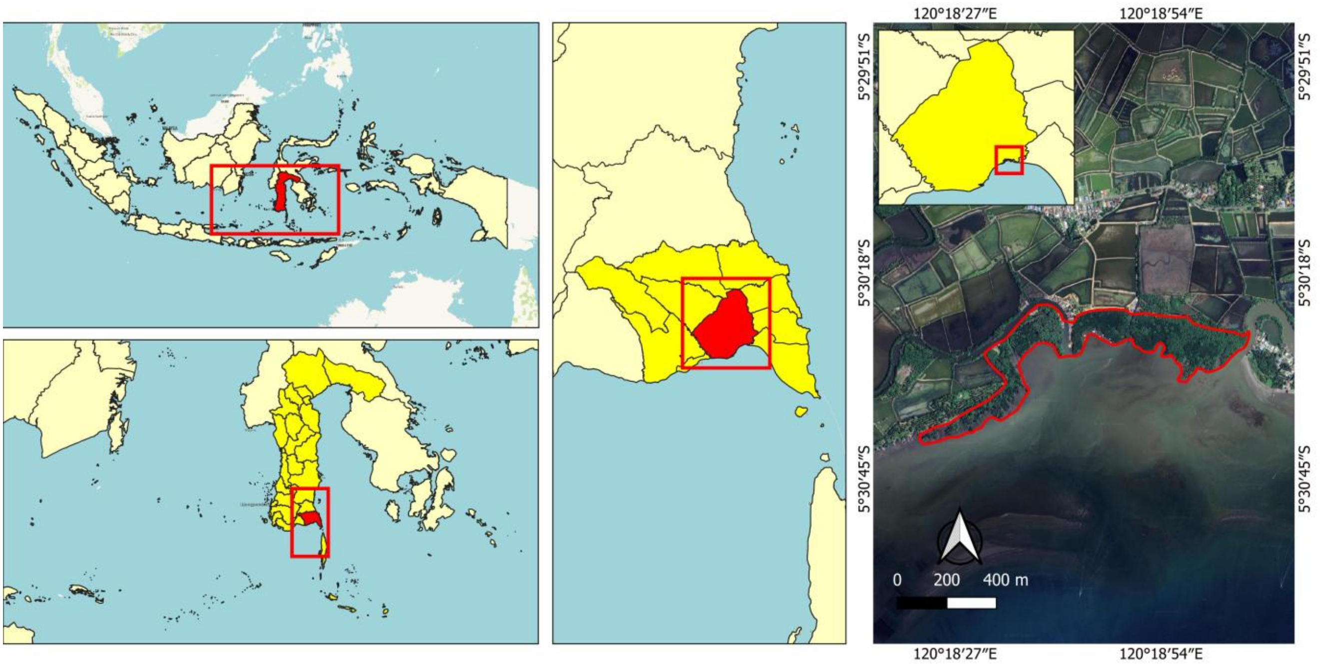

Figure 1. Sitemap location of Luppung Mangrove Forest, Bulukumba, South Sulawesi, Indonesia

The Luppung Mangrove Forest covers an area of 79.67 hectares, dominated by the mangrove species *Rhizophora apiculata* and *Avicennia marina*. In addition, it provides ecological protection alongside primary and secondary livelihood resources for the community. Such mangrove ecosystems are critical for analyzing the derivational holistic value due to their distinctive ecological attributes and socio-economic importance (Arifanti et al. 2022). Its ecosystem identifies the multifunctional character of mangroves, which provide biodiversity and coastal resilience (Alongi 2015). Field observations were conducted to collect data on the potential of mangrove forest stands. This was done through direct field measurements using 20 plots, each measuring 10×10 m (Fachrul 2012). The measured variables included vegetation type, tree density (trees per hectare), and trunk diameter.

Procedures

Primary data was gathered and collected through conducting structured interviews with 30 local beneficiaries, selected purposively based on their direct dependency on mangrove resources. Data were collected using questionnaire surveys to gather information about the respondents' backgrounds and their use of mangrove resources. Demographic data consisted of age, education, household income, number of dependents, and awareness of mangrove ecosystems. Respondents described the resources collected, how often they collected it, and the expenses involved. Participants were purposively selected on the basis of direct dependence on mangrove areas for their livelihoods.

To complement and validate surveying, mangrove sites were visited to gauge condition and take stock of the actual resources used. This mixed approach is quite common in environmental studies, enabling the integration of local knowledge and direct observation of the study area. This helps enhance the understanding of the ecosystem services on offer (Warer et al. 2024; Chand et al. 2025). For accuracy and context relevance, local and regional market prices, wage levels, and infrastructure costs were collected as secondary data from government publications and earlier empirical research. Secondary data, such as information on local wage rates, water prices, and timber unit values, were compiled from relevant references and documented with their corresponding data sources.

This research's TEV framework covers the structural basis within which the services of mangrove ecosystems are organized into three fundamental groups: provisioning, regulating, and supporting services. TEV incorporates direct use, indirect use, option, and existence values (Himes-Cornell et al. 2018; Mohamed et al. 2024). Distinct types of ecosystem service values for mangrove ecosystem services were calculated using different approaches and are presented in USD ha^{-1} $year^{-1}$. All monetary estimates in this study were adjusted using the 2023 exchange rate (1 USD = IDR 15,935; Bank Indonesia 2023). The classification of services was based on internationally recognized guidelines, following the Millennium ecosystem Assessment (MA) and The Economics of Ecosystems and Biodiversity (TEEB). Every assumption and parameter source was clearly recorded to maintain transparency and allow others to reproduce the analysis.

Data analysis

The valuation of mangrove ecosystems for the purpose of provisioning services based on the market price approach, which consists of the direct economic benefits derived from mangrove resources. Here, the economic value of mangrove resources, including timber, firewood, seeds, and bark used for medicine, was estimated, and the valuation of these resources for annual value focused on collection practices, production costs, and local market prices for harvested quantities. To ensure the results were transparent and dependable, all underlying assumptions, including tree density, yield estimates, and unit pricing, were documented in tables and thoroughly examined for consistency before the valuation process. The total provisioning service value (VPS) was then calculated using the following formula:

$$\boldsymbol{V_{ps}} = \sum_{i=1}^{n} [(\boldsymbol{P_i} \times \boldsymbol{Q_i}) - \boldsymbol{C_i}]$$

Where V_{ps} represents the total annual value of provisioning services (USD $year^{-1}$), Pi is the market price of product i (USD kg^{-1} or USD $unit^{-1}$), Qi denotes the annual harvest quantity (kg or unit $year^{-1}$), and Ci is the annual production cost for product i (USD $year^{-1}$). Yield estimates were adjusted again, considering sustainable harvesting levels due to the 25-year growth period for *R. apiculata* to ensure long-term ecological balance and continuity of resources (Agustriani et al. 2023; Owuor et al. 2024).

The regulating services focused on the estimated costs of certain parameters and the lifespans of services. This analysis provides useful justification on how changes to construction cost or service duration affect the economic value of the whole assessment, thus invaluably contributing to the defensibility and comprehensiveness of the assessment. The valuation is determined using the following equation:

$$\boldsymbol{V_{AP}} = \frac{\boldsymbol{C_{bw}} \times \left(\frac{\boldsymbol{L_m}}{\boldsymbol{L_{std}}}\right)}{\boldsymbol{A_m} \times \boldsymbol{D}}$$

In this equation, V_{AP} refers to abrasion protection value (USD ha^{-1} $year^{-1}$), C_{bw} is the cost of a 150-meter breakwater (USD 183,316.41), L_m is the length of the mangrove protected coastline (741.3 m), L_{std} is the standard reference length (150 m), A_m is the mangrove area in hectares, and D is the lasting period in years (20 years). Sensitivity analyses complemented the results to illustrate how changes in construction expenses or service duration could influence the overall valuation outcomes, thereby accounting for uncertainty and variability in cost assumptions. Although this approach is based on a constructed analogue, it nevertheless offers a tangible and politically salient estimate of mangrove protection services (Effiong and Ewah 2025).

The economic value of seawater intrusion prevention was determined through the avoided cost approach, which equated the role of mangroves to the savings households experience from not needing to purchase or treat additional clean water. Data on the number of households (NHH), water consumption levels (Wc), and unit water prices (Pw) were obtained from district-level statistics and field surveys, then compiled systematically to ensure data traceability. The equation applied was:

$$V_{SIP} = \frac{N_{HH} \times W_c \times P_w \times 12}{A_m}$$

Where V_{SIP} is the seawater intrusion prevention value (USD ha^{-1} year^{-1}), N_{HH} is the number of households utilizing groundwater, W_c is the monthly water consumption per household (m^3), P_w is the price of water (USD per m^3), and A_m is the mangrove area (ha). All parameter sources, calculation bases, and working assumptions were meticulously reported to prevent arbitrary estimations and to support the transparency and reproducibility of the valuation process. This approach overlooks the value provided to households because of the natural filtration systems provided by mangroves (i.e., avoiding the need to purchase clean water), which contributes to the ecosystem water quality, an important indirect use value (Kristiningrum et al. 2020).

Mangroves provide numerous ecosystem services including the sequestering of carbon, which is valued at USD 863.68 annually per hectare. Here, carbon sequestration is considered at a rate of 188.99 Mg CO_2 per hectare annually, and the valuation is based on continuous annual flow as opposed to a fixed reserve of carbon. The calculation was based on current prices from the voluntary carbon market, with adjustments made for transaction expenses to represent a more accurate and practical economic value. The corresponding computation was presented through a standard valuation formula:

$$V_{CO2} = (C_{abs} \times P_{net})$$

$P_{net} = P_{gross} - TC$, with P_{gross} = USD 5,80 per Mg CO_2 (based on the 2023 voluntary market rate), and TC = USD 1.23 per Mg (Antinori and Sathaye 2007), thus P_{net} = USD 4.57 per Mg CO_2.

Where V_{CO2} is the carbon sequestration value (USD ha^{-1} year^{-1}), C_{abs} is the carbon sequestration rate of the mangrove (in Mg CO_2 ha^{-1} year^{-1}), and P_{net} is the net carbon price (USD 4.57 per Mg CO_2, reflecting current voluntary market conditions, after accounting for costs). The estimation of carbon mitigation value took into consideration transaction costs, which were referenced from global data (Antinori and Sathaye 2007). Several scenarios were examined concerning variations in the periods of carbon storage and the possible risks of leakage, as described by Alongi (2020).

In estimating the value of biodiversity, a benefit transfer method was used, starting with the baseline figure of USD 15 ha^{-1} year^{-1} as offered by Ruitenbeek (1992). To bring this figure to current estimations, it was adjusted for the Consumer Price Index (CPI) as well as Purchasing Power Parity (PPP). To enhance the reliability and context of this value, it was also cross-checked against other recent studies on the valuation of mangroves. Considerations of biogeographic similarity and regional economic conditions, such as local wage levels in Bulukumba and West Papua were incorporated to enhance the validity of value transfer. The adjusted value V_{BD} was computed as:

$$V_{BD} = V_{PB} \times \left(\frac{RMW_{BLK}}{RMW_{PB}}\right)$$

Where V_{BD} is the adjusted biodiversity value for Bulukumba (USD ha^{-1} year^{-1}), V_{PB} is the baseline per-hectare value from West Papua, Indonesia (USD 15 ha^{-1} year^{-1}), and RMW_{BLK} and RMW_{PB} are the regional monthly wages for Bulukumba and West Papua. The updated estimates focused more on using Consumer Price Indeks (CPI) and Purchasing Power Parity (PPP) adjustments instead of wage-based changes. This was done to avoid making the values too high (Osmaleli et al. 2013).

The valuation of mangrove ecosystem services quantified the benefits of provisioning, regulating, and supporting services, and aggregated these values using the specified equation:

$$V_{ES} = V_{PS} + V_{RS} + V_{SS}$$

In this equation, V_{ES} denotes the overall value of ecosystem services, while V_{PS}, $V_{RS,}$ and V_{SS} refer to the combined values of provisioning, regulating, and supporting services, respectively. This demonstrates the interconnected nature of mangrove ecosystem functions and the synergistic influence on the total value of the ecosystem. The TEV reflects an estimate, taking into account the context and the analysis's assumptions. This method was adopted with the understanding of the value limitations on the estimation and the hyper-realism to help in the economics of guiding policy and the management of policy.

The entire valuation ecosystem services framework in the study was built on field economic framing and ecosystem services economic valuation. The socio-economic gaps were also reflected in the valuation of ecosystem services using the benefits transfer technique, which captured variations in community dependence and access to mangrove resources. To strengthen methodological rigor and ensure reproducibility, scenario-based sensitivity analyses (±25% variation) were conducted, and all key assumptions were explicitly documented to enhance transparency and facilitate critical evaluation. This contributes to the enhanced precision and applicability of mangrove valuation in Indonesia and the discourse on sustainable governance and strategies concerning the green economy.

RESULTS AND DISCUSSION

The comprehensive primary data indicated a total economic value of the Luppung Mangrove Ecosystem of USD 10,899.40 ha^{-1} $year^{-1}$, employing the TEV framework. This valuation includes provisioning, regulating, and supporting services. The mangroves are thus crucial for both ecological functionality and economic resilience, particularly for coastal communities in Bulukumba, who depend significantly on mangrove-derived resources for subsistence and income.

Provisioning services value

The ecosystem functions provided by the Luppung Mangrove Forest are of great importance for subsistence as well as the economic activities of local communities. The products obtained include wood, firewood, as well as seeds and bark with medicinal properties from *R. apiculata* and *A. marina*. These species are also well known in the literature for their diverse utilizations as construction timber, fuel wood, and in traditional medicine (Agustriani et al. 2023; Owuor et al. 2024). All provisioning service values in this study are net estimates, calculated after subtracting costs and adjusted to reflect sustainable harvest levels that keep mangrove resources available over time.

Table 1 describes the value for provisioning services of Luppung Mangrove Ecosystem. The estimation of the economic value of mangrove wood was based on an average stand density of approximately 100.25 stems per hectare, a rotation period of 25 years, and a market price of USD 0.25 per stem. Based on these parameters, the annual wood value was estimated at approximately USD 100.25 per hectare, resulting in a total value of about USD 7,986.92 for the entire 79.67-hectare mangrove area.

Values represent net annualized benefits derived under the assumption of sustainable harvesting, with value ranges determined through sensitivity and scenario analyses applying a variation of ±25% to capture potential fluctuations in cost and yield conditions.

The value of firewood was evaluated using an average yield of six bundles of firewood per mangrove tree at a unit price of USD 0.63 per bundle. Only a sustainable fraction of trees was assumed to be harvested each year, resulting in 2,406 bundles ha^{-1}, and an annual value of USD 1,515.78. For the entire forest, this equals USD 120,762.19. Similar case studies done in Southeast Asia have verified these findings, bringing to light the importance of mangrove firewood as an energy source, as well as a resource for income for the rural coastal communities (Agustriani et al. 2023).

The economic value associated with mangrove seeds, chiefly the propagules from *R. apiculata*, was calculated based on a yield of 25 propagules for each tree. At the prevailing market price of USD 0.0038 per propagule, these propagules provide a substantial economic contribution. This brings the figure to yearly USD 3,035.43 for the Luppung forest. In the case of propagules, they not only help restore the local ecosystems, but they also help economically via reforestation and rehabilitation (Lugina et al. 2019; Syah 2019).

The study also investigated the bark of mangroves for its medicinal value. Some mangrove species were used in traditional medicine, particularly for treating diarrhea, and are still used for that purpose today. For the purpose of this analysis, a conservative estimation of bark extraction of 5 kilograms per tree, at a price of USD 0.50 per kilogram, was assumed. This provides an annual estimated value of USD 1,002.50 per hectare, or approximately USD 79,869.18 for the total area of mangroves studied. How profitable this can be is determined by the availability of bark. The economic evaluation improved- rather than weakened- the case for conservation due to the fact that the overexploitation of mangrove resources can result in the weakening and ultimately death of the trees. This demonstrates the interrelation of local culture, community livelihood, and the ecology of mangrove bark (Thomas et al. 2017).

Bark, timber, medicinal extracts, and seeds are vital parts of a mangrove's economic value. In Luppung, the collection of *R. apiculata* wood and firewood is an income-generating activity while also providing a household energy source, corroborating findings from Sembilang National Park (Agustriani et al. 2023). The cultural practice of healing with bark also maintains indigenous medicinal practice and serves the dual purposes of health and environmental protection (Syah 2019).

Notably, a high economic valuation of mangrove resources can lead to overexploitation, especially for firewood and timber, which can result in negative ecological outcomes. Recovery from overharvesting is likely to take decades, as *R. apiculata* trees take around 25 years to mature. For this reason, economic valuation should be integrated with participatory management and supported by clear legal protection to maintain both ecological integrity and community welfare.

Table 1. Total value of provisioning services of the Luppung Mangrove Ecosystem, South Sulawesi, Indonesia

Provisioning service	USD ha^{-1} $year^{-1}$	USD $year^{-1}$ (total 79.67 ha)
Wood	100.25 (75.19-125.31)	7,986.92 (5,990.19-9,983.65)
Firewood	1,515.78 (1,136.84-1,894.73)	120,762.19 (90,571.64-150,952.74)
Seeds	38.10 (28.58-47.63)	3,035.43 (2,276.27-3,793.79)
Medicinal bark	1,002.50 (751.88-1,253.13)	79,869.18 (59,901.89-99,836.48)
Total	2,656.63 (1,992.47-3,320.79)	211,653.71 (158,740.28-264,567.14)

Note: Range based on basic sensitivity analysis of ±25%. Source: Author's analysis using field data (2023)

Regulating services value

In the Luppung area, mangrove forests contribute to ecosystem functions such as preventing erosion, controlling saltwater intrusion, and sequestering carbon from the atmosphere. These ecosystem services contribute to environmental preservation and the livelihoods of residents in the area. The preparation of rational land use and land-use policy and policy measures for conservation recognizes the value of these services economically.

The valuation of the services the mangroves provide in the Luppung area was assessed and is described in Table 2. Estimation of replacement cost was used to value services for the construction of a 150-meter breakwater, which was valued at approximately USD 183,316.41. That led to the valuation of the service for the protection of mangroves at approximately USD 1,153.49 per hectare each year, and for the entire Luppung mangroves area, it was valued at USD 91,898.55. The value estimation confirms that considering the economic value of mangroves as natural defense systems protecting coastlines is more cost-effective than having artificial barriers constructed (Malik et al. 2016; Utami et al. 2021).

The economic value of preventing seawater intrusion was calculated by measuring the savings in clean water expenses and was termed the avoided cost method. In this case, the amount was calculated as USD 16.65 ha^{-1} $year^{-1}$ and approximately USD 1,326.51 per year for the total Luppung mangrove area. Input assumptions (NHH, Wc, Pw) were tabulated from household surveys and district statistics. This research was consistent with the previous studies, which indicated that mangroves are helpful in water conservation by restricting the recharge of seawater into coastal aquifers (Indriawan et al. 2021).

At a current voluntary carbon market price of USD 4.57 per Mg CO_2, mangrove carbon sequestration was valued at approximately USD 863.68 ha^{-1} $year^{-1}$ based on the rate of absorption being approximated at 188.99 Mg CO_2 per hectare. This ecosystem's total carbon sequestration value yields about USD 68,809.39 annually. This valuation corroborates the robust climate mitigation services provided by mangroves. It is consistent with global forest assessments that consider these ecosystems as some of the most efficient natural carbon sinks (Alongi 2020).

This study assesses coastal abrasion protection, intrusion prevention, and carbon storage within the scope of specific ecosystem services provided by mangroves. Although these services may not be immediately visible, they significantly aid in mitigating climate change effects and safeguarding coastlines. The estimated replacement cost of USD 1,153.49 ha^{-1} $year^{-1}$ emphasizes the economic value of mangrove ecosystems as natural coastal barriers. This figure highlights that maintaining mangrove forests is not only an ecological necessity but also a cost-effective alternative to constructing artificial protective structures (Malik et al. 2016; Utami et al. 2021).

Mangroves contribute substantially to the resilience and protection of coastal communities by mitigating seawater intrusion, which is critical for sustaining agriculture and local water resources. Research by Indriawan et al. (2021) highlights how mangroves support the sustainability of freshwater in coastal aquifers. Our findings suggest that the value of this service is about USD 16.65 per hectare each year. Additionally, mangroves are unique in their carbon retention abilities, estimated at USD 863.68 per hectare every year. Per hectare, mangrove forests sequester more carbon than most tropical rainforests, making them more effective sinks. Their capability underscores their role in the climate system (Himes-Cornell et al. 2018; Alongi 2020).

The value of the supporting services is greater than that of the regulating services, which is correct. However, the regulating services provide invaluable ecological defense value against climate and coastal threats. Within policy-deserving frameworks, mangrove ecosystems continue to be chronically under-appreciated, even with evident ecological and economic value. By quantifying their benefits transparently, this study provides empirical evidence to support climate adaptation strategies, conservation zoning, and ecosystem-based coastal defense initiatives, while also informing the development of PES mechanisms (Rahim et al. 2023).

Supporting services value

This study aims to highlight biodiversity as an important supporting service that helps keep ecosystems balanced and resilient. In Indonesia, mangrove forests are key to preserving biodiversity by providing habitats and supporting many species. The economic contributions of ecosystem services in the Luppung Mangrove area are summarized in Table 3. Value ranges were further refined through sensitivity and scenario analyses, accounting for potential fluctuations in construction expenses, water pricing, and carbon market rates, to capture realistic uncertainty in the valuation outcomes.

Table 2. Total value of regulating services of Luppung Mangrove Ecosystem, South Sulawesi, Indonesia

Regulating Service	USD ha^{-1} $year^{-1}$	USD $year^{-1}$ (total 79.67 ha)
Abrasion protection	1,153.49 (865.12-1,441.86)	91,898.55 (68,923.91-114,873.18)
Seawater intrusion prevention	16.65 (12.49-20.81)	1,326.51 (995.03-1,658.38)
Carbon sequestration	863.68 (647.76-1,079.60)	68,809.39 (51,607.30-86,012.16)
Total	2,033.82 (1,525.37-2,542.28)	162,034.44 (121,526.23-202,543.71)

Note: Range based on basic sensitivity analysis of ±25%. Source: Author's analysis using field data (2023)

The biodiversity value was estimated using the benefit transfer method, based on Ruitenbeek (1992). The value was adjusted using CPI and PPP data and compared with recent studies to ensure accuracy (Ali et al. 2024). The new estimate for Luppung is USD 6,208.95 ha^{-1} $year^{-1}$, or USD 494,667.05 for the entire site. Even though the numbers are derived from indirect assessment methods, the results highlight the fundamental function of mangroves in sustaining elevated biodiversity and providing a habitat for a multitude of organisms, along with a myriad of ecological interactions in complex systems (Ali et al. 2024). The supporting service in this study generated significant economic value, particularly in biodiversity

The Luppung Mangrove Ecosystem plays a vital role in supporting numerous species, with its biodiversity estimated at approximately USD 6,208.95 ha^{-1} $year^{-1}$. Compared to previous studies, such as Osmaleli et al. (2013) in Pabean Udik, which found biodiversity values of only about USD 41.05 per hectare, the Luppung ecosystem exhibits much higher ecological and economic significance. Differences between estimated and actual values show the need for site-specific adjustments, such as considering inflation, purchasing power, and biogeographic conditions, to make the results more accurate (Ruitenbeek 1992; Ali et al. 2024).

Supporting services bolster provisioning and regulating functions. Degradation of these services would trigger cascading impacts across ecosystems. Including socio-economic impact assessments in policies can help protect ecosystems while improving community welfare and resilience (Dabalà et al. 2023).

Total value of environmental services

Table 4 reveals the total environmental services value of the Luppung Mangrove Ecosystem. About each of the ecosystem services, the value of the Luppung Mangrove Ecosystem is approximately USD 10,899.40 ha^{-1} $year^{-1}$. Hence, for the entire 79.67-hectare area, the value is estimated to be USD 868,355.20 per year. As illustrated in Figure 2, within the ecosystem services, supporting services represent the largest allocation of the total value, which is about 56.97%. This is followed by provisioning, which accounts for approximately 24.37%, and regulating services, which account for roughly 18.66%.

This evaluation illustrates the significant roles that the Luppung Mangrove Forest fulfills. It is essential to highlight the significance of mangroves in safeguarding ecological integrity, socio-economic factors, and bolstering resilience to climate change. Using the TEV framework ensures the integration of both primary field data and secondary references, creating a comprehensive and adaptable model for future ecosystem valuation research. The case study provides a basis for the development of data-informed environmental management and policy in Southeast Asia and other regions with comparable ecosystems.

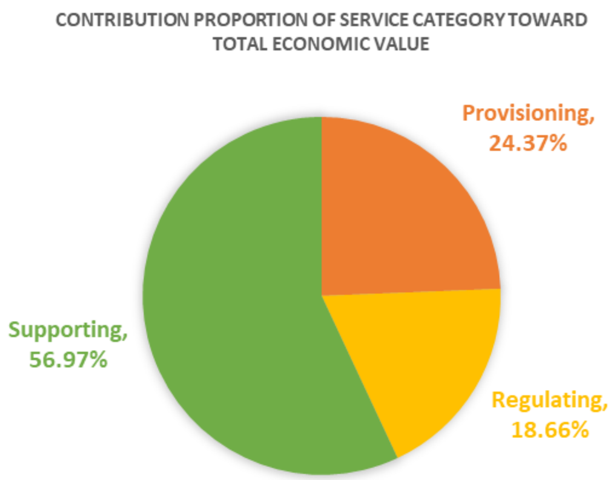

Figure 2. Contribution proportion of each service category toward the total economic value. Source: Author's analysis using field data (2023)

Table 3. Total value of supporting services of the Luppung Mangrove Ecosystem, South Sulawesi, Indonesia

Supporting service	USD ha^{-1} $year^{-1}$	USD $year^{-1}$ (total 79.67 ha)
Biodiversity	6,208.95 (4,656.71-7,761.19)	494,667.05 (371,000.50-618,334.16)
Total	6,208.95 (4,656.71-7,761.19)	494,667.05 (371,000.50-618,334.16)

Note: Range based on basic sensitivity analysis of ±25%. Source: Author's analysis using field data (2023)

Table 4. Total economic value of Luppung mangrove environmental services

Service category	USD ha^{-1} $year^{-1}$	USD $year^{-1}$ (79.67 ha)	Contribution (%)
Provisioning	2,656.63 (1,992.47-3,320.79)	211,653.71 (158,740.28-264,567.14)	24.37
Regulating	2,033.82 (1,525.37-2,542.28)	162,034.44 (121,526.23-202,543.71)	18.66
Supporting	6,208.95 (4,656.71-7,761.19)	494,667.05 (371,000.50-618,334.16)	56.97
Total	10,899.40 (8,174.55-13,624.25)	868,355.20 (651,452.46-1,085,259.56)	100.00

Note: Range based on basic sensitivity analysis of ±25%. Source: Author's analysis using field data (2023)

Ecosystem service valuation and policy implications

Evaluation of mangrove ecosystem services using the TEV framework enhances land-use planning and environmental management. This particular research is significant in the sense that it attempts to monetize services that have been traditionally viewed as cost-free. However, TEV estimates rely strongly on the assumptions used in the benefit transfer method, and therefore should not be viewed as exact market prices but rather as indicative measures of value. This integration of ecology into the finance and policy sphere is what drives the importance of the research. The aim is to incorporate these environmental aspects into national planning efforts in countries like Indonesia, especially within the RPJMN and KLHK conservation initiatives. This approach highlights the importance of nature in our economic and policy-making processes (Getzner 2020; Barbier et al. 2021).

The recognition of the carbon sequestration capacity of mangroves strengthens their argument for integration into the national climate action and carbon offset frameworks. Equally, the understanding of the high valuation of coastal protection services supports the limitation of mangrove deforestation, encouraging policy to favor natural coastal defenses over expensive, artificial constructions (Nopiana et al. 2023). This is entirely in line with Indonesia's Folu Net Sink 2030 commitments. However, the reliance on variable carbon prices and site-specific factors suggests that these estimates are likely to change with differing economic or environmental conditions and should, therefore, be used with discretion.

The valuations of the ecosystem services are factors in the establishment of PES schemes. These established systems are designed to reward local communities financially for their efforts in ecological conservation (Balke and Friess 2015; Tian et al. 2022). PES is especially relevant in Indonesia, where many depend on natural resources for daily needs. Proper incentives and strong tenure systems are critical for success. Our findings suggest PES design must explicitly address governance capacity, equity, and monitoring to avoid elite capture or unsustainable extraction.

It is important that the communities are engaged in our valuation studies if the economic value of the services rendered is to be relevant and capture the real meaning of the services to their culture. In our research, we held structured interviews with local beneficiaries, which greatly enriched our results. Listening to the perspectives of those who depend on and have a deep understanding of the mangroves allowed us to gain valuable insights, making our valuation more relevant and aligned with their lived experiences (Thahira et al. 2023; Chand et al. 2025).

Participatory methods also improve the legitimacy and practical effectiveness of conservation policies. Communities are more willing to support sustainability practices when they are rewarded with better ecosystem services or paid through PES. The participatory approach boosts community mobilization, but the need for effective safeguards to secure long-term ecological prosperity is paramount (Mohamed et al. 2024).

The assessment of ecosystem services can assist in the development of Ecosystem-based Adaptation (EbA), particularly in areas vulnerable to climate change effects. The valuation and identification of services such as coastal defense, water regulation, and the conservation of biodiversity present an opportunity for policymakers to focus on nature-based solutions (Gosari et al. 2024).

Integrating these monetary values into spatial planning and structural development may reduce exposure to climate risks and vulnerabilities of the communities, as well as improve their ecological values. An identified example illustrates how planning and investment toward ecosystem services return incentivized land use budgeting can improve land use efficiency while advancing social equity (Bhadra et al. 2023). Yet, decision-makers and planners should acknowledge the uncertainty inherent in TEV estimates and use them together with ecological indicators, rather than relying on them as the sole basis for policy or management decisions.

Advanced strategies for financing EbA frameworks, such as green bonds and environmental taxes, which allocate funds to conservation and restoration projects, can be informed by valuation. Moreover, quantifying the economic valuation of ecosystem services strengthens Indonesia's participation in REDD+ and the Green Climate Fund initiatives, which Indonesia participates in, acknowledging the multifunctional benefits of mangroves for mitigating and adapting to climate change impacts (Kelleway et al. 2017).

The estimated total value of approximately USD 10,899.40 ha^{-1} year^{-1} for the Luppung Mangrove Forest exceeds many values reported in other Indonesian and global studies. For instance, Ashournejad et al. (2019) estimated the ecosystem service value of Iran's Nayband Marine National Park at approximately 5.5 million USD each year. Luppung's reasonably high value per hectare is likely due to the dense stands of mangroves, the greater ecological diversity of the area, its biogeophysical conditions, as well as the local benefit transfer revisions of economic-contextual subsidies. However, direct comparison across sites should be treated with caution due to methodological and contextual differences.

For equity evaluations and guiding conservation funding, such comparisons can provide useful context. They highlight the diversity and variation of mangrove ecosystems, indicating the need for tailored evaluations and appraisals. Future valuation studies should incorporate social and cultural dimensions, community dependence, and human pressures on mangrove ecosystems (Daulay et al. 2023). Recognizing the limitations of the benefit transfer method, it is still useful when accompanied by site-specific information and verification.

The application of ecological economics to the management of mangroves will advance conservation and foster sustainable development. For decision makers, economic valuation functions provide the basis for the recognition and the protection of natural capital essential for the maintenance of biodiversity and the livelihoods of local people. Nonetheless, these monetary values must be viewed as close approximations, not exact substitutes, for the ecological functions and services offered by ecosystems.

In conclusion, this research provides the first comprehensive assessment of the economic value of the Luppung Mangrove Forest located in Bulukumba District, Indonesia. This research highlights the substantial economic value mangroves offer through several ecosystem services. Although the value for supporting services is considerable, ecosystem services of supporting, provisioning, and regulating functions in mangroves have been predominantly underestimated, which is the result of certain methodological choices, particularly the benefit transfer assumption. The use values derived from the forest include timber, firewood, seeds, and medicinal bark. The regulating services provided by mangroves include coastal abrasion protection, prevention of seawater intrusion, and carbon sequestration. The justification for the protection of these ecosystems is twofold: the economic and ecological repercussions. The socio-ecological literature on mangrove forests spanning across continents aids in contributing to climate change mitigation efforts and supports the remaining biodiversity in coastal and climate-sensitive ecosystems. The results provide an empirical foundation for developing the PES mechanisms, integrating mangrove valuation into local climate adaptation strategies, and the need for more focus on the methodology aspect of the valuation of natural capital.

The study's scope was limited by its reliance on benefit transfer assumptions and static valuation parameters, which may not fully capture seasonal or cultural variations in ecosystem use. The sample size and spatial coverage were also confined to a single mangrove area, limiting generalization across regions. Future research should employ dynamic valuation models, spatial analysis, and participatory approaches to quantify changes over time and assess policy effectiveness. Integrating socio-cultural valuation, biodiversity indices, and long-term monitoring would further strengthen the evidence base for mangrove conservation economics.

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