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Towards Sustainable Eco-Mina Tourism: Biophysical Characterization and Development Pathways of Mangrove Ecosystems in Sorong District, Southwest Papua, Indonesia

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ABSTRACT

Mangrove ecosystems provide critical coastal protection, biodiversity support, and ecosystem services, making them valuable candidates for sustainable eco-mina tourism development. This study evaluated the biophysical characteristics and development potential of mangrove ecosystems in Sorong District, Southwest Papua, Indonesia, to inform sustainable tourism planning. Field surveys at three stations assessed mangrove species composition, structural attributes, and ecological indices, alongside measurements of water and soil quality, which were integrated into a weighted land suitability analysis. Results showed that mangrove stands were dominated by *Rhizophora apiculata* and *Bruguiera gymnorrhiza*, with secondary species such as *Avicennia alba* and *Xylocarpus moluccensis* contributing to biodiversity and regeneration capacity. Ecological indices indicated moderate to high diversity and evenness, reflecting ecosystem stability. Land suitability analysis classified all surveyed stations as moderately suitable (S2) for eco-mina tourism, with station 3 achieving the highest suitability score. Water and soil quality were generally favorable, though localized nutrient constraints highlight the need for careful environmental management. Overall, Sorong's mangrove ecosystems exhibit strong potential for sustainable eco-mina tourism, supported by ecological integrity and land suitability that can guide strategic development.

INTRODUCTION

Indonesia has an extensive and diverse coastal zone that serves as a transitional interface between terrestrial and marine ecosystems **(Kathiresan & Bingham, 2001; Krauss *et al.*, 2014)**. These coastal areas encompass several distinct ecosystems, including mangroves, coral reefs, seagrass beds, and estuaries, all directly influenced by oceanic waves and winds. Among these, mangrove ecosystems are unique in their ability to thrive in intertidal zones and muddy shorelines **(Kasnir *et al.*, 2009; Muharam, 2014; Prasenja *et al.*, 2017)**.

Indonesia possesses the largest mangrove area globally, accounting for approximately 23% of the world's mangroves, or about 3,489,140.68 ha in 2015 **(http://ppid.menlhk.go.id/, 2017; Nanlohy & Febriadi, 2021)**. By 2021, this had slightly declined to 3,311,208 ha (21% of the global total) **(Farah, 2021)**. The country harbors 202 mangrove plant species, comprising 89 tree species, five palm species, 19 climbers, 44 ground herbs, 44 epiphytes, and one fern species **(Setyawan, 2015)**, including both true mangroves and associated species.

Mangrove forests are highly productive ecosystems that provide direct and indirect benefits such as fuelwood, construction materials, medicinal resources, and fisheries products **(Sobari *et al.*, 2006; Imran & Efendi, 2016)**. Ecologically, they function in coastal protection, nursery provision for fish and shrimp, biodiversity conservation, nutrient cycling, and cultural as well as recreational services **(Kushartono, 2009; Setyawan, 2015; Umam *et al.*, 2015; Nugroho, 2019)**. Mangroves also support aquaculture **(Mulyadi *et al.*, 2010; Syamsu *et al.*, 2018)**, serve as industrial raw materials **(Setyawan, 2015; Khoiriyah, 2020)**, and contribute to birdwatching tourism **(Saeni & Maruapey, 2022)**.

In West Papua Province, mangrove forests covered about 438,252.70 ha **(BP DAS Membramo, 2006)**. In Sorong Regency, mangroves occupied roughly 46,833.29 ha, with a degradation rate of 5.84% of the provincial total **(SLHD Report, 2009; Yanti *et al.*, 2022)**. Following the establishment of Southwest Papua Province in December 2022, Sorong Regency became one of its administrative regions. Here, mangroves are concentrated in Sorong Timur and Sorong Kepulauan Districts, covering around 1,379.66 ha (0.04% of Indonesia's total), with 7–12 mangrove species recorded **(KKP-RZWP3K, 2012; Handayani *et al.*, 2020)**.

Field surveys in Klawalu mangrove ecotourism, Sorong Timur, reported dominance of *Rhizophora* species, alongside *Bruguiera* and *Ceriops* **(Naa *et al.*, 2020)**. Key species include *Rhizophora stylosa*, *Bruguiera gymnorrhiza*, *Xylocarpus granatum*, *Sonneratia caseolaris*, *Avicennia alba*, *Rhizophora apiculata*, *Bruguiera parviflora*, and *Ceriops tagal*. Rehabilitation programs, such as those by LPSPL Sorong in 2021, have engaged local communities and government agencies. However, degradation persists due to aquaculture expansion, timber harvesting, pollution, reclamation, sedimentation, mining, and natural disturbances **(Istomo & Naibaho, 2017; Nugroho, 2019; Rukman *et al.*, 2021)**, with some customary landowners converting mangroves into ponds (field observation, 2024). These pressures underscore the need for conservation-based management integrating land suitability and carrying capacity assessments.

One promising approach is eco-mina tourism, which combines ecological preservation with aquaculture and tourism, particularly through silvofishery systems that integrate forestry (*wana*), fisheries (*mina*), and tourism **(Sambu *et al.*, 2022)**. This model conserves mangrove habitats while generating socio-economic benefits through education, recreation, and fisheries-related activities **(Kathiresan & Bingham, 2001; Prasenja *et al.*, 2017)**. Successful applications have been reported in mangrove ecotourism sites across Indonesia **(Prasenja *et al.*, 2017; Prasenja, 2018)**, Kodingareng Keke coastal tourism **(Haerani *et al.*, 2019)**, and marine tourism **(Sutomo *et al.*, 2019)**.

Despite its promise, comprehensive studies that integrate biophysical assessments with land suitability and carrying capacity analysis for eco-mina tourism remain limited, especially in Papua. Prior research in Sorong has primarily addressed mangrove management and stakeholder participation **(Tabalessy, 2014; Serkadifa *et al.*, 2018; Handayani *et al.*, 2020)** but has not combined ecological characterization with feasibility evaluation. To fill this gap, the present study integrates biophysical characterization with land suitability and carrying capacity assessments to establish a sustainability-oriented framework for eco-mina tourism. Given the ecological importance and socio-economic potential of mangroves in Sorong, this research provides a novel contribution by offering an integrated biophysical assessment—covering vegetation diversity, water quality, and land suitability—as a scientific foundation for promoting sustainable eco-mina tourism in Southwest Papua, Indonesia.

MATERIALS AND METHODS

1. Study area and period

This observational study was conducted from October 2023 to March 2024 within the mangrove ecosystem of Sorong District, Sorong Regency, Southwest Papua, Indonesia. The study site encompasses approximately 1,621 hectares of mangrove forest in Warmon Village (Fig. 1). Geographically, the area lies between latitudes 1º03' to 1º16' South and longitudes 110º37' to 113º37' East. Complementary analyses of water and soil quality parameters were performed at the Water Quality Laboratory of the Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar.

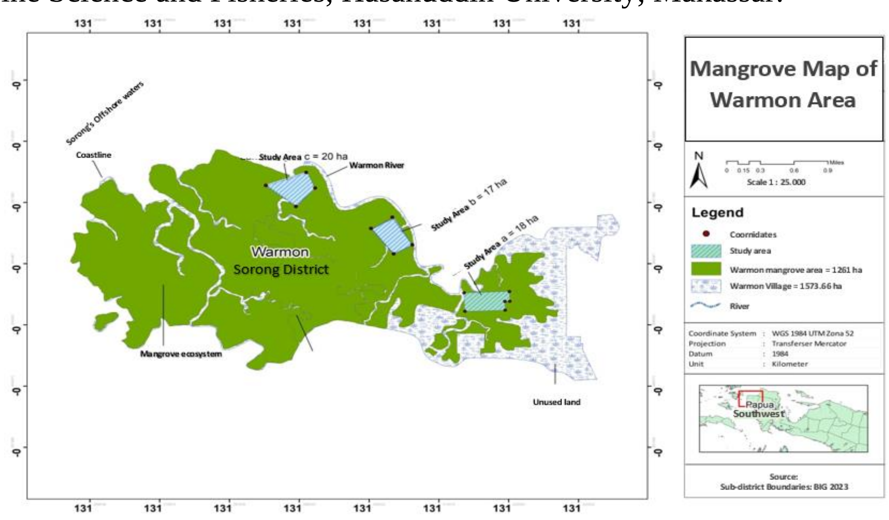

Fig. 1. Map of the research site (Blue box)

2. Research design and instruments

This research employed an exploratory design with a quantitative descriptive approach, integrating survey and identification methods. The research instruments and materials essential for the effective conduct of this study and subsequent data processing are summarized in Table (1). These include spatial maps of the study area to guide field navigation and plotting, stationery supplies for recording and documentation, optical equipment such as binoculars for detailed observation, and a global positioning system (GPS) device for precise geolocation data collection. Digital documentation was facilitated using a digital camera, while verbal data were captured through a voice recorder. Field measurements were conducted using measuring tapes and rolls for delineating plot boundaries, complemented by rulers and cutting tools (cutters) for sample preparation. Structured data collection was supported by standardized questionnaires designed for various respondent groups. Finally, computer hardware and specialized software were employed for efficient data entry, management, statistical processing, spatial analysis, and the generation of analytical outputs.

Table 1. Detailed research instrument

Objective	Data Type	Data Source	Data Collection Technique
Describing the current structure and ecological model of the mangrove area in relation to eco-mina tourism integration	**Primary Data**: - Importance Value Index (IVI) - Dominance Index - Species Diversity Index - Species Abundance Index	Field observation (vegetation plots)	In situ ecological survey (vegetation sampling and observation)
Assessing the current environmental condition of the mangrove area for eco-mina tourism development	**Primary Data**: - Water quality parameters - Soil quality parameters	Field & laboratory tests (soil and water analysis)	Ground Control Point (GCP) survey with GPS; Water and soil sampling; laboratory analysis

3. Data collection

The data collection encompassed field observations, which were quantified and analyzed to describe current conditions and uncover facts related to the bioecological and cultural potential supporting eco-mina tourism management in the mangrove area of Sorong District. Following primary data were collected directly through *in situ* field observations and documentation.

a) Vegetation analysis

Vegetation in the mangrove ecosystem was surveyed using a transect plot method with discontinuous plots (Fig. 2). Observation plots were laid along a 600-meter transect with a width of 20 meters, totaling 1.8 hectares of sampled area. According to **Wyatt-Smith (1995)** and **Antonius (2018)**, a single plot of 0.6 hectares in tropical rainforest is sufficiently representative of stand structure. The sampling design included plots of varying sizes corresponding to growth stages, including seedlings (2 m × 2 m); saplings or pancang (5 m × 5 m); poles or tiang (10 m × 10 m); and mature trees (20 m × 20 m). For each growth stage, 15 plots were established along three transects, resulting in 45 plots per growth level.

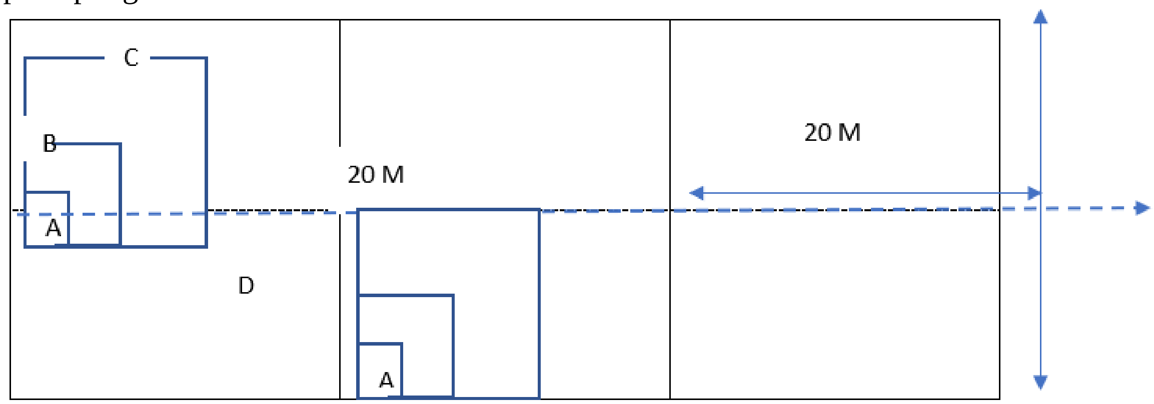

Fig. 2. Vegetation observation plot shape

Tree species identification followed diameter-based classification as per **Antonius (2018)**, including mature trees (DBH ≥ 35 cm); poles (DBH 10–35 cm); saplings (DBH < 10 cm, height > 1.5m); and seedlings (height < 1.5m, including understory plants). Diameter at breast height (DBH) was measured at approximately 1.3m above ground or 20cm above buttress roots. Rare and protected species, including epiphytes such as orchids, were recorded along the transects based on presence and aesthetic or conservation value.

b) Quality of water and soil data collection

Oceanographic parameters were measured at three sampling points per site, including temperature, salinity, depth, pH, dissolved oxygen (DO), nitrate, phosphate, ammonia, nitrite, organic nitrogen, organic carbon, C/N ratio, and organic matter content. Instruments used included thermometers, salinometers, water level meters, pH meters, and DO meters. Nutrient analyses were conducted using spectrophotometry and titration methods (Kjeldahl for N-organic, Walkley-Black for organic carbon). The C/N ratio was calculated as:

$$\text{C/N ratio} = \frac{\text{Carbon Organic Value}}{\text{Total Nitrogen Value}}$$

4. Data analysis

a) Importance value index (IVI)

For pole and tree size classes, the importance value index (IVI) was calculated using the formula: IVI = Relative Density (RD) + Relative Dominance (RDo) + Relative Frequency (RF), while for seedling and sapling classes, IVI was calculated as IVI = Relative Density (RD) + Relative Frequency (RF).

b) Dominance index (D) and species diversity index (H')

This index represents the degree of dominance concentration of species within the community and is computed as *D* = ∑ (n1/N, whereas *H'* describes the biological organization level of the community, calculated using the Shannon-Wiener diversity formula: *H* = - ∑ {(n1/N) log (n1/N)}, where *n1* is the importance value of species -i and *N* reflects the total importance value of all species.

c) Species evenness index (e)

This index is influenced by species diversity and richness, calculated as e = H/log S, where *e* is species evenness, *H* is the species diversity index, and *S* is the total number of species.

d) Land suitability scoring and weighting

The suitability class for aquaculture and eco-mina tourism development was determined by calculating weighted scores (Bobscore), integrating parameter weights (Bobkes) and parameter scores (Bobpar) for each relevant factor, following the formula:

$$Bobscore = \frac{\sum(Bobkes \times Bobpar)}{\sum Bobpar}$$

Bobscore = (Bobkes−1 × Bobpar−1) + (Bobkes−2 × Bobpar−2) +⋯+ (Bobkes−n × Bobpar−n) Bobpar−1 + Bobpar−2 +⋯+ Bobpar−n. Assessing land suitability through a weighted scoring system, as summarized in Table (2).

Table 2. Environmental quality criteria and scoring

No.	Parameter	Range	Score	Weight	Total
1	Temperature (°C)	25–32 / 12–25 / <12 or >32	3 / 2 / 1	3	9 / 6 / 3
2	Salinity (ppt)	10–20 / 20–35 / <10 or >35	3 / 2 / 1	3	9 / 6 / 3
3	Depth (cm)	70–120 / 80–110 or 120–150 / <70 or >150	3 / 2 / 1	2	6 / 4 / 2
4	Transparency (cm)	30–40 / 25–30 or 40–60 / <25 or >60	3 / 2 / 1	2	6 / 4 / 2
5	pH (water)	6–8 / 4–6 or 8–9 / <4 or >9	3 / 2 / 1	2	6 / 4 / 2
6	Dissolved Oxygen (mg/L)	4–7 / 2.5–4 / <2.5	3 / 2 / 1	1	3 / 2 / 1
7	Nitrate (NO_3, ppm)	0.3–0.9 / 0.9–3.5 / >3.5 or <0.3	3 / 2 / 1	1	3 / 2 / 1
8	Phosphate (mg/L)	>0.21 / 0.1–0.21 / 0.051–0.1	3 / 2 / 1	1	3 / 2 / 1
9	Ammonia (ppm)	0–0.03 / 0.03–0.05 / 0.05–0.08	3 / 2 / 1	1	3 / 2 / 1
10	Nitrite (NO_2, ppm)	0–0.1 / 0.1–0.25 / 0.26–0.45	3 / 2 / 1	1	3 / 2 / 1
11	Total N (%)	>0.5 / 0.4–0.5 / 0.25–0.4	3 / 2 / 1	0.5	1.5 / 1 / 0.5
12	Organic Carbon (%)	1.5–2.5 / 0.5–1.5 / <0.5 or >2.5	3 / 2 / 1	0.5	1.5 / 1 / 0.5
13	C/N Ratio (%)	5–8 / 8–12 / <5 or >12	3 / 2 / 1	1	3 / 2 / 1
14	Organic Matter (%)	3–5 / 1–3 / <1 or >5	3 / 2 / 1	1	3 / 2 / 1
15	Soil pH	<0.5 / 0.5–1.5 / >1.5	3 / 2 / 1	0.5	1.5 / 1 / 0.5

RESULTS AND DISCUSSIONS

1. Vegetation analysis

a) Importance value index (IVI)

The analysis of the importance value index (IVI) across the three stations (Fig. 2) revealed that *Rhizophora apiculata* exhibited the highest ecological dominance, particularly at station 1 (143.05%) and station 2 (141.36%). *Bruguiera gymnorrhiza* also showed high IVI values at STA-1 (114.21%) and station 2 (104.48%), although its contribution sharply declined at station 3 (27.24%). Conversely, *Avicennia alba* increased progressively from station 1 (39.30%) to station 3 (73.04%), indicating a broader distribution in the seaward zone. Other species, such as *Xylocarpus moluccensis* (122.11% at station 1) and *X. granatum* (30.30% at station 2), demonstrated site-specific dominance, suggesting microhabitat specialization. In contrast, species such as *Avicennia lanata*, *Rhizophora mucronata*, *Rhizophora* sp., and *Sonneratia alba* exhibited relatively low IVI values (<30%) and were limited in their occurrence across stations.

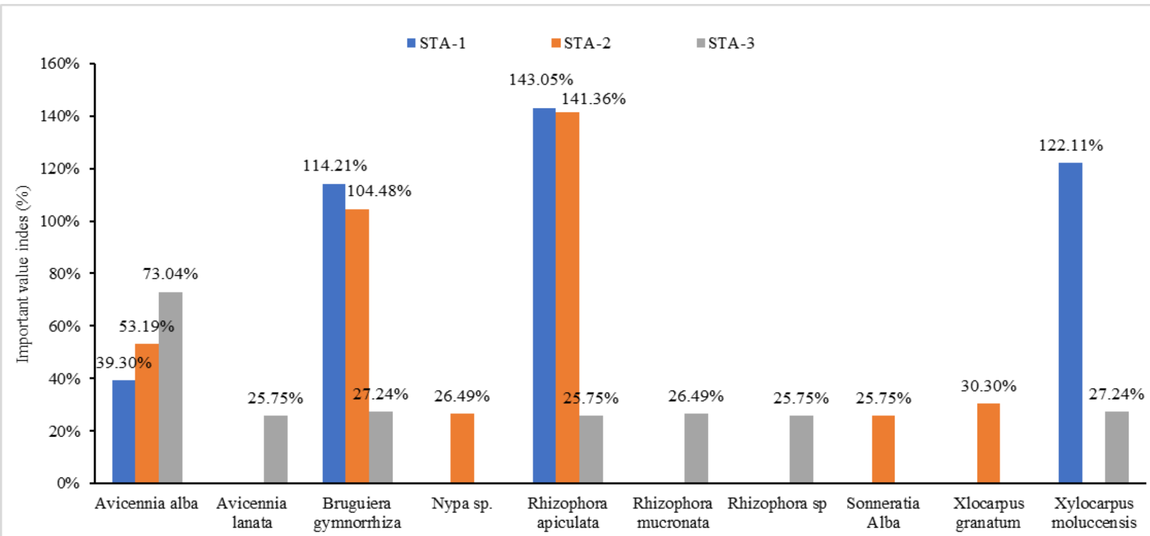

Fig. 2. Importance value index for each station

When analyzed across growth classes (Fig. 3), *R. apiculata* maintained strong dominance, particularly at the sapling stage (143%) and to a lesser degree at the pole stage (70%). *B. gymnorrhiza* was dominant in the tree class (112%), while *X. moluccensis* showed consistently high importance across growth stages (92% in poles and 79% in seedlings). In contrast, *A. alba* had moderate values across stages (52% in poles and 61% in saplings), indicating its adaptive capacity but limited competitive dominance compared with *Rhizophora*. Minor species such as *A. lanata*, *Nypa* sp., and *S. alba* contributed less than 20%, suggesting marginal roles in the current regeneration dynamics.

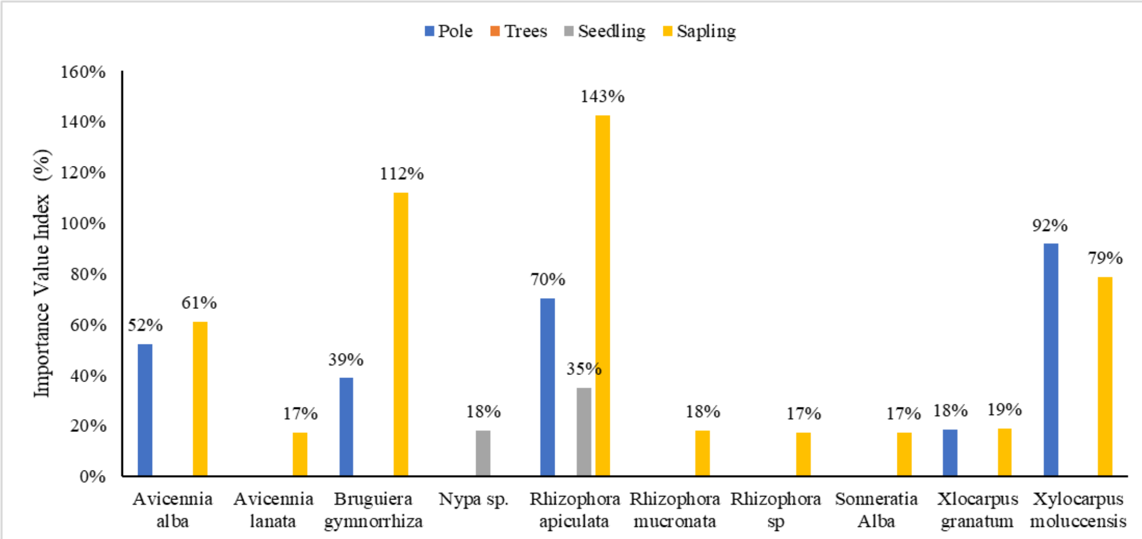

Fig. 3. Importance value index of mangrove for each growth class

The IVI results reveal a clear dominance of *R. apiculata* and *B. gymnorrhiza* in most stations, which aligns with their well-established ecological role in stabilizing shorelines and forming dense stands in Indo-Pacific mangrove ecosystems **(Tomlinson, 2016; Hassan *et al.*, 2018; Sese *et al.*, 2025)**. The dominance patterns have practical implications for eco-mina tourism: areas dominated by a few species may require targeted planting or conservation to enhance visual appeal and ecological stability for visitors, while diverse assemblages can provide more engaging educational and recreational opportunities **(Friess *et al.*, 2019)**.

In contrast, the relatively high importance of *X. moluccensis* at specific sites suggests localized habitat suitability, possibly linked to soil salinity and hydrological gradients. This species' consistent presence across multiple growth stages indicates its potential long-term role in forest succession and structural heterogeneity **(Giesen *et al.*, 2007)**. Meanwhile, *A. alba* displayed increasing dominance toward the seaward station (station 3), reflecting its pioneer role in colonizing open and unstable substrates. Such zonation patterns are consistent with the general ecological distribution of *Avicennia* spp., which often dominate the seaward edge due to their pneumatophore-based aeration system **(Kathiresan & Bingham, 2001)**.

Species with lower IVI values, such as *S. alba*, *A. lanata*, and *N. fruticans*, play complementary roles in maintaining species diversity. However, their limited distribution suggests they are less competitive under the current site conditions. However, their persistence in specific niches indicates resilience against environmental fluctuations, which may be ecologically significant under future climate change scenarios **(Lovelock & Duarte, 2019)**. The results suggest that a few key species dominate the studied mangrove stands, with *R. apiculata* and *B. gymnorrhiza* as ecological keystones. At the same time, *A. alba* and *X. moluccensis* contribute significantly to zonation and successional processes. This structure reflects a typical Southeast Asian mangrove assemblage and underscores the need for species-specific management strategies to maintain ecosystem resilience.

The Importance Value Index (IVI) analysis across species (Fig. 4) reveals that *R. apiculata* dominates the mangrove community with an exceptionally high IVI of 185%. This suggests that the species is ecologically the most influential within the study area, playing a central role in maintaining the structural and functional integrity of the mangrove ecosystem. Similarly, *B. gymnorrhiza* (124%) and *X. moluccensis* (125%) exhibit substantial ecological importance, reinforcing the structural heterogeneity of the mangrove stands. In contrast, species such as *A. lanata*, *R. mucronata*, *Rhizophora* sp., *S. alba*, and *Nypa* sp. show markedly lower IVI values (17%–18%). Their limited contribution indicates a relatively minor ecological role, possibly due to competitive exclusion, environmental filtering, or niche specialization within the mangrove community.

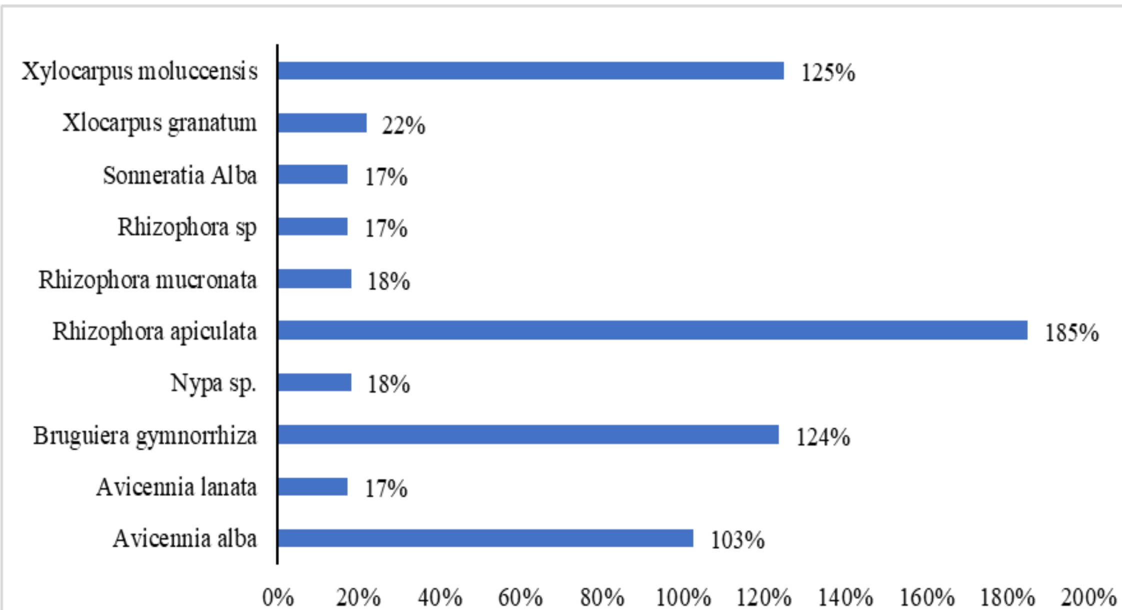

Fig. 4. Importance value index for each species

These results highlight a dominance hierarchy where a few species exert disproportionate influence over community composition, a common characteristic of mangrove ecosystems where few taxa often shape forest structure and ecological functioning **(Farhath *et al.*, 2025)**. The coexistence of both dominant and minor species is ecologically significant, as less dominant taxa often provide complementary ecological functions, contribute to species richness, and enhance ecosystem resilience under environmental stressors **(Friess *et al.*, 2019)**.

From a management perspective, the strong dominance of *R. apiculata* underscores its value for conservation and restoration programs, given its ecological stability and high capacity for natural regeneration. However, the relatively low IVI of other species suggests the need for active measures to maintain species diversity, as monoculture-like dominance may reduce long-term ecosystem resilience to climate change, hydrological alteration, or anthropogenic disturbance **(Akram *et al.*, 2023)**.

b) Dominance (D), diversity (H'), and evenness index (e)

The ecological indices calculated for the mangrove vegetation across the three stations provide insights into community structure, species dominance, and diversity patterns (Fig. 5). Station 3 exhibited the highest species diversity index (H′ = 1.6081) and a low dominance index (D = 0.2650), indicating a relatively balanced and heterogeneous assemblage.

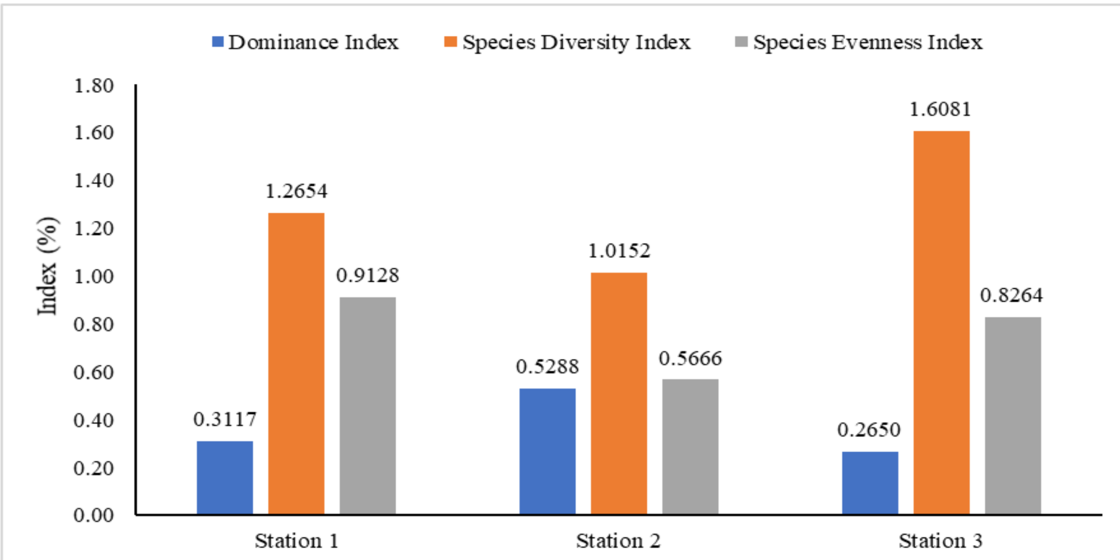

Fig. 5. Dominance, diversity, and evenness indices for all stations

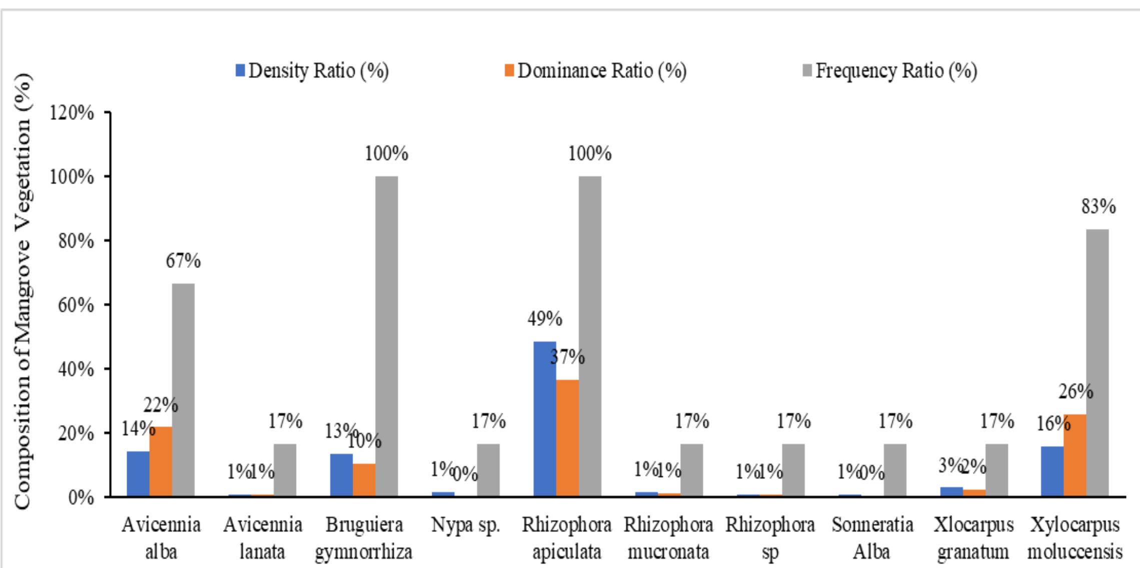

Fig. 6. Relative density, dominance, and frequency (%) for each species

Such high diversity and evenness suggest sites that can support interactive tourism activities like guided walks, birdwatching, and educational signage, providing visitors with a more heterogeneous and engaging experience **(Park *et al.*, 2019)**. In contrast, station 2 had the lowest diversity (H′ = 1.0152) and the highest dominance (D = 0.5288), which may limit aesthetic and recreational value due to visually monotonous stands, but still offers potential for focused aquaculture or research-based tourism. High dominance with low evenness (E = 0.5666) indicates reduced ecological stability, as ecosystem processes such as nutrient cycling and habitat heterogeneity may be constrained when few species dominate **(Tomlinson, 2016; Friess *et al.*, 2019)**. Station 1 showed intermediate diversity and evenness, supporting moderately balanced eco-tourism activities.

Relative density and frequency analysis confirm *R. apiculata* as the keystone species (density 49%, dominance 37%, frequency 100%) (Fig. 6). From a tourism perspective, the presence of visually and structurally dominant species like *R. apiculata* can enhance landscape appeal for visitors, but maintaining subordinate species is crucial to ensure ecological heterogeneity and sustain multi-use tourism activities **(Donato *et al.*, 2011)**. *X. moluccensis* also plays a significant structural role, while *A. alba* and *B. gymnorrhiza* contribute moderately, reinforcing community heterogeneity. Conversely, *A. lanata*, *R. mucronata*, *S. alba*, and *Nypa* sp. exhibit low densities and frequencies, highlighting their minor yet ecologically complementary roles. These low-abundance species are crucial for maintaining genetic diversity, supporting regeneration processes, and buffering the ecosystem against environmental stressors **(Lovelock & Duarte, 2019)**.

The combination of high dominance indices at certain stations with varying species diversity suggests spatial heterogeneity in environmental conditions or anthropogenic pressures, such as localized hydrology, sediment deposition, or human disturbance. For instance, the dominance of *R. apiculata* may be associated with its superior tolerance to tidal inundation and variable salinity. In contrast, the lower abundance of *Nypa* sp. and *S. alba* reflects their more specialized ecological niches **(Kathiresan & Bingham, 2001)**. From a management perspective, these findings imply that while current mangrove stands can support eco-mina tourism, maintaining species diversity through targeted conservation of subordinate species is essential to ensure long-term ecosystem stability and resilience.

2. Water and soil quality parameters

The water and soil quality assessment across the three sampling stations in Sorong District revealed relatively consistent ecological conditions, with some variations in key parameters, as detailed in Tables (3, 4, and 5). Water temperature and salinity were consistently suitable for mangroves and brackish-water aquaculture (25.91– 31.73°C; 11.92– 19.33ppt). These conditions allow integration of aquaculture species such as milkfish or mud crabs into eco-mina tourism activities, linking ecological health with visitor experience **(Arifanti *et al.*, 2022)**.

Table 3. Land suitability based on water and soil quality parameters at station 1

Parameter	Weight	Field data	Score	Weighted
Temperature (°C)	3	31.73	3	9
Salinity (ppt)	3	17.5	3	9
Depth (cm)	2	24.17	1	2
Transparency (cm)	2	100	1	2
pH (water)	2	5.35	2	4
Dissolved Oxygen (mg/L)	1	2.24	1	1
Nitrate (NO_3, ppm)	1	0.0986	1	1
Phosphate (mg/L)	1	0.0091	1	1
Ammonia (ppm)	1	0.0053	3	3
Nitrite (NO_2, ppm)	1	0.001	3	3
Total N (%)	0.5	0.0022	1	0.5
Organic Carbon (%)	0.5	1.0758	2	1
C/N Ratio (%)	1	18.16	1	1
Organic Matter (%)	1	2.15	2	2
Soil pH	0.5	7	3	1.5

Table 4. Land suitability based on water and soil quality parameters at station 2

Parameter	Weight	Field data	Score	Weighted
Temperature (°C)	3	29.95	3	9
Salinity (ppt)	3	19.33	3	9
Depth (cm)	2	12.17	1	2
Transparency (cm)	2	100	1	2
pH (water)	2	5.44	2	4
Dissolved Oxygen (mg/L)	1	2.72	2	2
Nitrate (NO_3, ppm)	1	0.0712	1	1
Phosphate (mg/L)	1	0.0083	1	1
Ammonia (ppm)	1	0.0037	3	3
Nitrite (NO_2, ppm)	1	0.0017	3	3
Total N (%)	0.5	0.0027	1	0.5
Organic Carbon (%)	0.5	0.6803	2	1
C/N Ratio (%)	1	13.33	1	1
Organic Matter (%)	1	1.36	2	2
Soil pH	0.5	7	3	1.5

Table 5. Land suitability based on water and soil quality parameters at station 3

Parameter	Weight	Field data	Score	Weighted
Temperature (°C)	3	25.91	3	9
Salinity (ppt)	3	11.92	3	9
Depth (cm)	2	44.67	1	2
Transparency (cm)	2	75	1	2
pH (water)	2	5.89	2	4
Dissolved Oxygen (mg/L)	1	2.32	1	1
Nitrate (NO_3, ppm)	1	0.0626	1	1
Phosphate (mg/L)	1	0.0082	1	1
Ammonia (ppm)	1	0.0225	3	3
Nitrite (NO_2, ppm)	1	0.0033	3	3
Total N (%)	0.5	0.0023	1	0.5
Organic Carbon (%)	0.5	0.5665	2	1
C/N Ratio (%)	1	6.03	3	3
Organic Matter (%)	1	1.13	2	2
Soil pH	0.5	7	3	1.5

Furthermore, depth and transparency, however, exhibited substantial variability, such as depths were relatively shallow across sites (12.17– 44.67cm), while transparency was consistently high at stations 1 and 2 but lower at station 3 (75%). Water pH was slightly acidic (5.35–5.89) at all stations, which is marginal but still tolerable for mangrove-associated biota. Dissolved oxygen (2.24– 2.72mg/ L) was below aquatic organisms' recommended threshold, suggesting localized hypoxic conditions. Nutrient concentrations, including nitrate, phosphate, and total nitrogen, were consistently low across stations, whereas ammonia and nitrite remained within suitable thresholds. Soil quality parameters indicated moderate levels of organic carbon (0.5665–1.0758%) and organic matter (1.13–2.15%), with C/N ratios ranging from 6.03 at station 3 to 18.16 at station 1, reflecting different stages of organic matter decomposition. Soil pH was consistently neutral (7), providing a stable substrate for mangrove vegetation.

The weighted scoring analysis integrated these parameters into a composite land suitability index. All stations fell into the S2 (moderately suitable) class, with scores ranging narrowly between 2.00 and 2.10 (Table 6). This consistency suggests that while the sites are generally ideal for eco-mina tourism development, certain limiting factors, particularly shallow depth, low dissolved oxygen, and marginal pH, prevent them from achieving optimal (S1) classification.

Table 6. Land suitability summary

Station	Sum Weighted Score	Total Weight	Bobscore	Class
1	41	20.5	2	S2 (Suitable)
2	42	20.5	2.048780	S2 (Suitable)
3	43	20.5	2.097561	S2 (Suitable)

The results indicate that the mangrove ecosystems in Sorong District exhibit biophysical conditions supportive of eco-mina tourism development, albeit with moderate limitations. Water temperature and salinity were consistently within the favorable range for mangrove health and brackish-water aquaculture, aligning with previous findings that mangroves thrive between 25– 32°C and under salinity conditions of 10– 25ppt **(Tarunamulia *et al.*, 2024; Zhou *et al.*, 2024)**. These parameters ensure the physiological tolerance of mangrove species and provide suitable conditions for culturable organisms such as milkfish and mud crabs, which are commonly integrated into eco-mina systems **(Arifanti *et al.*, 2022)**.

Nevertheless, dissolved oxygen levels below 3mg/ L across all stations are concerning, as they fall short of the 4– 7mg/ L required for robust aquatic productivity **(Haseeba *et al.*, 2025)**. This indicates that aquaculture-based tourism may require management interventions (e.g., aeration) to maintain aquatic health and ensure safe interaction for visitors, which is a critical feasibility consideration. Similarly, slightly acidic pH (5.35–5.89) may constrain aquaculture but remains tolerable for mangroves, suggesting careful pond management is needed for integrated tourism activities **(Mandal & Barr, 2019)**.

Soil properties were moderately fertile with neutral pH, supporting mangrove stability and nutrient cycling. This ensures that eco-tourism infrastructure, such as boardwalks or observation platforms, can be developed with minimal ecological disturbance. The wide C/N ratios observed between stations reflect differing decomposition dynamics, which could influence nutrient cycling and organic enrichment **(Donato *et al.*, 2011)**. Neutral soil pH (7) is a significant strength, as it supports mangrove vegetation stability and sediment-associated microbial processes critical for nutrient regeneration **(Kida *et al.*, 2020)**.

Overall, the S2 classification underscores the potential of these sites for eco-mina tourism, provided management strategies are implemented to mitigate limiting factors. Improvements could include aeration or hydrological modification to address dissolved oxygen deficits and nutrient supplementation to enhance aquaculture viability. Integrating ecological indices (H′, D, E) with water and soil parameters provides a practical framework for selecting tourism sites that balance ecological integrity, aquaculture potential, and visitor experience.

Although comprehensive socio-economic data are not yet available, this biophysical assessment provides a critical baseline for planning eco-mina tourism initiatives. The observed vegetation structure, species diversity (H′), dominance (D), and evenness (E), along with water quality parameters (DO, pH, salinity), highlight areas suitable for low-impact aquaculture and recreational activities **(Kathiresan & Bingham, 2001; Friess *et al.*, 2019; Arifanti *et al.*, 2022)**. For instance, stations with higher species diversity and evenness, such as station 3, may offer more visually attractive and ecologically stable sites for tourism and educational activities, whereas stations with higher dominance indices may require targeted conservation to prevent monoculture-like conditions **(Lovelock & Duarte, 2019; Park *et al.*, 2019)**.

These findings emphasize that site selection for eco-mina tourism should consider both ecological resilience and aesthetic or functional attributes that attract visitors. The integration of biophysical indicators into management planning can inform stakeholder engagement, guide community-based aquaculture placement, and support the long-term sustainability of tourism activities, even before full socio-economic assessments are conducted **(Kathiresan & Bingham, 2001; Haerani *et al.*, 2019; Sutomo *et al.*, 2019; Sambu *et al.*, 2022)**. Future research will complement this baseline with direct surveys on community participation, economic benefits, and stakeholder perceptions, further strengthening the planning and development of eco-mina tourism in Sorong District.

CONCLUSION

This finding demonstrates strong potential for sustainable eco-mina tourism in Sorong, Southwest Papua. Mangrove vegetation is dominated by *R. apiculata* and *B. gymnorrhiza*, which exhibit the highest importance value indices and dominance ratios, providing structural stability and key ecosystem functions such as shoreline protection and habitat provision. Secondary species, including *A. alba* and *X. moluccensis*, enhance community heterogeneity and contribute to regeneration potential. Based on the integration of ecological indices (diversity, dominance, evenness) and environmental parameters (DO, pH, salinity), we propose a strategic framework for eco-mina tourism development that includes: (1) site selection prioritizing areas with high diversity and structural stability, (2) active conservation of dominant and subordinate species to maintain ecological resilience, (3) monitoring and management of water and soil quality to support aquaculture integration, and (4) design of visitor infrastructure that minimizes ecological disturbance. Land suitability assessment based on weighted scores indicates that all surveyed stations fall within the “suitable” class (S2) for eco-mina tourism development. Targeted interventions to address identified limitations, such as improving dissolved oxygen levels and mitigating acidic conditions, are recommended to ensure long-term ecosystem health and tourism feasibility. Overall, these results provide a practical roadmap for implementing eco-mina tourism in Sorong, balancing ecological integrity, socio-economic opportunities, and sustainable community engagement.

REFERENCES

Akram, H.; Hussain, S.; Mazumdar, P.; Chua, K.O.; Butt, T.E. and Harikrishna, J.A. (2023). Mangrove health: A review of functions, threats, and challenges associated with mangrove management practices. *Forests*, **14**(9), 1698. https://doi.org/10.3390/f14091698

Antonius. (2018). *Management of peat swamp forest ecotourism for the welfare of communities around the Baning Nature Tourism Park area*. Doctoral Program in Environmental Science, Postgraduate Program, Brawijaya University, Malang.

Arifanti, V.B.; Sidik, F.; Mulyanto, B.; Susilowati, A.; Wahyuni, T.; Subarno; Yulianti; Yuniarti, N.; Aminah, A.; Suita, E. et al. (2022). Challenges and strategies for sustainable mangrove management in Indonesia: A review. *Forests*, **13**(5), 695. https://doi.org/10.3390/f13050695

Donato, D.C.; Kauffman, J.B.; Murdiyarso, D.; Kurnianto, S.; Stidham, M. and Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, **4**(5), 293-297. https://doi.org/10.1038/ngeo1123

Farah, N. (2021, November 5). Econusa. Nature. Culture. Conservation. From EcoNusa: https://econusa.id/id/ecodefender/mengenal-wanamina/

Farhath, A.A.; Nandan, S.B.; Sreelekshmi, S.; Rifga, M.; Naeem, I.; Hershey, N.R. and Ntakirutimana, R. (2025). Mangrove ecosystems in the Maldives: A nationwide assessment of diversity, habitat typology and conservation priorities. *Earth*, **6**(3), 66. https://doi.org/10.3390/earth6030066

Friess, D.A.; Rogers, K.; Lovelock, C.E.; Krauss, K.W.; Hamilton, S.E.; Lee, S.Y.; Lucas, R.; Primavera, J.; Rajkaran, A. and Shi, S. (2019). The state of the world's mangrove forests: Past, present, and future. *Annual Review of Environment and Resources*, **44**(1), 89-115. https://doi.org/10.1146/annurev-environ-101718-033302

Giesen, W.; Wulffraat, S.; Zieren, M. and Scholten, L. (2007). *Mangrove guidebook for Southeast Asia*. FAO & Wetlands International.

Haerani, N.U.; Kasnir, M. and Asbar, A. (2019). Coastal tourism management strategy based on suitability and carrying capacity in Turtle Village, Selayar Islands Regency. *Journal of Indonesian Tropical Fisheries (Joint-Fish): Jurnal Akuakultur, Teknologi Dan Manajemen Perikanan Tangkap, Ilmu Kelautan*, **2**(2), 136-147. https://jurnal.fpik.umi.ac.id/index.php/JOINT-FISH/article/view/47

Handayani, H.; Mustasim, M. and Suruwaky, A.M. (2020). Community perception and participation towards the mangrove ecosystem in East Sorong District, Sorong City, West Papua Province. *Jurnal Airaha*, **9**(01), 58-62.

Haseeba, K.P.; Aboobacker, V.M.; Vethamony, P. and Al-Khayat, J.A. (2025). Water and sediment characteristics in the Avicennia marina environment of the Arabian Gulf: A review. *Marine Pollution Bulletin*, 117963. https://doi.org/10.1016/j.marpolbul.2025.117963

Hassan, M.K.; Jintana, V.; Kuittinen, S. and Pappinen, A. (2018). Management practices and aboveground biomass production patterns of Rhizophora apiculata plantation: Study from a mangrove area in Samut Songkram Province, Thailand. *BioResources*, **13**(4), 7826-7850. https://doi.org/10.15376/biores.13.4.7826-7850

Imran, A. and Efendi, I. (2016). Mangrove Inventory on the Cemara Coast of West Lombok. *JUPE: Mandala Education Journal*, **1**(1), 105-112.

Istomo, K.C. and Naibaho, B.D. (2017). Biomass potential on several mangrove planting models in Java Island, Indonesia. *AACL Bioflux*, **10**(4), 754-767.

Kasnir, M.; Fahrudin, A.; Bengen, D.B. and Boer, M. (2009). Analysis of the suitability and carrying capacity of marine tourism management in the Spermonde Islands, Pangkajene and Kepulauan Regency. Postgraduate School, Bogor Agricultural University, Bogor. https://repository.ipb.ac.id/handle/123456789/55126

Kathiresan, K. and Bingham, B.L. (2001). Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology*, **40**, 81-251. https://doi.org/10.1016/S0065-2881(01)40003-9

Khoiriyah, U. (2020). Development of green leaf mangrove forest ecotourism to improve the economy of the Daun Village community, Sangkapura District, Gresik Regency. *Al-Idarah: Jurnal Manajemen dan Bisnis Islam*, **1**(1), 98-112.

Kida, M. and Fujitake, N. (2020). Organic carbon stabilization mechanisms in mangrove soils: A review. *Forests*, **11**(9), 981. https://doi.org/10.3390/f11090981

Krauss, K.W.; McKee, K.L.; Lovelock, C.E.; Reef, R. and Chen, L. (2014). How mangrove forests adjust to rising sea level. *New Phytologist*, **202**(1), 19-34.

Kristensen, E.; Bouillon, S.; Dittmar, T. and Marchand, C. (2021). Organic carbon dynamics in mangrove ecosystems: A review. *Aquatic Botany*, **176**, 103449. https://doi.org/10.1016/j.aquabot.2021.103449

Kushartono, E.W. (2009). Some biophysical and chemical aspects of soil in the Mangrove Area of Pasar Banggi Village, Rembang Regency. *Marine Science: Indonesian Journal of Marine Sciences*, **14**(2), 76-83.

Lovelock, C.E. and Duarte, C.M. (2019). Dimensions of blue carbon and emerging perspectives. *Biology Letters*, **15**(3), 20180781. https://doi.org/10.1098/rsbl.2018.0781

Mandal, R.N. and Bar, R. (2019). *Mangroves for building resilience to climate change* (1st ed., 362 pp.). Apple Academic Press.

Ministry of Environment. (2017). Miliki 23% Ekosistem Mangrove Dunia, Indonesia Tuan Rumah Konferensi Internasional Mangrove 2017. http://ppid.menlhk.go.id/: http://ppid.menlhk.go.id/siaran_pers/browse/561

Muharam. (2014). Mangrove planting as an effort to rehabilitate land and the environment in the North Coastal Area of Karawang Regency. *Scientific Solutions Journal*, **1**(1), 1-14.

Mulyadi, E.; Hendriyanto, O. and Fitriani, N. (2010). Mangrove forest conservation as ecotourism. *Journal of Environmental Engineering*, **2**(1), 11-18.

Naa, L.; Wanggai, C. and Siburian, R. (2020). Ecotourism potential of Klawalu mangrove forest, Sorong City, West Papua. *Median*, **12**(2), 57-64.

Nanlohy, L.H. and Febriadi, I. (2011). Identification of the economic value of the Klawalu mangrove tourism area in Sorong City. *Journal of Fisheries and Marine Research*, **3**(2), 319-331.

Nugroho, T.S. (2019). Analysis of land suitability and carrying capacity of mangrove ecotourism in the Muara Kubu Mangrove Area, West Kalimantan. *Journal of Natural Resources and Environmental Management*, **9**(2), 483-497.

Park, J.; Kim, H.S.; Jo, H.K. and Jung, I.B. (2019). The influence of tree structural and species diversity on temperate forest productivity and stability in Korea. *Forests*, **10**(12), 1113. https://doi.org/10.3390/f10121113

Prasenja, Y. (2018). The role of the community in managing ecotourism on Lusi Island, Sidoarjo Regency. *Indonesian Geography Magazine*, **32**(2), 123-129.

Prasenja, Y.; Abimanyu, T.A. and Dietrich, B.G. (2017). Sustainability analysis of mangrove ecosystems for ecotourism activities on Lumpur Island, Sidoarjo. *Journal of Tropical Marine Science and Technology*, **9**(1), 175-184.

Rukman, W.Y.; Safitri, D.; Thahir, R. and Magfirah, N. (2021). Reforestation as a response to the impact of abrasion due to the opening of salt ponds in Pallengu, Jeneponto Regency. *ABDIPRAJA (Community Service Journal)*, **2**(1), 50-56.

Sabang, H. and Rahmiyah, S. (2012). Soil organic matter and nitrogen content in mangrove ecosystems. *Journal of Soil Science and Environmental Management*, **3**(8), 134-140.

Saeni, F. and Maruapey, A. (2022). Waterbird Population in Klawalu Mangrove Tourism Park, Sorong City. *Journal of Fisheries and Marine Research*, **4**(1), 423-434.

Sambu, A.H.; Sribianti, I. and Ali, M.Y. (2022). *Mangrove management model: Based on education and tourism*. Makassar: Nas Media Pustaka.

Serkadifa, Y.S.; Matinahoru, J.M. and Pattimahu, D.V. (2018). Analysis of mangrove management strategies using the exponential comparison method in Sorong City, West Papua. *Journal of Small Island Forests*, **2**(1), 101-108.

Sese, K.; Galvin, S.; Brodie, G.; Katovai, E.; Pene, S. and Sirikolo, M. (2025, May 8). Diversity of mangrove flora of Marau, Solomon Islands [Preprint]. *Research Square*. https://doi.org/10.21203/rs.3.rs-6608285/v1

Setyawan, E. (2015). *Mangrove forest ecotourism management strategy based on the suitability and carrying capacity of the area in Pasarbanggi Village, Rembang Regency, Central Java Province*. Semarang: Dissertation. Postgraduate Program, UNDIP, Semarang.

Sobari, M.P.; Azis, N. and Adrianto, L. (2006). Economic analysis of alternative mangrove ecosystem management in Barru District, Barru Regency. *Fisheries Economics Bulletin*, **6**(3), 11026.

Sutomo, D.D.; Rauf, A. and Kasnir, M. (2019). A study on the development of marine tourism potential on Kodingareng Keke Island, Makassar. *Agri Sains Journal*, **20**, 72-78. https://jurnal.fpik.umi.ac.id/index.php/JOINT-FISH/article/view/31

Syamsu, I.F.; Nugraha, A.Z.; Nugraheni, C.T. and Wahwakhi, S. (2018). Study of land cover changes in the mangrove ecosystem on the east coast of Surabaya. *Media Konservasi*, **23**(2), 122-131.

Tabalessy, R. (2014). *Mangrove ecosystem management in Sorong City, West Papua Province*. Postgraduate Program, Sam Ratulangi University, Manado.

Tarunamulia; Ilham, M.; Sammut, J.; Paena, M.; Basir; Kamariah; Taukhid, I.; Asaf, R.; Athirah, A.; Akmal and Syaichudin, M. (2024). Impact of soil and water quality on the sustainable management of mangrove-compatible brackishwater aquaculture practices in Indonesia. *Environmental Research Communications*, **6**(8), 085013. https://doi.org/10.1088/2515-7620/ad7b6d

Tomlinson, P.B. (2016). *The botany of mangroves* (2nd ed.). Cambridge University Press.

Umam, K.; Sudiyarto, S. and Winarno, S.T. (2015). Strategy for developing mangrove ecotourism in Wonorejo, Surabaya. *AGRARIS: Journal of Agribusiness and Rural Development Research*, **1**(1), 38-42.

Yanti, D.W.; Paruntu, I.P. and Kepel, I.C. (2022). *Mangrove ecotourism: Mangrove bioecology, sustainability, and strategic planning for the development of the Jeflio Mangrove Ecotourism Area, Sorong Regency*. CV. Ruang Tentor.

Zhou, J.; Yang, J.; Qin, J.; Li, J.; Liu, X. and Wei, P. (2024). Nursery cultivation strategies for a widespread mangrove (Kandelia obovata Sheue & al.): Evaluating the influence of salinity, growth media, and genealogy. *Forests*, **15**(4), 574. https://doi.org/10.3390/f15040574