

# Ecological suitability and tourism carrying capacity of mangrove ecosystems for sustainable ecotourism development: a case study in Budo village, North Sulawesi

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**Abstract.** This study evaluates the Budo mangrove's ecological suitability and tourism carrying capacity, providing suitability classes and daily capacity thresholds used to set visitor quotas and habitat-based zoning for sustainable ecotourism management. Field surveys along five transects quantified stand structure (abundance, density, relative density/frequency/ dominance, importance value index) and diversity (species richness, Shannon–Wiener diversity, evenness), complemented by multidimensional scaling (MDS) to assess spatial differentiation. *Rhizophora* strongly dominates the community, particularly *R. mucronata*, with localized *Sonneratia* that contribute disproportionately to basal area and habitat heterogeneity. Diversity varied moderately among transects, with one transect exhibiting the most even assemblage and two showing stronger dominance, consistent with structural metrics. The tourism suitability index (TSI) indicates a "conditionally suitable" (S2) status, while the site-level carrying capacity is estimated at 105 visitors per day under normal operating conditions. Integrating TSI, carrying capacity, and biophysical constraints into the decision matrix support conservation zoning schemes with utilization to maintain ecosystem sustainability: routing along robust *Rhizophora* corridors, restricting access around *Sonneratia* patches and low-density areas, implementing quota- and time-slot-based visitation, and adopting low-impact infrastructure. Coupled with sustained ecological monitoring and inclusive community participation, these measures are recommended to balance ecosystem integrity with local socio-economic benefits. The approach provides a transparent, transferable framework for aligning ecotourism development with mangrove conservation in data-limited coastal settings.

**Key Words:** Budo village, ecological impact, ecotourism capacity, mangrove, tourism suitability.

**Introduction.** Mangrove ecosystems are widely recognized as vital coastal habitats that stabilize shorelines, provide nursery grounds for fishes and other marine fauna, and deliver essential ecosystem services, including wave attenuation and sediment trapping (Cuenca-Ocay 2019). From a climate-mitigation perspective, mangroves rank among the most carbon-rich tropical forests: global syntheses report exceptionally high ecosystem carbon stocks, and mangrove losses, despite covering only ~0.7% of tropical forests, contribute approximately ~0.02-0.12 Pg C yr<sup>-1</sup> (Rumengan et al 2018; Richards et al 2020; Adame et al 2021). Evidence from Indonesia underscores the importance of this blue carbon asset: mean ecosystem carbon stocks are ~1,083±378 Mg C ha<sup>-1</sup>, and historical losses imply substantial annual greenhouse gas emissions, reinforcing the strategic role of mangrove conservation in national mitigation (Murdiyarso et al 2015). Indonesia hosts the world's largest mangrove extent (~3.1-3.3 million ha), so site-level management decisions carry disproportionate ecological weight (World Bank 2021; Bunting et al 2022; Leal & Spalding 2024).

Socio-economically, mangrove ecotourism is promoted as a sustainable livelihood pathway that balances conservation goals with community well-being. Recent research shows that, when designed around conservation/restoration principles, mangrove-based

ecotourism can enhance local income and employment and strengthen environmental education without driving over-exploitation (Blanton et al 2024; Moussa et al 2024). Delivering these outcomes requires careful governance, especially regulating visitor numbers according to site-specific carrying capacity and adopting low impact infrastructure such as boardwalks and educational trails (Winata et al 2020; Skiniti et al 2024; Mandiangan et al 2024).

Nationally, mangrove ecotourism initiatives are expanding, yet outcomes hinge on local governance parameters, including carrying capacity, community participation, and impact control. In North Sulawesi, Budo village exemplifies a community-engaged model. Recent assessments document tangible socio-economic benefits and outline SWOT-based strategies to keep tourism aligned with conservation, while emphasizing visitation controls to avoid exceeding ecological thresholds along mangrove pathways (Towoliu et al 2020; Oroh et al 2024). These insights highlight the urgency of rigorous ecological suitability and capacity assessments.

Against this backdrop, the present study evaluates the ecological suitability of Budo's mangrove ecosystem for sustainable ecotourism development. We assess key biophysical parameters, mangrove belt width, species diversity, and stand density, associated biota, and tidal conditions, and delineate suitability zones for conservation-oriented visitation. The outcomes aim to: (i) provide a scientific basis for zoning and safe ecological visitation capacity; (ii) recommend low-impact infrastructure and interpretation programs; and (iii) strengthen community-based co-management. Thus, this research is expected to provide direct benefits for sustainable management in Budo village and serve as a reference for good practices in developing mangrove ecotourism in Indonesia.

## Material and Method

**Description of the study sites.** This research was conducted from April to June 2023 in Budo Village, Wori District, North Minahasa Regency, North Sulawesi (Figure 1). This village is known for its rich marine ecotourism potential, and it is currently being developed as a mangrove ecotourism destination. The village community has a strong understanding of local identity, which needs to be communicated to tourists, thus adding value to tourism development in the village. The built tourism facilities reflect local culture, attracting more visitors and increasing local income.

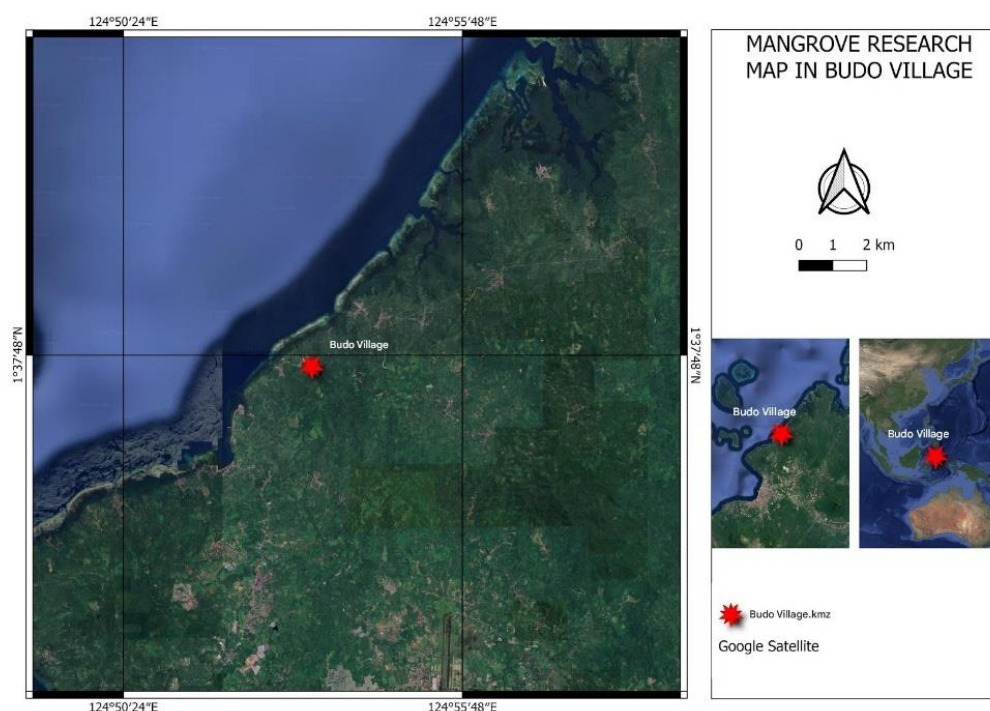


Figure 1. Research site (Budo village) (Source: based on Google Earth Image).

**Field survey.** A stratified sampling design was applied to cover the entire mangrove zone in Budo village. In each zone, a 100-m main transect was established perpendicular to the shoreline, from the shore to the landward boundary, following standard coastal vegetation survey guidance (Cintrón & Schaeffer-Novelli 1984; English et al 1997). Systematic quadrat plots measuring 10 × 10 m were established along the transects for stand inventory (Cintrón & Schaeffer-Novelli 1984; English et al 1997). All trees with diameter at breast height (DBH) ≥ 10 cm were identified to the species level in each quadrat and counted to obtain density, and DBH was measured with a dendrometer tape to the nearest 1 cm at 1.3 m above the ground surface (Kauffman & Donato 2012). For buttress-rooted species, measurements were taken directly above the tallest root to avoid bias (Kauffman & Donato 2012). The root architecture of dominant species was documented (Tomlinson 2016), while associated biotic components (fish, shrimp, crabs, mollusks, reptiles, birds) were observed and recorded. Water-quality parameters such as pH, conductivity, total dissolved solids (TDS), salinity, and temperature were also measured to complete the environmental characterization, following standard methods (APHA 2017).

**Vegetation structure.** Data analysis includes validation and standardization of all field data (units, coordinates, and outliers). The calculation of vegetation structure (density, frequency, dominance/basal area, importance value index, diversity index, and evenness index) is described in the equation below:

$$\text{Density of mangrove (D) (ind ha}^{-1}\text{)} = \frac{\text{Number of individual mangrove}}{\text{Total sample area}}$$

$$\text{Relative density of mangrove (RD) (\%)} = \frac{\text{Number of individuals in each species}}{\text{Total individuals of all species}} \times 100$$

$$\text{Frequency (F) (\%)} = \frac{\text{Number of plots in which a species occurs}}{\text{Total sample plots}}$$

$$\text{Relative frequency of mangrove (RF) (\%)} = \frac{\text{Frequency of a mangrove species}}{\text{Frequencies for all mangrove species}} \times 100$$

$$\text{Dominance (C) (m}^2\text{ ha}^{-1}\text{)} = \frac{\text{Total basal areas of each tree species from all plots}}{\text{Total areas of all measured plots}}$$

$$\text{Relative dominance of mangrove (Rc) (\%)} = \frac{\text{Total basal areas of the species}}{\text{Total basal areas of all mangrove species}} \times 100$$

Importance value index (IVI) = Relative density + Relative frequency + Relative dominance

$$H' = -\sum_{i=1}^s pi \ln pi$$

Notes:  $H'$  is the diversity index;  $s$  is the species count;  $pi$  is the proportion of the  $s$ . Diversity index criteria are divided into 3 (three) categories:  $H' < 1$  = low species diversity;  $1 < H' < 3$  = moderate species diversity;  $H' > 3$  = high species diversity.

$$E' = \frac{H'}{H'_{Max}}$$

Notes:  $E'$  is the evenness index;  $H'$  is the diversity index,  $H'_{max}$  is  $\ln S$ , and  $S$  is the number of species.  $E = 0-1$ ;  $E$  approaching 0 means the distribution of individuals between species is not even, or there are dominant types;  $E$  approaching 1 means the distribution of individuals between species is even.

**Tourism suitability index (TSI) and carrying capacity index(CCI).** The calculation of the TSI and the CCI are crucial analytical tools in tourism development, particularly in the context of ecotourism. Both are used to evaluate an area's suitability as a tourist destination and the environment's capacity to support these activities. The CCI measures a location's suitability for tourism, while the CCI indicates the number of visitors a site can receive each day without damaging the environment.

**Water quality.** Water quality analyses included measurements of pH, conductivity, total dissolved solids (TDS), salinity, and temperature.

**Inter-transect similarity and decision framework.** Inter-transect similarity was modeled using multidimensional scaling (MDS) on normalized data, where the distance between points indicates the degree of dissimilarity or similarity. We then created spatial maps for the five transects (T1-T5) to visualize and interpret the resulting similarity patterns. Differences between transects were tested using ANOVA if assumptions were met, and Kruskal–Wallis tests if not, followed by appropriate post hoc comparisons. The five transects were also assessed for the relationship between the TSI and environmental variables using Pearson or Spearman coefficients. Furthermore, we integrated the TSI, carrying capacity, and biophysical constraints into a decision matrix to identify conservation zones with limited use and establish ecologically safe daily visitation limits.

**Results.** Across the five sampled transects (T1-T5) in Budo village, the mangrove stand is dominated by *Rhizophora*. Summary data for all species are presented in Table 1. *Rhizophora mucronata* showed the most significant contribution to all structural metrics ( $n = 28.20$ ; total density =  $112.80 \text{ ind } 100 \text{ m}^{-2}$ ;  $\Sigma F = 1.00$ ), with the highest relative density and total dominance ( $\text{RD}\Sigma = 62.21$ ;  $\text{RC}\Sigma = 45.67$ ) and the greatest importance ( $\text{IVI}\Sigma = 150.15$ ) (Table 2). This finding is consistent with previous studies, which have shown that *Rhizophora* patterns in the Indo-Pacific region often dominate fringe and riparian zones (Tomlinson 2016; Friess et al 2019). *Rhizophora apiculata* forms a consistent co-dominant layer ( $\Sigma n = 12.4$ ; density =  $49.60 \text{ ind } 100 \text{ m}^{-2}$ ;  $\Sigma F = 0.79$ ;  $\text{IVI}\Sigma = 83.99$ ) (Table 2), a typical association within Rhizophoraceae belts (Tomlinson 2016). Although numerically scarce, *Sonneratia alba* expresses a clear basal-area signal ( $\text{RC}\Sigma = 17.58$ ;  $\text{IVI}\Sigma = 31.93$ ;  $n = 1.8$ ), indicating patches of larger stems in specific microhabitats - a pattern frequently linked to wave exposure and soft-sediment deltaic settings (Alongi 2009; Hogarth 2015). *Bruguiera gymnorrhiza* is sparse ( $\Sigma n = 1.40$ ;  $\text{IVI}\Sigma = 25.63$ ), and *Avicennia marina* is rare ( $\Sigma n = 0.8$ ;  $\text{IVI}\Sigma = 8.30$ ) (Table 2), occurring locally, reflecting substrate and inundation tolerances across genera (Tomlinson 2016; Friess et al 2019).

Spatially, *R. mucronata* retains high frequency at every transect (RF ~29.41-51.02% per transect), while stations with *S. alba* contribute disproportionately to dominance despite low abundance, consistent with zonation driven by inundation regime, hydrodynamic exposure, and sedimentary context (Hogarth 2015; Friess et al 2019). This structure - numerical dominance by *Rhizophora* with localized *Sonneratia* patches - supports the design of interpretation routes that disperse visitors along robust *Rhizophora* corridors and limit access to high-dominance *S. alba* patches to minimize trampling and edge effects, aligned with ecotourism carrying-capacity and low-impact infrastructure principles (Cifuentes 1992; Yulianda 2019; Skiniti et al 2024).

Species diversity varied modestly among the transects shown in Table 3 ( $N = 33$ -52 individual plots<sup>-1</sup>;  $S = 3$ -5 species.). Transect 1 showed the richest and most evenly distributed assemblage ( $S = 5$ ;  $H' = 1.211$ ;  $J' = 0.752$ ) with a full complement of *Rhizophora*, *Bruguiera*, *Sonneratia*, and *Avicennia*. Transect 2 had the highest abundance ( $N = 52$ ) but lower diversity ( $S = 4$ ;  $H' = 0.821$ ;  $J' = 0.592$ ), indicating numerical dominance by a few taxa - consistent with the adverse effect of dominance on Shannon diversity (Shannon 1948; Magurran 2004). Transect 3 showed the best evenness ( $J' = 0.764$ ) with three species ( $S = 3$ ;  $H' = 0.840$ ), reflecting a more balanced distribution of individuals across species (Pielou 1966; Magurran 2004). Transect 4 maintained intermediate diversity ( $S = 4$ ;  $H' = 0.959$ ;  $J' = 0.691$ ). Transect 5 was the most dominant community ( $S = 3$ ;  $H' = 0.496$ ;  $J' = 0.451$ ). Of the five observation transects, *Rhizophora* species showed substantial prevalence across all sites, dominating. The prevalence of *Rhizophora* in the Indo-Pacific is not only a characteristic of this region but also plays a key role in maintaining ecological balance and diversity (Tomlinson 2016; Friess et al 2019).

Table 1

Structural metrics of mangrove species (density, relative density, frequency, relative frequency, dominance, relative dominance, and importance value index) across five transects (T1–T5) in the Budo mangrove area

| Transect   | Species              | <i>n</i> | Density<br>(ind/100 m <sup>2</sup> ) | Relative<br>density (%) | Frequency<br>(%) | Relative<br>frequency<br>(%) | Dominance<br>(m <sup>2</sup> ha <sup>-1</sup> ) | Relative<br>dominance<br>(%) | Importance<br>value index<br>(%) |
|------------|----------------------|----------|--------------------------------------|-------------------------|------------------|------------------------------|---|------------------------------|----------------------------------|
| Transect 1 | <i>R. mucronata</i>  | 25       | 100                                  | 50.00                   | 1.00             | 29.41                        | 3.75  | 11.10                        | 90.51                            |
|            | <i>R. apiculata</i>  | 16       | 64                                   | 32.00                   | 0.80             | 23.53                        | 3.07  | 9.10                         | 64.63                            |
|            | <i>B. gymnorhiza</i> | 2        | 8                                    | 4.00                    | 0.40             | 11.76                        | 2.79  | 8.27                         | 24.04                            |
|            | <i>S. alba</i>       | 3        | 12                                   | 6.00                    | 0.40             | 11.76                        | 20.78   | 61.55                        | 79.32                            |
|            | <i>A. marina</i>     | 4        | 16                                   | 8.00                    | 0.80             | 23.53                        | 3.37  | 9.97                         | 41.50                            |
| Transect 2 | <i>R. mucronata</i>  | 37       | 148                                  | 71.15                   | 1.00             | 51.02                        | 5.08  | 47.39                        | 169.57                           |
|            | <i>R. apiculata</i>  | 11       | 44                                   | 21.15                   | 0.75             | 30.61                        | 1.85  | 17.29                        | 69.05                            |
|            | <i>B. gymnorhiza</i> | 2        | 8                                    | 3.85                    | 0.20             | 8.16                         | 2.53  | 23.56                        | 35.57                            |
|            | <i>S. alba</i>       | 2        | 8                                    | 3.85                    | 0.25             | 10.20                        | 1.26  | 11.77                        | 25.82                            |
|            | <i>A. marina</i>     | 0        | 0                                    | 0.00                    | 0.00             | 0.00                         | 0.00  | 0.00                         | 0.00                             |
| Transect 3 | <i>R. mucronata</i>  | 20       | 80                                   | 60.61                   | 1.00             | 51.02                        | 3.30  | 56.38                        | 168.01                           |
|            | <i>R. apiculata</i>  | 11       | 44                                   | 33.33                   | 0.75             | 30.61                        | 1.28  | 21.81                        | 85.75                            |
|            | <i>B. gymnorhiza</i> | 2        | 8                                    | 6.06                    | 0.20             | 8.16                         | 1.28  | 21.81                        | 36.03                            |
|            | <i>S. alba</i>       | 0        | 0                                    | 0.00                    | 0.25             | 10.20                        | 0.00  | 0.00                         | 10.20                            |
|            | <i>A. marina</i>     | 0        | 0                                    | 0.00                    | 0.00             | 0.00                         | 0.00  | 0.00                         | 0.00                             |
| Transect 4 | <i>R. mucronata</i>  | 17       | 68                                   | 43.59                   | 1.00             | 51.02                        | 2.00  | 38.22                        | 132.83                           |
|            | <i>R. apiculata</i>  | 19       | 76                                   | 48.72                   | 0.75             | 30.61                        | 2.56  | 48.88                        | 128.21                           |
|            | <i>B. gymnorhiza</i> | 1        | 4                                    | 2.56                    | 0.25             | 10.20                        | 0.28  | 5.37                         | 18.14                            |
|            | <i>S. alba</i>       | 2        | 8                                    | 5.13                    | 0.20             | 8.16                         | 0.39  | 7.53                         | 20.82                            |
|            | <i>A. marina</i>     | 0        | 0                                    | 0.00                    | 0.00             | 0.00                         | 0.00  | 0.00                         | 0.00                             |
| Transect 5 | <i>R. mucronata</i>  | 42       | 168                                  | 85.71                   | 1.00             | 51.02                        | 2.71  | 75.36                        | 212.09                           |
|            | <i>R. apiculata</i>  | 5        | 20                                   | 10.20                   | 0.75             | 30.61                        | 0.63  | 17.57                        | 58.39                            |
|            | <i>R. gymnorhiza</i> | 0        | 0                                    | 0.00                    | 0.25             | 10.20                        | 0.00  | 0.00                         | 10.20                            |
|            | <i>S. alba</i>       | 2        | 8                                    | 4.08                    | 0.20             | 8.16                         | 0.25  | 7.07                         | 19.32                            |
|            | <i>A. marina</i>     | 0        | 0                                    | 0.00                    | 0.00             | 0.00                         | 0.00  | 0.00                         | 0.00                             |

Note: *n* = number of individuals.

Table 2

Mean density, relative density, frequency, relative frequency, dominance, relative dominance, and importance value index of mangrove species across five transects (T1-T5) in the Budo mangrove area

| Species              | <i>n</i><br>(mean) | Density<br>(ind/100 m <sup>2</sup> ) | Relative<br>density (%) | Frequency<br>(%) | Relative<br>frequency (%) | Dominance<br>(m <sup>2</sup> ha <sup>-1</sup> ) | Relative<br>dominance<br>(%) | Importance<br>value index<br>(%) |
|----------------------|--------------------|--------------------------------------|-------------------------|------------------|---------------------------|---|------------------------------|----------------------------------|
| <i>R. mucronata</i>  | 28.20              | 112.80                               | 62.21                   | 1.00             | 42.25                     | 3.37  | 45.69                        | 150.15                           |
| <i>R. apiculata</i>  | 12.40              | 49.60                                | 29.08                   | 0.76             | 31.98                     | 1.88  | 22.93                        | 83.99                            |
| <i>B. gymnorhiza</i> | 1.40               | 5.60                                 | 3.29                    | 0.26             | 10.53                     | 1.38  | 11.80                        | 25.63                            |
| <i>S. alba</i>       | 1.80               | 7.20                                 | 3.81                    | 0.26             | 10.53                     | 4.54  | 17.58                        | 31.93                            |
| <i>A. marina</i>     | 0.80               | 3.20                                 | 1.60                    | 0.16             | 4.71                      | 0.67  | 1.99                         | 830                              |

Note: n = number of individuals.

Table 3

The number of individuals, species richness, diversity, and evenness of the Budo mangrove area

| Transect   | <i>R. mucronata</i><br>( <i>n</i> ) | <i>R. apiculata</i><br>( <i>n</i> ) | <i>B. gymnorhiza</i><br>( <i>n</i> ) | <i>S. alba</i><br>( <i>n</i> ) | <i>A. marina</i><br>( <i>n</i> ) | Total<br>( <i>N</i> ) | Richness<br>( <i>S</i> ) | Shannon<br>( <i>H'</i> ) | Evenness<br>( <i>J'</i> ) |
|------------|-------------------------------------|-------------------------------------|--------------------------------------|--------------------------------|----------------------------------|-----------------------|--------------------------|--------------------------|---------------------------|
| Transect 1 | 25.00                               | 16.00                               | 2.00                                 | 3.00                           | 4.00                             | 50.00                 | 5.00                     | 1.211                    | 0.752                     |
| Transect 2 | 37.00                               | 11.00                               | 2.00                                 | 2.00                           | 0.00                             | 52.00                 | 4.00                     | 0.821                    | 0.592                     |
| Transect 3 | 20.00                               | 11.00                               | 2.00                                 | 0.00                           | 0.00                             | 33.00                 | 3.00                     | 0.840                    | 0.764                     |
| Transect 4 | 17.00                               | 19.00                               | 1.00                                 | 2.00                           | 0.00                             | 39.00                 | 4.00                     | 0.959                    | 0.691                     |
| Transect 5 | 42.00                               | 5.00                                | 0.00                                 | 2.00                           | 0.00                             | 49.00                 | 3.00                     | 0.496                    | 0.451                     |

Note: n = number of individuals; S = number of species.

Based on the TSI assessment shown in Figure 2, the mangrove ecosystem in Budo village is classified as "Conditionally Suitable (S2)" with an average value of around 54-56%. This means that ecotourism development can only occur if daily planning and management implement clear sustainability measures such as carrying capacity-based visitor quotas, the implementation of limited-use conservation zoning, low-impact infrastructure, and routine ecological monitoring (Winata et al 2020). The mangrove belt thickness parameter consistently scored 5 across transects, reflecting a relatively uniform and robust stand structure. Species composition varied among transects; transect 3 achieved the highest score (9), indicating comparatively higher species diversity than transects 1 and 2 (each 6). Stand density at transects 1 and 2 was scored as 6, consistent with vegetation conditions that support ecosystem functioning. Scores for associated biota were lower (2-3), yet still confirm the presence of ecologically and interpretively important fauna fish, crabs, mollusks, and birds that enhance the site's tourism appeal (Winata et al 2020; Blanton et al 2024). The tide parameter was uniform (score 2) across transects, indicating stable hydrological conditions compatible with visitation (Yulianda 2019). Taken together, these results support conservation-oriented ecotourism, contingent on sustainable management strategies notably limiting visitation in line with carrying capacity and adopting low-impact infrastructure to safeguard ecological integrity (Cifuentes 1992; Winata et al 2020; Skiniti et al 2024).

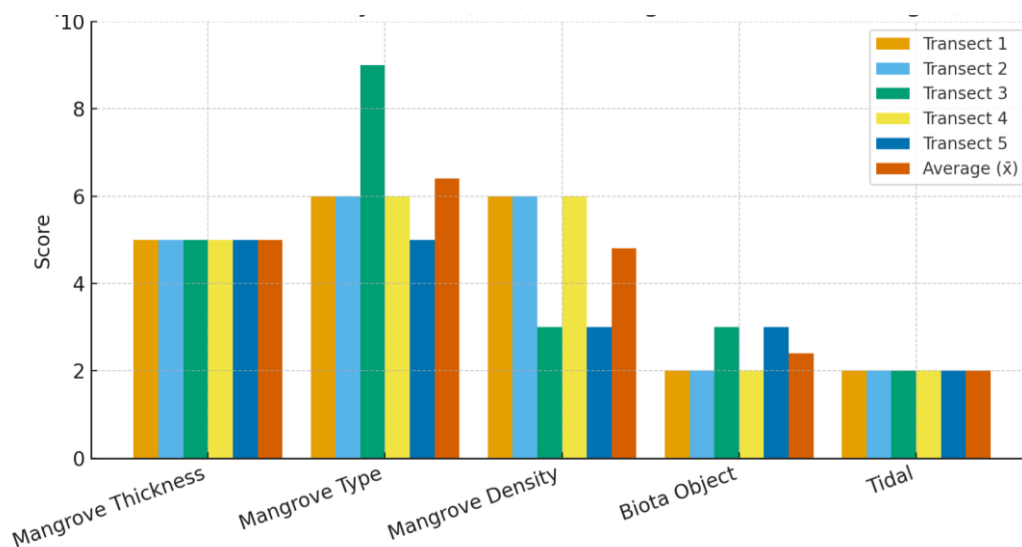


Figure 2. Suitability parameters score for mangrove ecotourism in Budo village.

The TSI for the Budo mangrove ecosystem was evaluated using five core environmental parameters mangrove belt thickness, species composition, stand density, associated biota, and tides. Each parameter was scored according to the TSI guideline categories (Yulianda 2019), and assigned weights reflecting its relative contribution to sustainable ecotourism potential; this weighting scheme and scoring logic have been widely applied in Indonesian mangrove-ecotourism assessments (Bengen et al 2006; Winata et al 2020).

The TSI-based scoring (mangrove belt thickness, species composition, stand density, associated biota, and tides) revealed a consistent cross zone pattern. Thickness and tide were constant (scores 5 and 2 across all transects), and thus did not drive spatial separation; differentiation was primarily controlled by species, density, and biota (Yulianda 2019; Winata et al 2020). The MDS in Figure 3, configuration clustered T1, T2, and T4 (species = 6; density = 6; biota = 2), indicating similar and relatively stable conditions (Borg & Groenen 2005; Legendre & Legendre 2012). T3 separated strongly along Dimension 1 due to the highest species score (9) but lower density (3), indicating it as highly informative for biodiversity interpretation while warranting careful visitor load management (Cifuentes 1992). T5 separated along Dimension 2 (species = 5; density = 3; biota = 3), suggesting a comparatively stronger biota contribution despite a sparser

stand. Overall, a largely uniform community structure with two departures (T3 and T5) supports a phased interpretation route a main corridor through T1, T2, and T4, with targeted education nodes at T3 (species diversity) and T5 (biota), while controlling visitation in line with carrying capacity and employing low impact infrastructure (Cifuentes 1992; Yulianda 2019; Skiniti et al 2024).

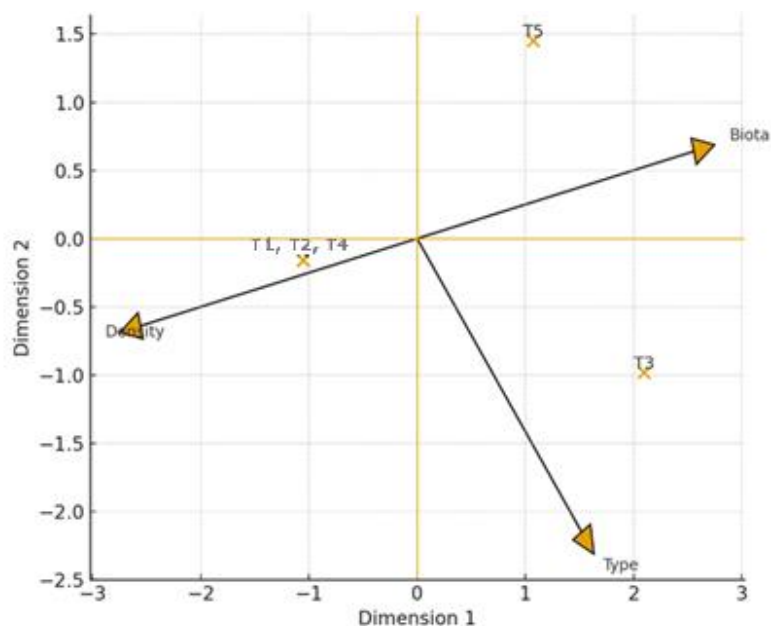


Figure 3. Weighted MDA (scores x weights) with variable loading Stress-1 = 0.000.

Field measurements in Budo village yielded a carrying capacity of 105 visitors day<sup>-1</sup>, representing the maximum ecological intake under normal operations (Table 4), assuming even visitor distribution along the boardwalk and compliance with minimum spacing (Cifuentes 1992; Zacarías et al 2011). We translated the daily capacity into time-slot quotas of 7-8 slots per day, with 14-16 visitors per slot, to avoid crowding in narrow sections and maintain the intended visit duration (Saveriades 2000; Skiniti et al 2024). Within the study’s management framework, explicitly considering biophysical constraints and zoning (use/limited/conservation), daily visitation limits can be tightened during high-risk periods (e.g., extreme tides) or within limited/conservation zones, thereby aligning visitation levels with ecosystem integrity and visitor safety (Dudley 2008).

Table 4

Analysis of the carrying capacity of the mangrove ecotourism area in Budo village

| <i>Category</i>       | <i>Parameter</i>                               | <i>Value</i>              |
|-----------------------|--|---------------------------|
| Main result           | Ecological potential of visitors per unit area | 1 person/unit area        |
|                       | Carrying capacity of the area                  | 105 visitors/day          |
| Supporting parameters | Usable area                                    | 3,000 m <sup>2</sup>      |
|                       | Unit area for a specific category              | 200 m <sup>2</sup> (or m) |
|                       | Total hours available per day                  | 14 hours                  |
|                       | Average time spent per visitor                 | 2 hours                   |

**Discussion.** The suitability of mangrove ecosystems for ecotourism development is shaped by interrelated biophysical and environmental factors. In Budo village, the TSI is primarily governed by mangrove belt thickness which supports interpretive trail design and coastal protection - species diversity that elevates educational and aesthetic value, stand density underpinning habitat quality and ecosystem functioning, the presence of associated biota (fishes, crabs, mollusks, shrimps, and birds) that enhance visitor appeal but warrant targeted protection, and stable tidal conditions that influence trail

accessibility and visitor safety. Collectively, these determinants must be integrated into conservation oriented planning and management to sustain mangroves' ecological roles as coastal buffers, biodiversity habitats, and significant blue carbon stores (Cifuentes 1992; Alongi 2009; Murdiyarso et al 2015; Tomlinson 2016; Winata et al 2020; Friess et al 2019; Yulianda 2019; Blanton et al 2024; Skiniti et al 2024).

Mangrove ecotourism in Budo village offers clear educational and economic opportunities, yet also entails ecological risks if governance is inadequate. Increased visitation can lead to physical trail damage or poorly sited infrastructure, as well as wildlife disturbance (birds, fish, crabs, mollusks) via noise, litter, and unregulated human wildlife interactions (Newsome et al 2012; Blanton et al 2024). Installing facilities within the intertidal zone can alter local hydrological regimes and sediment dynamics, potentially degrading habitat quality (Alongi 2009; Friess et al 2019). Overexploitation for tourism purposes (e.g., collecting ornamental biota or pruning vegetation) can disrupt ecosystem balance and diminish blue carbon storage and coastal protection functions (Murdiyarso et al 2015; Tomlinson 2016). To prevent such outcomes, sustainability oriented management is essential - designing trails based on suitability analyses, regulating visitor numbers to carrying-capacity thresholds, implementing visitor education, and engaging local communities in monitoring and conservation so that ecotourism advances community well being while maintaining mangrove ecological integrity (Cifuentes 1992; Dudley 2008; Yulianda 2019; Skiniti et al 2024).

This study establishes a daily carrying capacity of 105 visitors day<sup>-1</sup> for the Budo mangrove ecotourism area. This value is lower than the 214 visitors day<sup>-1</sup> reported by Wiharso et al (2020) for the boardwalk route in Berakit village, indicating that Budo's ecological intake is more limited and therefore requires stricter visitation management (Marion et al 2016; Cahill et al 2018; Skiniti et al 2024). Consistent with Mendrofa & Davinay (2024), such restrictions should be integrated with management practices that prevent ecosystem degradation in high-use sections, namely zone-based visitor allocation, routine on-site monitoring, and conservation oriented visitor education (Cahill et al 2018; Minata et al 2024). Moreover, Wati & Idajati (2017) emphasize the need to uphold ecotourism principles and ensure inclusive governance to minimize stakeholder conflict highly relevant to Budo, where active community engagement and inter agency coordination are essential (Blanton et al 2024). Finally, in line with Faiqoh et al (2018), development strategies should prioritize targeted promotion, improvements to low impact infrastructure, and interpretive programming that connects visitors with local communities, while safeguarding blue-carbon functions and overall mangrove ecosystem integrity (Richards et al 2020; Adame et al 2021; Bunting et al 2022; Leal & Spalding 2024). Taken together, daily carrying capacity based quota setting, limited use conservation zoning, community participation, and continuous education are pivotal to maintaining mangrove ecosystem health while supporting local economic benefits (Marion et al 2016; Blanton et al 2024; Skiniti et al 2024).

**Conclusions.** Mangrove ecosystems in Budo village, characterized by *Rhizophora* dominance with *Sonneratia* patches and medium species diversity, are conditionally suitable for tourism. Consequently, sustainable ecotourism development should be guided by quota and time slot based visitation controls, the implementation of limited use conservation zoning (with main corridors in *Rhizophora* stands and restrictions in sensitive habitats), low impact infrastructure, regular ecological monitoring, and strong community participation coupled with visitor education.

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