Integrated Ecological and Socio-Economic Assessment for Sustainable Marine Ecotourism Development in Lihaga Island: An Ecosystem Service-Based Approach

Indri S. Manembu[1], Noldy G.F. Mamangkey[1], Hermanto W.K. Manengkey[1], Unstain N.W.J. Rembet[2], Ari B. Rondonuwu[2]*.

[1]Marine Science Study Program, Faculty of Fisheries and Marine Science
[2]Management of Aquatic Resources Study Program, Faculty of Fisheries and Marine Science. Sam Ratulangi University, Jl. Kampus Unsrat Bahu, Manado 95115, North Sulawesi, Indonesia.

*Corresponding author: indrimanembu@unsrat.ac.id

Abstract. Lihaga Island, positioned within Indonesia's Likupang Special Economic Zone, exemplifies the challenge of balancing tourism development with ecosystem conservation. This study integrates ecological and socio-economic assessments to inform sustainable management of marine ecotourism. Ecological data were collected using the Line Intercept Transect method across three stations at 3- and 10-meter depths. Results revealed a mean hard coral cover of 30.63%, which is classified as moderate according to the Indonesian Ministry of Environment Decree No. 4/2001, though significant spatial variation was observed across stations. Thirty-four coral genera were identified, dominated by Porites (36.12%). The Tourism Suitability Index scored 62%, indicating conditional suitability for diving and snorkeling. Community surveys (n=60) demonstrated overwhelming support for ecotourism (90% positive), with all respondents expressing interest in tourism village programs. However, 40% lacked tourism experience, indicating a need for capacity building. Findings reveal that sustainable development requires integrated spatial zoning, community empowerment, reef restoration, and monitoring systems. This research contributes integrated assessment frameworks for ecotourism in Indonesian Special Economic Zones and provides actionable recommendations for policymakers and stakeholders.

Keywords: coral reef assessment, ecosystem services, marine ecotourism, sustainable tourism

INTRODUCTION

Small islands represent unique socio-ecological systems characterized by limited resources, exceptional biodiversity, and heightened vulnerability to anthropogenic pressures. The concept of 'islandness' amplifies these vulnerabilities, as geographic isolation, restricted spatial extent, and limited carrying capacity make small island ecosystems particularly sensitive to rapid tourism development (Kelman, 2018; Klöck & Nunn, 2023). Within this context, ecotourism has emerged as a theoretical pathway to reconcile economic development with ecosystem conservation, defined as responsible travel to natural areas that conserves the environment, provides livelihoods to local communities, and incorporates educational elements (Yulianda, 2019).

However, evidence from mature tourism destinations demonstrates that unplanned development frequently generates negative environmental externalities, including coral reef degradation, biodiversity loss, and ecosystem service decline (Hughes et al., 2017). Small island contexts exacerbate these vulnerabilities due to limited spatial extent, high dependency on natural resources, and exceptional sensitivity to environmental disturbances (Klöck & Nunn, 2023). Sustainable marine ecotourism management must therefore integrate ecological assessments with social elements as tourism stakeholders in management processes, ultimately generating benefits for the economic sector while maintaining ecosystem integrity (Phelan et al., 2020).

In 2019, the Government of Indonesia established 18 Special Economic Zones (SEZ) nationwide through various government regulations, including the Likupang SEZ in North Sulawesi (Government Regulation No. 85/2019), which integrates Lihaga Island as a priority tourism development area. Subsequently, Presidential Regulation No. 3/2020 designated 5 Super Priority Tourism Destinations nationwide, including Likupang, demonstrating the Indonesian government's commitment to accelerating tourism sector growth. This dual

designation creates unique opportunities for coordinated regional development while simultaneously intensifying pressure on fragile marine ecosystems and traditional community structures.

Lihaga Island, positioned within this policy framework, exemplifies the critical challenge of balancing rapid tourism development with ecosystem conservation. The island's marine environment features coral reef ecosystems providing essential ecosystem services, including coastal protection, biodiversity support, and tourism potential. However, these ecosystems face multiple anthropogenic stressors, including historical blast fishing impacts (Hampton-Smith et al., 2021; Pet-Soede et al., 1999), increasing tourist pressure, and development-related coastal modifications. Understanding the current ecological status and socio-economic context provides the foundation for evidence-based management strategies that can reconcile development objectives with sustainability imperatives.

This study addresses a critical research gap in integrated assessment frameworks for ecotourism development within Indonesia's Special Economic Zones. While previous research has examined either ecological conditions or socio-economic dimensions in isolation, few studies have systematically integrated both perspectives to inform holistic management strategies (Prihadi et al., 2024). This research employs a comprehensive approach combining: (1) benthic ecological assessment using standardized methods (Beenaerts & Berghe, 2007; Wang et al., 2024), (2) coral reef biodiversity evaluation through taxonomic surveys, (3) tourism suitability analysis incorporating multiple environmental parameters (Naranjo-Arriola, 2021), and (4) community perception assessment through structured surveys (Yudha Prakasa et al., 2023). The integration of these complementary methods generates actionable recommendations grounded in both ecological capacity and social acceptance.

The primary objectives of this research are: (1) to assess the current ecological status of Lihaga Island's marine ecosystems through benthic cover analysis and coral diversity evaluation, (2) to determine tourism carrying capacity through Tourism Suitability Index (TSI) calculation incorporating environmental parameters, (3) to evaluate community perceptions, readiness, and capacity for ecotourism development, and (4) to develop integrated management recommendations synthesizing ecological and socio-economic findings. These objectives directly address the practical needs of policymakers, tourism planners, and local communities navigating the complex dynamics of sustainable tourism development in small island Special Economic Zones.

METHODS

Study Area

This research was conducted in the marine waters surrounding Lihaga Island, located at coordinates 01°32'28"N and 125°09'43"E in North Minahasa Regency, North Sulawesi Province, Indonesia. Lihaga Island is administratively part of Gangga Satu Village, Likupang Timur Sub-district, and is positioned within the Likupang Special Economic Zone designated by Government Regulation No. 85/2019. The island is one of several small islands within the Likupang tourism cluster, which also includes Gangga Island, Sarena Island, and Kinabuhutan Island. Field research was conducted during February-June 2023, encompassing both dry and transitional seasons to capture representative conditions.

Three research stations were strategically established based on preliminary surveys and accessibility considerations. Station 1 was positioned on the western side of Lihaga Island, characterized by relatively protected waters and historically lower fishing pressure. Station 2 was located on the northwestern section, representing an intermediate exposure zone with moderate wave action. Station 3 was established on the northern coast, characterized by greater

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exposure to ocean currents and historically higher fishing intensity. This spatial distribution enabled assessment of ecological variation across different exposure gradients and anthropogenic pressure levels (Figure 1).
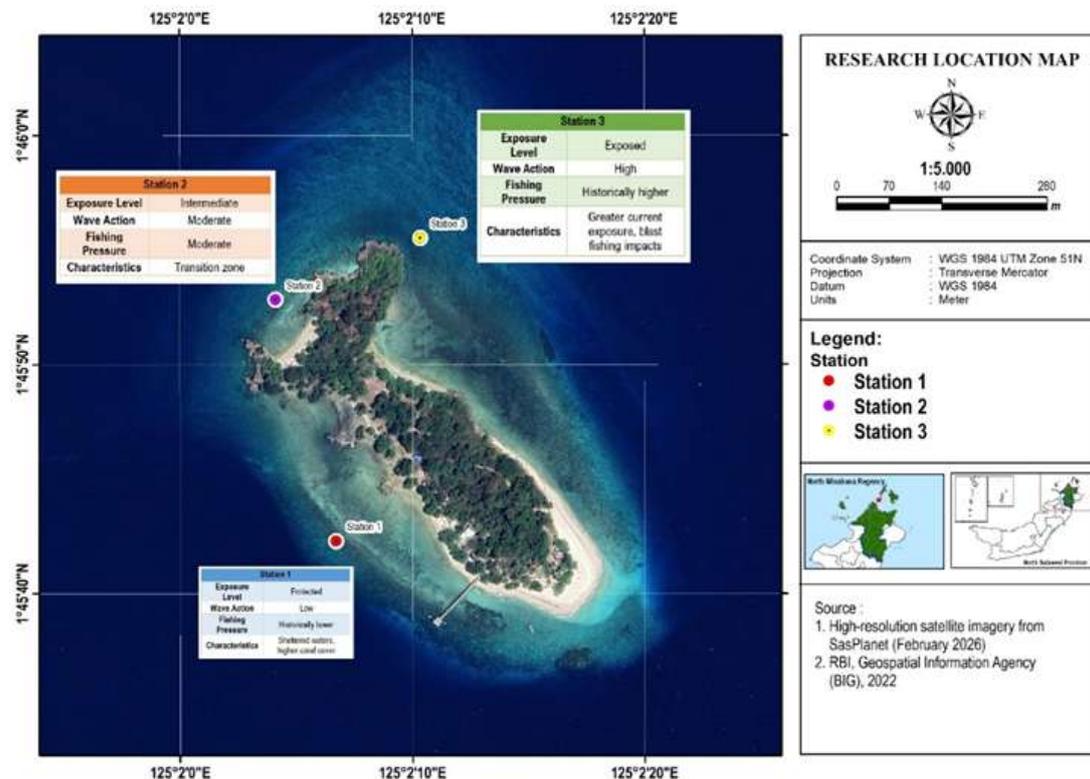

Figure 1. Research location map

Ecological Assessment

Benthic cover composition was quantified using the Line Intercept Transect (LIT) method following standardized protocols (English et al., 1997; Permana et al., 2020). At each station, horizontal transect lines (50 meters length) were deployed at two depth strata: 3 meters and 10 meters, representing shallow reef crest and reef slope zones respectively. Transects were positioned parallel to the reef contour to maximize representation of typical reef structure. All benthic organisms and substrata intersecting the transect line were recorded to the nearest centimeter, categorized into major functional groups including hard coral (HC), dead coral (DC), dead coral with algae (DCA), soft coral (SC), rubble (R), sand (S), sponge (SP), other biota (OT), and algae (A). Three replicate transects were established at each depth within each station, generating six transects per station and 18 total transects across the study area.

Percentage cover for each benthic category was calculated as: Percentage cover (%) = (Length of category / Total transect length) × 100. The ecological status of hard coral cover was categorized based on the national standard established by the Indonesian Ministry of Environment Decree No. 4/2001 (Kepmen LH 4/2001), using the following thresholds: excellent (75–100%), good (50–74.9%), moderate (25–49.9%), and poor (<25%). Hard coral diversity was assessed through in situ taxonomic identification to genus level following morphological characteristics described in Veron (2000). Coral colonies along each transect were photographed, counted, and identified based on colony morphology, corallite structure, and growth form. Diversity was quantified using the Shannon-Wiener diversity index (H'): $H' = -\Sigma(p_i \times \ln p_i)$, where p_i represents the proportion of individuals belonging to genus i. Diversity

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values were interpreted as: low diversity (H' < 1.0), moderate diversity (H' = 1.0-3.0), and high diversity (H' > 3.0) (Morris et al., 2014).

Tourism Suitability Analysis

Tourism carrying capacity was evaluated through calculation of the Tourism Suitability Index (TSI) following the weighted matrix approach (Yulianda, 2019). Seven environmental parameters were measured: (1) water visibility measured using Secchi disk depth, (2) current velocity quantified using drift buoys over standardized distances, (3) coral reef depth measured using dive computers, (4) coral lifeform diversity categorized into growth form types, (5) percentage hard coral cover derived from LIT data, (6) reef fish abundance estimated through visual census, and (7) beach width measured during low tide using measuring tape. Each parameter was assigned a suitability score based on established criteria and weighted according to relative importance for diving and snorkeling activities. The TSI was calculated as: TSI = $\Sigma(S_i \times W_i)$, where S_i represents the suitability score for parameter i and W_i represents the corresponding weight. TSI values were classified into categories: highly suitable (S1: 75-100%), suitable (S2: 50-74%), conditionally suitable (S3: 25-49%), and unsuitable (N: <25%).

Socio-Economic Assessment

Community perceptions and readiness for ecotourism development were assessed through structured questionnaire surveys administered to local residents. A purposive sampling approach was employed to select 60 respondents representing diverse demographic categories including age, gender, occupation, and residential proximity to coastal areas. Questionnaires were designed to capture multiple dimensions: (1) demographic characteristics including age, education, occupation, and income levels, (2) awareness and understanding of ecotourism concepts, (3) perceptions of potential benefits and challenges associated with tourism development, (4) willingness to participate in tourism-related activities, and (5) previous experience with tourism or community-based development programs. Interviews were conducted in the local language (Bahasa Indonesia and Minahasan dialect) by trained enumerators familiar with local cultural context. Response data were coded, tabulated, and analyzed using descriptive statistics to identify patterns in community attitudes and capacity. Free-form responses were categorized thematically to identify recurrent concerns, expectations, and suggestions regarding ecotourism development.

Table 1. Biophysical Suitability Criteria and Weighted Scoring Scheme for Marine Diving Tourism

No.	Parameter	Weight	Highly Suitable (S)	Score	Moderately Suitable (SB)	Score	Unsuitable (TS)	Score
1	Live coral cover (%)	5	> 67	3	34–67	2	< 34	1
2	Coral life-form diversity (number of types)	5	> 10	3	6–10	2	< 6	1
3	Water clarity (%)	5	> 80	3	50–80	2	< 50	1
4	Reef fish richness (species)	3	> 50	3	26–50	2	< 26	1
5	Current velocity (m s^{-1})	3	0–0.1	3	> 0.1–0.5	2	> 0.5	1
6	Reef depth (m)	1	1–3	3	> 3–5	2	> 5	1
7	Reef flat width (m)	1	> 100	3	20–100	2	< 20	1

Source: Yulianda, 2019

Table 2. Biophysical Suitability Criteria and Weighted Scoring Scheme for Marine Snorkeling Tourism

No.	Parameter	Weight	Highly Suitable (S)	Score	Moderately Suitable (SB)	Score	Unsuitable (TS)	Score
1	Coastal typology	5	Gently sloping sandy beach	3	Moderately sloping	2	Steep shoreline	1
2	Beach width (m)	5	> 5	3	3–5	2	< 3	1
3	Water depth (m)	5	0–2	3	> 2–5	2	> 5	1
4	Substrate composition	3	Sandy	3	Sand with coral fragments	2	Coral rubble	1
5	Current velocity (cm s^{-1})	3	< 34	3	34–51	2	> 51	1
6	Beach slope (°)	3	< 25	3	25–45	2	> 45	1
7	Water clarity (%)	1	> 50	3	30–50	2	< 30	1
8	Presence of hazardous biota	1	Absent	3	Limited presence (e.g., sea urchins)	2	Frequent or multiple hazardous species	1
9	Freshwater availability (km from site)	1	< 1	3	1–2	2	> 2	1

Table 3. Biophysical Suitability Criteria and Weighted Scoring Scheme for Marine Recreational Beach Tourism

No.	Parameter	Weight	Highly Suitable (S)	Score	Moderately Suitable (SB)	Score	Unsuitable (TS)	Score
1	Reef fish richness (species)	5	> 75	3	20–75	2	< 20	1
2	Water clarity (%)	5	> 80	3	50–80	2	< 50	1
3	Live coral community cover (%)	3	> 65	3	25–65	2	< 25	1
4	Coral life-form diversity (number of types)	3	> 10	3	4–10	2	< 4	1
5	Sea surface temperature (°C)	3	23–25	3	26–36	2	< 23 or > 36	1
6	Salinity (‰)	3	30–36	3	28–30	2	< 28 or > 36	1
7	Reef depth (m)	3	3–20	3	21–30	2	< 3 or > 30	1
8	Current velocity (cm s^{-1})	1	0–25	3	26–50	2	> 50	1

RESULTS AND DISCUSSION

Benthic Cover Composition

Benthic cover analysis revealed substantial spatial heterogeneity across the three research stations, reflecting differential exposure to anthropogenic disturbances and environmental gradients. At the 3-meter depth stratum, hard coral cover varied significantly among stations. Station 1 (59.53%) was categorized as being in 'good' condition, whereas

Station 2 (16.47%) and Station 3 (16.17%) were categorized as 'poor' based on the Kepmen LH 4/2001 criteria. However, the overall mean cover for Lihaga Island (30.63%) remains within the 'moderate' category. Station 1 exhibited the highest hard coral cover (59.53% at 3m depth), approaching the threshold for good condition (50-74.9%), suggesting relatively effective historical protection or recovery from disturbances. In contrast, Stations 2 and 3 displayed markedly lower hard coral percentages, dominated instead by abiotic components including dead coral (DC), rubble (R), and sand (S) substrata.
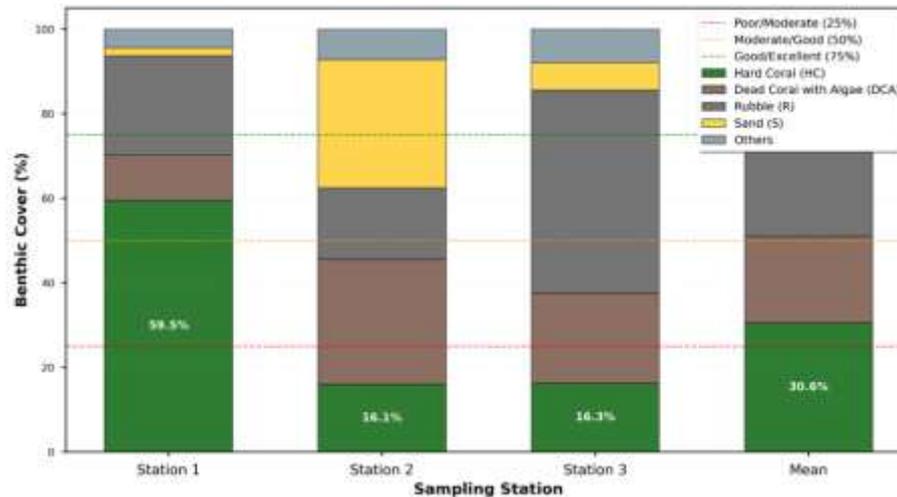

Figure 1. Benthic cover composition and mean percentage cover (%) across three sampling stations in Lihaga Island. Dashed lines indicate reef health thresholds based on Kepmen LH 4/2001: Poor (<25%), Moderate (25–50%), Good (50–75%), Excellent (>75%). HC = Hard Coral; DCA = Dead Coral with Algae; R = Rubble; S = Sand.

Note: HC: Hard Coral; DCA: Dead Coral with Algae; R: Rubble; S: Sand. 'Others' includes Soft Coral, Sponge, Fleshy Seaweed, and Other Biota. Dashed horizontal lines represent reef health status categories: Poor (<25%), Moderate (25–50%), Good (50–75%), and Excellent (>75%) according to the Indonesian Ministry of Environment Decree No. 4/2001 (Kepmen LH 4/2001).

The prevalence of dead coral and rubble substrata at Stations 2 and 3 provides strong evidence of historical blast fishing impacts, a destructive practice documented throughout Indonesian waters (Hampton-Smith et al., 2021; Pet-Soede et al., 1999). Blast fishing generates immediate coral mortality through explosive shock waves and leaves characteristic signatures including extensive rubble fields and reduced structural complexity. Field observations documented substantial rubble accumulations at both northern stations, with individual fragments displaying the angular, fractured morphology characteristic of blast-damaged colonies rather than the rounded forms typical of natural wave-driven fragmentation. While blast fishing has reportedly ceased in recent years due to enforcement efforts and community awareness programs, the ecological legacy persists through reduced live coral cover and compromised three-dimensional reef structure.

Vertical depth stratification revealed relatively modest variation in hard coral cover between 3-meter and 10-meter depths within individual stations, suggesting that depth-related factors (light availability, wave energy) exert less influence on coral distribution than do anthropogenic disturbance histories. This pattern contrasts with many Indo-Pacific reefs where hard coral cover typically peaks at intermediate depths (5-15 meters) where light availability and wave disturbance are optimally balanced. The lack of pronounced depth gradients in Lihaga

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Island may reflect the overriding influence of blast fishing disturbance, which affects both shallow and deeper reef zones relatively uniformly.

Coral Diversity

Taxonomic surveys documented a total of 34 hard coral genera across the three research stations, representing substantial generic richness comparable to other Indonesian reef systems, such as those found in the Seribu Islands (Permana et al., 2020). The assessment was conducted using the Line Intercept Transect (LIT) method, which has been validated for its consistency and reliability in estimating both coral cover and taxonomic richness (Beenaerts & Berghe, 2007; Wang et al., 2024). Station 1 harbored 19 genera, Station 2 supported 25 genera, and Station 3 contained 22 genera. The higher generic richness at Stations 2 and 3, despite lower percentage hard coral cover, suggests these disturbed sites maintain taxonomic diversity even as absolute coral abundance declines, possibly due to colonization by opportunistic or stress-tolerant genera following disturbance events. Detailed community structure and diversity indices for each station are presented in Table 4.

Table 2. Hard coral diversity indices in Lihaga Island waters

No.	Index	Station 1	Station 2	Station 3
1	Number of Genera (S)	19	25	22
2	Number of Colonies (N)	105	101	118
3	Diversity Index (H')	0.725	1.115	1.208
4	Evenness Index (E)	0.567	0.798	0.900
5	Dominance Index (D)	0.380	0.152	0.074

The Shannon-Wiener diversity indices (H') revealed spatial variation in community complexity. Station 1 exhibited a low diversity level (H' = 0.725), characterized by a higher dominance index (D = 0.380) and lower evenness (E = 0.567). This indicates that while Station 1 has the highest coral cover, it is dominated by a few resilient taxa. In contrast, Stations 2 and 3 reached moderate diversity levels (H' > 1.0), with Station 3 showing the highest evenness (E = 0.900), suggesting a more balanced distribution of abundance among genera during the successional recovery process.

Genus-level composition analysis revealed Porites as the dominant taxon across all stations, comprising 36.12% of total coral abundance. This prevalence of Porites aligns with regional patterns throughout degraded Indonesian reefs, where this genus demonstrates exceptional tolerance to environmental stress including elevated temperatures, sedimentation, and physical disturbance (Loya et al., 2001). Other abundant genera included Acropora, Montipora, Pocillopora, and Fungia, collectively representing the characteristic assemblage composition of moderate-energy reef environments in the Indo-Pacific region.

The coexistence of high generic richness with moderate percentage cover suggests potential for ecological recovery if anthropogenic pressures are effectively managed. Diverse coral assemblages provide ecological insurance through functional redundancy, where multiple genera contribute to essential ecosystem functions including reef accretion, habitat provision, and wave attenuation (Obura et al., 2019). This diversity also enhances reef resilience to future disturbances by increasing the probability that at least some taxa will survive and recover from episodic stress events such as coral bleaching or disease outbreaks. Realizing this recovery potential requires sustained protection from destructive fishing practices and careful management of tourism impacts to ensure long-term sustainability (Apdillah et al., 2020; Ayuningrum et al., 2025).

Tourism Suitability

The integrated Tourism Suitability Index (TSI) analysis yielded an aggregate score of 62%, classifying Lihaga Island's marine environment as conditionally suitable (S2 category: 50-74%) for diving and snorkeling activities (Naranjo-Arriola, 2021; Yulianda, 2019).

Table 4. Marine Tourism Suitability Index (TSI) Assessment for Diving and Snorkeling Activities at Lihaga Island

No	Parameter	Weight (a)	Observation (b)	Score (c)	Maximum Score (d)	Weighted Value (c × d)
1	Water clarity (m)	5	18	3	5	15
2	Current velocity (m/s)	5	0.23	3	5	15
3	Water depth (m)	5	3–20	2	5	10
4	Coral cover (%)	4	47.04	2	4	8
5	Reef fish species richness	3	47	2	3	6
6	Coral life form diversity	2	6	2	2	4
7	Fish functional groups	2	Target, indicator	2	2	4
Total TSI						62
Suitability category						**Moderately suitable (S2)**

Note: TSI = (Total weighted value / Maximum possible value) × 100% = (62/130) × 100% = 47.7%, classified as S2 (Moderately suitable). Scoring criteria: 3 = highly suitable, 2 = moderately suitable, 1 = marginally suitable. Weights and scoring criteria follow Yulianda (2019). TSI classification thresholds: S1 (Highly suitable) = 75–100%; S2 (Moderately suitable) = 50–<75%; S3 (Conditionally suitable) = 25–<50%; N (Not suitable) = <25% (Hasriyanti, 2025; Yulianda, 2019). Field measurements conducted at three stations during February–June 2023

As detailed in Table 4, the assessment integrates seven weighted parameters, with the overall score reflecting strong physical conditions (water clarity, current velocity, depth) but moderate biological parameters (coral cover, life form diversity, fish richness). This classification indicates that the site possesses adequate environmental characteristics to support marine tourism development but requires specific management interventions to address identified limitations and prevent degradation (Apdillah et al., 2020; Ayuningrum et al., 2025). The TSI methodology integrates multiple parameters with differential weightings, providing a more nuanced assessment than single-parameter approaches (Naranjo-Arriola, 2021; Sahri et al., 2022).

Individual parameter assessment revealed several strengths supporting tourism suitability. Water visibility measurements averaged 8-12 meters across stations, providing adequate conditions for underwater observation and photography, well within the recommended range for marine ecotourism activities (Ayuningrum et al., 2025; Hasriyanti, 2025). Current velocities remained within safe ranges for recreational diving and snorkeling (typically <50 cm/s), though variability existed across sites and tidal states, consistent with previous findings in similar small island contexts (Sahri et al., 2022). Reef fish abundance, while not systematically quantified through formal census protocols, appeared moderate based on visual observations, with diverse assemblages including charismatic megafauna such as sea turtles observed during surveys. Beach width measurements indicated adequate space for access infrastructure and visitor facilities, particularly along the western and southwestern coastlines.

However, several parameters scored below optimal levels, constraining overall suitability. Hard coral cover percentages (30-31% mean) fall within the moderate category

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rather than the good or excellent categories that would maximize aesthetic appeal and ecological interest for visitors (Apdillah et al., 2020). Coral lifeform diversity, while taxonomically diverse at the genus level, exhibited reduced architectural complexity compared to pristine reef systems, with lower abundance of large branching and tabular Acropora formations that create visually impressive reef structures. These limitations reflect the historical impacts of blast fishing (Hampton-Smith et al., 2021; Pet-Soede et al., 1999) and suggest that enhancing tourism value requires active reef restoration targeting structural complexity and coral cover improvement (Obura et al., 2019).

Community Perceptions and Readiness

Survey results demonstrated overwhelmingly positive community attitudes toward ecotourism development, with 70% of respondents (42 individuals) expressing strong support, 20% (12 individuals) agreeing with development plans, and only 10% (6 individuals) expressing disagreement or concerns. This high acceptance level reflects several factors including: (1) awareness of the Special Economic Zone designation and associated development opportunities, (2) recognition of declining fisheries productivity and need for livelihood diversification, (3) exposure to preliminary tourism activities generating positive economic benefits, and (4) effective communication by government agencies and NGOs regarding sustainable tourism concepts (Yudha Prakasa et al., 2023).

When queried specifically about interest in participating in tourism village programs, all 60 respondents expressed positive interest, with 37 individuals (61.7%) indicating very high interest and 23 individuals (38.3%) expressing moderate interest. This unanimous enthusiasm suggests substantial community ownership of the tourism development vision and willingness to actively participate in implementation. Respondents identified multiple potential roles including: homestay operators (n=28), tour guides (n=22), handicraft producers (n=15), food vendors (n=25), and boat operators (n=18), indicating diverse livelihood opportunities aligned with varied skill sets and resource endowments.

However, assessment of community capacity revealed mixed readiness levels requiring targeted interventions. Of the 60 respondents, 36 individuals (60%) reported previous experience with tourism or tourism village programs through participation in government-sponsored training programs, exposure to nearby tourism operations, or family connections to tourism businesses. The remaining 24 respondents (40%) lacked formal tourism experience, identifying capacity gaps in areas including: hospitality service standards, foreign language proficiency (particularly English), financial management, marketing and promotion, waste management, and environmental conservation principles. These gaps highlight the need for comprehensive capacity building programs preceding large-scale tourism expansion (Prihadi et al., 2024).

Integrated Management Implications

The integration of ecological and socio-economic findings generates several critical insights for sustainable ecotourism development in Lihaga Island. First, the moderate ecological condition and conditional tourism suitability classification indicate that the marine environment can support tourism activities but requires active management to prevent further degradation and enhance visitor experience quality. Second, the strong community support combined with capacity gaps suggests that participatory development approaches must be coupled with systematic capacity building to ensure equitable benefit distribution and sustained local engagement. Third, the spatial heterogeneity in reef condition across stations indicates that zoning strategies should differentiate conservation and utilization areas based on ecological status and recovery potential.

These findings demonstrate strong alignment with ecosystem service framework principles (Phelan et al., 2020), where coral reef ecosystems simultaneously provide provisioning services (fisheries resources), regulating services (coastal protection, carbon sequestration), and cultural services (aesthetic values, recreation, education). Sustainable ecotourism development must maintain the ecological foundations supporting these multiple services while optimizing cultural service delivery through tourism. This requires avoiding common pitfalls observed in rapidly developing tourism destinations, where short-term economic prioritization compromises long-term ecological integrity and ultimately undermines tourism attractiveness.

CONCLUSION

This integrated assessment reveals Lihaga Island's marine environment exhibits moderate hard coral cover (30.63-31.70%) with spatial variation reflecting historical blast fishing impacts, maintains moderate taxonomic diversity (34 genera dominated by Porites), and achieves conditional tourism suitability (TSI = 62%) for managed diving and snorkeling. Community perceptions demonstrate overwhelming support (90% positive) with high interest in participatory programs, but 40% require capacity building.

Sustainable development requires: (1) integrated spatial zoning differentiating conservation and utilization areas, (2) active reef restoration in degraded zones, (3) comprehensive community capacity building programs, (4) visitor management protocols with carrying capacity limits, and (5) benefit-sharing mechanisms ensuring equitable distribution. Implementation depends on multi-stakeholder collaboration involving government agencies, Special Economic Zone authorities, academic institutions, private operators, and community organizations.

This research contributes integrated assessment frameworks for ecotourism in Indonesian Special Economic Zones. Future research should monitor intervention effectiveness through longitudinal assessments and examine transferability to other small island contexts facing similar development pressures.

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