Available online at: https://jtos.polban.ac.id/index.php/jtospolban
Journal of Tourism Sustainability
Volume 5 No 3, 2025 (Special Issues): 53-60
DOI: 10.35313/jtospolban.v5i3.174

Revitalizing Mangrove Botanical Garden Ecotourism in Surabaya Through Bamboo Fencing Innovation to Mitigate Coastal Abrasion

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Abstract

Global climate change continues to significantly impact coastal ecosystems, particularly mangrove forests significantly, which are critical in maintaining ecological stability and protecting coastal areas from erosion. The Surabaya Mangrove Botanical Garden, Indonesia's only mangrove botanical garden, is increasingly vulnerable to coastal abrasion due to rising sea levels and the intensification of extreme weather events. This study explores the potential application of bamboo fencing as an environmentally friendly innovation to mitigate coastal erosion and revitalize ecotourism in the area. Utilizing a literature-based method, this research evaluates the effectiveness of bamboo barriers in reducing wave energy, facilitating sediment deposition, and enhancing mangrove regeneration. The findings indicate that bamboo fences serve as a natural coastal defense mechanism, strengthening shoreline resilience, supporting ecosystem sustainability, and promoting conservation-based ecotourism. Furthermore, this initiative aligns with the United Nations Sustainable Development Goals (SDGs), particularly Goal 13 (Climate Action) and Goal 15 (Life on Land), by integrating nature-based solutions into coastal management strategies.

Keywords: Surabaya Mangrove Botanical Garden, coastal abrasion, bamboo fencing, climate change, conservation ecotourism

INTRODUCTION

Mangrove forests, unique intertidal ecosystems along coastlines and estuaries, provide essential ecological functions including shoreline stabilization, biodiversity support, and carbon sequestration (Alongi, 2024). These ecosystems serve as protective buffers against coastal erosion and storm surges and hold immense potential for development into sustainable ecotourism destinations that integrate environmental conservation with community welfare (Giri et al., 2023).

However, the accelerating impacts of climate change—rising global temperatures, altered precipitation patterns, and increased frequency of extreme weather events—threaten the long-term viability of nature-based tourism worldwide. Ecotourism, which inherently depends on the integrity of natural ecosystems, is particularly vulnerable to environmental degradation caused by climate-induced stressors (UNEP, 2024; Dogru et al., 2023). As such, protecting these ecosystems is not only an ecological imperative but also an economic necessity.

Mangrove ecosystems play a critical role in climate change mitigation due to their capacity to sequester carbon up to four times greater than terrestrial forests (Taillardat et al., 2023; Macreadie et al., 2024). In addition to acting as natural carbon sinks, mangroves offer recreational, educational, and scientific value, positioning them as keystone assets in developing climate-resilient ecotourism frameworks (Duarte et al., 2023).

A notable example is the Surabaya Mangrove Botanical Garden (SMBG), located on the eastern coastal zone of Surabaya, Indonesia. As the nation's first and only mangrove botanical garden, SMBG is a conservation hub and a destination for eco-education and recreation. In 2024, the site attracted over 43,000 visitors, with an

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average monthly visitation rate of 6,000, underscoring its growing importance as an urban ecotourism site (East Java Provincial Communication Office, 2024).

Despite its growing popularity, SMBG faces acute threats from ongoing coastal abrasion, a result of both anthropogenic pressures and natural coastal dynamics. Addressing this issue requires context-sensitive and environmentally friendly solutions. One such intervention is using bamboo fencing, a green technology increasingly adopted in coastal restoration efforts. Recent studies indicate that bamboo fences can reduce wave energy by up to 70%, facilitating sediment deposition and promoting mangrove recolonization (Purnobasuki, 2024; Thampanya et al., 2023).

Nevertheless, the success of bamboo fences is highly dependent on site-specific geographical conditions, including tidal energy, sediment load, and local community engagement. Effective implementation thus demands an integrated management approach that combines ecological engineering with participatory governance (Sari et al., 2024; Nguyen et al., 2025). As a nature-based solution, bamboo fencing holds significant promise in supporting early-stage mangrove rehabilitation while acting as a low-cost, sustainable barrier against wave-driven erosion. This study explores the effectiveness of bamboo fences as a climate-adaptive strategy for mitigating coastal erosion and enhancing mangrove ecosystem resilience in SMBG. Through a literature-based analysis, the research evaluates the ecological and socio-technical dimensions of bamboo fence deployment in mangrove conservation..

LITERATURE REVIEW

Coastal Ecosystems and the Threat of Erosion

Coastal ecosystems are dynamic transitional zones between terrestrial and marine environments, characterized by their high ecological complexity and substantial socio-economic value. These ecosystems comprise various habitats—including mangroves, seagrasses, coral reefs, and estuaries—that serve as buffers against extreme weather events, support biodiversity, and underpin livelihoods (Barbier et al., 2023). However, coastal zones are increasingly threatened by natural processes and anthropogenic disturbances, with coastal erosion emerging as a major environmental hazard. Erosion involves land displacement due to wave action, tidal currents, and sea-level rise. While naturally occurring, its pace has been significantly accelerated by human activities such as unregulated coastal development, sand mining, and the conversion of natural landscapes into urban or industrial zones (Rahman et al., 2024). The degradation or removal of protective vegetation—especially mangroves—exacerbates the vulnerability of coastlines. Mangrove forests act as natural barriers by attenuating wave energy and trapping sediments. In their absence, the shoreline is left exposed, increasing the risk of erosion and leading to severe socio-economic and ecological consequences (Ismail, Ali & Givani, 2024; UNESCO, 2024).

Mangroves as Natural Coastal Defenses

Mangroves possess a unique root architecture—dense, interlocking, and complex—that enables them to function as natural wave breakers. Their aerial and prop roots reduce hydrodynamic forces, dissipate wave energy, and facilitate sediment retention, making them highly effective in stabilizing coastlines (Alongi, 2024; McLeod et al., 2023). These processes prevent land loss and promote sediment accretion, contributing to coastal land formation over time. In addition to mitigating erosion, mangroves provide a robust defense against hydro-meteorological hazards such as tropical storms, tidal surges, and even tsunamis (Rogers et al., 2023). Restoration and reforestation of mangrove forests are increasingly recognized as nature-based solutions (NbS) for climate adaptation and coastal resilience. The ecological services offered by mangroves further reinforce the urgency of their conservation as a strategic measure to ensure both environmental and community sustainability (DasGupta & Shaw, 2023).

Sustainable Mangrove-Based Ecotourism

Mangrove ecotourism offers a sustainable pathway to reconcile environmental protection with community development. By emphasizing environmental education, cultural engagement, and local economic benefit, it aligns with the three pillars of sustainability—ecological integrity, social equity, and economic viability (Dewi & Martayadi, 2024; UNWTO, 2023). Visitors to mangrove ecotourism sites not only offer natural beauty but are also exposed to the ecological importance of mangroves in carbon sequestration, climate regulation, and biodiversity conservation. Moreover, ecotourism encourages coastal communities' capacity building and income generation through employment as tour guides, homestay operators, food vendors, and local artisans (Díaz-Caravantes et al., 2023). Nonetheless, the rapid growth of ecotourism must be regulated to prevent ecological overshoot, habitat disturbance, and commodification of conservation spaces. Thus, inclusive

governance, involving community stakeholders, tourism operators, and government agencies, is essential to ensure sustainability in the long term (Hernández et al., 2023).

Bamboo Fences as an Eco-Friendly Innovation

Bamboo fencing represents a low-tech yet innovative eco-engineering approach to coastal protection. Constructed along shorelines, bamboo fences reduce wave energy and surface currents, enabling the natural accumulation of sediments—a prerequisite for successful mangrove recolonization (Thampanya et al., 2023). Studies have shown that such structures can decrease wave intensity by up to 70%, effectively slowing erosion and creating suitable conditions for mangrove restoration (Purnobasuki, 2024; Nguyen et al., 2025). Bamboo fences are biodegradable, cost-effective, and relatively easy to install and maintain. Their efficacy, however, is contingent upon site-specific parameters such as substrate type, prevailing wind directions, and local oceanography. Therefore, this method should be deployed with broader conservation strategies, including integrated waste management, community education, and active mangrove planting (Setyawan et al., 2024).

Community and Governmental Roles in Mangrove Conservation

Sustainable ecotourism and mangrove conservation success hinges on active community participation and institutional support. Local communities possess indigenous knowledge and direct experience with the ecosystem, making their involvement crucial in planting, monitoring, and guarding mangrove areas (Nguyen et al., 2025). Engaging local stakeholders enhances stewardship, fosters a sense of ownership, and strengthens social capital. Simultaneously, the government must provide clear regulatory frameworks, financial incentives, and technical assistance to ensure effective conservation efforts. A multi-actor approach—encompassing communities, private sectors, NGOs, and policy-makers—is needed to build inclusive, adaptive, and resilient governance systems for coastal zones (Le et al., 2023). Community-based ecotourism improves environmental outcomes and contributes to socio-economic empowerment when backed by institutional support.

METHODS

Research Design

This study adopts a qualitative-descriptive approach using a systematic literature review (SLR) as the primary data collection and analysis method. This approach is appropriate for examining the complex interplay between mangrove ecosystems, coastal abrasion, and environmentally friendly mitigation strategies. The literature review enables the integration of empirical findings, theoretical insights, and policy analyses from various academic and institutional sources. The objective is to critically evaluate the effectiveness of bamboo fencing as a nature-based solution for mitigating coastal abrasion and supporting mangrove regeneration, particularly in the context of climate change adaptation and sustainable development. The narrative synthesis technique analyses and interprets data from selected sources by categorizing and organizing information thematically, formulating a robust conceptual framework, and drawing evidence-based conclusions. This study aligns its findings with the Sustainable Development Goals (SDGs)—specifically Goal 13 (Climate Action) and Goal 15 (Life on Land)—by assessing how bamboo fencing contributes to the preservation of terrestrial ecosystems and resilience against climate-induced coastal degradation.

Study Site

The research focuses on the Surabaya Mangrove Botanical Garden (SMBG) in East Surabaya, Indonesia (Medokan Sawah Timur, Segoro Tambak Sedati, Medokan Ayu, Rungkut District). The site, formally established on July 26, 2023, encompasses 27 hectares, resulting from integrating the Gunung Anyar and Medokan Sawah Mangrove Ecotourism Areas. As Indonesia's only official mangrove botanical garden, SMBG houses 57 species of mangroves, representing approximately 36% of all known mangrove species in the country. Its role as both a conservation area and a community-based ecotourism destination makes it an ideal case for examining the intersection of ecological restoration and socio-economic development.

Data Collection

Data was collected between March and May 2025, using a multi-source document analysis strategy within the literature review framework. A total of 50 peer-reviewed scientific articles, 15 technical research reports, and 10 policy documents were systematically gathered and analyzed. The search process involved academic databases such as Scopus, ScienceDirect, SpringerLink, Google Scholar, and national journal portals (e.g., Garuda, Neliti). Government and NGO publications were also consulted. The following keywords were used in

various combinations to optimize search relevance: "mangrove erosion", "bamboo fences", "abrasion mitigation", "mangrove ecotourism", "coastal conservation".

To ensure the validity and reliability of the findings, the following inclusion criteria were applied: 1) Relevance to the study's objectives, 2) Published within the last 10 years (2015–2025), with emphasis on recent studies (2020–2025), 3) Methodological rigor and transparency, and 4) Credible sources (indexed journals, official reports, policy papers). Documents failing to meet these criteria were excluded to maintain scientific rigor and minimize bias.

Data Analysis

Data were analyzed through narrative synthesis, wherein information from the selected literature was organized thematically into key categories: (1) coastal abrasion dynamics, (2) mangrove degradation, (3) bamboo fence technology, and (4) ecotourism and conservation practices. This method allowed the development of an integrated perspective on the ecological, technical, and socio-political aspects of bamboo fences as an environmentally friendly intervention. In synthesizing the data, the study also explored the scalability of the solution and its alignment with national coastal resilience strategies..

RESULTS AND DISCUSSION

Overview of the Surabaya Mangrove Botanical Garden (SMBG)

The Surabaya Mangrove Botanical Garden (SMBG), located in East Java, Indonesia, spans 34 hectares, making it the country's only thematic mangrove botanical garden. It lies adjacent to the Java Sea to the north and the northern coast of Surabaya to the east. This site has become a national model for integrating mangrove conservation, environmental education, and ecotourism development. SMBG consists of three primary zones—Medokan Ayu, Gunung Anyar, and Wonorejo—each of which contributes uniquely to conservation, education, and community engagement. Collectively, these zones host over 50 mangrove species, representing 36% of Indonesia's national mangrove biodiversity.

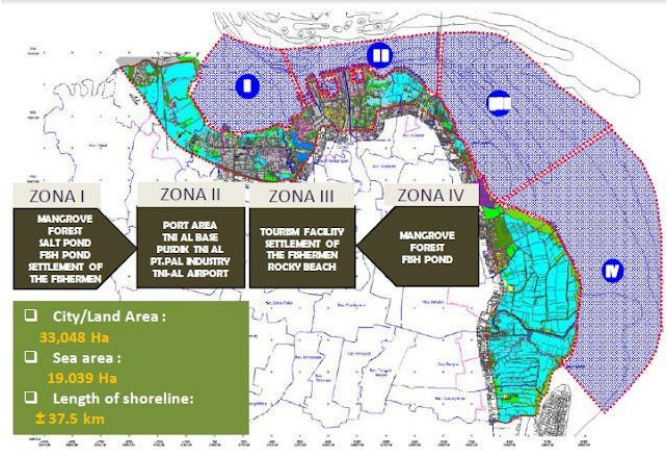

Figure 1. Map of Mangrove Ecotourism in Surabaya
Source: Limaura.com

Distribution and Characteristics of Ecotourism Zones

Medokan Ayu Area

With an area of approximately 16 hectares, the Medokan Ayu zone, governed by Surabaya's Department of Food Security and Agriculture, is officially designated as a conservation area under Mayoral Decree No. 188.45/145/436.1.2/2018 and Surabaya Regulation No. 41/2023. The area is managed by the Technical Implementation Unit (UPT) of SMBG and serves as a hub for scientific research, ecological education, and guided ecotourism. Mangrove species in this area are arranged taxonomically, creating a structured educational trail for visitors. The area also provides critical habitat for coastal bird species, aquatic invertebrates, and estuarine fauna, contributing to biodiversity conservation and ecological resilience.

Gunung Anyar Area

Spanning 11 hectares, Gunung Anyar is the core center for public engagement. As of mid-2024, it recorded over 43,000 visitors, with a monthly average of 6,000 visitors, including school groups and eco-education

programs. Facilities include educational boardwalks, interactive exhibits, photography areas, and nature-based play zones. This area exemplifies contemporary ecotourism management, merging environmental education with recreational experiences. The Surabaya city government continues to enhance this site by expanding species collections, improving infrastructure, and reinforcing environmental messaging.

Wonorejo Area

The Wonorejo zone (7 hectares) lies in the eastern coastal margin and has long served as a natural defense zone against coastal erosion and tidal flooding. Officially integrated into SMBG in July 2023, this area now supports formal conservation and education programs. It provides habitat for shorebirds, estuarine fish, and mangrove crabs, making it ecologically vital. Collaborative governance involving local communities, research institutions, and municipal authorities is key to managing Wonorejo. Community-led conservation and education programs are emphasized, ensuring that ecotourism contributes economically, ecologically, and socially.

Bamboo Fences as an Eco-Innovation for Abrasion Mitigation

Bamboo fences have emerged as a low-tech, high-impact solution for mitigating coastal erosion, particularly in low-to moderate-energy coastal environments such as East Surabaya. Installed parallel to the coastline, bamboo structures function as natural wave breakers, significantly reducing the velocity and force of incoming waves, thereby promoting sediment deposition and facilitating mangrove regeneration. According to multiple empirical studies, bamboo fences can reduce wave energy by up to 70%, depending on design, wave exposure, and sediment conditions (Thampanya et al., 2023; Purnobasuki, 2024; Nguyen et al., 2025).

Key Findings from Literature and Field Observations

A study by (Kumalawati and Harahap, 2021) in coastal Tangerang, Indonesia, demonstrated that 12–15 cm of new sediment had accumulated behind the structures after six months of bamboo fence installation. Similar trends have been observed in SMBG zones of Gunung Anyar and Medokan Ayu, where fenced areas showed: 1) Reduced propagule damage; 2) Increased propagule survival rates by up to 60% compared to non-fenced areas; and 3) Accelerated mangrove seedling establishment. Additionally, the microhabitats formed around the bamboo fences supported colonization by oysters, small crabs, algae, and phytoplankton—indicating the formation of early-stage functional ecosystems. As a biodegradable material, bamboo offers ecological advantages by decomposing naturally and leaving no harmful residues. Its affordability and local availability further increase its applicability in community-driven conservation projects.

Supporting Global Literature

These local results align with findings from global contexts: In Thailand and Vietnam, bamboo fences are part of national coastal restoration strategies and have shown long-term success in shoreline stabilization (Ruangpan et al., 2023). In the Philippines, similar eco-engineering methods have been integrated into community-based disaster risk reduction programs (Cruz et al., 2024).

Ecological and Socio-Economic Implications

The deployment of bamboo fences at SMBG contributes to ecological restoration and enhances the resilience of the local ecotourism economy. The resulting increase in mangrove density: 1) Enriches the ecotourism experience by increasing biodiversity visibility; 2) Reduces infrastructure vulnerability to wave damage; and 3) Strengthens community engagement through participation in fence construction, monitoring, and mangrove planting. Furthermore, these initiatives support Indonesia's national targets on blue carbon ecosystems, aligned with Nationally Determined Contributions (NDCs) and global climate commitments (UNFCCC, 2024).

Discussion

Interpretation of Key Findings

The findings of this study reinforce the growing consensus in global coastal science that nature-based solutions (NbS) are ecologically effective and socially inclusive in managing coastal vulnerabilities. Applying bamboo fences in the Surabaya Mangrove Botanical Garden (SMBG) demonstrated measurable improvements in sediment accumulation, mangrove propagule survival, and microhabitat formation—foundational for long-term mangrove regeneration. These outcomes support earlier research that considers bamboo fencing a cost-effective method for wave attenuation and shoreline stabilization (Thampanya et al., 2023; Nguyen et al.,

2025). Moreover, the increase in propagule survival rate by up to 60% in protected zones underscores the importance of physical intervention in supporting early-stage mangrove reforestation in degraded areas.

Bamboo Fencing as a Scalable and Sustainable Eco-Engineering Solution

The bamboo fence approach aligns with eco-engineering principles, which advocate for using natural materials and systems to solve environmental challenges (Ruangpan et al., 2023). Unlike hard infrastructure (e.g., seawalls), bamboo fencing is non-invasive, biodegradable, low-cost, and does not disrupt local hydrodynamics or biodiversity corridors. Furthermore, bamboo's high availability in tropical countries and its low-carbon footprint during construction enhance its viability in community-based restoration programs. In SMBG, the strategic placement of fences in low to medium wave-energy areas amplified their effectiveness, indicating the need for site-specific design optimization—a critical success factor noted in several comparative studies across Southeast Asia (Macintosh & Ashton, 2023).

Ecotourism as a Catalyst for Conservation

One of the unique aspects of the SMBG initiative is the integration of ecotourism with conservation. The study shows that well-managed ecotourism activities in Gunung Anyar and Medokan Ayu contribute to public environmental awareness and provide alternative livelihoods, particularly for local communities involved as tour guides, nursery caretakers, or eco-craft producers. This relationship echoes findings in global literature that ecotourism, when governed inclusively, can serve as a vehicle for the financial sustainability of conservation areas, reduce over-reliance on government budgets, and promote local stewardship (Díaz-Caravantes et al., 2023; Hernández et al., 2023). Moreover, the educational value embedded in the design of the SMBG strengthens its role as a living laboratory for environmental literacy.

Limitations and Critical Challenges

Despite its promise, the bamboo fencing approach is not without limitations: 1) Site Dependence: Its effectiveness varies significantly based on sediment type, wave exposure, and local hydrodynamics; 2) Maintenance Needs: While bamboo is biodegradable, it is also prone to biofouling and decay, requiring periodic maintenance or replacement; 3) Temporal Effectiveness: Bamboo fences are more effective during early restoration stages but may not suffice for long-term shoreline protection without complementary interventions; and 4) Lack of Standardization: Varying design parameters across sites can lead to inconsistent outcomes, underscoring the need for guideline-based implementation frameworks. These challenges highlight the importance of integrating bamboo fencing within a larger adaptive coastal management strategy, involving ecosystem monitoring, engineering oversight, and community co-management.

Policy Implications and Alignment with SDGs

The implementation of bamboo fences in SMBG directly supports multiple targets within the UN Sustainable Development Goals: 1) SDG 13 – Climate Action: Through carbon sequestration and disaster risk reduction; 2) SDG 14 – Life Below Water: By protecting coastal biodiversity and marine nurseries; 3) SDG 15 – Life on Land: Through ecosystem restoration and resilience building; and 4) SDG 11 – Sustainable Cities and Communities: Enhancing urban resilience through green infrastructure. Policy-makers should thus consider bamboo fencing not just as a conservation tool, but as a cross-sectoral solution that intersects climate adaptation, community empowerment, and green tourism. Furthermore, this case supports Indonesia's commitments under the Nationally Determined Contributions (NDCs) and the Mangrove for Coastal Resilience Initiative (MCR).

CONCLUSION

This study demonstrates that bamboo fencing, as a form of eco-engineering, is a viable and effective solution for mitigating coastal abrasion and enhancing mangrove ecosystem resilience in low- to medium-energy coastal environments such as the Surabaya Mangrove Botanical Garden (SMBG). Bamboo fences support both the ecological and structural restoration of degraded coastal zones by reducing wave energy, promoting sedimentation, and increasing mangrove propagule survival. Beyond their physical function, bamboo fences contribute to the broader goals of nature-based solutions (NbS) by being low-cost, biodegradable, and socially inclusive. Their implementation in SMBG has strengthened coastal resilience and supported sustainable ecotourism development, local community engagement, and environmental education.

The success of bamboo fencing in Surabaya affirms the need for integrated and site-specific restoration strategies that align with national climate adaptation policies and the Sustainable Development Goals (SDGs)—

particularly SDG 13 (Climate Action) and SDG 15 (Life on Land). However, site conditions, material durability, and long-term maintenance challenges require further attention to ensure scalability and sustainability. Future initiatives should focus on: 1) Developing technical guidelines for bamboo fence design based on coastal typologies; 2) Strengthening multi-stakeholder collaboration between local governments, academic institutions, and communities; and 3) Incorporating longitudinal monitoring to assess ecological outcomes over time.

Integrating bamboo fencing into coastal conservation and ecotourism planning represents a practical, science-based, and community-driven model for sustainable coastal management in the face of climate change.

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