

Enhancing Waste Management and Marine Ecosystem Protection for Tourism Sustainability on Buluh Island

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Abstract. This study evaluates waste management strategies on Buluh Island to enhance marine ecosystem protection and ensure tourism sustainability. The research highlights a significant relationship between waste accumulation and the degradation of marine ecosystems, which threatens both the environment and the island's tourism sector. Utilizing qualitative interviews, environmental assessments, and surveys with key stakeholders, the study identifies the pressing challenges of plastic waste and insufficient infrastructure. The findings recommend localized waste management interventions, community-driven initiatives, and circular economy practices that can mitigate environmental impact and support the island's economic future. These insights provide a model for sustainable tourism in small coastal communities, integrating waste reduction with marine conservation efforts.

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1 Introduction

Marine and coastal tourism is commonly recognized as one of the most rapidly expanding sectors in modern tourism [1]. The health of marine ecosystems is increasingly recognized as a critical factor in the sustainability of coastal and island tourism destinations [2]. Marine ecosystems not only support biodiversity and fisheries but also serve as a cornerstone for tourism industries [3], particularly in regions like Pulau Buluh, located within the Batam Archipelago, Riau Island Province, Indonesia. Pulau Buluh, a small island community in the Riau Islands Province, is heavily reliant on both tourism and marine resources. However, in recent years, the island has been facing growing challenges due to marine pollution, particularly from plastic waste, which threatens the very ecosystems that sustain both local livelihoods and the tourism sector.

Waste management is critical not only for sustaining tourism but also for preserving the overall environmental health of island regions [4]. Islands are particularly vulnerable to marine pollution due to their geographic isolation, limited infrastructure, and reliance on marine ecosystems for both economic and ecological stability. Effective waste management plays a vital role in protecting biodiversity, supporting fisheries, and maintaining clean waters, which are essential for the local economy and the long-term sustainability of island communities. Without proper intervention, waste—especially plastic—can lead to ecosystem degradation, impacting not only tourism but also local livelihoods, food security, and climate resilience [5].

Tourism in Pulau Buluh is predominantly focused on its natural beauty—pristine waters, coral reefs, and coastal mangroves—which attract visitors seeking marine-based recreational activities such as snorkeling, fishing, and eco-tours. Yet, the rapid growth of tourism, combined with insufficient waste management practices, has exacerbated the pollution of these vital ecosystems. The presence of marine debris, especially plastic waste, is not only an eyesore for tourists but also poses a direct threat to marine life, with species such as turtles, fish, and birds increasingly at risk. If left unchecked, this environmental degradation could erode the island's reputation as a tourism destination and further endanger local biodiversity.

Despite efforts to promote sustainable tourism in Indonesia, there is a critical gap when it comes to the integration of marine ecosystem protection into tourism standards [6], particularly in smaller and more isolated islands like Pulau Buluh. Existing sustainable tourism frameworks often focus on broader environmental, social, and economic goals but fall short in addressing the unique challenges faced by smaller coastal communities that rely on fragile marine environments. The one-size-fits-all nature of these standards often overlooks the nuanced needs of places like Pulau Buluh, where the impacts of marine pollution are more localized and the resources to combat them are more limited. As a result, local tourism operators and communities struggle to implement effective marine conservation measures that align with sustainable tourism practices [7].

One of the most pressing environmental challenges facing Pulau Buluh is the management of plastic waste, much of which ends up in the surrounding marine environment. The island's limited infrastructure and resources mean that waste is often inadequately managed, with much of it either burned in open areas or dumped into the ocean, exacerbating the pollution problem [8]. This not only affects the marine ecosystems that are central to the island's tourism appeal but also poses a health risk to the local population [9]. The lack of a comprehensive waste management system directly undermines the island's potential to develop a sustainable tourism model that could benefit both the environment and the local economy [10].

A key component of addressing this issue is the implementation of a localized waste management strategy that aligns with the principles of sustainable tourism [11]. Such a strategy would involve both the reduction of waste generation at the source and the

improvement of waste collection and disposal systems. In the context of Pulau Buluh, community-based waste management initiatives could be particularly effective. These initiatives would empower local residents and tourism operators to take active roles in managing waste, promoting practices such as waste separation, recycling, and the reduction of single-use plastics [12].

Moreover, the development of a circular economy model—where waste is minimized, and materials are reused or recycled—could provide economic benefits to the local community [13]. Recycled materials could be repurposed into marketable products, such as handicrafts made from plastic waste, which could then be sold to tourists as part of a broader eco-tourism experience [14]. This would not only create additional income streams for local residents but also reinforce the connection between sustainability and economic opportunity in the minds of both tourists and locals [15].

This study aims to evaluate waste management strategies on Buluh Island with a focus on protecting the marine ecosystem and enhancing tourism sustainability. It seeks to identify the challenges posed by waste accumulation, assess the effectiveness of current practices, and propose actionable solutions that align with both environmental conservation and economic growth in small coastal communities. Through a localized approach, this study aims to assess the current state of marine pollution, particularly plastic waste [8], and its impact on both the marine environment and the tourism industry [16]. By examining the effectiveness of existing sustainable tourism standards, the study will identify areas where these frameworks fall short in supporting marine conservation efforts. Additionally, it will explore the potential for community-driven solutions and the role of local stakeholders in promoting responsible tourism practices that prioritize the health of the marine ecosystem [17].

This research holds critical significance in addressing both local and global sustainability challenges. Marine pollution, particularly from plastic waste, not only threatens biodiversity but also jeopardizes the economic future of island communities like Pulau Buluh, which rely on healthy ecosystems for tourism and fisheries. By evaluating waste management strategies, this study contributes to broader efforts to mitigate the global marine pollution crisis while providing scalable solutions for other island communities facing similar environmental and economic pressures.

1.1 Difficulties in Implementing Sustainable Tourism in Buluh Island

While effective waste management and marine ecosystem protection are critical for the development of sustainable tourism in Pulau Buluh, the implementation of these strategies faces several significant challenges. One of the primary issues is the island's limited infrastructure and resources. As a small island community, Pulau Buluh (on Figure 1) lacks adequate waste management facilities, and much of the plastic and other waste ends up either being openly burned or disposed of directly into the ocean. This not only exacerbates marine pollution but also undermines efforts to implement sustainable tourism practices that depend on a foundational level of environmental protection.

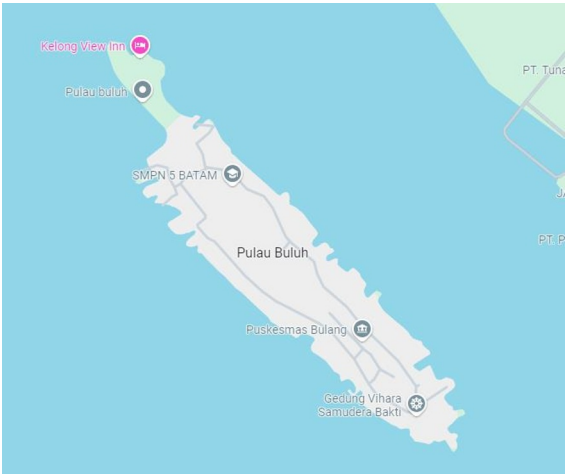


Fig 1. Pulau Buluh

While effective waste management and marine ecosystem protection are critical for Pulau Buluh, the island faces significant challenges in implementing sustainable practices. One of the most alarming issues is the sheer volume of waste impacting the marine environment. Recent data reveal that approximately 2 tons of waste accumulate on the island every 4 hours, coming from both internal sources—waste generated by the local population—and external sources, primarily waste from passing ships. This accumulation of marine debris poses a severe threat to the island's fragile marine ecosystems, which are critical not only for local biodiversity but also for the region's overall environmental health. The marine litter in Pulau Buluh can be seen on Fig 2 below:

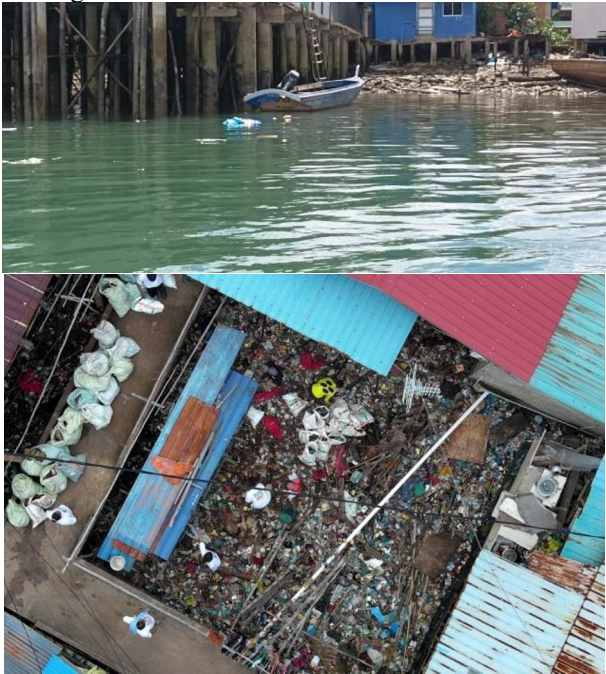


Fig 2. Marine Litter on Pulau Buluh

Additionally, there is a significant lack of incentives and support from both local and national governments to help the community and tourism businesses in Pulau Buluh transition to more sustainable practices. Although governmental policies often emphasize the importance of sustainability, tangible support in the form of funding, technology, or waste management infrastructure is limited. This lack of support makes it difficult for tourism operators to invest in systems that would reduce waste and protect the marine environment. For example, the use of modern waste management technologies, such as IoT-enabled monitoring systems for tracking waste disposal or plastic recycling programs, could significantly reduce pollution, but such technologies are often out of reach for small island communities due to financial and logistical constraints.

1.2 Local Governance's Role in Promoting Sustainable Tourism with Focus on Marine Ecosystem Protection

The role of local governance in promoting sustainable tourism is critical, particularly in areas like Pulau Buluh, where the health of marine ecosystems directly influences the tourism industry. Local governments must not only prioritize economic growth but also protect the marine environment, which is central to the region's appeal as a destination [18]. However, marine ecosystem protection in tourism is often overlooked due to competing priorities, lack of resources, and insufficient enforcement of environmental regulations [19]. The degradation of marine habitats through pollution, overfishing, and unregulated tourism activities has put immense pressure on Pulau Buluh's natural resources.

One of the main responsibilities of local governance is to implement and enforce policies that safeguard marine ecosystems while supporting tourism development [20]. This includes stricter regulations on waste disposal, especially plastic waste that heavily impacts coastal and marine environments. Despite this need, local governance in Pulau Buluh has faced challenges in integrating comprehensive waste management systems that address the influx of waste from both local activities and tourism [21]. For instance, inadequate waste collection and recycling infrastructure have led to significant amounts of plastic waste being discharged into the ocean, thereby threatening coral reefs and marine life—key attractions for tourists [22].

Moreover, local governments play a vital role in creating awareness about marine conservation among tourism operators and the local population. However, many local governance efforts have fallen short in promoting education programs that focus on sustainable tourism practices, such as reducing single-use plastics, responsible waste disposal, and eco-friendly tourism activities [23]. The lack of educational initiatives has led to persistent harmful practices by both locals and tourists, further deteriorating the health of marine ecosystems [24].

2 Marine Coast Tourism and Impact from Tourism

Coastal tourism encompasses a wide array of tourism, leisure, and recreational activities occurring within coastal areas and nearby offshore waters. This includes the development of coastal tourism infrastructure such as accommodations, restaurants, the food industry, and vacation homes, along with supporting infrastructure like retail shops, marinas, and activity providers. Additionally, coastal tourism activities involve recreational boating, ecotourism focused on the coast and marine environments, cruises, swimming, recreational fishing, snorkeling, and diving [25].

Marine tourism refers to recreational activities that involve traveling away from one's home, with a primary focus on the marine environment, defined as saline and tide-affected waters [26]. This definition is important because it highlights not only the biological and

recreational aspects but also emphasizes that marine and coastal tourism encompasses land-based activities such as whale watching from the shore, reef walking, cruise ship provisioning, and yachting events, all of which fall under the broader scope of marine tourism [27].

It is now widely acknowledged that tourism can have detrimental effects on both the physical and marine environments [28]. Similar to other areas of tourism, growing concerns about the environmental impacts and the broader implications for sustainable development have increasingly shaped research on ocean and marine tourism [29]. Advances in technology [30][31], such as transportation innovations like tourist submarines and recreational tools like scuba diving, have made ocean environments more accessible to tourists than ever [32]. For instance, governments and private enterprises now view marine parks, coral reefs, and locations easily accessible to scuba divers as valuable natural resources that can be developed through tourism [33].

However, the notion that tourism inherently has a negative impact has become somewhat of a cliché in much of modern travel literature. While it is true that unplanned and poorly managed tourism can harm the natural environment [34], our overall understanding of the relationship between tourism and the environment, especially in coastal regions, remains limited [35]. Discussions about the effects of tourism development often rely on broad generalizations rather than focusing on the outcomes of scientific research concerning its impact on particular environments or specific species [36].

The scarcity of data on the environmental impacts of tourism, especially in island microstates, can be attributed to several factors [37]. First, significant business and political interest in environmental issues has only surfaced in recent years [38]. Second, many governments in less developed regions have prioritized economic development, healthcare, welfare, and education over environmental monitoring and conservation due to limited financial resources [39]. Third, as a result of these priorities, the necessary resources and scientific expertise have generally been unavailable to conduct the extensive research required.

Local tourism professionals in Pulau Buluh have expressed growing concerns regarding the sustainability of their industry, especially in relation to the protection of marine ecosystems. Many tourism operators, including hotel managers, restaurant owners, and tour guides, recognize that the island's natural beauty, particularly its marine biodiversity, is the main draw for tourists. However, they also acknowledge that this very attraction is under significant threat due to pollution, overfishing, and unregulated tourism activities that harm the delicate marine environment.

One of the primary concerns raised by local tourism professionals is the impact of plastic waste on the island's marine ecosystems [40]. With inadequate waste management systems in place, plastic waste often ends up in the ocean, where it damages coral reefs and endangers marine life [41]. These professionals have noted that while tourists are attracted to the clear waters and diverse marine life, the increasing amount of visible pollution, such as plastic debris on beaches and in the water, detracts from the overall tourist experience. Many have expressed frustration over the lack of infrastructure to properly manage and recycle waste, emphasizing that more needs to be done to ensure sustainable tourism practices that protect the marine environment [42].

Another aspect of the coastal environment significantly impacted by tourism in tropical and subtropical regions is the removal and dredging of mangroves and estuaries for the development of marinas and resorts. These mangrove and estuarine areas are crucial as nursery grounds for various fish species [43]. The destruction of these natural habitats through dredging or infilling can lead to a severe decline in fish populations. Additionally, such activities can disrupt the entire estuarine food chain, resulting in a loss of ecological diversity. The loss of mangroves also diminishes shoreline protection, making coastal areas

more vulnerable to erosion and storm surges [44]. Furthermore, the removal of mangroves not only affects the cleared area but also impacts other coastal regions by increasing the transport of marine sediment [45].

3 Methodology

This study employs a mixed-method approach, integrating qualitative interviews with key stakeholders, environmental assessments, and surveys. The qualitative interviews involved 50 stakeholders, including local government officials, environmental experts, and tourism operators, selected for their pivotal roles in the implementation and regulation of waste management and marine ecosystem protection. The rationale behind choosing these stakeholders was to gain a comprehensive understanding of both policy-level insights and on-the-ground challenges faced by tourism businesses. The environmental assessments were carried out to evaluate marine pollution, specifically from plastic waste, and its impact on the island's biodiversity. Additionally, surveys were distributed to tourists and local residents to gather perceptions on sustainable tourism practices and the impact of waste management on the marine environment. This mixed-method approach provides a holistic view of the interconnectedness between waste management and tourism sustainability. Conducted in Bahasa Indonesia, interviews explore various topics, including tourism challenges, governmental initiatives, and sustainability impacts. To ensure validity, interpretive criteria such as prolonged engagement, purposive sampling, and research protocol adherence are employed. Transcripts undergo review to enhance confirmability, while data triangulation and independent analysis bolster credibility.

The following methodological (Fig 3) steps outline the approach taken in this research:

1. **Qualitative Interviews with Local Stakeholders.**
Semi-structured interviews were conducted with 50 key stakeholders in Pulau Buluh, including local government representatives, tourism operators (hotels, restaurants, and tour agencies), environmental NGOs, and community leaders. These interviews aimed to gather insights into the challenges and opportunities related to marine ecosystem protection, particularly concerning the role of tourism. Interview questions focused on current waste management practices, the perceived impact of tourism on marine biodiversity, and stakeholder engagement in sustainable tourism initiatives.
2. **Surveys of Tourists and Residents.**
Two sets of surveys were distributed: one to fifty tourists visiting Pulau Buluh and another to fifty local residents. The tourist survey assessed awareness and attitudes toward sustainable tourism practices, including their use of plastic and participation in eco-friendly activities. The resident survey aimed to understand local perceptions of tourism's impact on the marine environment, the effectiveness of waste management practices, and the economic benefits of tourism.
3. **Environmental Monitoring**
To evaluate the direct impact of tourism activities on marine ecosystems, environmental monitoring was conducted at key tourist hotspots around Pulau Buluh. This included water quality testing, measurement of marine debris (especially plastic waste), and biodiversity assessments of coral reefs and marine species. The data collected were analyzed to identify patterns of environmental degradation linked to tourism, focusing on coral reef health, levels of marine waste, and overall ecosystem diversity.
4. **Evaluation of Waste Management Infrastructure.**
An in-depth analysis of the existing waste management infrastructure in Pulau Buluh was conducted to assess its capacity to handle waste generated by tourism. The analysis included site visits to local waste disposal facilities and interviews with waste management authorities to determine the challenges they face, such as limited resources

and lack of technology. The study also examined the alignment of waste management systems with marine ecosystem protection goals.

5. Policy and Governance Analysis.

A review of local policies related to tourism, environmental conservation, and waste management was conducted to evaluate the effectiveness of existing governance frameworks in supporting marine ecosystem protection. This review focused on the implementation of policies that regulate tourism activities, control pollution, and promote sustainable waste management practices. The research also explored the role of local governance in facilitating collaboration between stakeholders, including community groups, tourism businesses, and environmental organizations.

6. Data Analysis.

The qualitative data from interviews and field observations were analyzed using thematic coding to identify common themes and patterns regarding stakeholder perspectives on marine conservation and waste management. Quantitative data from the surveys and environmental monitoring were analyzed using descriptive statistics to measure the extent of tourism's impact on the marine environment and the effectiveness of current waste management practices. Comparative analysis was used to assess the differences in awareness and attitudes between tourists and local residents.

7. Workshops and Focus Groups.

Following the data collection, two workshops were conducted with local stakeholders to present preliminary findings and gather feedback on potential solutions. The workshops facilitated discussions on improving waste management strategies and enhancing collaboration between tourism operators and environmental groups to protect marine ecosystems. Focus groups were also held with community members to explore community-driven approaches to sustainable tourism and marine conservation.

8. Ethical Considerations.

All participants were informed about the study's objectives, and their consent was obtained prior to conducting interviews and surveys. Confidentiality was maintained throughout the research process, and data were anonymized to protect the identities of participants.

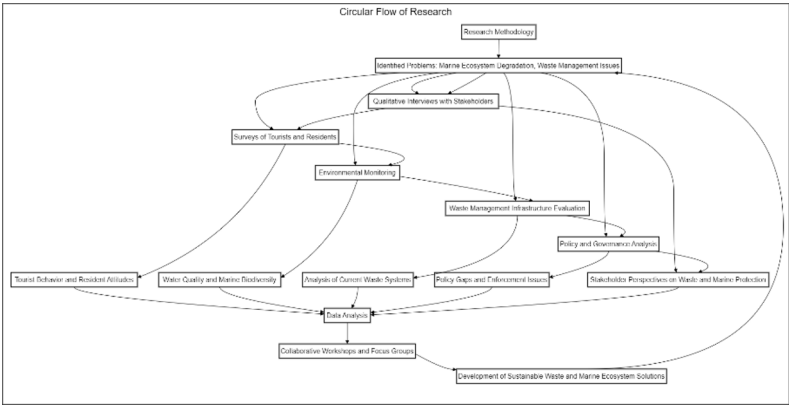


Fig. 3. Flow Diagram of This Research

4 Result and Discussion

The findings of this study align with similar research conducted in other coastal regions. For instance, research on coastal tourism impacts in Tidung Island, Jakarta [46], revealed parallel challenges related to marine debris accumulation and the degradation of marine biodiversity. These comparisons highlight the broader relevance of the waste management strategies identified in this study and emphasize the need for tailored, localized approaches to waste management in island and coastal regions globally. The results of this study underscore the critical challenges faced by Pulau Buluh in managing its waste and protecting its marine ecosystems. The findings demonstrate a significant relationship between tourism development, waste accumulation, and the degradation of the island's marine environment. A comprehensive evaluation of current waste management strategies and their impact on marine ecosystems reveals gaps in infrastructure, regulatory enforcement, and stakeholder engagement, all of which are necessary to achieve sustainable tourism.

1. Marine Ecosystem Degradation Due to Waste Accumulation.

The marine environment surrounding Pulau Buluh is facing severe degradation, primarily due to the accumulation of waste. The study's environmental monitoring revealed that approximately 2 tons of wastes accumulate in the waters around the island every 4 hours. This waste originates from two main sources: internal waste generated by local residents and businesses, and external waste carried by ocean currents from passing ships.

- **Internal Waste and Its Impact on Marine Ecosystems**

The waste generated by the island's population, including single-use plastics and organic waste, is a major contributor to the pollution of coastal waters. Inadequate waste management infrastructure has led to widespread improper disposal practices, such as open dumping and burning of waste, which allows significant amounts of debris to leak into the ocean. This pollution has had a profound impact on the island's coral reefs, seagrass beds, and mangrove ecosystems, which are critical habitats for marine biodiversity.

- **External Waste from Passing Ships**

In addition to locally produced waste, Pulau Buluh faces a considerable influx of external waste from passing ships, which discharge waste into the ocean. This external waste, consisting largely of plastics and fishing debris, is carried by ocean currents and deposited on the island's shores. The continuous arrival of external waste further exacerbates the pressure on marine ecosystems, overwhelming local clean-up efforts and causing widespread damage to coastal habitats.

2. Evaluation of Current Waste Management Strategies.

The waste management infrastructure in Pulau Buluh is not adequately equipped to handle the volume of waste produced by the local population and the additional burden of external marine debris. The findings indicate that existing waste collection and disposal systems are outdated, with limited capacity for waste processing or recycling. This has resulted in the widespread leakage of waste into the marine environment, where it directly affects biodiversity and water quality.

- **Inadequate Waste Collection and Recycling.**

Local authorities and businesses rely heavily on basic waste collection systems that lack the necessary capacity to manage the growing waste problem. The absence of comprehensive recycling facilities has meant that much of the waste, particularly plastics, is either incinerated in open spaces or dumped into the ocean. This improper disposal exacerbates the accumulation of microplastics in marine ecosystems, further disrupting food chains and endangering marine species. The

lack of financial resources to invest in modern waste management technologies, such as waste-to-energy plants or community-based recycling programs, has left the island with limited options for addressing the waste issue.

One of the most significant outcomes of this research is the development of a partnership between Pulau Buluh and a waste management company specializing in converting plastic waste into paving blocks. This collaboration not only addresses the local waste accumulation problem but also provides an economic opportunity for the community by transforming waste into materials for infrastructure projects. This model can be practically applied to similar islands facing waste management challenges. By replicating this partnership model, other island communities could adopt sustainable practices that integrate environmental and economic benefits, reducing plastic waste while promoting infrastructure development

- **Community Involvement and Waste Reduction Efforts.**

Interviews with local stakeholders revealed that while there is awareness of the need for improved waste management, actual engagement in sustainable practices is low. Most businesses, particularly small tourism operators, struggle to adopt eco-friendly waste management systems due to the high costs associated with these technologies. Moreover, local communities have limited access to education and resources on how to reduce and manage waste sustainably. Without coordinated efforts between local government, businesses, and residents, the waste problem in Pulau Buluh will continue to grow, further endangering the island's marine ecosystems.

However, a positive development in addressing this issue has been the active participation of NGOs and students from Institut Teknologi Batam (ITEBA), who have initiated efforts to clean up the island and its surrounding waters (Fig 4). These collaborative efforts have resulted in the removal of approximately 5 tons of plastic waste from the ocean, significantly alleviating the immediate pressure on marine ecosystems. The involvement of students from ITEBA in these clean-up initiatives has not only contributed to the direct reduction of marine debris but also helped raise awareness among the local community and tourists about the importance of protecting marine environments.



Fig 4. NGO and Students Helping Collecting Waste

3. **Marine Ecosystem Health and Biodiversity Loss.**

The continuous accumulation of waste, combined with poor waste management practices, has had a detrimental effect on marine biodiversity in Pulau Buluh. Coral

reefs, mangroves, and seagrass beds, which are vital to the health of the marine ecosystem, are in decline due to pollution and habitat destruction. Coral reefs, in particular, have experienced significant bleaching, and many fish species have been found with plastic particles in their digestive systems, indicating widespread contamination of the food chain.

- **Impact on Coral Reefs and Marine Life**

Coral reefs, which are among the most biologically diverse ecosystems in the world, are particularly vulnerable to pollution. In Pulau Buluh, the reefs are suffering from multiple stressors, including plastic debris that entangles corals, sedimentation that suffocates coral polyps, and pollutants that increase water toxicity. These factors contribute to coral bleaching and a reduction in reef resilience. As the reefs decline, so too does the marine biodiversity that depends on these ecosystems, including fish species that are essential to local fisheries.

4. **Policy and Governance Challenges in Waste Management.**

The findings also highlight significant challenges in the policy and governance framework surrounding waste management and marine protection in Pulau Buluh. While there are existing regulations aimed at controlling waste and protecting marine ecosystems, enforcement remains weak, and coordination between local authorities and stakeholders is insufficient. The top-down approach to policy-making has failed to involve local communities and businesses in developing practical solutions tailored to the island's unique challenges.

- **Gaps in Enforcement and Regulation.**

Local authorities face difficulties in enforcing waste disposal laws, particularly when it comes to illegal dumping from ships and improper waste management by local businesses. Despite international maritime regulations prohibiting the discharge of waste at sea, enforcement in the waters around Pulau Buluh is lax, allowing ships to continue polluting the marine environment with impunity. On the island, local businesses and residents often resort to unsustainable waste disposal practices due to a lack of affordable alternatives, further exacerbating the problem.

5. **Opportunities for Improved Waste Management and Marine Protection.**

Despite these challenges, there are several opportunities to improve waste management and protect the marine environment in Pulau Buluh. The development of community-based waste management programs, where residents and businesses take an active role in waste reduction and recycling, could significantly reduce the environmental impact of tourism and local activities. Moreover, strengthening regulations to prevent illegal waste dumping from ships and providing financial incentives for businesses to adopt sustainable practices are essential steps toward protecting Pulau Buluh's marine ecosystems.

6. **Promoting Eco-Friendly Tourism Practices.**

Tourism operators can play a key role in reducing the environmental impact of their activities by promoting eco-friendly practices, such as reducing plastic use, offering reusable products, and educating tourists about marine conservation. Additionally, government support through subsidies or tax breaks for businesses that invest in sustainable waste management technologies would encourage wider adoption of eco-friendly solutions.

7. **Actionable Recommendations for Waste Management Strategies**

Based on the findings of this study, several actionable recommendations can be proposed for improving waste management on Pulau Buluh and other similar coastal regions:

- Strengthening partnerships with waste management companies or NGO to develop local solutions such as converting plastic waste into paving blocks or other products that possible to made from plastic waste.
- Implementing community-based recycling programs that promote education on waste separation and reduction of single-use plastics.
- Introducing policy incentives for tourism operators to adopt eco-friendly practices, such as offering reusable products and reducing plastic consumption.
- Increasing enforcement of regulations to prevent illegal waste dumping from passing ships, which significantly contributes to marine debris.
- Expanding public awareness campaigns to encourage both residents and tourists to engage in sustainable waste management practices."

4.1 Endogenous Sustainability in Pulau Buluh

The concept of endogenous sustainability emphasizes the importance of local communities taking control over sustainable development practices, especially in managing their resources and environment [47]. In the case of Pulau Buluh, this approach is particularly relevant as the island faces significant challenges from both internal and external waste, which threatens its marine ecosystems. The collaboration between local stakeholders, including the community, NGOs, and educational institutions like Institut Teknologi Batam (ITEBA), has been a critical factor in fostering local sustainability initiatives.

In line with the principles of reciprocal determinism, where communities and individuals interact and influence each other, Pulau Buluh has initiated efforts to not only manage waste but also protect its marine environment through adaptive, community-driven management. A key example of this is the partnership with a company that transforms plastic waste into paving blocks, providing both an environmental solution and economic benefits for the local population. This initiative enables the community to repurpose waste into useful materials for infrastructure development, contributing to economic and environmental sustainability.

Through social learning and adaptive management, the community of Pulau Buluh has gained valuable experience in waste management and environmental conservation, reinforcing the idea that local solutions, tailored to the specific needs and challenges of the area, can lead to more sustainable outcomes. By integrating local stakeholders in decision-making processes and leveraging the knowledge gained from on-the-ground practices, Pulau Buluh is creating a model of endogenous sustainability that aligns economic development with environmental protection.

This approach, however, faces challenges such as limited financial resources and the need for more comprehensive policies that support local initiatives. Despite these obstacles, the community's capacity to adapt and innovate offers a promising path forward for sustaining both the island's economy and its marine ecosystems.

5 Conclusion

The findings of this study highlight the critical relationship between waste management and marine ecosystem protection in Pulau Buluh. The island faces significant challenges due to both internal waste generated by local residents and external waste from passing ships. The accumulation of approximately 2 tons of waste every 4 hours has severely impacted the marine environment, threatening the health of coral reefs, marine biodiversity, and overall ecosystem resilience. While efforts by local stakeholders, including the collaboration with a company to convert plastic waste into paving blocks, have shown promise, the scale of the

waste problem continues to exceed the current capacity of the island's waste management infrastructure.

The involvement of partnership company, NGOs and ITEBA students, which resulted in the removal of 5 tons of plastic waste, demonstrates the potential for community-driven solutions. However, without a long-term, comprehensive waste management strategy that addresses both internal and external sources of pollution, Pulau Buluh's marine ecosystems will remain vulnerable. Endogenous sustainability, which empowers the local community to take control of their environmental challenges, is a key approach that needs further support and expansion.

For future research, there should be a focus on evaluating the long-term impact of the plastic-to-paving block initiative, including its environmental and economic effects on Pulau Buluh. Research should also involve continuous monitoring of marine ecosystem health, particularly the condition of coral reefs and water quality, using advanced technologies like IoT sensors. Additionally, it is crucial to explore behavioral changes among residents and tourists concerning waste management practices, and to assess the effectiveness of educational campaigns promoting waste reduction. Furthermore, future studies should examine stronger policy and enforcement mechanisms to prevent waste dumping by passing ships, as well as the potential for economic incentives for tourism operators who adopt environmentally friendly practices, in order to foster a more sustainable tourism industry.

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