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Pentahelix Synergy in Coral Conservation: Restoring Ecological Health and Enhancing Social Trust through CBPR in Prigi Bay

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Graphical Abstract

Abstract
Coral reef ecosystems at Mutiara Beach, Trenggalek, face degradation due to sedimentation and high-intensity tourism. This study documents a community service initiative using a Community-Based Participatory Research (CBPR) approach to rehabilitate the reef and empower local stakeholders. Through a Pentahelix synergy involving academics, government, security forces (TNI), the private sector, and the community, a total of 3,800 coral fragments of the Acropora genus were successfully transplanted onto 12 iron rack units. Results indicate that this intervention established a biological foundation for increased coral cover and reef fish populations in a previously damaged area. Furthermore, the project addresses the immense ecological pressure of a 252% surge in annual visitor volume at Mutiara Beach, which rose from 126,581 in 2022 to a peak of 445,743 in 2024. The initiative successfully established a sustainable "field laboratory," strengthened social trust, and demonstrated that integrating technical restoration with multi-stakeholder collaboration is vital for long-term marine conservation in high-traffic tourism zones.

Keywords: Coral Transplantation, CBPR, Pentahelix Synergy, Mutiara Beach, Coastal Empowerment.

1. INTRODUCTION

Coral reefs are among the most critical marine ecosystems, fuctioning as essential habitats, spawning grounds, nursery areas, and feeding grounds for a vast array of marine biota, including fish, mollusks, and crustaceans [1]. Beyond their high ecological value, they provide significant socio-economic benefits as major attractions for marine tourism, sources of food, and natural barriers that protect coastlines from erosion and heavy wave action. However, these ecosystems are under increasing global threat from climate change, leading to widespread coral bleaching [2].

At the local level, Mutiara Beach in Trenggalek faces specific pressures that have led to the significant degradation of its marine environment [3]. According to official sectoral statistics for Mutiara Beach, visitor volume surged by 252% between 2022 and 2024, rising from 126,581 to a peak of 445,743 annual visitors [4]. This massive influx of tourism activity, combined with significant terrestrial sedimentation, has placed immense stress on the surrounding coral reefs. While the area still contains remnants of coral genera such as *Acropora*, *Montipora*, and *Pocillopora*, much of the original reef structure has been damaged by these intensifying human and environmental factors. By 2025, although visitor numbers stabilized at 314,755, the cumulative impact of the 2024 peak necessitated urgent structural rehabilitation. Consequently, this quantitative baseline of tourism pressure justifies the implementation of the 2025 restoration project to ensure the long-term sustainability of the beach's primary tourism asset.

Table 1. Visitor Volume

Year	Annual Visitor Volume
2021	40394
2022	126581
2023	-
2024	445743
2025	314755

source: https://satudata.trenggalekkab.go.id

This conservation initiative is grounded in a robust legal framework in Indonesia, which mandates the perfection and restoration of marine resources. Key regulations supporting this work include low No. 27/2007 [5] regarding the management of coastal areas and small islands, law No. 32/2009 on environmental protection and management [6], and Ministry of Marine Affairs and Fisheries Regulation No. 24/2016 [7], which provides technical guidelines for coral reef rehabilitation. The Ministry of Tourism has implemented a pentahelix collaboration approach that brings together government, academia, industry, local communities, and the media to promote tourism that is both community-focused and environmentally sustainable [8].

As an implementation of the tridharma of higher education, the Marine Science program at UIN Sunan Ampel Surabaya initiated this restoration project to bridge the gap between academic theory and practical environmental conservation. The program aims not only to physically restore the reef but also to cultivate environmental literacy among coastal residents and provide students with hand-on experience in marine management. By utilizing a Pentahelix synergy [9], this project seeks to create a sustainable model of participatory conservation that involves the government, the military (TNI), the private sector, and the local community [10, 11].

2. METHOD

The project was conducted at Mutiara Beach, located administratively in Tasikmadu Village, Watulimo District, Trenggalek Regency, East Java Province. The activity took place over a two-month period from October 1 to November 8, 2025. The site was selected because it is a coastal area with high marine biodiversity potential that has suffered degradation from terrestrial sedimentation and tourism activities. Figure 1 show the coral transplanted location (in the red block).

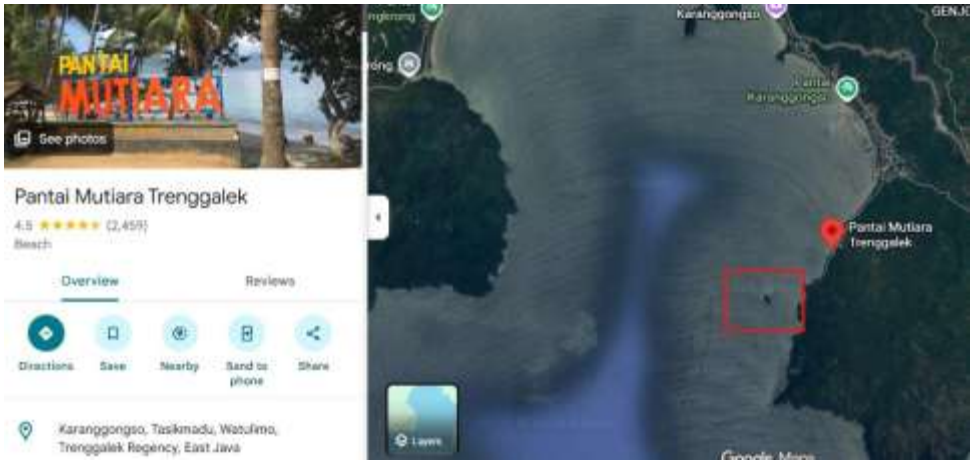

Figure 1. Coral Transplanted Location

Materials and Equipment Technical implementation relied on specific materials and equipment to ensure the success of the transplantation, including:

- Media: 12 units of iron rack tables (*kerangka besi*) served as the primary transplantation substrate.
- Biological Material: A total of 3,800 coral fragments were used, with the genus *Acropora* specifically selected for its relatively rapid growth rate.

Table 2. Tools

No	Tools	Use
1.	Scuba diving gear	Diving gear
2.	Camera	Documentation
3.	Cable ties	Securing fragments
4.	Buckets	To store the fragments
5.	Boats	Transport to the location
6.	Iron rack tables	Transplantation substrate

The initiative utilized the Community-Based Participatory Research (CBPR) approach. This framework emphasizes active involvement and tangible contributions from all participants, grounded in the community's desire to address environmental challenges such as declining fish catches, increasing water turbidity, and massive coastal abrasion. This approach ensured that local stakeholders were partners in the research and restoration process rather than just passive recipients. The study utilized direct participatory observation and technical performance evaluation during the demonstration phase (see Figure 2). Environmental literacy was measured by the participants' ability to successfully replicate the demonstrated techniques—specifically the correct handling of *Acropora* fragments and the secure application of cable ties to the iron racks without damaging the coral tissue.

Figure 2. *Demonstration of coral fragment attachment techniques*

The restoration was carried out through several collaborative stages:

1. Capacity Building: Marine Science students acted as facilitators and field instructors, providing technical understanding of transplantation methods, fragment handling, and genus identification to the community and young students.
2. Fragment Preparation: Participants worked together on the beach to prepare the iron racks and secure the coral fragments using cable ties, ensuring each fragment was stable and not physically damaged.
3. Deployment: The completed racks were transported by boat to the designated transplantation coordinates.
4. Underwater Installation: Divers with professional competence from the Mutiara Dive Center, Pokmaswas Rembeng Raya, and the university carried out the final placement of the racks on the seabed to ensure they were positioned safely and stably.

Collaborative Participation Reflecting the Pentahelix synergy [12], the methodology integrated various stakeholders, including the Trenggalek District Government, TNI Kodim 0806, Pokmaswas Rembeng Raya, Mutiara Dive Center, and local elementary school teachers and students.

3. RESULTS AND DISCUSSION

Ecological Rehabilitation and Technical Scale (T-0 Baseline)

The technical execution of the project resulted in a large-scale biological intervention at Mutiara Beach. Unlike traditional small-scale efforts, this initiative established a high-density restoration site summarized in the quantitative metrics below.

Table 3. Quantitative Metrics of Ecological Intervention

Parameter	Metric	Technical Specification
Total Fragments	3800 units	Genus: *Acropora*
Media Units	12 units	Format: Iron Rack Tables
Deployment Depth	2 – 6 meters	Substrate: Sand and Dead Coral
Methodology	CBPR	Pentahelix Participation

The selection of the *Acropora* genus was a strategic scientific choice based on its relatively rapid growth rate [13, 14], which is essential for accelerating the recovery of reef structural complexity in high-traffic tourism zones. While long-term growth percentages require multi-year monitoring, the successful deployment of 3,800 fragments provides the necessary biological foundation (T-0 baseline) for increased coral cover and reef fish biodiversity. The final underwater installation was a collaborative effort between the Mutiara Dive Center, Pokmaswas Rembeng Raya, and Marine Science students. This specialized team ensured that the 12 racks were positioned safely and stably on the seabed to serve as a T-0 baseline for the site's new status as a "Field Laboratory" for continuous environmental monitoring. Figure 3 is explicitly defined as the T-0 baseline documentation, representing the initial state of the restoration site before the first monthly growth cycle.

Figure 3. Transplanted coral racks

Knowledge Transfer and Environmental Literacy

A core objective of the Community-Based Participatory Research (CBPR) framework was the cultivation of environmental literacy. The project successfully provided a comprehensive technical understanding of transplantation methods, fragment handling, and genus identification to a diverse group. The marine science student completed to give a basic education about coral transplantation, the importance of protecting the ecosystem, to the coastal residents and young students from local elementary schools (Figure 4.). Success was defined by the participants' ability to correctly identify the *Acropora* genus and demonstrate precise fragment-handling techniques to prevent tissue damage during attachment. The outcome was successful preparation and securing of 3,800 fragments with zero reported physical damage during the assembly phase serves as quantitative evidence of a high level of knowledge transfer and increased environmental literacy.

Figure 4. Knowledge Transfer

The Pentahelix Synergy in Action

The success of this program is attributed to a robust Pentahelix synergy that integrated five key sectors:

- Academics: UIN Sunan Ampel provided the technical framework and established a sustainable research presence.
- Government: The Trenggalek District Government, through its Agriculture and Tourism offices, provided essential institutional support.
- Community: Groups like Pokmaswas Rembeng Raya and the Mutiara Dive Center were the primary actors in the field, ensuring community ownership of the reefs.
- Security (TNI): Kodim 0806 Trenggalek played a unique and vital role by providing security through sea patrols to prevent destructive fishing, which protected the restoration site and provided moral support to the fishermen.
- Private Sector/Media: Collaborations with entities like PT. Jetti (for biorock technology) and the media helped broaden the project's impact and visibility.

This collaborative model demonstrated that when environmental literacy is integrated with community welfare and institutional security, it creates a resilient framework for coastal management.

4. CONCLUSION

The 2025 coral restoration initiative at Mutiara Beach successfully established a verifiable biological and social foundation for long-term coastal resilience. The project achieved its primary ecological objective through the high-volume deployment of 3,800 *Acropora* fragments secured onto 12 iron rack units, providing a critical T-0 baseline for reef structural recovery. This technical scale confirms that the intervention is not merely symbolic but a significant biological injection into a degraded ecosystem.

The social objectives were satisfied through a measurable increase in environmental literacy among coastal residents and students. As evidenced by the technical competency evaluations conducted during the Capacity Building stage, participants demonstrated a high level of knowledge transfer by successfully preparing 3,800 fragments with minimal physical damage. This transition from passive observation to technical mastery proves the effectiveness of the Community-Based Participatory Research (CBPR) framework in fostering local ownership.

Furthermore, the project validates the Pentahelix synergy as a resilient model for marine management. The integration of TNI-led security patrols and the establishment of a permanent field laboratory ensure that the technical and social gains are protected from destructive practices and supported by continuous academic monitoring. This initiative provides a data-driven, scalable model for marine conservation that successfully bridges the gap between academic theory and practical community empowerment in high-traffic tourism zones.

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