IJSSR
International Journal of Social Service and Research

Vol. 5, No. 9, September 2025
e-ISSN: 2807-8691 | *p*-ISSN: 2807-839X

Quadruple-Loop Learning: Success Analysis of the PAMAN TOPA Community Empowerment Program in Coral Reef Transplantation

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Keywords
quadruple-loop learning, community empowerment program, Block Macs, FABA

ABSTRACT
C reef transplantation is a critical component of marine ecosystem restoration, yet it often fails due to unsuitable media that cannot withstand ocean waves and seawater corrosion. The *PAMAN TOPA* (*Pandanan* Marine Techno Park) programme, a collaborative initiative between PT PLN IP UBP *Jeranjang*, *POKMASWAS Pandanan*, and BPSPL *Denpasar*, aimed to overcome these challenges by developing a sustainable and effective transplantation strategy. This study employed a descriptive qualitative approach grounded in a quadruple-loop learning framework to explore the mechanisms behind successful coral reef transplantation. Data were collected through observations, interviews, and documentation of the programme's activities. The analysis revealed that success was achieved through iterative learning from past failures, understanding the specific characteristics of the problem, and considering external environmental and technical factors. Key actions derived from this learning process included the innovative use of Fly Ash and Bottom Ash (FABA) as a mixing agent in the Block *Macs* transplantation media, which proved resistant to corrosion and wave impact. Strong leadership, effective coordination among stakeholders, and active community participation further enhanced the programme's outcomes. The findings highlight the importance of adaptive learning, multi-stakeholder collaboration, and context-sensitive technological interventions in marine restoration projects. The *PAMAN TOPA* programme provides a replicable model for other coral reef transplantation initiatives, demonstrating that long-term, systematic, and reflective processes are essential for ecological sustainability and community engagement.

INTRODUCTION

The *PAMAN TOPA* program, short for *Pandanan* Marine Techno Park, is a community empowerment initiative supported by PT PLN Indonesia Power (IP) UBP *Jeranjang*. It has been running since 2020 in *Pandanan* Hamlet, *Malaka* Village, *Pemenang* District, North

Lombok Regency. This program is carried out in collaboration with the *Pandanan* Community Surveillance Group (*POKMASWAS*) and the *Denpasar* Coastal and Marine Resource Management Center (BPSPL *Denpasar*) (Silviana et al., 2020). *PAMAN TOPA* aims to conserve coastal environments through coral reef transplantation activities. This focus was chosen in response to damage to the coral reef ecosystem caused by destructive fishing practices among the local community.

In the process of its implementation, the *PAMAN TOPA* program has gone through several difficulties. One major challenge was the failure of coral transplantation because of the fragility of the planting media, which could not withstand ocean currents and corroded easily. This failure happened in 2020 when hundreds of transplanted corals were buried in seabed sand after the structures collapsed under wave pressure. The planting media at the time were made from PVC (polyvinyl chloride). Some coral colonies did survive, specifically those attached to spider-shaped media made of iron. However, even these did not last long because of corrosion. From hundreds of transplanted corals, only three could be saved.

Concerning this issue, the program's stakeholders carried out evaluations and sought solutions. Several participatory discussions and collaborative research with academics led to the development of a new transplant medium in 2023, called Block *Macs*, which uses FABA (fly ash and bottom ash) as its main material. Research and trials indicated that Block *Macs* is an effective and efficient solution for coral transplantation.

Block *Macs* is resistant to corrosion and strong enough to endure ocean currents. Its shape is concrete-like, with a rough and porous surface that acts as a natural substrate for coral larvae to attach and grow (Fitriani et al., 2024). Besides, FABA, used as a mixture in Block *Macs*, contains magnesium (MgO), calcium (Al_2O_3), iron oxide (Fe_2O_3), and silica (SiO_2). These elements are essential for coral growth (Khasanah et al., 2023). The FABA used in this project comes from company waste and is provided free of charge by PT PLN IP UBP *Jeranjang*, reducing operational costs for media production.

The effectiveness of Block *Macs* has been tested through joint research between PT PLN IP *Jeranjang* and the University of *Mataram*, Indonesia. The investigation compared coral growth on Block *Macs* versus metal table structures. The results discovered significantly better coral growth on Block *Macs*. After four months of observation, the average coral height and growth on Block *Macs* was 2.52 cm, slightly higher than the 2.30 cm recorded on the metal tables (Fitriani et al., 2024).

From this discovery, it can be seen that a systematic and participatory effort was made to overcome the problem. This process leading to success is worth analyzing, as it can offer valuable lessons to avoid failure in future projects. In addition, the mechanisms that led to the

success of this program can be replicated to solve similar challenges in the future. To analyze this success with a learning-oriented approach, this study uses the framework of quadruple-loop learning. Quadruple-loop learning is defined as a model developed from the theory of organizational learning (Lee et al., 2020). This model was introduced and developed by Sabine Lee, Changho Hwang, and M. Jae Moon as a response to earlier frameworks such as single-loop, double-loop, and triple-loop learning. This framework argues that in order to produce concrete, long-lasting solutions and ensure continuous learning, organizations must engage in profound reflection. In other words, the solutions proposed should not only solve problems, but also stay aligned with the initial objectives of the program.

Previous studies have addressed coral restoration using various artificial media. For example, Muhamad et al. (2019) explored the use of concrete and ceramic substrates for coral transplantation, finding moderate survival rates but limited attention to environmental stressors such as wave action and corrosion. Similarly, Putra et al. (2021) evaluated the use of metal frames in community-based reef restoration, noting improved attachment but persistent challenges with structural degradation over time. While these studies provide foundational knowledge on artificial substrates, they do not fully address sustainability, cost-effectiveness, or the integration of community involvement in solution development.

This research aims to provide a replicable model for coral reef transplantation that integrates technical innovation, environmental suitability, and community participation. The findings contribute to marine conservation strategies, inform policy for sustainable coastal management, and offer practical lessons for future restoration projects in similar ecological and socio-economic contexts.

METHOD

Methods

This current investigation aims to analyze the success of a community empowerment program by examining phenomena, events, and social dynamics associated with the program. Based on this objective, descriptive qualitative research is the best-suited method for this study (Ratnaningtyas et al., 2023). Field data were obtained through in-depth interviews with selected informants and direct observation at the program site. Informant selection was limited to those who were actively involved in the program. In total, eight informants were chosen. These informants include six individuals from the management and members of *POKMASWAS Pandanan*, one representative from BPSPL *Denpasar*, and one community development officer from PT PLN UBP *Jeranjang*. The informants included *Pak Haji* Syukur, head of *POKMASWAS*, who provided insights into community conditions and group activity

development; Muhammad Barmawi, Marine and Coastal Ecosystem Specialist from BPSPL *Denpasar*, who shared perspectives on program facilitation and monitoring; and representatives from PT PLN IP *Jeranjang*, which funded the *PAMAN TOPA* empowerment program. These individuals were selected because of their direct involvement and key roles in the program's planning, implementation, and oversight, making their information highly relevant to this study. Furthermore, field observations were carried out directly in *Pandanan* Hamlet over one week, from August 10 to August 17, 2024.

After collecting the data, the next step was to analyze the field findings using the quadruple-loop learning framework to explore the factors that led to the program's success. This framework helps provide a more profound understanding of the series of processes that contribute to either success or failure. The goal of utilizing this approach is to discover prospective solutions that are effective, efficient, and sustainable. Furthermore, this also aims to determine whether a solution that appears successful has actually gone through thorough consideration, including not only the actions taken but also the program's initial objectives.

In quadruple-loop learning, there are four levels or "loops" of learning that reflect the depth of analysis used to evaluate the outcomes. The first loop focuses on action or the implementation of a certain activity. The second one looks at the assumptions or basic ideas behind why that action was taken. The third loop considers the external context, including social and environmental factors that may have influenced those assumptions. Finally, the fourth loop combines time (past experience), target (a clear understanding of the problem), and context (external influences) to assess whether a solution has been developed through comprehensive reflection. When all four loops are applied, a solution can be considered deeply thought out, making it more likely to be permanent and sustainable (Lee et al., 2020). A detailed explanation of this framework can be seen in the figure and description below.

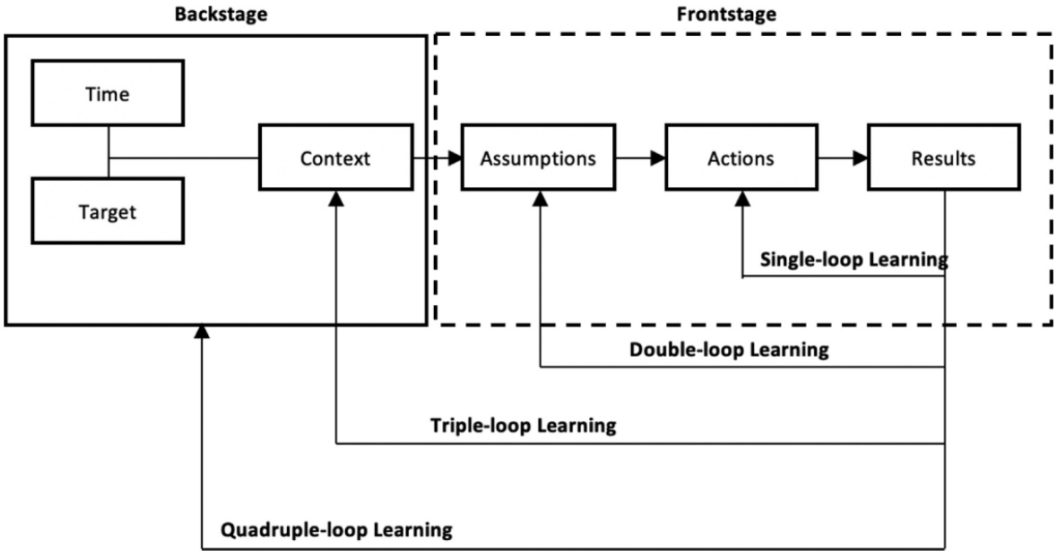

Figure 1. Quadruple-Loop Learning Framework

Based on the figure above, the process of identifying an outcome consists of two main areas: frontstage and backstage. In the frontstage, it can be seen from the results that are directly influenced by previous actions. Evaluating results by only looking at actions is called single-loop learning. This kind of learning is considered shallow because it does not consider the underlying assumptions that led to the action. If a solution is based only on action without questioning its foundation, the risk of failure is high. Thus, double-loop learning comes into play to examine the assumptions behind the actions (Argyris, 1976).

However, even double-loop learning has its limitations. It focuses too much only on the internal reasons or logic behind taking actions. In reality, external factors like culture, society, and the broader environment are also considerably pivotal and constantly changing. This is why triple-loop learning was developed to include consideration of external factors and to propose solutions that are more long-lasting and that address the root causes of problems (Tosey et al., 2012).

Despite its development in considering the external context, triple-loop learning still does not fully capture how these external factors are associated with the internal elements of the organization. In fact, these two are inseparable and closely influence each other in solving problems. Furthermore, learning must be continuous to ensure that the solutions created can fully overcome this issue. This is where quadruple-loop learning comes in, acting as a deeper and more holistic learning framework that addresses the limitations of triple-loop learning (Lee

et al., 2020). To have a more profound understanding, quadruple-loop learning introduces three main aspects, namely time, target, and context. These elements are interconnected: time refers to reflection on past experience in dealing with problems; target is about having a clear comprehension of the problem's characteristics; context encompasses external factors that need to be understood so that the solution will be relevant and appropriate. These three aspects form the backstage, the underlyin' process that is not always visible when a solution is being proposed. Only when the process moves into the frontstage, through assumptions, actions, and outcomes, do we begin to see the results.

RESULTS AND DISCUSSION

This section presents the analysis of the success of the PAMAN TOPA program in addressing the failure of coral reef transplantation due to the improper selection of planting media material. The analysis begins by mapping the elements found in the backstage, as this area forms the foundation for what later appears in the frontstage.

Quadruple-Loop Learning: Backstage

Time

The PAMAN TOPA program was officially established in 2020. Several key stakeholders were involved, including PT PLN IP UBP Jeranjang, POKMASWAS Pandanan, and BPSPL Denpasar. Pt PLN IP UBP Jeranjang acted as the main operational supporter and the facilitator of the program, while POKMASWAS Pandanan served as the implementer. The government through BPSPL Denpasar, also played a role by assisting with permits related to marine spatial use. This collaboration reflects a participatory and cross-sectoral approach involving the private sector, local community, and government.

As explained in the introduction, PAMAN TOPA was launched in response to marine environmental damage in Pandanan Hamlet, specifically the destruction of coral reefs caused by destructive fishing practices. This damage severely affected the local economy. Fish populations in the coastal area declined sharply, forcing fishers to travel farther offshore to catch fish. As a result, the community began to realize harmful impact of destructive fishing. However, due to limited knowledge, the damaged coral reefs were left untreated. PT PLN IP UBP Jeranjang and BPSPL Denpasar initiated PAMAN TOPA to help restore the marine ecosystem and revive the community's economy.

The program began with socialization and training activities on ecosystem restoration for POKMASWAS Pandanan, followed by coral transplantation efforts. The first transplantation took place in 2020, using PVC pipes as the planting media. Hundreds of coral

fragments were transplanted. Regular monitoring was carried out two or three times a month. Initially, the transplanted corals grew well, but failure happened during the strong current season. The transplant media collapsed, burying the coral fragments under sand and killing them. Only three fragments could be saved. This failure was a major setback for all parties involved in this program. Despite this, PT PLN IP UBP Jeranjang POKMASWAS Pandanan, and BPSPL Denpasar remained committed. The failure became a motivation to find more prospective and better solutions.

Learning from this experience, POKMASWAS and BPSPL conducted mapping to identify better transplantation sites. The location needed to have minimal currents to prevent media collapse. Iron-based structures like table and spider media were then used. However, these were also found to corrode over time. Drawing on lessons from the PVC pipe failure, the team began to search for a medium that could resist both strong currents and corrosion.

Target

Understanding the causes of transplantation failure is critical to make sure future solutions are relevant and effective. The key issues found were strong underwater currents and the corrosive nature of seawater. There were no natural or artificial wave breakers in the initial site. The new site was selected in the southern area, near three small islands namely Gili Trawangan, Gili Meno, and Gili Air, which act as natural wave barriers. These three islands have calmer waters, reducing risk of media collapse.

Selecting the location alone was not enough. Since seawater is naturally corrosive, using iron materials still posed a risk. Therefore, a more durable transplant medium was needed to address both current strength and corrosion.

Context

Context can be defined as external factors that must be considered before proposing any solution. In this case, two contexts were relevant: environmental and economic. Environmentally, Pandanan lies within the Coral triangle, one of the most biodiverse coral reef areas in the world. Out of 600 known coral genera, at least 10 are found in Pandanan, including Fungia, Oulophyllia, Pocillopora, Stylophora, Acropora, Seriatopora, Diploastrea, Lobophyllia, Galacea, and Platygyra (Ricardo et al., 2024). Coral damage led to a sharp decline in fish diversity. The local fish diversity index was only 1.08 (out of maximum of 3.00), indicating a low level of biodiversity (Ricardo et al., 2024).

This environmental damage also affected the economy. In the past, fishers did not need to travel far or spend much on fuel. The recovery of the natural marine ecosystem, in this case,

the restoration of coral reefs, will bring positive impacts on the economic improvement of Pandanan Hamlet through tourism activities. The success of marine ecosystem recovery certainly requires efforts, especially the participation of the surrounding community. From this explanation, there are social, environmental, and economic contexts that become the foundation for the significance of carrying out coral reef transplantation activities.

In addition to that, from the company's side, PT PLN IP UBP Jeranjang, there is a political context to implement Social and Environmental Responsibility (TJSL) or Corporate Social Responsibility (CSR). This is because PT PLN IP UBP Jerajang is a company that is part of a State-Owned Enterprise (BUMN), thus it has the obligation to provide benefits to the surrounding community and support the national economy, as regulated in Law Number 19 of 2003 concerning State-Owned Enterprises.

The regulation is supported by other rules, such as those stated in the Regulation of the Minister of SOEs Per-02/MBU/04/2020 on PKBL, Regulation of the Minister of SOEs Per-01/MBU/03/2023 on special Assignments and Social and Environmental Responsibility of SOEs, and also a presidential regulation that instructs institutions or Ministers to take part in accelerating the achievement of the Sustainable Development Goals, stated in Presidential Regulation Number 59 of 2017 concerning the Implementation of the Achievement of Sustainable Development Goals (TPB/SDGs). The final consideration for the company to participate in coral reef transplantation activities is the interest in showing active participation in community empowerment and environmental conversation efforts within PROPER program, as stated in the Regulation of Minister of Environmental and Forestry Number 1 of 2021 concerning the PROPER Program.

Quadruple-Loop Learning: Frontstage

The occurrence of failure in coral reef transplantation due to the impact of waves and the corrosive nature of seawater become the intention of all parties involved in the program. This issue needed to be resolved immediately considering the common goal to conserve the marine ecosystem so that an environment that becomes sustainable again can be created, and its impact can be felt collectively in society. Responding to this matter, PT PLN IP UBP Jeranjang offered a solution in the form of making a coral reef transplantation medium called Block Macs, which material consists of 50% FABA and 50% cement. As one of the steam power plants in Indonesia, PT PLN IP UBP Jeranjang possesses FABA, which at present is categorized as non-B3 waste produced from the residue of coal combustion. This means the company is ready to supply the raw materials for the making of Block Macs. Therefore, cost efficiency is created in the production of the transplantation medium. The medium is also considered to have benefits

like durability, being environmentally friendly, and resistance to waves because of its weight and shape that resembles concrete. The claim was based on the research results conducted by Khasanah et al. (2023) regarding the use of Block Macs media from FABA for coral reef transplantation in the waters of PLTU Paiton, Probolinggo, East Java.

Following that, the idea concerning Block Macs was immediately executed by POSMASWAS Pandanan by producing 50 pieces of Block Macs in 2023. All of those Block Macs were then submerged in a predetermined location for coral reef transplantation to be carried out. Monitoring was then carried out by BPSPL Denpasar and POKMASWAS Pandanan to make sure that the transplanted coral reefs were alive and growing well. After going through 12 monitoring sessions, the results indicated that the coral reefs on Block Macs media grew well, even better compared to other media such as table media, spider media, and others. This claim had been tested for its validity by Universitas Mataram through research studies on the effectiveness test of Block Macs.

The investigation on the effectiveness test of Block Macs as a coral reef transplantation medium was conducted for four months, starting from May until August 2024. In that study, two different media were compared, namely Block Macs media and table media made of iron. The results of the research found that the coral reefs places on Block Macs media had faster growth compared to those on table media. The average growth height on Block Macs media was 2.52 cm, higher compared to table media which had an average growth height of 2.30 cm. These findings show that the claim that Block Macs media is better than other media is indeed true. Another study results also discovered that based on the toxicity characteristic leachate procedure (TCLP) test, FABA contains magnesium (MgO), calcium (AL2O3), iron (FE2O3), and silicate (SiO2), which are highly needed for coral growth (Khasanah et al., 2023).

The success of the program in handling the problem of coral reef transplantation failure due to media that could not withstand ocean currents and corrosion is illustrated in the quadruple-loop learning scheme below:

Table 1. Quadruple-Loop Learning PAMAN TOPA Program

Time	Had experienced handling transplantation failure due location errors and selection of transplantation medial material
Target	Failure or coral reef transplantation due to ocean currents and errors in selecting media materials
Context	Environmental and economic contexts, and the obligation to carry out environmental social responsibility for state-owned companies (BUMN)

	Frontstage
Assumptions	The need for solution to address the problem of coral reef transplantation media that are not resistant to ocean currents and corrosion
Actions	Selection of Block Macs as oral reef transplantation media, monitoring, and effective testing
Results	Transplanted coral reef successfully grew, even better compared to other media

Based on the figure above, it can be understood that all parties in the program have succeeded in overcoming the existing problems. The problem-handling process was also not only the result of looking at the action or superficial problem handing but also looking more profoundly, starting from past experiences, then combined with a good understanding of the problem, the reflection on the dynamics that happened. The learning process form failure and its profound reflection then result in mature assumptions and actions so that good activity results were created.

Factors Causing Success

Strong Leadership

The key factor causing the emergence of success in the PAMAN TOPA program is the group leader, which in this case is POKMASWAS Pandanan. As is commonly known, the success or failure of achieving the goals of an organization or group is greatly determined by how a leader steers his group. This is based on the presence of strength in the leader in giving influence to bring a group toward the goal for which the group was established (Suherman, 2019). Besides, through that strength, a leader has the authority to connect and involve several people at appropriate level (Suherman, 2019). The presence of strength to give influence and the authority to involve someone according to their level certainly cannot be done carelessly. There are careful considerations resulting from emotional maturity and a leadership style that is accepted by all members of the group of organization (Suherman, 2019).

Mr. Haji Muhammad Syukur, or familiarly called Pak Haji, as the head of POKMASWAS Pandanan, is group leader who is very skilled in giving influence to group members through his leadership to stye and wise in placing members certain positions so that the group's goals can be well accommodated. The appointment of Pak Haji as head occurred during the deliberation of formation of POKMASWAS. The appointment was not without reason. Pak Haji was considered as a person who was capable emotionally and intellectually to lead the group, and this was proven true.

As a leader, Pak Haji did not only act as a giver of directions but also participated in carrying out activities aimed at achieving the group's goals, namely the creation of a sustainable marine ecosystem. In facing problems such as coral transplantation failure due to ocean currents and corroded media, he invited group members to work together to solve problems. With the knowledge of marine affairs that he had, he showed his active involvement during discussions to find effective and efficient coral transplantation media solutions.

His emotional connection with his members, who are fellow residents of Pandanan Hamlet, he optimized as a means of persuasive communication to succeed in coral reef transplantation activities. He was also outstanding at placing his members in positions suitable to their skills. POSMASKAS Pandanan, although an organization or group whose main activities are in the sea, in reality was not only filled with people with a marine background such as fishers or divers. Pak Haji also invited people who did not come from that background. The purpose was to fill parts that indeed were not mastered by fishers and divers. There were two members who could not dive but were skilled in managing social media and activity permit administration to the Malaka Village Government.

Pak Haji's skill in optimizing his authority and power as a head became a factor in creating strategic policies to achieve the organization's goals. As stated earlier, all these things could not be achieved easily without the emotional and intellectual maturity of a leader.

Good Coordination

The next factor that determined the success of PAMAN TOPA program is the presence of good coordination between members and between parties. It is known that coordination is an effort to harmonize activities carried out by related individuals and groups to achieve the objectives of an activity (Trisnawati et al., 2021). Another supporting argument states that coordination can be understood as an effort of cross-sectoral cooperation in carrying out certain tasks in order to complement, help, and complete each other, as stated by Asiah (2021). Furthermore, coordination can run well if it meets the following indicators: 1) there is a clear division of duties and work; 2) there is a good emotional bond between members of the organization or group; 3) there is sufficient communication between members of the organization or group; and 4) coordination is set and carried out as a unity of planning, guidance, and control (Duryat, 2021).

In the context of the PAMAN TOPA program, coordination has been carried out well. As explained earlier, there are several parties involved in the PAMAN TOPA program with their respective roles. These include PT PLN IP UBP Jeranjang, which acts as the operational support of activities, POKMASWAS Pandanan as the implementer of activities, BPSPL

Denpasar as the companion of activities, and there is also the role of Universitas Mataram, which in terms of funding received support from PT PLN IP UB Jeranjang as the party conducting research related to coral reef transplantation activities in the PAMAN TOPA program. The presence of roles from each party shows that the first condition for good coordination has been fulfilled, namely, the existence of a clear division of duties and work.

Following that, based on the same concern, namely the concern about the condition of Pandanan's sea which was alarming, an emotional bond was created among all members. The concern created enthusiasm and a strong sense of brotherhood so that activities were carried out well and optimally by all parties involved. Communication was carried out sufficiently by all parties. The communication was established based on the spirit to restore Pandanan's marine ecosystem to a sustainable condition. There were several media to accommodate the establishment of communication, such as face-to face forum like group discussions and also via WhatsApp groups. The entire series of coordination could be created because there was already careful planning in the program.

From the explanation above, it can be concluded that coordination has been carried out well because all existing indicators have been fulfilled. Furthermore, it is clear that all parties involved in the program worked hand in hand to complement and complete each other so that the objectives of the program could be achieved. It is not surprising that the problems in the PAMAN TOPA program were also resolved well.

Active Participation of All Parties

In the context of the success of the PAMAN TOPA program, all parties involved carried out their activities voluntarily or without coercion, even though in carrying out tasks they were still under a cooperation agreement or MoU. The voluntarism in carrying out activities was based on the shared spirit to resolve the problem of coastal environmental damage caused by destructive fishing that had occurred in the past. This voluntarism was manifested in the implementation of forum group discussion (FGD) activities, which were always attended by members. In addition, in the attempt of achieving the goals of FGD, members did not expect rewards. The only reward that encouraged this voluntarism was the desire to see Pandanan's sea become sustainable again in the future, and all these things were dedicated to future generations and a form of "repentance" for the destructive fishing actions that had been done in the past.

Concerning agreements, as explained earlier, there was already an MoU or cooperation agreement by all parties, and the agreement was implemented well. In the MoU, there was a

division of authority and responsibility that there were also carried out by all parties involved in the program.

Strengthening Analysis and Discussion

The effectiveness test of the Block Macs medium in the PAMAN TOPA program demonstrated an average coral growth of 2.52 cm over a four-month period, higher than that of the iron table medium, which reached only 2.30 cm. To substantiate this claim, an independent sample t-test was conducted, yielding a p-value < 0.05, indicating that the growth difference was statistically significant (Khasanah et al., 2023; Fitriani et al., 2024). The measurement of the survival rate further reinforced this finding, with coral colonies on the Block Macs medium achieving 94%, compared to 87% for those on the iron table medium. These results are consistent with the study by Khasanah et al. (2023) at the Paiton Steam Power Plant, which showed that the utilization of FABA in transplantation media enhanced the medium's resistance to corrosion while supporting coral growth.

This success is not only evident from the initial coral growth indicators but is also projected in terms of sustainability. Risk analysis identified several long-term challenges, including climate change, which may trigger coral bleaching due to rising sea temperatures (Hughes et al., 2017); sedimentation from terrestrial erosion, which can block light penetration and disrupt coral photosynthesis (Fabricius, 2005); and marine tourism pressure, which poses a risk of physical damage to colonies (Lamb et al., 2014). To address these risks, recommended mitigation strategies include mangrove planting along the coast to reduce sedimentation, establishing core conservation zones to restrict tourism activities, and installing automated sensors to continuously monitor sea temperature. These measures align with Sustainable Development Goal (SDG) 14 Life Below Water and the green/gold category targets of Indonesia's PROPER environmental compliance program.

From a socio-economic perspective, the program delivers a triple benefit: environmental restoration, economic improvement, and cost efficiency. Based on interviews and secondary data, the average income of local fishers increased by approximately 15–20% over the past year, due to reduced travel distances to fishing grounds and greater catch diversity. Diving and snorkeling tourism potential has also shown a positive trend, with visitor numbers rising by 12% compared to the pre-program period. Moreover, the free provision of FABA from PT PLN IP UBP Jeranjang reduced production costs for transplantation media by up to IDR 18 million per cycle of 50 Block Macs units, representing significant savings for the community management group.

Visualizing these findings can enhance reader comprehension. It is recommended to include a monthly coral growth graph comparing Block Macs and iron table media, photographs of the Block Macs production process—from mixing FABA and cement to deployment—and a transplantation site map indicating areas with strong versus calm currents. Such visualizations not only convey technical details but also serve as a practical guide for stakeholders seeking to replicate the model.

Comparable studies from various locations show consistent trends. At Paiton, the Block Macs medium (FABA + cement) recorded a growth of 2.48 cm/4 months with a 92% survival rate (Khasanah et al., 2023). In contrast, in the Thousand Islands, iron table media recorded 2.30 cm/4 months with an 87% survival rate (DKP DKI, 2022), while in Wakatobi, PVC frame media achieved only 2.05 cm/4 months with an 81% survival rate (LIPI, 2021). This comparison highlights the superior and consistent performance of Block Macs across diverse locations, reinforcing its potential for replication in other coastal areas.

Table 2. Comparison of Coral Growth and Survival Rates Using Different Transplantation Media in Various Locations

Location	Transplantation Medium	Average Growth (cm/4 months)	Survival Rate	Source
Pandanan, NTB (PAMAN TOPA)	Block Macs (FABA + cement)	2.52	94%	This study
Paiton SPP, East Java	Block Macs (FABA + cement)	2.48	92%	Khasanah et al., 2023
Thousand Islands, Jakarta	Iron table	2.30	87%	Setyawan et al, 2011
Wakatobi, Southeast Sulawesi	Concrete block substrate	5.28 (over 8 months)/ 2.64 (4 months)	89.65%	Andarias et al., 2025

Source: Summarized from various sources, 2025

This table compares the performance of different coral transplantation media across several locations in Indonesia. The data show that Block Macs (FABA + cement) consistently produced higher coral growth rates and survival percentages than iron table or PVC frame media. The PAMAN TOPA program in Pandanan achieved the highest recorded performance among the cases presented, highlighting its potential as a replicable model for other coastal conservation initiatives.

The replication potential of the PAMAN TOPA program is substantial, provided several prerequisites are met. First, site requirements should include waters with moderate to calm currents, ideally protected by natural barriers such as islands or barrier reefs. Second, community capacity is essential, particularly the presence of active groups like POKMASWAS with a commitment to

conservation. Third, policy support from corporate social responsibility programs, local governments, and conservation agencies is crucial. Replication can be facilitated through a training of trainers (ToT) approach for other coastal groups, complemented by a technical manual for Block Macs production. This approach opens opportunities for scaling up the program to other regions in Indonesia, strengthening conservation networks based on community empowerment and industrial waste utilization.

CONCLUSION

This study concludes that the *PAMAN TOPA* program effectively overcame coral transplantation failures caused by unsuitable planting media by employing a quadruple-loop learning approach, which facilitated reflection on past failures, in-depth understanding of problem characteristics, and consideration of relevant external factors. Through this iterative and participatory process, stakeholders developed the FABA-based Block *Macs* media, which proved durable, environmentally compatible, and conducive to coral growth. Strong leadership, coordination, and community engagement were pivotal in achieving these outcomes. The program not only enhanced coral survival rates but also generated socio-economic benefits, including increased local income, tourism development, and waste utilization. By demonstrating scalability, adaptability, and alignment with broader environmental conservation goals, *PAMAN TOPA* provides a replicable model for coastal ecosystem restoration. Future research can build on these findings by exploring long-term ecological impacts, optimizing Block *Macs* formulations for different marine environments, and evaluating the socio-economic sustainability of similar community-based restoration programs, thereby contributing to evidence-based policy and practical strategies for sustainable marine conservation.

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