JIPK. Volume 17 No 1 February 2025
Sinta 1 (Decree No: 158/E/KPT/2021)

e-ISSN:2528-0759; p-ISSN:2085-5842
Available online at https://e-journal.unair.ac.id/JIPK

JIPK
(JURNAL ILMIAH PERIKANAN DAN KELAUTAN)
Scientific Journal of Fisheries and Marine

Research Article

Growth and Survival Rate of *Pocillopora* spp. Fragments on Coral Tree and Coral Table Media in Semut Kecil Island, Anambas Islands

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OPEN ACCESS

ARTICLE INFO

Received: April 20, 2024
Accepted: August 13, 2024
Published: Sept 02, 2024
Available online: Feb 11, 2025

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Keywords:
Pocillopora
Transplantation media
Coral reef

Abstract

Pulau Semut Kecil, Anambas Islands, are located within the coral reef triangle, as one of the largest Marine Protected Areas (MPAs) in Indonesia. Coral reefs possess significant functional attributes within ecosystems, and their condition is progressively deteriorating due to anthropogenic activities. This situation necessitates restoration endeavors, primarily through coral transplantation methodologies. The methods involved the introduction or relocation of donor corals into substrates such as tree transplantation media and tables, exhibiting high success rates. This study was conducted to determine the growth and survival rate of *Pocillopora* spp. The direct survey approach was used and the different coral transplanting media were statistically analyzed with the ANOVA test and SPSS software. The results of the growth of coral fragments *Pocillopora* spp. Reported coral tree media and table with an average value of 0.55 cm/month and 0.15 cm/month. The survival rate of *Pocillopora* spp. coral fragments in tree media and table was 97.3% and 87.0%. The media for dropping coral trees and table did not affect the growth and survival rate. This coral transplantation method can facilitate for the restoration of degraded ecosystem and ecological succession.

Cite this as: Iriani, F. A., Arifin, R., Winata, M. J., Muharam, M. R., Putri, N. P., Ruswanti, C. D, Ritonga, A. R., Riviani, R., & Riyanti. (2025). Growth and Survival Rate of *Pocillopora* spp. Fragments on Coral Tree and Coral Table Media in Semut Kecil Island, Anambas Islands. *Jurnal Ilmiah Perikanan dan Kelautan,* 17(1):87–97. https://doi.org/10.20473/jipk.v17i1.56844

1. Introduction

The Anambas Islands are located in the Regency Riau Archipelago Province. The Anambas Archipelago lies on the Nusantara International Shipping Lane 1 (ALKI 1), connecting Singapore and Malaysia with substantial economic expansion, including commerce in products and services. The Archipelago is a coral triangle area that makes Anambas one of the largest Marine Protected Areas (KKP) in Indonesia (Arafat *et al.*, 2020). Based on the Decree of the Minister of Maritime Affairs and Fisheries of Indonesia number 30 of 2022, these islands are designated as a Marine Protected Area (MPA) with an area of 1,265,401.51 Ha and one of the coastal ecosystems targeted by management initiatives is the coral reef environment (Harahap *et al.*, 2014).

Coral reefs are underwater structures made of calcium carbonate released by corals (Ammar *et al.*, 2013). The ecosystems are habitats for various types of biotas with high economic, and conservation value (Harahap *et al.*, 2014) as well as important functional values in marine life and ecosystems. Based on study from Putra *et al.* (2021), stated that after fisheries limitation protection, economically significant coral reef fish in the Anambas Islands were recovered in marine reserves over time, but this did not alter the rate of coral cover increase over time. The high potential of coral reefs can lead to an increase in the rate of overexploitation, causing high damage (Najmi *et al.*, 2023). These structures are in decline due to a combination of global and local environmental stressors such as climate change, pollution and nutrient runoff, sedimentation, destructive fishing practices (Henley *et al.*, 2022; Erftemeijer *et al.*, 2012) and bleaching (Baker *et al.*, 2008). Because to harmful fishing methods such utilizing bombs or poisonous potassium, the coral reefs of Anambas Island were classified as being in bad to good condition (Harahap *et al.*, 2014).

The sustained advancement of coastal development and land-use practices is projected to result in a heightened influx of nutrients into coastal systems. This is anticipated to occur with the foreseen rise in temperatures (Rabalais *et al.*, 2009). Even though nutrient enrichment has a negative effect on the coral reef ecosystems, zooxanthellae benefit from a larger nutrient supply, which enhances their population (Houlbre`que and Ferrier-Page, 2008; Sawall *et al.*, 2011). The increasingly alarming condition of coral reefs requires activities to restore degraded ecosystems to their original condition with restoration that supports recovery (Horoszowski-Fridman and Rinkevich, 2016). Coral reef restoration can be conducted with rehabilitation activities, such as replanting or creating media as a new habitat for juveniles to grow and develop into adults (Nasution and Munandar, 2018). Furthermore, coral transplantation is one of the efforts that can be used to restore coral reefs to be better either natural or artificial based in water ponds (Prastiwi *et al.*, 2012).

The most transplanted species are those of the genus *Acropora, Pocillopora, Seriatopora,* and *Hydnopora*. These species have fast growth and form branches and the survival rate depends on the treatment of the fragments, which are physiological factors and responses to environmental conditions. Survival rates are influenced by fastening techniques, seed sources not far from the transplantation site, and adaptability to the aquatic environment. This is because coral fragments change to a new environment where transplanted fragments will be more adaptable (Mustahal and Rahmawaty, 2011).Specific environmental conditions, combined with the relatively low experience of restoration in this region and species-specific considerations were used. *Pocillopora* branching corals are major reef builders and often reproduce through natural fragmentation (Sandoval *et al.*, 2018). However, few studies were conducted using the coral genus *Pocillopora* (Combillet *et al.*, 2022). The genus *Pocillopora* is widely distributed with high survival rate and the growth is branched (branching) vertically and horizontally (Prameliasari *et al.*, 2012). Transplantation of coral *Pocillopora damicornis* has been conducted successfully using three different lengths fragment in Pacific coast of Colombia (Lizcano-Sandoval *et al.*, 2018) and coral clusters (CC) technique in Carrizales Reef Colima, Mexico (Liñán-Cabello *et al.*, 2011).

The advantage of the coral tree is a low-cost material, making this method ideal to implement with a simple design and portability, demonstrating its practical use, and adjustable height (Nedimyer *et al.*, 2011). The advantages of coral table media are good in long-term use, robust, hardly carried away by currents, and accelerate the attachment of coral polyps naturally, but have high costs because of the iron material (Ramses *et al.*, 2019). Different direct transplant protocols used have resulted in varying degrees of success as well as damage inflicted by donor colonies and pressure placed on transplant material (Cruz *et al.*, 2015). However, all previous studies focused on different coral genera such as *Acropora*, and the process carried out in other waters was then applied and modified in Semut Kecil Island, Anambas Islands. A few studies have tested coral resilience for growth and survival by comparing the effectiveness in terms of materials used in both transplantation media. This study aimed to determine the difference in the growth and survival of *Pocillopora* spp using two different transplantation media. This research will be adding value supporting reef restoration effort.

2. Materials and Methods

2.1 Materials

This study used the equipment : coral fragments (*Pocillopora* spp.); SCUBA gear (SCUBAPRO, USA) for underwater sampling; Suunto Zoop Novo dive computer (Suunto, Finland) for monitoring depth and dive time; Olympus TG-6 (Olympus, Japan) for documentation; PVC tree frame (diameter: 150 cm, height: 120 cm); coral table frame (length: 150 cm, width: 100 cm, height: 60 cm); subsurface buoy (diameter: 30cm) monofilament fishing line (Krisbow, Indonesia) for attaching the fragments to the tree frame; cement (Tiga Roda, Indonesia) for making cement blocks and tree frame weights; epoxy resin (Pioneer, USA) for attaching the fragments to the cement blocks; and laptop (ASUS Zenbook, China) for data recording and processing.

2.1.1 Ethical approval

This study does not require ethical approval because it does not use experimental animals.

2.2 Methods

A direct survey was used in this study according to Sugiyono (2018). The direct survey method was to collect data on the growth and survival of coral fragments by measuring and counting the number of living corals. Data collection included measurements and survival rates of fragments by monitoring coral fragments for twelve nights after a month to take photos of corals and determine the survival of Coral Fragments.

2.1.2 Time and study site

This study was conducted from August 2022

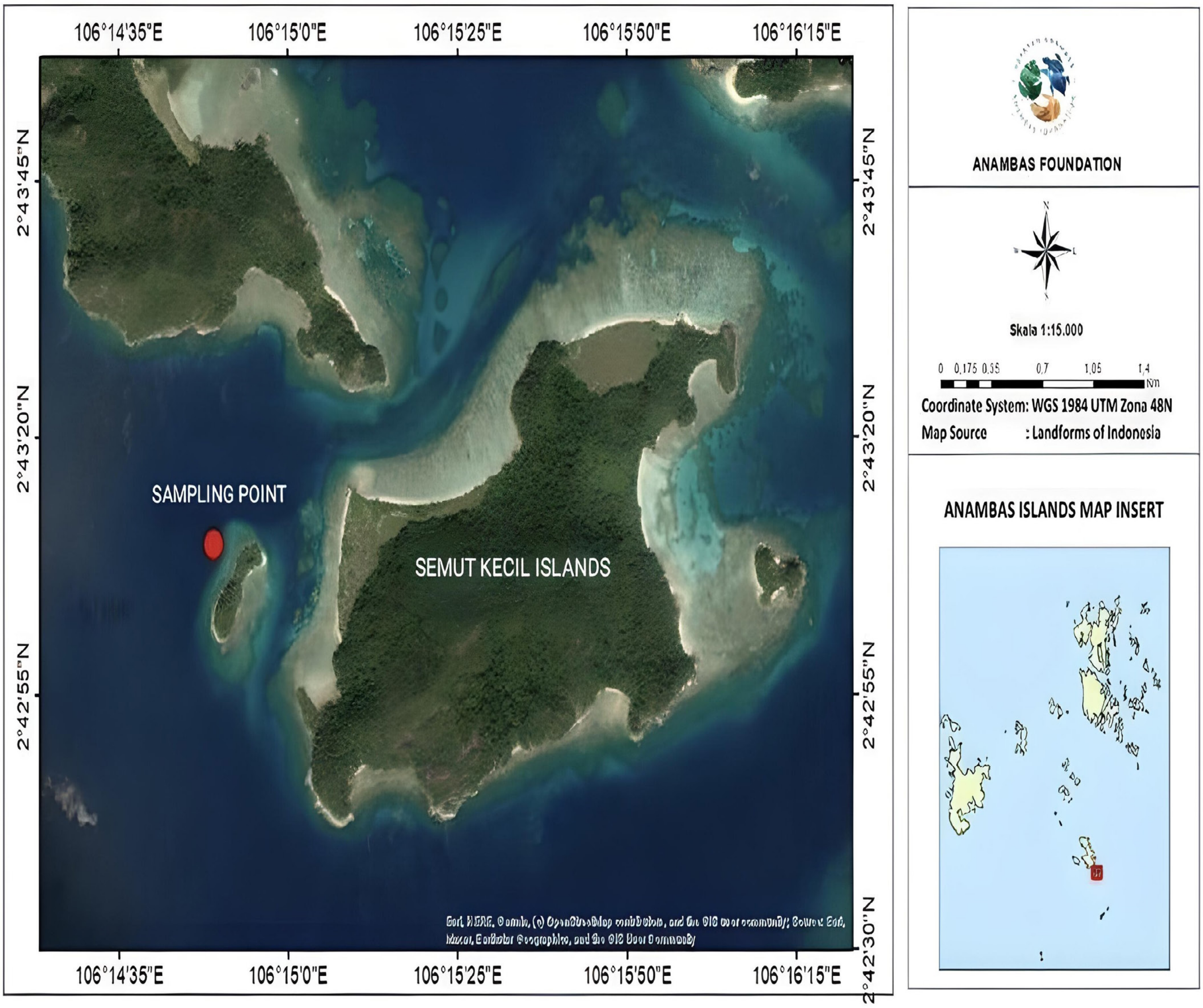

Figure 1. Map of study site.

to November 2022 in the waters of Semut Kecil, Anambas Marine Protected Area, Riau Islands Province (Figure 1). Data on growth length and survival of coral fragments were collected once a week for three months.

2.1.3 Procedure

Coral reef restoration efforts have evolved in recent decades (Kerby *et al.*, 2023) to transplant corals using a variety of media, including trees and tables. Coral tree nurseries are simple frameworks that resemble a tree shape with a PVC pipe base material, where corals are attached or hooked using monofilament to the tree framework (Nedimyer *et al.*, 2011). The tree is attached to the seafloor using weights and supported by subsurface buoys and the substrate can float and stand upright in the water. This method reduces the burden of threats and potential sources of mortality common to coral bench habitats that disrupt early sexual recruitment and small asexual fragments (Henley *et al.*, 2022). According to Harris *et al.* (2017), coral transplantation uses table media made of iron bars in the form of a frame and a wire rack. The rack is used as a place to tie the substrate on

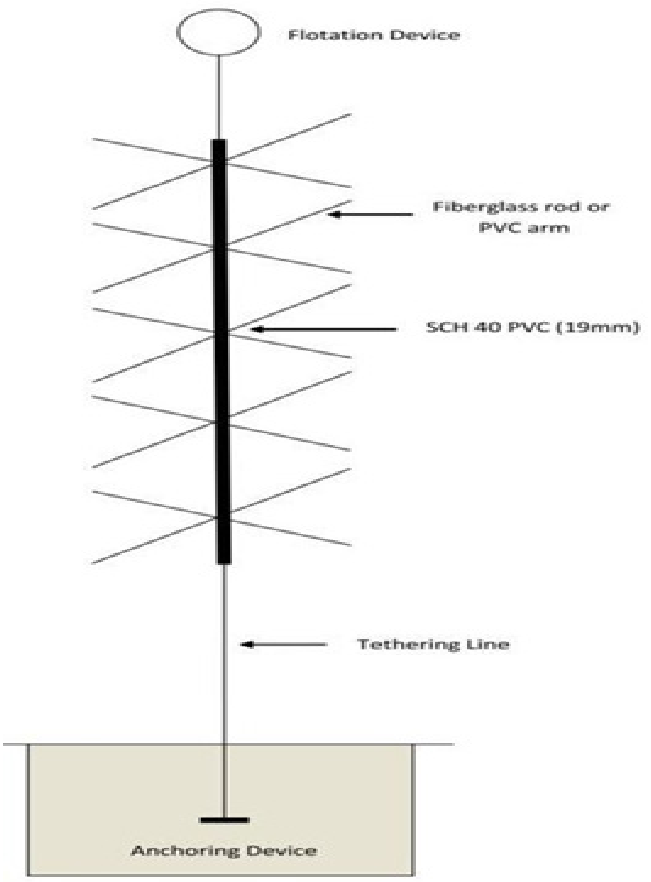

Figure 2. A typical coral tree nursery design. This widely used design for coral tree media was tied to a buoy so that the media could float. Source: Nedimyer *et al.* (2011).

which a cement block is placed to attach coral fragments. Transplant media with different basic materials that have advantages and disadvantages are still in the process of being refined for use.

The transplanted coral fragments from *Pocillopora* spp. were collected around the waters of Semut Kecil Island at the depth of 5m and placed in a basket during the fragment transportation process. The fragment collection was assisted by Scubapro SCUBA equipment and the mother colony was cut using cutting pliers into several parts with a size of 2-5 cm (Edwards *et al.*, 2010). Growth rate was examined in five coral samples from each media that were tagged using waterproof paper and tied with cable ties to be observed. While survival rate data was collected with a total of 60 and 51 fragments on the coral tree and table media. An experimental method of direct observation was carried out by grafting coral fragments on the coral tree and table media placed close to the donor location at a depth of 5 m and with a distance of 5 m between media to provide a similar environment (depth, water temperature, salinity, etc.). A crossed pipe model tied using a polystyrene buoy was applied to the coral tree media (Figure 2), while the coral table used an iron frame model (Figure 3) with a substrate of cement and sand attached using marine epoxy.

2.3 Analysis Data

According to Ricker (1975), the calculation of absolute growth achievement of transplanted corals can be calculated using the following formula:

$$\beta = Lt - L_0 \quad \text{.....(i)}$$

Where:

β = Increase in length/height of coral fragments

Lt = Average length/height of coral fragments after t-observation

L_0 = Average length/height of initial coral fragments

The growth rate of transplanted corals according to Ricker (1975), the formula used is as follows:

$$\alpha = \frac{L_{i+1} - L_i}{t_{i+1} - t_i} \quad \text{.....(ii)}$$

Where:

α = The rate of increase in length or width of the transplanted coral fragment

L_{i+1} = Average length or height of fragments at time i+1

L_i = Average length or height of fragments at the time i

t_{i+1} = time i + 1

t_i = time i

According to Ricker (1975), survival observation was known by comparing the number of corals alive at the end of the study (Nt) compared to the number of corals (No). The data obtained were then analyzed to determine the survival value calculated using the following equation:

$$SR = \frac{N_t}{N_o} x\ 100\% \quad \text{...(iii)}$$

Where:

SR = Survival Rate

Nt = Number of individuals at the end of the study

No = Number of individuals at the start of the study

Figure 3. Design of coral table with iron frame model and cement media with sand mixture used for attachment of coral sampling fragments.

Statistical analysis was carried out using the One-Way ANOVA test with the SPSS 2.6 software application with the hypothesis (H0), where the transplant medium did not affect the response variable and the hypothesis (H1) that the transplant medium affected the response variable. The decision-making was as follows: a) If significance > 0.05 then accepted rejected, b) If the significance < 0.05 then rejected accepted.

3. Results and Discussion

3.1 Results

3.1.1 Coral growth

The results of the absolute growth of the coral fragments were obtained with five samples used in different media. Investigation of *Pocillopora* sp. during 3 months revealed that the different media provided different growth on coral fragment. The average value of absolute growth on coral tree and table was at 0.55 cm/month and 0.15 cm/month (Figure 4) and the fragment growth rate with the final observation value was 0.44 cm/month and 0.12 cm/month (Figure 5). Coral fragments on the table media located close to the seabed compared to coral trees affected their growth by relying on nutrient uptake in the sediment. Furthermore, fragment growth in suspended methods such as coral tree media was more constant due to the lack of external influences from sediment deposition attached to corals and transplant media. Coral fragments on coral table media located close to the seabed compared to coral trees affected their growth by relying on nutrients in the sediment.

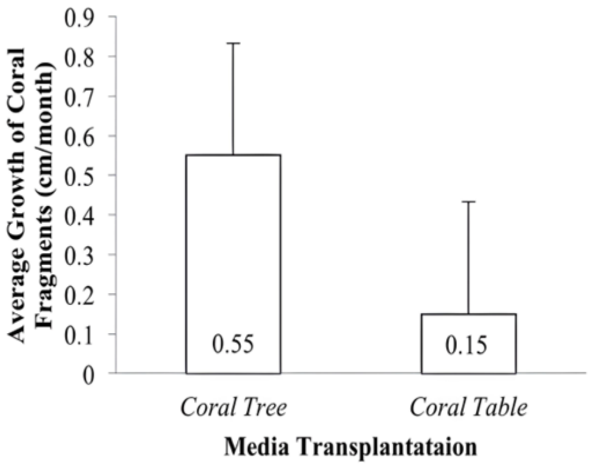

Figure 4. The growth of coral fragment growing in different media, data are presented as means ± standard of error of mean (n=60).

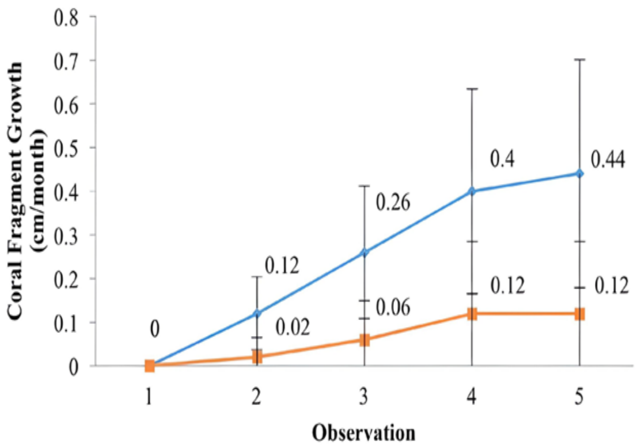

Figure 5. Coral growth rate (Blue: Coral Tree and orange: Coral Table) during 3 months observation with 2 weeks interval time (1-5 interval time every 2 weeks).

3.1.2 Survival rate

The results of coral fragments in both media showed a difference in the percentage of survival, with an average value of 97.3% and 87.0% in coral tree and table media (Figure 6). The survival value of the study can be categorized as quite high, and this corresponds to Haris *et al.* (2017) where the value was greater than 75%. One of the predominant factors contributing to the survival rate is the stress threshold exhibited by the corals, coupled with the congruence of the environmental attributes. This similarity in environmental conditions enables a seamless acclimatization process for the transplanted corals to flourish in their new surroundings. According to Harriot and Fisk (1988), transplantation activities can be considered successful when the number of living coral fragments is greater than 50%.

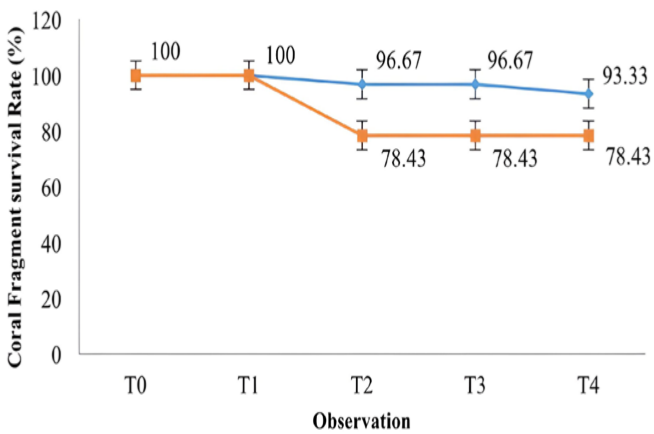

Figure 6. Survival rate for *Pocillopora* spp. (Blue: Coral Tree and orange: Coral Table) during 3 months observation with 2 weeks interval time (T indicates interval time every 2 weeks).

3.1.3 Significance value

The results of the growth analysis obtained exhibited a probability or significance value of 0.049, hence the significance was smaller than 0.05 and was accepted. The transplant medium was present but did not affect the growth of *Pocillopora* spp. and the survival of coral fragments obtained 0.012. The significance value was smaller than 0.05 and was accepted since the transplant medium was present but had no effect on the growth of *Pocillopora* spp. Furthermore, the letter (A) showed no effect of transplantation media on the growth of coral fragments of *Pocillopora* spp. (Figure 8). Observation the growth rate of *Acropora formosa* using five different media transplantation had no significant difference in the fragments elongation and colony diameters (Khasanah *et al.*, 2019). On the other study, (Maneval *et al.*, 2021) reported that the growth rates of *Acropora cervicornis* were significantly higher for fragments on frames compared to on trees.

3.2 Discussion

3.2.1 Size-effect and factors

From the present results, it appears that this was similar to Bouwmeester *et al.* (2023) where coral growth factors were influenced by the length of irradiation. The coral table was closer to the seabed than the tree, where growth also relies on taking nutrients in the sediment. The distance of placing the coral table is ± 70 cm from the bottom surface, hence there is still a lack of sediment attached to the media. This is because high sedimentation can also affect coral polyps in the photosynthesis process and cause inhibition of coral growth (Pratiwi *et al.*, 2019). Diverse effects of sediments on corals include suffocation, abrasion, shading, and suppression of coral recruitment. Corals or entire reefs may degrade at the spatial scale as a result of sediment delivery that leads to deposition and deteriorating of the water quality (Rogers and Ramos-Scharrón, 2022). Despite the continual movement of the sediment, the system maintains its dynamic stability (Bellwood and Fulton, 2008; Goatley and Bellwood, 2012). In the coral tree media, there was one death of fragments and in the coral table media, there were two deaths. This was due to fragments detaching and changing color to white because the fragments were covered by the basic substrate with sand type. The mortality of coral fragments ensued due to a weakened binding that led to detachment from the substrate, resulting in an inability to acclimate to their novel environment.

Coral branches that become overgrown by algae and undergo a transition in color to white are a consequence of the expulsion of zooxanthellae from stressed coral polyp tissue. The growth pattern exhibited by coral fragments entails an augmentation in new branching, conforming to the contours of the substrate medium. Initial observation at time T0 shows a scarcity of branches, while at the final observation of T4, a substantial increase in branching is evident (Figure 7). According to Prameliasari *et al.* (2012), the shape of the cement substrate has more horizontal growth because the fragments grow creeping.

Radial corallite growth was characterized by the addition of new branches, as well as coral polyps that enveloped cable ties and iron frames on the coral table. The rate of coral growth corresponds to the escalation of the limestone skeleton, quantified over a specified unit of time, including measurements of volume per unit time or the amalgamation of components such as calcium within the same timeframe. In coral polyps, zooxanthellae reside, fulfilling the photosynthetic requirements through the provision of inorganic substances. This symbiotic relationship extends to the metabolic processes, where additional nutrients such as ammonia and phosphate are furnished as indispensable elements. At the commencement of the study, the waters of Semut Kecil in the Anambas Islands exhibited a temperature of 29℃. According to Suryadi *et al.* (2022), the optimal temperature limit for marine biota was between 28-32℃, which plays a role in the survival pattern of planula in the metabolic process. Changes in temperature of 1-3℃ can also interfere with the metabolism of coral animals and drastic increases or decreases can inhibit the growth of coral animals and cause death. Numerous studies have demonstrated that coral bleaching occurs as a result of zooxanthellae becoming "inactive" due to increased temperatures (Curran and Barnard, 2021; Thatje, 2021; Weis, 2008). Cunning *et al.* (2015) stated that corals grow more slowly at higher temperatures, regardless of the type of symbiont. The media coverage regarding the demise of corals can be attributed to the fragmentation of coral structures resulting from weakened binding forces. Consequently, the whitening of these fragments ensued due to an overgrowth of algae on the coral branches. In this context, algae emerge as formidable contenders for spatial dominance and light acquisition, posing a significant threat to coral health by colonizing its surface. The adherence to the coral substrate is particularly accelerated isn the vicinity of the seafloor, owing to the proximate nature of the underlying medium. Prameliasari *et al.* (2012) stated that coral growth factors exhibited susceptibility to the duration of irradiation exposure. The development of the seabed ecosystem is intricately tied to the capacity of the coral to derive nourishment from sediment-bound nutrients. However, it is imperative to note that an excessive accumulation of sediment within the polyps can disrupt the photosynthesis process and impede optimal coral growth (Pratiwi *et al.*, 2019). Positioning the coral tree and table at an approximate separation of 70 cm ensures the mitigation of sediment accumulation on the substrates to a minimum.

3.2.2 Mortality

The survival rate of *Pocillopora* spp. on coral tree and table media for three months in the waters of Semut Kecil Island, Anambas Islands decreased. The decrease in the number of coral fragments occurred due to fragments released from the media due to less strong binding techniques. Rani *et al.* (2017) asserted that binding methods possessing relatively weaker strength were susceptible to displacement by robust currents. Consequently, the binding mechanisms may lead to detachment from the media framework, resulting in the discoloration of corals to a pale white color. This alteration in pigmentation is concomitant with an overgrowth of algae on the coral surface. Mutmainah and Clara (2017) asserted that coral bleaching constituted an occurrence impeding growth and escalating the mortality index of coral reefs. This alteration in coloration arises from the stress experienced by zooxanthellae or pigments, resulting from their adjustment to environmental changes (Prastiwi *et al.*, 2012). The ability of corals to salinity and temperature stressors relies on several variables. Kuanui *et al.* (2015) discovered that corals of different ages and species did not react to environmental changes in the same physiological way.

The coral growth rate is intricately linked to the augmentation in the mass of its limestone skeleton over a specific timeframe, the volume accrued per unit time, or the amalgamation of skeletal constituents, such as calcium, per unit time. Hermatypic coral colonies harbor symbiotic zooxanthellae, which reside within coral polyps and provide essential inorganic substances required for photosynthesis. The metabolic byproducts of corals, taking the form of nutrients such as ammonia and phosphate, transform vital nutrients used by the zooxanthellae. According to Mompala *et* impede the ability to disengage from their skeletons, ultimately resulting in the demise of the corals. Therefore, a procedure for algae removal becomes *al.* (2017), the encasement of corals can significantly imperative to ensure the survival and vitality of the

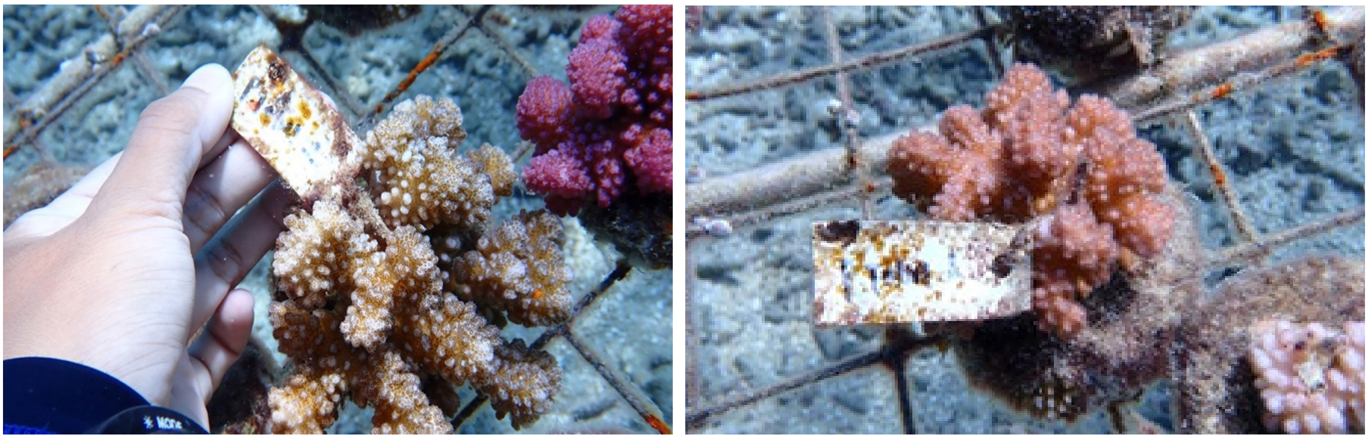

Figure 7. New branching resulting from fragmentation of *Pocillopora* spp.

Figure 8. Average values of growth and survival rate of *Pocillopora* spp. coral fragments from the results of the Complete Random Design test to determine differences in each transplantation media.

coral colonies. The algae that adhere to both corals and their substrates necessitate a monthly cleansing regimen to facilitate the growth and viability of coral fragments. Additionally, the achievement of a survival rate for coral fragments is contingent on several factors, including the dimensions of the fragments employed. An optimal fragment size for successful coral transplantation has been determined within the range of 3 to 5 cm. This specific fragment size, commonly adopted for restoration efforts, small (length < 3.5 cm), me- dium (3.5–6.5 cm) or large (> 6.5 cm) (Knoester *et al.,* 2024). Lizcano-Sandoval *et al.* (2018) mentioned that the longer the fragment size, the faster the growth rate. The size of the transplant fragments used determined the success of coral transplantation. The observation results were concluded to be successful, characterized by well-developed transplanted corals shown (Figure 7). The growth of radial corallite was characterized by the addition of new branches, as well as growth on corals and polyps. One factor considered for high survival was minimizing coral stress levels by having continuous seawater flow (Haris *et al*., 2017).

Survival rates of 83.5% have been observed in the restoration of *Pocillopora damicornis* by transplanting or dispersal of fragments (Lizcano-Sandoval *et al*., 2018). Sangpaiboon and Kongjandtre, (2023) evaluated the growth and mortality of *P. damicornis* fragments transplanted on fixed substrates at several sites on Eastern Thailand. They discovered that mortality fluctuated on an annual cycle between 20% and 100%. These variances were caused by the absence of a set experimental duration, as well as by changes in the observational techniques, coral species employed in the studies, growth measurement methods, and transplantation procedures.

4. Conclusion

In conclusion, the growth of fragment length in coral tree and table media was at an average value of 0.55 cm/month and 0.15 cm/month with survival rates of 97.3% and 87.0%, respectively. Coral tree media and table were reported to be good because the average values and survival rates obtained were quite high, while the transplant media did not affect the growth and survivability rate of *Pocillopora* spp. coral fragments. Transplanting coral fragments onto coral trees and coral tables presents a practical and relatively simple method for achieving successful coral reef restoration in the Anambas Islands, which could also be replicated in other region and is one effort aimed at making a tangible contribution to the recovery of the world's coral reef ecosystems.

Acknowledgement

The authors would like to thank the Anambas Foundation for funding this study. The authors are also grateful to Mr. Andi Lala from the Anambas Foundation team for helping as a boat crew during the study on Semut Kecil Island, Anambas Island, as well as to all reviewers who have provided criticism and suggestions for improving the manuscript.

Authors' Contributions

The contributions of each author are as follows, Fringgar Ariqa Iriani; collected, processed, analyzed data, and drafted the manuscript. Reyhan Arifin; data collection. Muhammad Rifat Muharam, Novita Permata Putri, Corina Dewi Ruswanti, and Abdul Rahman Ritonga; data collection and drafting the main conceptual ideas. Riviani Riviani; drafting analysis and revising critically. Riyanti; drafting the main conceptual ideas and critically revising the article. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

Declaration of Artificial Intelligence (AI)

The author(s) affirm that no artificial intelligence (AI) tools, services, or technologies were employed in the creation, editing, or refinement of this manuscript. All content presented is the result of the independent intellectual efforts of the author(s), ensuring originality and integrity.

Funding Information

This study project was partially sponsored by the Anambas Foundation.

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