Acropora formosa Development in Various Depths at Pramuka Island, Seribu Island National Park

Muhammad Irhas, Syawaludin A Harahap, Sunarto, Rudyansyah Ismail, Ibnu Faizal*

Marine Science Department, Faculty of Fisheries and Marine Science, Universitas Padjadjaran
Jl. Raya Bandung-Sumedang Km. 21 Jatinangor, Sumedang, Jawa Barat 45363 Indonesia
Email: ibnu.faizal@unpad.ac.id

Abstract

Coral transplantation is a proven method for restoring degraded marine ecosystems affected by environmental changes and human activities. This study investigates how depth influences the growth and survival of Acropora formosa using the RakSagon structure at Gosong Pramuka Island, Seribu Islands. RakSagon is a hexagonal dome frame made of 10 mm iron, coated with a resin-catalyst mixture, and designed with two tiers to support coral fragment attachment. The observation spanned 378 days and was divided into three monitoring periods (t0–t3) with varying intervals. The study analyzed growth, survival, and effectiveness at depths of 3, 5, and 7 m. Additionally, the ratio between coral length and width (0.38–1.08) was measured to identify horizontal or vertical growth tendencies. The highest growth occurred at 7 m, averaging 1.41–1.74 cm.mo^{-1}, while the lowest was at 3 m (0.68–0.99 cm.mo^{-1}). Growth varied between observation periods, with the second interval showing the most notable increase. Fragment survival was evaluated using the Survival Rate (SR) and Mortality Index (MI); the MI value of 0.305 indicated moderate mortality, with a 69% success rate (25 of 36 fragments survived). A one-way ANOVA test revealed a significant difference in growth rates among the depths (P= 0.004), confirming that depth plays a crucial role in transplantation outcomes. The findings suggest that a depth of 7 m offers optimal conditions for coral growth and survival, providing valuable insights for future reef restoration programs and stakeholder initiatives.

Keywords: *Coral Reefs, Acropora, growth rate, effective rate, restoration*

Introduction

Indonesia has a coral reef ecosystem that plays a vital role in sustaining coastal environmental preservation (Haya and Fujii, 2020; Dhani Akbar *et al*., 2022; Darajati, 2023; Fauzan and Burhanuddin, 2023). Coral reefs serve essential ecological functions, such as spawning grounds, nursery grounds, and feeding grounds for marine species (Yap, 2013; Arai, 2015; Zurba, 2019). The condition of coral reefs in Indonesia can be classified as follows: about 36.18% are categorized as poor, 34.3% as fair, 22.96% as good, and 6.56% as very good (Hadi *et al*., 2018).

Coral reef ecosystem, hard corals (scleractinian corals) are divided into two main categories: *Acropora* and Non-*Acropora*. *Acropora* is the most dominant coral genus in Indonesia's reef ecosystems, with a wide distribution in tropical waters like Raja Ampat, Wakatobi, and the Thousand Islands (English *et al*., 1997; Ramadhan, 2016; Loupatty *et al*., 2023). The abundance of *Acropora* in Indonesia is due to its good adaptation to clear, current-rich waters. *Acropora* is known for its faster growth rate than non-*Acropora* corals (Luthfi *et al*., 2015; Mercado-Molina *et al*., 2020), especially branching species like *Acropora formosa*, which can grow up to 5-10 cm per year (Ishaq *et al*., 2023). *Acropora* requires high sunlight intensity, and its optimal growth is influenced by clear water quality and sufficient currents. The ideal water temperature for *Acropora* growth ranges between 24 and 29°C, allowing efficient biological processes within *Acropora* tissues. However, *Acropora* is more sensitive to environmental changes compared to non-*Acropora* corals, such as rising water temperatures (which cause coral bleaching), pollution, and sedimentation (Lieng *et al*., 2020; Castro-sanguino *et al*., 2021;).

Data shows that Indonesia's coral reefs are predominantly in poor condition (36.18%) (Hadi *et al*., 2018). Coral reefs face anthropogenic and natural threats, such as overfishing, sedimentation, pollution, and ocean acidification (Good and Bahr, 2021; Sadili *et al*., 2015; Tkachenko, 2023). The destruction of coral reefs can have significant ecological and economic impacts (Nama *et al*., 2023; Nursita and Tarbiyah, 2020; Zurba, 2019). As a response, many studies have been conducted to develop effective coral reef restoration strategies. Coral reef

*) Corresponding author

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restoration is restoring or rehabilitating coral reefs to a healthy and productive condition after damage or degradation (Heeger *et al*., 2001; Omori, 2011; Rinkevich, 2021). Research on coral reef restoration is part of global efforts to protect coral reefs and mitigate the damage caused by human activities. Coral reef restoration can help reduce the negative impacts of activities such as sand mining, waste disposal, and unsustainable fishing (Boström-Einarsson *et al*., 2020; Vandenberg *et al*., 2021; Voolstra *et al*., 2023).

One of the advantages of coral transplantation methods is their ability to accelerate the restoration process. By planting healthy coral fragments in damaged reef areas, these corals can grow and develop rapidly, restoring biodiversity and increasing the productivity of coral reef ecosystems (Pratiwi *et al*., 2019; Spadaro and Butler, 2021; Bowling, 2022). In the transplantation process, one of the critical factors for success is selecting the appropriate depth for coral growth (Gomez *et al*., 2014; Widiastuti *et al*., 2023; Tuhumena *et al*., 2024). This is because coral survival rates are highly dependent on water depth, which affects the amount of sunlight that penetrates the water. The deeper the water, the less light reaches the coral. Sunlight is crucial for coral because it supports photosynthesis by zooxanthellae (Kahng *et al*., 2019; Malik *et al*., 2023). A lack of light can very seriously threaten coral survival in the long term. The amount of light penetrating the water is also influenced by the visibility of the water. Water depth can also affect the distribution of corals in certain areas or waters (Scott *et al*., 2022).

Several aspects need to be considered when conducting transplantation activities to ensure success. From 1990 to 2020, 533 coral transplantation activities in Indonesia were recorded, but only 16% were considered successful, reaching long-term monitoring stages (Razak *et al*., 2022). Several studies have shown that coral transplantation techniques have positively contributed to speeding up coral regeneration. However, a common challenge is ensuring the effectiveness and efficiency of the binding materials used to attach coral fragments to the substrate. This is a crucial aspect, as it ensures that coral fragments remain connected to their substrate and are not dislodged by underwater currents (Yudasmara, 2015).

The coral transplantation method using hexagonal frames, or "spider frames", known for its high success rate. Its features a hollow frame structure that allows water to flow freely, effectively covering coral fragments and sand while stabilizing the substrate and enhancing coral growth and diversity (Paulangan *et al*., 2023; Syahrul *et al*., 2024). This method is expected to be an effective and efficient alternative for coral reef restoration. This research aims to assess the growth rate of coral reefs using the RakSagon (Hexagon Dome Frame) method at Pramuka Island, which is still not widely utilized.

Materials and Methods

This research was conducted from January 2022 to March 2023. The research locations were Gosong Pramuka Island in the Seribu Islands and the Marine Protected Area (MPA) (Figure 1). Administratively, Gosong Pramuka Island is situated in the Seribu Islands, Jakarta, while the Marine Protected Area (MPA) is located in the Panggang Island region of the Seribu Islands, Jakarta. Geographically, Gosong Pramuka Island is positioned at 5°44'45.60"S, 106°36'50.40"E, and the Marine Protected Area is located at 5°44'10.27"S, 106°36'34.93"E.

The coral reef condition in the waters of Gosong Pramuka falls within the moderate category across all three depths. At a depth of 3 m, coral cover is the lowest at 35.36%, while at 5 m, it reaches 36.40%. The highest coral cover is observed at a depth of 7 m, with a percentage of 38.12% (Riyantini *et al*., 2023). The Gosong Pramuka area, part of the Marine Protected Area (MPA) managed by the Seribu Islands National Park, is regulated through a zoning system implemented by Seribu Islands National Park.

Data collection

In this study, three selected depths (3, 5, and 7 m) were used to compare the effect of depth as a variable on the success factors of coral growth using the transplantation method. The transplantation medium used was a RakSagon (Hexagonal Dome Frame), made of a 10 mm diameter iron frame shaped like a hexagonal dome (Figure 2). The RaKsagon structure was coated with a mixture of resin and catalyst, followed by the attachment of beach sand. Two RakSagon were placed at each depth for each species of *Acropora formosa*. The 36 *A. formosa* fragments were distributed across the depths, with 12 fragments at each depth and two RakSagon per depth for each species (6 tied coral fragments). The RakSagon were tied at the base with small iron bars to prevent them from separating.

Initial data (t_0) was collected on March 8, 2022. The second data (t_1) was collected on June 27, 2022 (112 days), the third data (t_2) on August 11, 2022 (158 days), and the final data (t_3) on March 22, 2023 (378 days). Data was collected by diving and measuring the coral fragments using calipers with an accuracy of ± 0.01 cm. The measurements were taken underwater, and at least two divers were required to minimize diver bias (human factor) during the measurements. Measurements were made by vertically measuring the fragment from the cut point to the highest point of the coral. The highest branch of each fragment was selected as a reference for vertical scale measurement. While the maximum width between branches was used as the reference for horizontal scale measurement.

Data process and analysis

The survival rate of coral was analyzed using the formula expressed as a percentage calculated by dividing the number of live transplanted coral fragments by the total number of fragments and multiplying the result by 100 (Harahap *et al.*, 2022). This formula provides a straightforward way to quantify the success of coral transplantation efforts, indicating the proportion of coral fragments that have survived after transplantation relative to the initial number. The Mortality Index (MI) divides fragment life by the number of fragment samples. The ranges are from 0 to 1, illustrating that the closer the value is to 0, the lower the coral mortality ratio, and thus, the higher its health can be considered. Conversely, when the MI value approaches 1, it indicates a high coral mortality ratio or low health condition (English *et al*., 1997).

The observational data were analyzed using the coral growth rate formula measuring the fragment length and width increase. The increase in coral length (L) and width (W) was determined by subtracting the average growth observed at time t (Lt) from the initial average growth (L0), then dividing the result by the observation periods (t1, t2, and t3). This equation measures the growth rate, allowing researchers to quantify the length and width increase of coral fragments over a specified observation period.

Data analysis in this study was conducted using several statistical methods. Analysis of Variance (ANOVA) was employed to test the significance of the treatment effects on coral growth based on a Completely Randomized Design (CRD). A completely Randomized Design (CRD) is an experiment conducted randomly on a data group. This test is generally performed in relatively homogeneous environments. The following is the model for the completely randomized design (Rahmawati and Erina, 2020):

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

Note : i = 1,2, ..., t and j=1, 2, ..., r.; Y_{ij} = Response or observation from treatment i and replication j.; μ = Average; τ_i = Effect of treatment i; ε_{ij}= Effect of experimental error from treatment i and replication j.

Subsequently, a homogeneity test was conducted using Levene's method (Usmadi, 2020). using IBM SPSS Statistics 23 software. Tukey's test (Effective Rate) was conducted as a pairwise comparison test to determine which treatment variables were significantly affected (Williams *et al*., 2001; Hadiyantini *et al*., 2022).

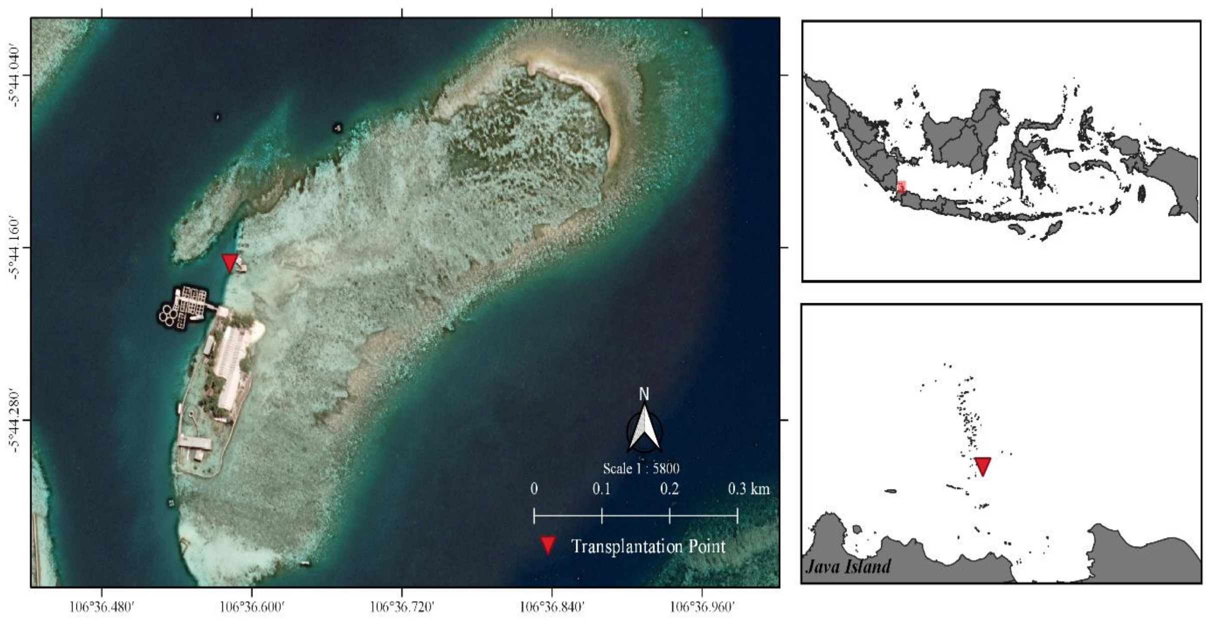

Figure 1. Research Location. The island is located in Gosong Pramuka (left). This area is on Seribu Island MPAs (right), located north of Jakarta Capital City, Indonesia.

Figure 2. The RakSagon (Hexagonal Dome Frame) design (left) and the fragments attachment positions in every corner of the frame on RakSagon (right).

Result and Discussion

The physical conditions such as temperature, salinity, dissolved oxygen, and pH were observed within the same research project (Riyantini *et al*., 2023). As for the three depth shows, the temperature range is between 29,21 - 29,99 °C, and for salinity ($^0/_{00}$), dissolved oxygen and pH are between 29,7–30,7; 6,8–8,5; and 7,3–8,2 accordingly. The results of the physical conditions show that all parameters in the area are optimal for coral reefs (Giyanto *et al*., 2017). Physical conditions, such as temperature, determine the growth of *A. formossa* (Clark *et al*., 2022). These parameters are essential to determine whether the physical factor is still in the ideal range for coral reefs.

Survival rate

The Mortality Index (MI) calculation for coral transplantation yielded a value of 0.305, indicating that the coral mortality rate in the area was categorized as moderate, with a coral transplantation success rate of 69%. Of the 36 coral seedlings transplanted, 11 fragments failed to grow or died. A more detailed analysis based on depth variation revealed that the lowest survival rate occurred at a depth of 3 m, where five fragments failed to grow or died, while at depths of 5 and 7 m, the number of failed fragments was three in both cases.

The mortality of coral fragments resulted from the high coverage of Dead Coral Algae (DCA) or ascidians, indicating that these waters were under pressure from sedimentation, potentially leading to eutrophication that allowed algae to multiply (Sakaria, 2022). The depth factor showed a slight influence on coral reef survival. In this location, the deeper areas experienced less turbulence and nutrient input, which led to disturbances around RakSagon, primarily caused by human activity.

Growth rate

The growth rate measured the coral fragments developed in length (L) and width (W) during the observation period. The growth rate varied at different depths and showed positive results (Figure 3). At a depth of 3 m, 7 out of 12 fragments exhibited maximum growth, with the highest recorded length increase of 0.99 cm.mo^{-1} and width increase of 0.685 cm.mo^{-1}. One fragment demonstrated the most significant growth, increasing in length by 13.49 cm over 378 d, and width growth achieved a maximum increase of 19.95 cm. At this depth, the maximum growth rate for length showed similar results to previous research using the same species and depth but yielded slightly different findings (Kambey, 2013), which recorded a growth rate of 0.90 cm.mo^{-1}.

The growth of fragments at a depth of 5 m shows that the increase at this depth tends to be slightly significant compared to the previous depth. The values showed maximum growth for both length and width, approximately 1.41 cm.mo^{-1} and 1.74 cm.mo^{-1}, respectively. This result showed quite a distinct number of similar researchers who performed transplantation at a depth of 5 m and recorded the highest growth rate of 0.183 cm.mo^{-1} over a research period of 4 mos (Hermanto, 2016). For this depth, the fragment succeeded in maximum growth until 11.31 – 15.05 cm in length and width. The most significant fragment growth compared to other depths occurred at a 7 m depth. The highest coral fragment length at this depth reached 16.92 cm, and the most considerable width increase occurred in another fragment, which increased by 25.80 cm over 378 days. The highest growth rate was 1.99 and 2.51 cm.mo^{-1} for length and width, respectively.

Generally, the most significant growth period of *A. formossa* growth per day is during the second monitoring (t_1 – t_2). During this period, the growth rate within all depths is between 0.039 – 0.086 cm.day^{-1}. The range covers both length and width growth. The second period is the shortest interval between monitoring (46 d). The third monitoring (t_2 – t_3) is the lowest growth rate period for length and width, ranging between 0.005 – 0.044 cm.d^{-1}.

The difference in growth rate per day in this research indicates factors influencing the condition. The first and second monitoring were during July – August, which is in the dry season with good light penetration compared to the wet season. Light penetration is an influencing factor in the growth of coral reefs (Pratiwi *et al*., 2019). Secondly, the current factor influenced sediment flow, as stronger currents during the dry season prevented sediment accumulation, while weaker currents during the wet season led to higher sediment deposition (Nurulita *et al*., 2018). As for technical factors, we cleaned the RakSagon from ascidians or other algae that grow around the substrate. However, this research does not quantify or calculate this factor.

The length-width growth relations are also considered to determine the correlation between these measurement parameters. The correlation value (R^2) is 0.758, which shows a strong positive correlation between length and width (Figure 5), with width growth tendency to dominate over length growth.

The length-width ratio is around 0.36 – 1.08, with values close to 1 indicating balanced or symmetrical growth, and a ratio higher or lower than 1 categorized an asymmetrical growth pattern, suggesting that environmental factors might be influencing one dimension more than the other. This result is essential to consider when designing coral transplantation media. As for every species/genus, it might tend to grow vertically or horizontally. RakSagon design accommodates both conditions where the fragments have sufficient vertical and horizontal space.

Effective rate

A significance value of 0.569 was obtained for the homogeneity test. This indicates that the data did not show significant differences in variability among the coral fragment depths. It can also be stated that the obtained data yielded a value greater than the alpha level (α= 0.005), suggesting that the coral fragment data are homogeneous in terms of variability following the homogeneity test requirements. Once the data was confirmed to be homogeneous, it could be processed using ANOVA.

The ANOVA test yielded a significance value of 0.004, which is less than the significance level of 0.05, indicating significant differences among the transplant depths. This difference may be due to the high mortality rate of corals observed at a depth of 3 m and the limited growth in fragment height at 5 m, leading to a depth of 7 m exhibiting the highest growth rates. The analysis also indicates that the three and 5-m depths form a single group, suggesting no significant difference between these two depths. The most effective depth is 7 m, which stands out as distinct group compared to 3 and 5 m. Coral growth

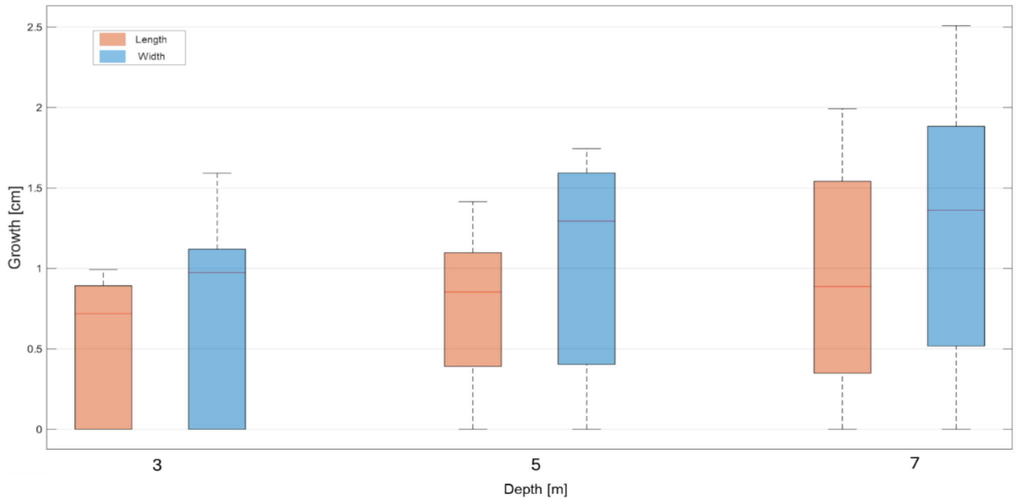

Figure 3. Monthly average distribution for growth in length and width in each depth. Length values are represented in the orange box, and width is in blue. The median is in centimeters with a red line inside the box indicating the mean value, and zero values in the minimum whisker suggest that the fragments have not survived/died.

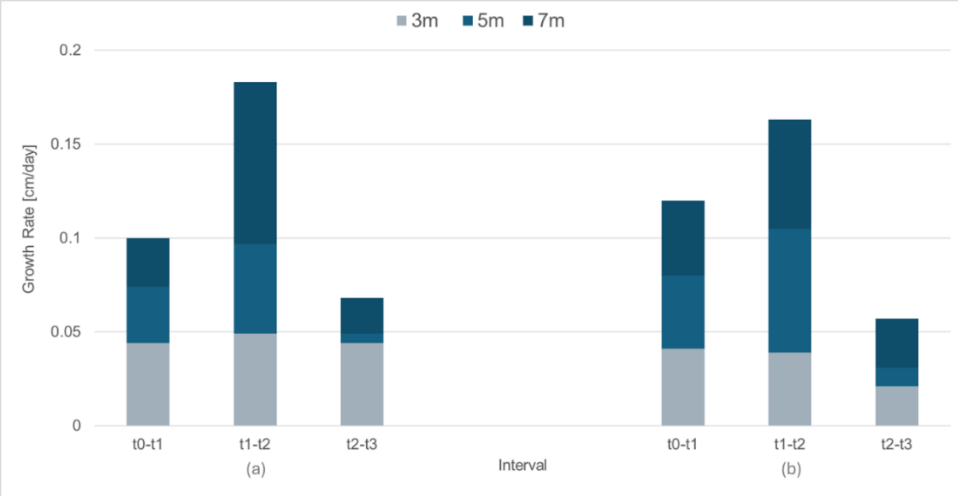

Figure 4. Growth rate per day between intervals of period of monitoring. Each bar represents each monitoring period, and color gradations represent depth. (a) showed value for length and (b) for width.

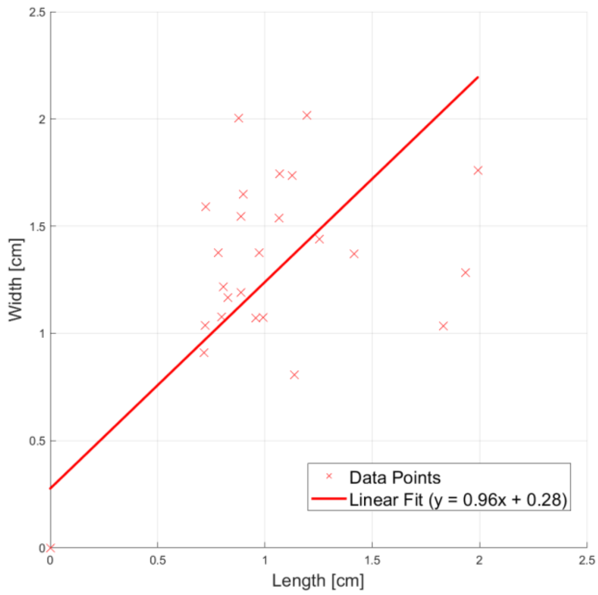

Figure 5. Correlation between length and width of *A. formossa* fragments. The X-axis represents the length distributions, and the y-axis is the width. Redline indicates the regression line and produces a linear equation between two factors.

a depth of 7 m demonstrates the highest growth rates compared to the other depths. This suggests that conditions at 7 m may be more conducive to coral growth, making it the most effective depth for transplantation.

One factor contributing to the effectiveness of growth at a depth of 7 m, as indicated by the study conducted by Riyantini *et al*. (2023), is that the natural coral cover in the waters of Gosong Pramuka at this depth reaches the highest level compared to the depths of 3 and 5 m. The presence of healthy and diverse natural coral communities can enhance the growth rates of transplanted corals, contributing to the success of the transplantation process, as healthy natural coral cover indicates the stability of the water conditions supporting the growth of transplanted corals (Prabowo *et al*., 2022). Transplantation sites with dense natural coral cover tend to be more successful in supporting the development of transplanted corals. Natural coral cover can also be an effective physical barrier, protecting transplanted corals from predation and excessive physical disturbances (Pelasula *et al*., 2023). In the ecological context of coral reefs, predation often occurs from organisms such as coral-eating fish and predator starfish (*Acanthaster plancii*), which can damage coral structures and hinder their growth. The natural coral cover creates complex habitats that can reduce predator access to newly transplanted corals (Boström-Einarsson *et al*., 2020).

Coral growth rates at greater depths are faster and more favorable than in shallower water conditions. Corals in deeper waters experience more stable conditions, allowing them to respond more specifically and achieve higher success rates in simulated parental habitat conditions (Ruiz-Diaz *et al*., 2022). Furthermore, the results of this study indicate that one limiting factor for coral growth is the emergence of ascidians in the transplantation framework, which hinders the development of fragments during transplantation. The excessive growth rates of ascidians on corals are influenced by the corals' morphology, size, orientation, and seasonal factors (Shenkar *et al*., 2008). Selecting the location of the RaKsagon installation is also the main factor in the success of the growth. The gentle slope of the area, coupled with the bed substrate in the form of sand, makes the frame more stable. In addition, oceanographic factors such as currents also play a role, and the current strength is not too strong in location. The strong current at a transplantation location can potentially disrupt the stability of the frame.

The challenges faced by coral performance include anthropogenic and non-anthropogenic. The main factors that make coral reefs vulnerable in the Seribu Islands are domestic waste, industrial waste, and environmentally unfriendly fishing (Bryant *et al*., 1998). Anthropogenic factors come from the large amount of marine debris, such as tree branches and plastic, that accumulates and gets caught in the frame, so it has a vast potential to cover fragments or disrupt the stability of the frame. Non-anthropogenic or natural factors come from the growth of competitor biota, Ascidian (Tunicata), which can interfere with the coral growth process and spatial competition. However, both of these things can be overcome by conducting regular monitoring. The monitoring covers cleaning all disturbances to improve coral fragments' life expectancy or survival rate. This will also lead to economic benefits. Good coral fragment growth will be able to provide to the community for the tourism sector through several conservation activities or in the fisheries sector. It can be used as a new parent stock in the ornamental coral trade market (Dee *et al*., 2014).

Conclusion

Based on the data and analysis, it was found that a depth of 7 m has the highest level of effectiveness compared to depths of 3 m and 5 m. The MI value of 0.305 indicates that the mortality rate of transplanted coral fragments is moderate, with a coral transplantation success rate of 69%. Out of the 36 transplanted coral fragments, only 11 did not survive. The research results show positive results that provide new information related to Indonesia's coral reef transplantation process. However, further monitoring needs to be done to monitor the exact anthropogenic factors around the location that harm the existence of coral fragments.

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References

Akbar, D., Pratama, R.A., Yudhyo, Sianturi, R.L., & Triyana, N. 2022. Strategi Pengembangan Blue Economy Wilayah Perbatasan Indonesia: Tata Kelola Ekonomi Maritim Pesisir Kepulauan Riau. *NeoRespublica: J. Ilmu Pemerintahan*, 4(1): 166–177. https://doi.org/10.52423/neores.v4i1.8

Arai, T. 2015. Diversity and conservation of coral reef fishes in the Malaysian South China Sea. *Rev. Fish. Biol. Fish.*, 25(1): 85-101. https://doi.org/10.1007/s11160-014-9371-9

Boström-Einarsson, L., Babcock, R.C., Bayraktarov, E., Ceccarelli, D., Cook, N., Ferse, S.C.A., Hancock, B., Harrison, P., Hein, M., Shaver, E., Smith, A., Suggett, D., Stewart-Sinclair, P.J., Vardi, T., & McLeod, I.M. 2020. Coral restoration – A systematic review of current methods, successes, failures and future directions. *PLoS ONE*, 15(1): 1-24. https://doi.org/10.1371/journal.pone.0226631

Bowling, C.M. 2022. Improving the heat tolerance of vulnerable corals through their algal symbionts. *OUR J: ODU Undergrad Res*, 9(1): p.2. https://doi.org/10.25778/79bz-qk75

Bridge, T.C.L., Hoey, A.S., Campbell, S.J., Muttaqin, E., Rudi, E., Fadli, N., & Baird, A.H. 2014. Depth-Dependent Mortality of Reef Corals Following a Severe Bleaching Event: Implications for Thermal Refuges and Population Recovery. *F1000Res*, 2: p.187. https://doi.org/10.12 688/f1000research.2-187.v3

Bryant, D., Burke, L., McManus, J.W., & Spalding, M. 2001. Reefs at risk: A map-based indicator of threats to the world's coral reefs. *SPC Women Fish. Newsl.*, (8): 27-27.

Castro-Sanguino, C., Carlos, J., Thompson, A., Wolff, N.H., Ferrari, R., Robson, B., Magno-Canto, M.M., Puotinen, M., Fabricius, K.E., & Uthicke, S. 2021. Reef state and performance as indicators of cumulative impacts on coral reefs. *Ecol. Indic.*, 123: p.107335. https://doi.org/10.1016/ j.ecolind.2020.107335

Clark, V., Mello-Athayde, M.A., & Dove, S. 2022. Colonies of *Acropora formosa* with greater survival potential have reduced calcification rates. *PLoS ONE*. 17(6): e0269526. https: //doi.org/10.1371/ journal.pone.0269526

CPH, S., Noviana, Putri, A., Rahardjo, M., Djumanto, LS, S., & D, A. 2020. Species composition and abundance of small fishes in seagrass beds of the Karang Congkak Island , Kepulauan Seribu National Park, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.,* 404(1): p.012063. https://doi. org/10.1088/1755-1315/404/ 1/012063

Darajati, M.R. 2023. Ekonomi Biru: Peluang Implementasi Regulasi Di Indonesia. *J. Soc. Gov.*, 4(5): 41-53. https://doi.org/10.55314/ tsg.v4i5.599

Dee, L.E., Horii, S.S., & Thornhill, D.J. 2014. Conservation and management of ornamental coral reef wildlife: Successes, shortcomings, and future directions. *Biol. Conserv.*, 169: 225-237. https://doi.org/10.1016/j.biocon.2013.11.025

English, S., Wilkinson, C., & Baker V. 1997. Survey Manual for Tropical Marine Resources. Townsville: Australian Institute of Marine Sciences. 390 p.

Fauzan, A.F., & Burhanuddin, A. 2023. Potensi dan tantangan pariwisata maritim Kepulauan Seribu. *Student Scientific Creativity J*, 1(6): 379-391. https://doi.org/10.55606/sscj-am ik.v1i6. 2391

Giyanto, Abrar, M., Hadi, T.A., Budiyanto, A., Hafizt, M., Salatalohy, A., & Iswari, Marindah, Y. 2017. Status terumbu karang di Indonesia 2017. In: Suharsono (ed). Pusat Oseanografi - LIPI. pp.1-41.

Gomez, E.D., Dizon, R.M., & Edwards, A.J. 2010. Methods of coral transplantation. In: Edwards, A.J. (ed). Reef Rehabilitation Manual. Coral Reef Targeted Research & Capacity Building for Management Program: St. Lucia, Australia. pp. 99-112.

Good, A.M., & Bahr, K.D. 2021. The coral conservation crisis: interacting local and global stressors reduce reef resiliency and create challenges for conservation solutions. *SN. Appl. Sci.*, 3(3):1-14. https://doi.org/10.1007/s424 52-021-04319-8

Hadi, T.A., Giyanto, Prayudha, B., Hafizt, M., Budiyanto, A., & Suharsono. 2018. Status Terumbu Karang Indonesia 2018. Pusat Penelitian Oseanografi Lembaga Ilmu Pengetahuan Indonesia. Jakarta. 26 p.

Hadiyantini, F., Sukmawati, D., & Gantini, T. 2022. Partisipasi Masyarakat dalam Program Gerakan Tanam dan Pelihara 50 juta Pohon terhadap Tingkat Penjualan Bibit Tanaman Hutan di Provinsi Jawa Barat (Suatu Kasus Pada Pengada/Pengedar Bibit Tanaman Hutan di Provinsi Jawa Barat). *Paspalum: J. Ilmiah Pertanian*, 10(2): p.200. https://doi.org/10. 35138/paspalum.v10i2.449

Harahap, S.A., Sunarto & Fatturochman, R. 2022. Growth of Montipora coral transplant at different depths. *World Scientific News*, 167: 1-15.

Haya, L.O.M.Y. and Fujii, M., Assessment of coral reef ecosystem status in the Pangkajene and Kepulauan Regency, Spermonde Archipelago. *Mar. Pol.,* 118: p.104028. https://doi.org/ 10.1016/j.marpol.2020.104028

Heeger, T., Sotto, F.B., Gatus, J.L., Laron, C., & Laron, C. 2001. Community-based coral farming for reef rehabilitation, biodiversity conservation and as a livelihood option for fisherfolk. *Responsible Aquaculture Development in Southeast Asia*, 1: 133-145.

Hermanto, B. 2016. The growth of Acropora formosa fragment in different sizes using transplantation method in Lembeh Strait. *Platax*, 3(2): p.90. https://doi.org/10.35800/jip.3.2.2015.13224

Ishaq, S.Y., Isdianto, A., & Septiandi, A.R. 2023. Ex-situ growth rate of *Montipora* and *Echinopora* corals in the coral breeding facility at Dawan District, Klungkung Regency, Bali. *J. Environ. Eng. Sustain. Technol*., 10(2): 61-68. https:/ /doi.org/10.21776/ub.jeest.2023.010.02.2

Kahng, S.E., Akkaynak, D., Shlesinger, T., Hochberg, E.J., Wiedenmann, J., Tamir, R., & Tchernov, D. 2019. Light, temperature, photosynthesis, heterotrophy, and the lower depth limits of mesophotic coral ecosystems. In: Mesophotic coral ecosystems. Springer International Publishing; p. 801–828. https://doi.org/10. 1007/978-3-319-92735-0_42

Kambey, A.D. 2013. The growth of hard coral (*Acropora* sp.) transplants in coral reef of Malalayang waters, North Sulawesi, Indonesia. *Platax*. 1(4): 196-203.

Lieng, L., Efriyeldi, E., & Thamrin, T. 2020. Density zooxanthella based on the life form of coral on Marak Island West Sumatera Province. *Asian J. Aquat. Sci.*, 3(3): 209–216. https://doi.org/10.31258/ajoas.3.3.209-216

Loupatty, S.R., Limmon, G.V., Kaya, S.M.J., & Manuputty, G.D. 2023. Distribusi dan kondisi jenis-jenis karang keras (Scleractinian) di perairan Dusun Airlouw dan Dusun Seri (distribution and condition of hard coral (Scleractinian) species in the waters of Airlouw and Seri village). *J. Agribisnis Perikanan*, 16(1): 103–108.

Luthfi, O.M., Nurmalasari, N., & Jauhari, A. 2015. Growth rate of staghorn coral (*Acropora*) on Coral Garden Program at Sempu Nature Reserve Malang. *Res. J. Life Sci.*. 2(3): 152–160. https://doi.org/10.21776/ub.rjls.2016.002.03.2

Malik, A., Minsaris, L.O.A., & Anzani, L. 2023. Pengaruh perbedaan modul transplantasi karang terhadap pertumbuhan karang di Pulau Pramuka. *Juvenil: J. Ilmiah Kelautan dan Perikanan*. 4(2): 90–103. https://doi.org/10.21107/juvenil.v4i2.19675

Mercado-Molina, A.E., Sabat, A.M., & Hernández-Delgado, E.A. 2020. Chapter three- Population dynamics of diseased corals: Effects of a shut down reaction outbreak in Puerto Rican *Acropora cervicornis*. In: Riegl BM, editor. *Population Dynamics of the Reef Crisis*. Academic Press. 87(1): 61–82. https://doi.org/10.1016/bs.amb.2020.08.001

Nama, S., Shanmughan, A., Nayak, B.B., & Bhushan, S. 2023. Impacts of marine debris on coral reef ecosystem: A review for conservation and ecological monitoring of the coral reef ecosystem. *Mar. Pollut. Bull*. 189: p.114755. https://doi.org/10.1016/j.marpolbul.2023.114755

Nursita, L., & Tarbiyah F. 2020. Menggagas pembangunan blue economy terumbu karang; sebuah pendekatan sosial ekonomi. *EcceS: Economics Social and Development Studies*. 7(1): 62–86. https://doi.org/10.24252/ecc.v7i1.13730

Omori, M. 2011. Degradation and restoration of coral reefs: experience in Okinawa, Japan. *Mar. Biol. Res.*, 7(1): 3–12. https://doi.org/10.1080/17451001003642

Paulangan, Y.P., Yusuf, S., Barapadang, B., Hamuna, B., Rumbiak, K., Ayer, P.I.L., Mandey, V.K., Wanimbo, E., & Baransano, N. 2023. Transplantasi karang dengan metode SPIDER di Pantai Harlen Kampung Tablasupa Kabupaten Jayapura Provinsi Papua. *J. Pengabdian Pada Masyarakat*. 8(3): 633–42. https://doi.org/10.30653/jppm.v8i3.359

Pelasula, D.D., Mufti, P., Wouthuyzen, S., & Syahailatua, A. 2023. Key success factors and problems in coral transplantation: A review. *Aquac Aquarium Conserv Legis*, 16(1):1-24. https://bioflux.com.ro/docs/2023.1-24.pdf

Prabowo, B., Rikardi, N., Setiawan, M.A., Santoso, P, Arafat, D., Subhan, B., Afandy, A. 2022. The perspective of high coral growth rate on the artificial reef: What is causing enhancement of coral growth rate on Nyamuk Island, Anambas?. *IOP Conf. Ser. Earth Environ. Sci.*, 967(1): p.12038. https://doi.org/10.1088/ 1755-1315/967/1/012038

Pratiwi, D.B., Ramses, R., & Efendi, Y. 2019. Perbedaan laju pertumbuhan dan tingkat kelangsungan hidup karang jenis Montipora tuberculosa berasal dari induk transplantasi dengan induk dari alam. *Simbiosa*. 8(1): p.10. https://doi.org/10.33373/sim-bio.v8i1.1529

Rahmawati, A.S., & Erina, R. 2020. Rancangan acak lengkap (RAL) dengan uji ANOVA dua jalur. *OPTIKA: J. Pendidikan Fisika*, 4(1):54–62. https://doi.org/10.37478/optika.v4i1.333

Ramadhan, A., Lindawati, L., & Kurniasari, N. 2017. Nilai ekonomi ekosistem terumbu karang di Kabupaten Wakatobi. *J. Sosial Ekonomi Kelautan dan Perikanan*, 11(2):133. https://doi.org/10.15578/jsekp.v11i2.3834

Razak, T.B., Boström-Einarsson, L., Alisa, C.A.G., Vida, R.T., & Lamont, TAC. 2022. Coral reef restoration in Indonesia: A review of policies and projects. *Mar. Pol.*, 137(1): p104940. https://doi.org/10.1016/j.marpol.2021.104940

Rinkevich, B. 2021. Ecological engineering approaches in coral reef restoration. *J. Mar. Sci.,* 78(1): 410–420. https://doi.org/10.1093/icesjms/fsaa022

Riyantini, I., Harahap, S.A., Kostaman, A.N., Aufaadhiyaa, P.A., Yuniarti, M.S., Zallesa, S., & Faizal, I. 2023. Kelimpahan, keanekaragaman dan distribusi ikan karang dan megabentos serta hubungannya dengan kondisi terumbu karang dan kualitas perairan di Gosong Pramuka, Taman Nasional Kepulauan Seribu. *Buletin Oseanografi Marina*. 12(2): 179–191. https://doi.org/10.14710/buloma.v12i2.48793

Ruiz-Diaz, C.P., Toledo-Hernández, C., Sánchez-González, J.L., & Betancourt, B. 2022. The effects of depth-related environmental factors on traits in *Acropora cervicornis* raised in nurseries. *Water.* 14(2): p.212. https://doi.org/10.3390/w14020212

Sadili, D., Sarmintohadi, Ramli, I., Rasdiana, H., Sari, R.P., Miasto, Y., Prabowo, Monintja, M., Tery, N., & Annisa, S. 2015. Pedoman Rehabilitasi Terumbu Karang (Scleractinia). Jakarta: Dit. KKHL-KKP RI. 88 p.

Sakaria, F.S.. 2022. Identification of dead coral types to determine the causes of coral reefs damage in Malili Waters, Bone Bay. *Maspari J.* 2: 91–98.

Scott, M.E., Tebbett, S.B., Whitman, K.L., Thompson, C.A., Mancini, F.B., Heupel, M.R., & Pratchett, M.S.. 2022. Variation in abundance, diversity and composition of coral reef fishes with increasing depth at a submerged shoal in the northern Great Barrier Reef. *Rev. Fish. Biol. Fish.,* 32(3): 941–962. https://doi.org/10.1007/s11160-022-09716-9

Shenkar, N., Bronstein, O., & Loya, Y. 2008. Population dynamics of a coral reef ascidian in a deteriorating environment. *Mar. Ecol. Prog. Ser.,* 367: 163–171. https://doi.org/10.3354/meps07579

Spadaro, A.J., & Butler, MJ. 2021. Herbivorous crabs reverse the seaweed dilemma on coral reefs. *Curr. Biol.,* 31(4): 853–859. https://doi.org/10.1016/j.cub.2020.10.097

Syahrul, Rauf, A., & Danial. 2024. 2024. Evaluation of coral growth and survival on spider frame transplant media on Samalona Island, Makassar. *Int. J. Multidiscip. Res. Growth Eval.,* 5(1): 468–471. https://doi.org/10.54660/ijmrge.2024.5.1.468-471

Tkachenko, K.S. 2023. Degradation of coral reefs under complex impact of natural and anthropogenic factors with Nha Trang Bay (Vietnam) as an example. *Biol. Bull. Rev.,* 13(5): 442–459. https://doi.org/10.1134/S2079086423050079

Tuhumena, J., Pangaribuan, R., Pane, L., Merly, S., Parenden, D., & Tuhumena, L. 2024. Coral recruitment and transplantation to support coral reef ecosystem recovery (overview). *Platax.* 12(1): 388–399. https://doi.org/10.35800/jip.v12i1.55333

Usmadi. 2020. Pengujian persyaratan analisis (uji homogenitas dan uji normalitas). *J. Inovasi Pendidikan,* 7(1): 50-62. https://doi.org/10.31869/ip.v7i1.2281.

Vandenberg, J., Humphries, A., Garcia-Quijanoa, C., Moore, A., Pollnac, R., & Abdullah, S. 2021. Assessing indicators and limitations of food security objectives in coral reef restoration. *Conserv Soc.,* 19(1): 68–79. https://doi.org/10.4103/cs.cs_20_33

Voolstra, C.R., Peixoto, R.S., & Ferrier-Pagès, C. 2023. Mitigating the ecological collapse of coral reef ecosystems. *EMBO Rep.* 24(4): e56826. https://doi.org/10.15252/embr.20 2356826

Widiastuti, K.A., Yuni, L.P.E.K., & Astarini, I.A. 2023. Pertumbuhan dan laju pertumbuhan karang *Stylophora pistillata* dengan jenis substrat berbeda yang ditanam pada tiga kedalaman di Pantai Serangan. *Metamorf. J. Biol. Sci.,* 10(1): p.51. https://doi.org/10.24843/meta morfosa.2023.v10.i01.p06

Wijayanti, D.P., Indrayanti, E., Asri, W.F., & Ambariyanto, A. 2015. Growth of *Favia* and *Favites* coral transplants based on polyps number. *Ilmu Kelautan: Indonesian Journal of Marine Science.* 20(1): 23–32. https://doi.org/10.14710/ik.ijms.20.1.23-32

Williams, I.D., Polunin, N.V.C., & Hendrick, V.J.. 2001. Limits to grazing by herbivorous fishes and the impact of low coral cover on macroalgal abundance on a coral reef in Belize. *Mar. Ecol. Prog. Ser.,* 222: 187–196. https://doi.org/10.3354/meps222187

Winslow, E.M., Speare, K.E., Adam, T.C., Burkepile, D.E., Hench, J.L., & Lenihan, H.S. 2024. Corals survive severe bleaching event in refuges related to taxa, colony size, and water depth. *Sci Rep.,* 14(1): p.9006. https://doi.org/10.1038/s41598-024 58980-1

Yap, H.T. 2013. Coral reef ecosystems. In: Orcutt J, editor. Earth System Monitoring: Selected Entries from the Encyclopedia of Sustainability Science and Technology. New York: Springer. p.77–106. https://doi.org/ 10.1007/978-1-4614-5684-1_5

Yudasmara, G.A. 2015. Analisis pertumbuhan karang *Acropora formosa* dalam proses transplantasi karang. In: *Pros Sem Nas FMIPA UNDIKSHA V.* p.388–394

Zurba, N. 2019. Pengenalan Terumbu Karang Sebagai Pondasi Utama Laut Kita. In *Unimal Press*. Unimal Press. 116 p