Multispecies coral transplantation: Examining survival rates and growth patterns

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ABSTRACT

Background: Coral transplantation is a widely respected technique used to cultivate coral reefs, serving the dual aims of repair and commercial activities. *Acropora* sp. and *Montipora* sp are well-known coral groups that are frequently transplanted for ornamental purposes. Nevertheless, prevailing transplantation methods predominantly prioritise the production of a single species, disregarding the inherent cohabitation of several coral species in their natural environments. This study aimed to investigate the survival and growth rates of *Acropora* sp. and *Montipora* sp. cultivated in a multispecies habitat.
Methods: The research employed a complete randomized design with six treatments. The first three treatments focused on monospecies control (*A. millepora*, *A. nana*, and *M. digitata*), while the remaining three involved multispecies combinations (*A. millepora* with *A. nana*, *A. millepora* with *M. digitata*, and *A. nana* with *M. digitata*). Substrates, made of a cement and sand mixture, were created with dimensions of 10 x 10 cm and a height of 2 cm. Coral fragments obtained from ornamental coral farmers on Pramuka Island were used for transplantation.
Results: After six months, 18 out of 24 fragments exhibited robust growth, with *A. millepora* showing the highest survival rate (100%). The combination of *A. millepora* and *M. digitata* displayed the most significant growth (0.80 cm/month for height and 0.77 cm/month for length) in multispecies cultivation.
Conclusion: *A. millepora* proved adaptable, displaying high survival rates and optimal growth conditions when combined with *M. digitata*. Successful multispecies cultivation, particularly with *A. millepora* and *M. digitata*, enhanced coral reef restoration and commercial coral farming, contributing to ecological health and economic significance.

Keywords: *Acropora millepora*, *Acropora nana*, *Montipora digitata*, coral transplantation, multispecies

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INTRODUCTION

Indonesia, the largest archipelagic nation in the world, possesses abundant biodiversity, particularly in its marine environment [1]. One of the marine biodiversity components is the coral reef ecosystem [2]. Coral reefs serve as vital locations where marine life and global natural cycles thrive. They act as wave barriers, gathering spots for fish and other marine organisms that serve as sources of protein and medicinal substances. Additionally, coral reefs are widely utilized as ornamental commodities for aquariums. The trade of ornamental corals in the Thousand Islands National Park region has become an alternative livelihood for the local population.
Ornamental corals are traded domestically and, notably, exported internationally. Consequently, coral reefs hold substantial economic value for Indonesia.
However, coral reefs in Indonesia have suffered extensive damage from both natural factors and, predominantly, human activities. The dependence of many communities on the sale of ornamental corals has led to overexploitation [3]. Large-scale harvesting of ornamental corals from the natural environment can diminish coral reef diversity and availability [4]. Natural restoration processes in coral reefs take a considerable amount of time and require an unpolluted and undisturbed environmental condition. One breakthrough in preventing damage or restoring coral reef ecosystems is through coral transplantation techniques.
Coral transplantation is currently widely practiced as a form of environmental conservation for marine ecosystems [5]. Transplantation is often carried out through fragmentation

methods, where live coral fragments are cut from a colony [6]. However, these fragments typically originate from a single coral species. This study implemented an alternative transplantation method by placing two distinct coral species on the same substrate, referred to as multispecies transplantation cultivation.

Acropora sp. and *Montipora* sp. are the most extensively cultivated coral species using transplantation methods, whether for coral reef ecosystem restoration or commercial trade [7]. Both of these coral types possess high aesthetic and market values. The transplantation of these two species has been confined to monospecies (single species) cultures thus far. Observations in their natural habitats (specifically, coral reef ecosystems) suggest that species are capable of coexisting with one another via intricate and dynamic relationships. This suggests that the ability to symbiotically interact is a determining factor in the appearance (shape, size, and color) and survival of organisms. Therefore, research on multispecies coral transplantation is essential. This study aimed to produce multispecies corals, the success of which can be measured through survival rates and growth rates.

MATERIALS AND METHODS

Materials

In this research, substrates are used to place coral fragments or pieces. Cement is utilized to attach coral fragments to the substrate. Coral racks or tables serve as the placement area for substrates containing coral fragments. The coral table is made of PVC pipes filled with cement, forming a rectangular structure measuring 2 m x 1 m with a height of 0.5 m, positioned at the bottom of the water. Underwater cameras are used for photographing during the study. GPS (Global Positioning System) is a digital tool employed to determine observation locations with satellite assistance (research coordinates: 05º44'03.7" S and 106º36'42.5" E). A boat is used to support research activities.

Experimental design

The experiment is conducted using a completely randomized design with six treatments. The first three treatments are control treatments (monospecies) consisting of *A. millepora*, *A. nana*, and *M. digitata*. The other three treatments are multispecies treatments, namely combinations of *A. millepora* with *A. nana*, *A. millepora* with *M. digitata*, and *A. nana* with *M. digitata*. These corals are then cultured on substrates. All treatments were replicated four times.

Substrate fabrication

The substrate was made from a mixture of cement and sand, molded into squares measuring 10 x 10 cm with a height of 2 cm.

Preparation of coral parents

Coral fragments used in this coral transplantation study were obtained from ornamental coral farmers engaged in trading activities on Pramuka Island. The corals used in transplantation were second-generation descendants of the parent colony, making them legally tradeable as ornamental corals and falling into the category of corals permitted for transplantation [8].

Construction of Transplantation Model

Transplanted fragments are then affixed to the transplantation model (concrete rack) using cement. The construction of the transplanted coral fragments can be observed in Figure 1.

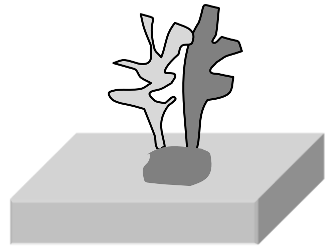

Figure 1. Transplanted Coral Fragments.

All samples used are branching coral species, namely *Acropora nana*, *Acropora millepora*, and *Montipora digitata*, which will be directly collected from their natural habitat. These samples will be planted on a substrate placed on a rack (Figure 2). The rack will be positioned at a depth of 2-4 meters in an area away from wave impacts but still within the natural habitat for the growth of these two coral species.

In the control group, *A. nana*, *A. millepora*, and *M. digitata* will each be grown separately to observe the growth capabilities of each coral. In the treatment group, combinations of *A. nana*, *A. millepora*, and *M. digitata* will be carried out. The two different coral types will be planted in the same substrate with adjacent positions. This is done to observe the interactions between corals. The first treatment involves cultivating *A. nana* together with *A. millepora* in one substrate. The second treatment involves *A. nana* with *M. digitata*. The third treatment involves *A. millepora* and *M. digitata*.

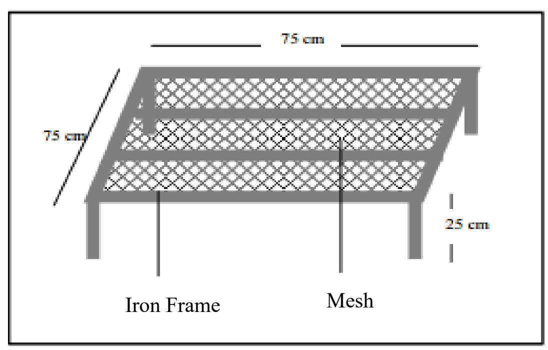

Figure 2. Transplantation model rack.

Measurement of survival or survival rate

Coral transplantation is considered successful if the survival rate is between 50-100%, where corals are transplanted to the same or similar habitat as their original habitat [9]. The survival rate of transplanted corals in a different habitat will be influenced by the coral's ability to adapt to its new environment. The method used to calculate the survival rate of transplanted corals involves the following calculation:

$$SR = (Nt / No) \times 100\ \%$$

Where:
SR = Survival Rate

Nt = Number of individuals at the end of the study
No = Number of individuals at the beginning of the study

Measurement of coral growth

The measured coral growth includes the increase in length (horizontal length visible from above) and height (vertical height visible from the side). Absolute growth is the total growth from the initial measurement to the final measurement. The method for measuring the length and height of coral fragments can be seen in Figure 3. Growth parameter measurements are conducted once a month at the research location. Measurements of length and height increments are carried out using a ruler or caliper.

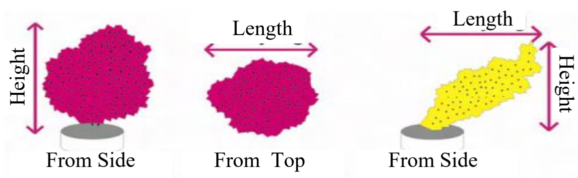

Figure 3. Method of measuring coral fragments [8].

To calculate the growth achievement of transplanted coral based on primary measurement data, the calculation is performed using the formula [10]:

$$\alpha = Lt - Lo$$

Where:
α = Growth achievement of length / height of transplanted coral fragments
Lt = Average length/height of fragments after month t
Lo = Average length/height of fragments at month 0

The measurement of the growth rate of transplanted coral is conducted using the formula [11]:

$$GR = (L_{i+1} - L_1) / (t_{i+1} - t_1)$$

Where:
GR = Growth rate of length or height of transplanted coral fragments (cm/month)
Li+1 = Average growth of length or width of coral fragments at time i+1
Lo = Average growth of length or width of coral fragments at time i
ti+1 = Observation time at i+1 (month)
ti = Observation time at i (month)

Data analysis

The data obtained in the field is processed and then analyzed using Microsoft Excel 2003 software.

RESULTS

Survival rates of coral fragments

After six months of planting, 18 out of 24 fragments that were planted have successfully grown and developed well. *A. millepora* exhibited the highest survival rate (100%) both in monospecies and multispecies cultivation. *M. digitata* showed a 100% survival rate when cultured in monospecies and when combined with A. nana. However, it decreased to 75% in the fourth month when cultured with *A. millepora*. Meanwhile, *A. nana* had the lowest survival rate, both in monospecies (50%) and multispecies (50% when combined with *A. millepora*, and 0% when combined with *A. nana*) (Table 1).
Following a period of six months of cultivation, the corals exhibited a growth in height ranging from 0.2 to 1.47 cm, and a growth in length ranging from 0.6 to 2.08 cm. The growth of corals cultivated with multiple species is variable, especially when *A. nana* and *M. digitata* were combined.

Table 1. Survival Rates of *A. millepora*, *A. nana*, and *M. digitata*.

Type	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Monospecies						
A.millepora (M)	100%	100%	100%	100%	100%	100%
A.nana (N)	100%	100%	50%	50%	50%	50%
M. digitata (D)	100%	100%	100%	100%	100%	100%
Multispecies						
MD	100%	100%	100%	100%	100%	100%
MN	100%	100%	100%	100%	100%	100%
ND	100%	100%	25%	25%	0%	0%
NM	100%	100%	50%	50%	50%	50%
DM	100%	100%	100%	75%	75%	75%
DN	100%	100%	100%	100%	100%	100%
Total fragment (n)	24	24	19	18	18	18

At the end of the measurement period (6 months of cultivation), the average height and length of *A. millepora* (M) in monospecies culture were 1.27 cm and 1.57 cm, respectively. In multispecies transplantation combined with *A. nana* (MN), the average height and length of *A. millepora* became 0.85 cm and 0.6 cm, while when combined with *M. digitata* (MD), the average height and length of *A. millepora* became 1.32 cm and 1.77 cm (Figures 4 and 5).
At the end of the measurement period, the average height and length of *A. nana* (N) in monospecies culture were 0.37 cm and 0.77 cm, respectively. In multispecies transplantation combined with *A. millepora* (NM), the average height and length of *A. millepora* were 0.2 cm and 1.5 cm, while when combined with *M. digitata* (ND) (Figures 6 and 7), *A. nana*

experienced 100% mortality (Table 1).
At the end of the measurement period, for *M. digitata* (D) cultured in monospecies, the average height and length of the coral were 1.47 cm and 2.4 cm, respectively. In multispecies transplantation combined with *A. millepora* (DM), the average height and length of *M. digitata* were 1.37 cm and 2.08 cm, while when combined with *A. nana* (DN), the average height and length of *M. digitata* became 0.55 cm and 1.45 cm (Figures 4 and 5).

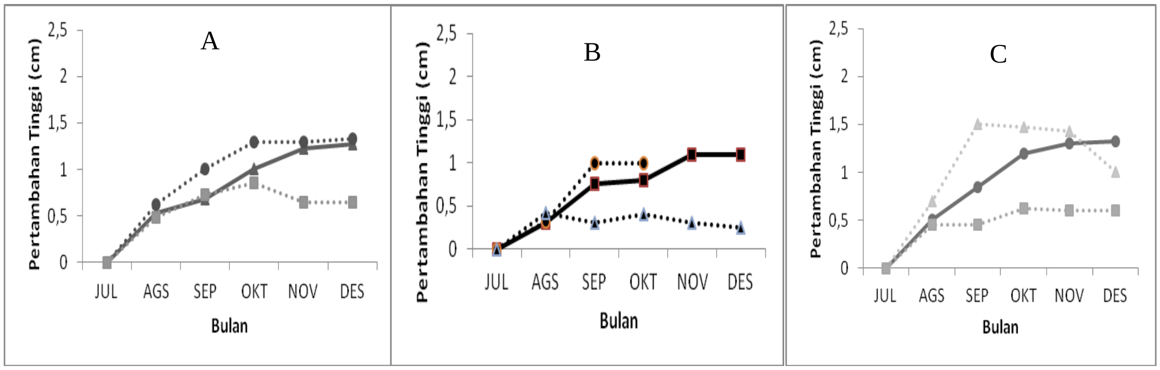

Figure 4. Length increment from *A. millepora* (A); *A. nana* (B); *M. digitata* (C) (—— : monospesies, ---: multispesies; ▲: *A. millepora* ; ■: *A. nana*; ●: *M. Digitata).*

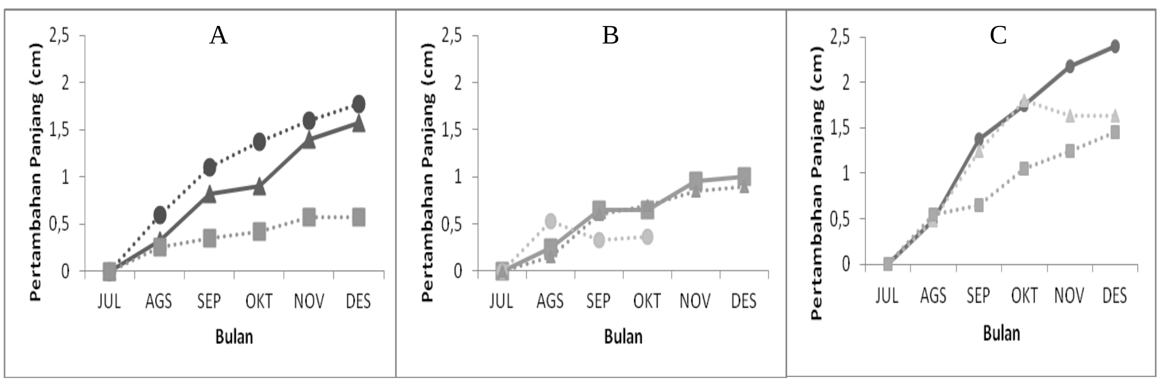

Figure 5. Height increment from *A. millepora* (A); *A. nana* (B); *M. digitata* (C) (—— : monospesies, ---: multispesies; ▲: *A. millepora* ; ■: *A. nana*; ●: *M. Digitata).*

In terms of shoot increment, monospecies transplantation cultivation tends to show more stable growth compared to multispecies transplantation, where shoot increment fluctuates significantly every month. After six months, the corals experienced shoot multiplication ranging from 7 to 24 shoots. *A. millepora* exhibited the highest shoot multiplication, with 24 shoots when cultivated in monospecies. The largest fluctuations occurred when corals were combined with A. nana (Figure 6).

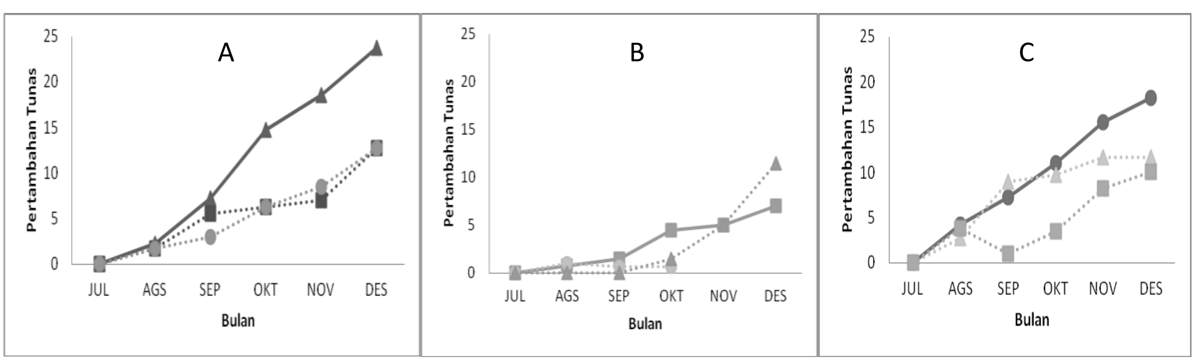

Figure 6. Shoot increment from *A. millepora* (A); *A. nana* (B); *M. digitata* (C) (—— : monospesies, ---: multispesies; ▲: *A. millepora* ; ■: *A. nana*; ●: *M. Digitata).*

The growth rate of *A. millepora* shows relatively similar growth rates whether cultured in monospecies or multispecies. Meanwhile, *A. nana* has the lowest growth rate, which is 0.35 cm/month for height and 0.25 cm/month for length when cultured in monospecies, especially when cultured alongside *A. millepora* (0.42 cm/month for height and 0.17 cm/month for length). *M. digitata* exhibits good growth rates when cultured in both monospecies and multispecies. *M. digitata* has the highest growth rate for length, which is 0.90 cm/month when cultured in monospecies and 0.80 cm/month for height when cultured with *A. millepora* (Table 2).

Table 2. The growth rates of *A. millepora*, *A. nana*, and *M. digitata* are indicated by their maximum height and length.

Type	Growth Rate (cm/month)	
Monospecies	**Height**	**Length**
A.millepora (M)	0.52	0.50
A. nana (N)	0.35	0.25
M. digitata (D)	0.50	0.90*
Multispecies		
MD	0.62	0.60
MN	0.47	0.25
ND	0.60	0.52
NM	0.42	0.17
DM	0.80*	0.77
DN	0.45	0.55

*The highest growth rates

DISCUSSION

Upon completion of the study, the monospecies transplantation exhibited a survival rate over 50%, but the survival rate for multispecies transplantation ranged from 0% to 100% (Table 1). Out of the three types of corals that were transplanted, both in single-species and multi-species arrangements, *A. nana* had the lowest proportion of survival, whereas *A. millepora* had the best rate of survival.

A. millepora can be regarded as the most resilient coral in comparison to other species due to its exceptional survival rate of 100%, both in monospecies and multispecies environments. Conversely, *A. nana* has the most minimal survival rate in both single-species and multi-species transplantation scenarios. *A. nana* is susceptible to bleaching and infections, which has led to its near-threatened status. *A. nana* exhibits a high degree of sensitivity to climatic change, and its survival rate is also influenced by competition with other organisms [12].

The most effective multispecies transplantation is combining *A. millepora* at a 100% rate with *M. digitata* at a 75% rate. Harriot and Fisk (1988) define successful transplantation as the achievement of a living coral count that falls within the range of 50-100% of the total transplanted corals [13]. In contrast, a transplantation that yielded less favorable results involved the combination of *A. nana* (0%) with *M. digitata* (100%). In this particular multispecies combination, only *M. digitata* managed to survive effectively. The decline in survival is attributed to the intrusion of other species [14]. Moreover, a decline in survival can be attributed to various factors, including the water conditions at the transplantation site and the presence of other species surrounding coral fragments.

The growth patterns in terms of height, length, and shoots exhibit similarities, as depicted in Figures 6, 7, and 8. After the 6-month maintenance period, the average height and length of the combined *A. millepora* (M) and *A. nana* (MN) declined. This suggests that the combination of A. nana can impede the vertical and horizontal growth of *A. millepora*. This behavior is a result of the combative tendencies exhibited by *A. nana*, which actively engages in territorial disputes with other corals in order to secure habitat [15]. The combative behavior of *A. millepora* impedes its growth. However, when *A. millepora* is mixed with *M. digitata*, it experiences enhanced length growth that surpasses that of *M. digitata*. *Montipora* spp. is classified as a non-aggressive coral in comparison to *Acropora* sp. [16]. Thus, it may be concluded that *A. millepora* has more strength in comparison to *M. digitata*.

After 6 months of planting, the average height and length sizes of *A. nana* (N) reduced compared to the previous month (November) when it was mixed with *A. millepora* (NM). However, when combined with *M. digitata* (ND), A. nana experienced complete mortality (Table 1). Despite being classified as a subordinate or low coral group, *Montipora* spp. retains the capacity to produce sweep tentacles as a means of protection [17]. This implies that *M. digitata* is a coral species with better survival resistance compared to *A. nana*.

At the conclusion of the measuring period, the average height and length of *M. digitata* (D) decreased for both combinations involving *A. millepora* (DM) and *A. nana* (DN). These findings indicate that the combinations of DM and DN hinder the growth of *M. digitata*, yet *M. digitata* is still able to thrive. According to Bak et al. (1982), *Montipora* spp. can still generate sweep tentacles for defense, while being classified as a subordinate or low coral group.

The multispecies transplantation (DM) had the highest growth rate of 0.80 cm/month, while the monospecies transplantation (D) had the longest growth rate of 0.90 cm/month. Monospecies transplantation eliminates competition for space among corals, resulting in elongated coral growth [11]. Individual corals typically have a growth pattern that is predominantly horizontal or expansive, with subsequent branch growth [18]. In the context of multispecies transplanting, the presence of other corals will impede the growth of coral, resulting in a vertical growth stimulation.

In multispecies transplanting, the combination of *A. millepora* with *M. digitata* displays the highest survival and growth rates. This suggests that *A. millepora* can successfully cohabit with *M. digitata*. The development rates of various species are influenced by factors such as the species type, the quantity of coral polyps, the reaction to environmental conditions, the patterns of adaptation, and the biological properties of the coral [19].

CONCLUSION

Multispecies coral production has been successfully carried out in suitable species. The combination of *A. millepora* with *M. digitata* is the most suitable and successful combination for joint transplantation, as indicated by the high survival rates, with A. millepora at 100% and M. digitata at 75%. The growth rates of both species are also relatively high, with *A. millepora* at 0.80 cm/month (in height) and *M. digitata* at 0.77 cm/month (in length). Among the three types of corals transplanted, both in monospecies and multispecies, *A. nana* is considered the most vulnerable coral due to its lowest survival rate, whereas *A. millepora* is classified as the most robust coral with the highest survival rate, which is 100%. Despite having the lowest survival rate, *A. nana* is considered the most aggressive coral species as it can inhibit the growth of other corals.

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