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COMPARISON OF GROWTH RATE OF *Acropora cervicornis* AND *Echinopora horrida* CORAL IN TRANSPLANTATION OF TURTLE, TABLE AND SPYDER MODELS ON BARRANG CADDI ISLAND

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ABSTRACT

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Coral transplantation has become one of the most widely applied approaches for accelerating reef recovery in degraded marine ecosystems. This study aimed to compare the growth rate and survival of Acropora cervicornis and Echinopora horrida transplanted using Turtle, Table, and Spyder models on Barrang Caddi Island, South Sulawesi. The experiment was conducted for eight weeks at depths of 7–10 m using 60 coral fragments equally distributed among three transplantation models. Growth rate was measured based on linear extension, while survival rate and oceanographic parameters were also monitored. Data were analyzed using descriptive statistics, one-way analysis of variance (ANOVA), and Welch's independent t-test. The results showed that A. cervicornis exhibited higher growth rates than E. horrida across all transplantation models. The Turtle model produced the highest growth of A. cervicornis (2.39 mm), whereas the Table model yielded the greatest growth of E. horrida (1.77 mm). Survival rates reached 90% for A. cervicornis and 100% for E. horrida. One-way ANOVA indicated significant differences among transplantation models for both species ($p < 0.05$). Oceanographic conditions remained within optimal ranges throughout the study. These findings demonstrate that transplantation model configuration significantly influences coral growth and that species-specific restoration strategies are essential for improving coral rehabilitation success.

INTRODUCTION

Coral reefs are among the most productive and biologically diverse marine ecosystems on Earth, providing habitat for approximately 25% of all marine species despite occupying less than 0.1% of the ocean floor (IPCC, 2023). These ecosystems play a crucial role in maintaining ecological balance, protecting coastlines from erosion, supporting fisheries production, and sustaining tourism-based economies. According to Hughes et al. (2018), coral reefs provide ecosystem services valued at billions of dollars annually and are indispensable for the livelihoods of millions of coastal communities. However, coral reefs worldwide are experiencing unprecedented degradation due to increasing sea surface temperatures, ocean acidification, pollution, and anthropogenic disturbances. The National Oceanic and Atmospheric Administration (NOAA, 2022) estimated that approximately half of the world's coral reefs have already been severely damaged, and up to 90% may disappear by 2050 if effective conservation measures are not implemented.

Climate change has emerged as one of the most significant threats to coral reef ecosystems. Rising sea temperatures have increased the frequency and severity of coral bleaching events, which disrupt the symbiotic relationship between corals and zooxanthellae and often lead to widespread mortality (Hoegh-Guldberg et al., 2019). In addition, ocean acidification reduces carbonate ion availability, thereby impairing coral calcification and skeletal formation (IPCC, 2023). Anthropogenic pressures such as destructive fishing practices, sedimentation, eutrophication, and coastal development further exacerbate coral reef degradation (Bruno & Valdivia, 2016). As a result, the resilience and recovery capacity of coral ecosystems have declined substantially in many tropical regions.

Indonesia is located within the Coral Triangle, a region recognized as the global center of marine biodiversity. According to COREMAP-LIPI (2021), Indonesia possesses approximately 2.5 million hectares of coral reefs, harboring more than 500 species of reef-building corals and thousands of associated marine organisms. These ecosystems support important economic sectors, including fisheries and marine tourism, and contribute significantly to food security and coastal protection. Nevertheless, the condition of Indonesian coral reefs remains alarming. Only a small proportion of reefs are classified as being in excellent condition, whereas a substantial percentage has experienced moderate to severe degradation due to both natural and anthropogenic factors (KKP, 2023). Consequently, coral reef restoration has become a priority in marine conservation programs throughout the country.

Among the various restoration strategies available, coral transplantation has gained considerable attention because of its relatively simple implementation and its potential to accelerate reef recovery. Coral transplantation involves the attachment of coral fragments to artificial or natural substrates to promote growth and facilitate ecosystem rehabilitation. According to Bongiorni et al. (2019), transplantation techniques have been successfully applied in several countries and have demonstrated positive outcomes in enhancing coral cover and increasing habitat complexity. Recent studies have also emphasized that active restoration can complement natural recovery processes, particularly in areas where recruitment rates are low or environmental disturbances persist (Boström-Einarsson et al., 2020).

The success of coral transplantation is influenced by numerous factors, including species characteristics, environmental conditions, and the design of transplantation structures. Growth and survival rates vary considerably among coral species because of differences in morphology, physiology, and adaptive capacity (Ladd et al., 2018). Branching corals generally exhibit faster growth rates than massive corals, making them particularly suitable for restoration programs aimed at rapid reef recovery. Environmental variables such as water temperature, light intensity, sedimentation, and water movement also play essential roles in determining transplantation success (Mizerek et al., 2020). Therefore, selecting appropriate coral species and suitable transplantation methods is crucial for achieving effective restoration outcomes.

Several transplantation models have been developed to improve coral growth and survival. Commonly used designs include table structures, dome-shaped frameworks, and open-frame systems. Each model provides different hydrodynamic characteristics, light exposure, and substrate stability, which subsequently affect coral performance (Omori, 2019). The table model provides a horizontal platform that facilitates fragment attachment and minimizes sediment accumulation. The turtle model, characterized by its dome-shaped structure, enhances water circulation and structural stability, whereas the Spyder model offers an open framework that promotes current flow and reduces biofouling. Previous studies have demonstrated that transplantation structure design significantly affects coral growth and colony development, although the most suitable model may vary depending on species and environmental conditions (Boström-Einarsson et al., 2020; Ladd et al., 2018).

Among reef-building corals, *Acropora cervicornis* and *Echinopora horrida* are considered promising candidates for restoration because of their ecological importance and relatively high adaptability. *Acropora cervicornis* is a branching coral species characterized by rapid growth and substantial contributions to reef complexity and habitat formation. According to Lirman and Schopmeyer (2016), branching *Acropora* species are among the most widely used corals in restoration programs due to their fast growth and ease of fragmentation. In contrast, *Echinopora horrida* exhibits a more compact morphology and is generally considered more tolerant of environmental fluctuations, although its growth rate is relatively slower (Madin et al., 2016). Comparing the performance of these two species under different transplantation models may provide valuable information for optimizing coral restoration strategies.

Barrang Caddi Island, located within the Spermonde Archipelago of South Sulawesi, represents an important area for coral reef conservation. The island is subjected to substantial anthropogenic pressures arising from fisheries, tourism activities, and coastal settlements, all of which contribute to coral degradation. Nevertheless, Barrang Caddi also possesses considerable potential for reef restoration because of its relatively favorable environmental conditions and accessibility for monitoring programs. Previous studies in the Spermonde Archipelago have primarily focused on coral cover assessment and reef health, whereas comparative evaluations of different transplantation models and species remain limited (Basda, 2025). Consequently, further investigations are required to identify effective restoration approaches suitable for local environmental conditions.

Understanding species-specific responses to different transplantation models is essential for improving restoration efficiency and maximizing ecosystem recovery. Comparative studies involving multiple coral species and transplantation designs provide important insights into the interactions between biological traits and structural characteristics. Such information is particularly valuable for developing evidence-based restoration strategies and enhancing the long-term sustainability of coral rehabilitation programs (Boström-Einarsson et al., 2020). Furthermore, identifying the most effective transplantation model can reduce maintenance costs and increase survival rates, thereby improving the overall success of restoration initiatives.

Therefore, this study aimed to (1) determine differences in growth rate and survival between *Acropora cervicornis* and *Echinopora horrida* transplanted under similar conditions on Barrang Caddi Island and (2) analyze the effects of turtle, table, and Spyder transplantation models on the growth performance of both coral species. The findings of this study are expected to contribute to the development of more effective coral restoration techniques and provide scientific information to support sustainable coral reef management in the Spermonde Archipelago and other tropical marine ecosystems with similar environmental characteristics.

METHOD

This This study was conducted in the waters surrounding Barrang Caddi Island, Barrang Caddi Village, Sangkarrang District, Makassar City, South Sulawesi (119°19′12″ E and 05°04′54″ S), at a depth ranging from 7 to 10 m. Field observations were carried out over eight weeks during the early months of 2026, with measurements performed at two-week intervals. A total of 60 coral fragments were used, consisting of two species, namely *Acropora cervicornis* (family Acroporidae) and *Echinopora horrida* (family Merulinidae). For each species, fragments were transplanted onto three different artificial substrates: Turtle model (dome-shaped frame), Table model (horizontal rack), and Spyder model (open-frame structure), with ten fragments assigned to each transplantation model. Coral transplantation has been widely recognized as an effective approach for accelerating reef recovery, and the selection of suitable substrate designs is considered a key factor influencing growth and survival performance (Omori, 2019; Boström-Einarsson et al., 2020). Throughout the study period, seawater quality parameters, including temperature, salinity, pH, and water transparency, were monitored at four observation periods (T0–T3) to characterize environmental conditions affecting coral development.

Coral growth was evaluated based on linear extension using the formula proposed by Effendie, expressed as:

$$P = (Lt - L_0) / t$$

Where P represents growth rate (mm per two weeks), L_t denotes the average fragment length at a given observation time, L_0 is the initial fragment length, and t is the duration of observation in weeks. Survival rate (SR) was calculated using the equation

$$SR = (Nt/N_0) \times 100\%$$

Where N_t and N_0 represent the number of surviving and initial coral fragments, respectively. Descriptive statistics were applied to summarize growth, survival, and environmental parameters. Differences among transplantation models were assessed using one-way analysis of variance (ANOVA) at a 95% confidence level ($\alpha = 0.05$), followed by Welch's independent *t*-test to identify specific pairwise differences among treatments. Similar statistical approaches have been widely employed in coral restoration studies to evaluate the effects of substrate configuration on coral performance and to determine the most suitable transplantation methods under varying environmental conditions (Ladd et al., 2018; Mizerek et al., 2020; Boström-Einarsson et al., 2020).

RESULT AND DISCUSSION

General Characteristics of the Study Area

Barrang Caddi Island is a small island located within the Spermonde Archipelago, approximately 11–11.5 km from Makassar City, South Sulawesi. The island covers an area of approximately 0.57 km^2 and is characterized by extensive coral reef ecosystems that support fisheries and coastal livelihoods. Despite its ecological importance, previous studies have reported that coral reef conditions around Barrang Caddi have experienced considerable degradation due to anthropogenic pressures and require restoration interventions (Abdul Rauf et al., 2024). The island is inhabited by more than one thousand residents whose primary occupation is traditional fisheries (Asniwati et al., 2022). Consequently, successful coral restoration in this area is expected to contribute not only to ecosystem recovery but also to the sustainability of local socioeconomic activities.

Growth Performance of *Acropora cervicornis*

Growth measurements of *Acropora cervicornis* over the eight-week observation period revealed differences among transplantation models. The average growth rates are presented in Table 1.

Table 1.
Average Growth Rate of *Acropora cervicornis* Under Different Transplantation Models

No.	Transplantation Model	Average Growth (mm/2 weeks)	Total Growth After 8 Weeks (mm)
1	Turtle Model	0.598	2.39
2	Table Model	0.565	2.26
3	Spyder Model	0.573	2.29

Source: Research data

The results demonstrated that the Turtle model produced the highest growth rate, with an average increase of 0.598 mm per two weeks and a cumulative growth of 2.39 mm after eight weeks. The Spyder and Table models yielded slightly lower growth values, reaching 2.29 and 2.26 mm, respectively. These findings indicate that branching colonies of *A. cervicornis* responded positively to the dome-shaped structure of the Turtle model. Statistical analysis further confirmed significant differences among transplantation models (Table 4), indicating that substrate configuration affected coral growth performance.

The superior performance observed in the Turtle model may be attributed to its hydrodynamic characteristics. The dome-shaped structure enhances water circulation around coral fragments and facilitates nutrient exchange while reducing mechanical stress caused by wave action. According to Omori (2019), efficient water flow is essential for supplying oxygen and planktonic food particles to coral polyps. Similarly, Yusuf et al. (2023) reported that low-profile structures resembling natural reef topography promote linear extension in branching corals by minimizing turbulence-induced damage. Branching species such as *A. cervicornis* possess high calcification rates and benefit greatly from environments with moderate current velocities and sufficient light availability (Ladd et al., 2018).

Growth Performance of *Echinopora horrida*

The growth response of *Echinopora horrida* differed from that observed in *A. cervicornis*. The average growth rates recorded under different transplantation models are summarized in Table 2.

Table 2.
Average Growth Rate of *Echinopora horrida* Under Different Transplantation Models

No.	Transplantation Model	Average Growth (mm/2 weeks)	Total Growth After 8 Weeks (mm)
1	Turtle Model	0.438	1.75
2	Table Model	0.443	1.77
3	Spyder Model	0.420	1.68

Source: Research data

Unlike *A. cervicornis*, the highest growth of *E. horrida* was recorded on the Table model, reaching 1.77 mm after eight weeks. Growth under the Turtle model was only slightly lower, whereas the Spyder model resulted in the lowest growth rate. Overall, *E. horrida* exhibited slower growth than *A. cervicornis*, reflecting differences in colony morphology and calcification patterns.

Massive and sub-massive corals generally allocate more energy to skeletal density than to rapid linear extension, resulting in lower growth rates compared with branching species (Madin et al., 2016). The Table model provides a broad and stable horizontal surface that supports lateral colony expansion and minimizes physical disturbance. Hidayat et al. (2021) reported that flat substrates are particularly suitable for massive coral species because they maximize mechanical stability and enhance attachment strength. In contrast, the narrower framework of the Spyder model provides less support for lateral growth, thereby limiting colony expansion (Rani et al., 2022).

Oceanographic Conditions

Environmental conditions recorded throughout the study are presented in Table 3.

Table 3.
Oceanographic Parameters Recorded During the Study

No.	Parameter	T0	T1	T2	T3	T4	Unit
1	pH	7.29	7.30	7.35	7.50	7.65	-
2	Temperature	30	30	30	30	31	°C
3	Salinity	30	30	30	30	30	ppt
4	Water transparency	100	100	100	100	100	%

Source: Research data

The measured environmental parameters remained within the optimal ranges for coral growth throughout the experiment. Seawater temperature ranged from 30 to 31°C, salinity remained constant at 30 ppt, and water transparency reached 100%, indicating excellent light penetration. In addition, pH gradually increased from 7.29 to 7.65 during the observation period.

The stability of these parameters likely contributed to the favorable growth and survival observed in both species. According to Ekel et al. (2021), temperatures between 28 and 31°C support optimal metabolic activity and calcification in tropical corals without inducing bleaching stress. Stable salinity also maintains osmotic balance and physiological processes (Nugroho et al., 2023). Furthermore, complete water transparency ensures maximum light availability for photosynthesis by symbiotic zooxanthellae, thereby increasing energy production and enhancing skeletal growth (Nayyiroh & Muhsoni, 2022). The increase in pH during the study may reflect intensified photosynthetic activity, which removes dissolved carbon dioxide from seawater and promotes calcification processes (Sitorus et al., 2023).

Survival Rate

Coral survival represents an important indicator of transplantation success. Both species exhibited high survival rates during the study period. *Acropora cervicornis* achieved a survival rate of 90%, whereas *Echinopora horrida* showed a survival rate of 100%.

The slightly lower survival of *A. cervicornis* is likely related to its branching morphology, which is more vulnerable to physical disturbances, sediment resuspension, and algal overgrowth. Conversely, the compact morphology of *E. horrida* provides greater resistance against external stressors. Similar findings were reported by Rani et al. (2022), who observed that massive corals generally possess higher survival rates than branching corals because of their stronger skeletal structure and lower susceptibility to fragmentation. The high survival percentages recorded in the present study indicate that all transplantation models provided suitable substrates for coral attachment and development.

One-Way ANOVA Analysis

The effects of transplantation models on coral growth were statistically evaluated using one-way ANOVA. The results are presented in Tables 4 and 5.

Table 4.
One-Way ANOVA Results for Growth Rate of *Acropora cervicornis*

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between groups	0.093	2	0.046	4.142	0.027	3.354
Within groups	0.302	27	0.011	-	-	-
Total	**0.395**	**29**	**-**	**-**	**-**	**-**

Table 5.
One-Way ANOVA Results for Growth Rate of *Echinopora horrida*

Source of Variation	**SS**	**df**	**MS**	**F-value**	**p-value**	**F-critical**
Between groups	0.045	2	0.022	5.912	0.007	3.354
Within groups	0.102	27	0.004	-	-	-
Total	**0.147**	**29**	**-**	**-**	**-**	**-**

Source: Research data

The ANOVA results demonstrated significant differences among transplantation models for both species ($p < 0.05$). However, the lower p-value observed for *E. horrida* indicates that this species was more sensitive to substrate configuration than *A. cervicornis*. These findings emphasize the importance of matching coral morphology with appropriate transplantation designs to maximize restoration success.

Welch's Independent *t*-Test

Pairwise comparisons among species and transplantation models were further analyzed using Welch's independent *t*-test (Table 6).

Table 6.
Welch's Independent *t*-Test Results

Comparison	t-value	p-value	Interpretation
AC Table vs EH Table	13.148	0.000	Significant
AC Turtle vs EH Turtle	19.803	0.000	Significant
AC Spyder vs EH Spyder	13.454	0.000	Significant
AC Table vs AC Turtle	-2.965	0.009	Significant
AC Table vs AC Spyder	-0.590	0.563	Not significant
AC Turtle vs AC Spyder	2.132	0.049	Significant
EH Table vs EH Turtle	0.885	0.388	Not significant
EH Table vs EH Spyder	3.077	0.008	Significant
EH Turtle vs EH Spyder	2.333	0.033	Significant

Source: Research data

The pairwise comparisons revealed that *A. cervicornis* exhibited significantly higher growth than *E. horrida* across all transplantation models. These differences are associated with species-specific growth strategies, as branching corals generally display higher calcification and linear extension rates than massive corals (Madin et al., 2016; Boström-Einarsson et al., 2020). Overall, the findings suggest that the Turtle model is the most suitable substrate for *A. cervicornis*, whereas the Table model provides the most favorable conditions for *E. horrida*, highlighting the importance of species-specific approaches in coral reef restoration programs.

CONCLUSION

The present study demonstrated that transplantation model configuration significantly affected the growth performance of both *Acropora cervicornis* and *Echinopora horrida* on Barrang Caddi Island. *Acropora cervicornis* exhibited higher growth rates than *E. horrida* under all transplantation models, indicating that branching corals possess greater linear extension capacity than massive corals. The Turtle model provided the most favorable conditions for *A. cervicornis*, producing the highest growth rate (2.39 mm), whereas the Table model was more suitable for *E. horrida*, resulting in the highest growth value (1.77 mm). Both coral species showed high survival rates, with *A. cervicornis* achieving 90% survival and *E. horrida* reaching 100%, suggesting that all transplantation structures provided suitable substrates for coral attachment and development. Statistical analyses confirmed significant differences among transplantation models and between species, highlighting the importance of matching coral morphology with appropriate substrate design. Overall, the results indicate that species-specific transplantation approaches can enhance the effectiveness of coral reef restoration and support sustainable management of degraded reef ecosystems.

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