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Diversity and Abundance of Sea Anemones on Coral Reefs Within the Marine Protected Areas of Angsana, Tanah Bumbu Regency

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ABSTRACT

This study aims to analyze the diversity and abundance of sea anemones, as well as the relationship between environmental factors and their community structure in the Angsana Marine Conservation Area (KKP), Tanah Bumbu Regency, South Kalimantan. The analysis showed that the total abundance of sea anemones differed significantly between stations (ANOVA, F= 5.039; *P*= 0.03), while the species composition did not differ significantly (PERMANOVA, F= 1.80; *P*=0.156). Beta-dispersion analysis showed uniform multivariate dispersion, indicating a similar community structure across sites. Envfit results identified sea surface temperature (SST), salinity, and coral cover as environmental factors significantly influencing abundance variation. The dominant species found were *Stichodactyla gigantea* and *Entacmaea quadricolor*, with low beta diversity. These findings suggest that spatial variation in the sea anemone community in the Angsana MPA is primarily influenced by differences in abundance due to environmental conditions, rather than species turnover. Spatial variation in sea anemones is primarily driven by differences in abundance, while species composition is relatively homogeneous. Environmental conditions such as sea surface temperature, salinity, and coral cover are the main factors influencing this pattern. Thus, anemone distribution is more influenced by local habitat quality than by species turnover.

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INTRODUCTION

Marine Protected Areas (MPAs) in Tanah Bumbu Regency consist of the Angsana MPA and the Sungai Loban MPA, which are separated by a sea channel with depths reaching up to 12 meters. The gap between these two groups of patch reefs is utilized as a coal shipping route, where the navigation channel runs closer to the Angsana MPAs. The construction of artificial structures along coastal areas and the increase in shipping traffic may disrupt the connectivity of marine species populations and are suspected to have negative impacts on sedentary species with limited dispersal abilities **(Goodsell, 2009; Giesler & Cottier-Cook, 2021; Secor *et al.*, 2025)**.

Sea anemones play an important role in benthic communities and serve various ecological functions such as being predators, filter feeders, and prey. Some species act as opportunistic feeders **(Santana *et al.*, 2001; Sun *et al.*, 2022)**. They utilize a variety of benthic or pelagic organisms that can be captured and ingested, including phytoplankton, zooplankton, benthic crustaceans, worms, mollusks, fish, and eggs **(Chintiroglou & Koukouras, 1992; Acuña & Zomponi, 1996; Quesada *et al.*, 2014; Ivanova & Grebelnyi, 2017)**. Several sea anemones are polyphagous opportunistic predators, preying on echinoderms, cnidarians, copepods, and jellyfish **(Dayton & Robilliard, 1970; Shick, 1991; Brueggeman, 1998; Amsler *et al.*, 1999; González-Muñoz *et al.*, 2012; Erralde *et al.*, 2020; Morejón-Arrojo *et al.*, 2025)**. Sea anemones may be vulnerable to changes in physical conditions such as environmental stress caused by anthropogenic disturbances and unpredictable climate change scenarios **(Hayashi & Reimer, 2020)**.

Sea anemone habitats are found in both warm and cold waters. They can live solitarily or in colonies, usually attached to hard substrates such as coral fragments or sand. Some species slightly bury part of their bodies into muddy substrates **(Rifa'i, 2016; Ariadi *et al.*, 2025)**. Generally, sea anemones are found in less fertile and shallow coral reef areas, within caves, or along reef slopes. Environmental parameters that affect sea anemone abundance and growth include temperature, seasonal effects, radiation and nutrient levels, and pollutants **(Chomsky *et al.*, 2004; Hill & Scott, 2012; Hobbs *et al.*, 2013; Thomas *et al.*, 2014)**.

Anemones are not only vulnerable to global disturbances such as ocean warming but also face threats from local sources. They are highly susceptible to habitat destruction, both natural and anthropogenic. Mooring buoys and boat anchors can easily tear and dislodge these soft-bodied organisms from the substrate. Other human activities, such as dredging, can damage corals by smothering colonies or reducing photosynthetic capacity, worsening bleaching effects **(Erftemeijer *et al.*, 2012; Appeldoorn *et al.*, 2016; Jones *et al.*, 2016; Bessell-Browne *et al.*, 2017)**. Fishing activities, particularly trawling (including bottom lampara nets), can also damage benthic environments and harm anemone populations as well as their ecosystem functions **(McConnaughey *et al.*,**

2000; Kaiser *et al.*, 2006). These activities can resuspend sediments, increasing turbidity—as observed at the Kima patch reef and Bajangan Atak patch reef—which is also caused by propeller wash and backflow from tugboats, especially during vessel repositioning maneuvers **(Clarke *et al.*, 2015; Liao *et al.*, 2015; van Rijn, 2018; Asmawi, 2020)**.

The Kima, Batu Anjir, Batu Tengah, and Bajangan patch reefs are part of the Angsana MPAs. The proximity of these patch reefs to coal terminals and shipping routes increases the potential for turbidity due to sediment resuspension and other disturbances, such as collisions with tugboats and barges. This poses a potential threat to the ecosystems of these patch reefs. Considering the ecological significance of sea anemones as both integral components of coral reef ecosystems and symbiotic hosts for anemone fish and anemone shrimp **(Shimek, 2006; Lujan, 2024; Kobayashi *et al.*, 2025)**, as well as their ecological and economic importance, research on the diversity and abundance of sea anemones within the four patch reefs of the Angsana MPAs is necessary, especially to provide baseline information for guiding effective conservation and management strategies in this vulnerable area. Such information is essential for detecting early ecological changes and supporting adaptive management within the MPA.

MATERIALS AND METHODS

Research Location

The research was conducted on coral reef patching in the Angsana Marine Protected Area (MPA), South Kalimantan, Indonesia, from March to May 2025. The study focused on patch reefs: (1) Kima (Km), located at 3°47'47.10"S and 115°36'26.50"E, which is strongly influenced by terrestrial runoff during the rainy season; (2) Batu Anjir (BA), located at 3°48'37.20"S and 115°37'04.9"E, still affected by terrestrial runoff but has served as an annual monitoring site since 2010 by PT. Borneo Indobara, and also as a coral transplantation site by the company in 2012, 2018, 2019, 2020, 2021, 2022, 2023, and 2024; (3) Batu Tengah (BT), located at 3°49'8.67"S and 115°37'12.06"E, not influenced by terrestrial runoff but has experienced several ship collisions; and (4) Bajangan (Bj), located at 3°49'53.63"S and 115°37'9.63"E, also not affected by terrestrial runoff and has undergone several rehabilitation activities (Fig. 1).

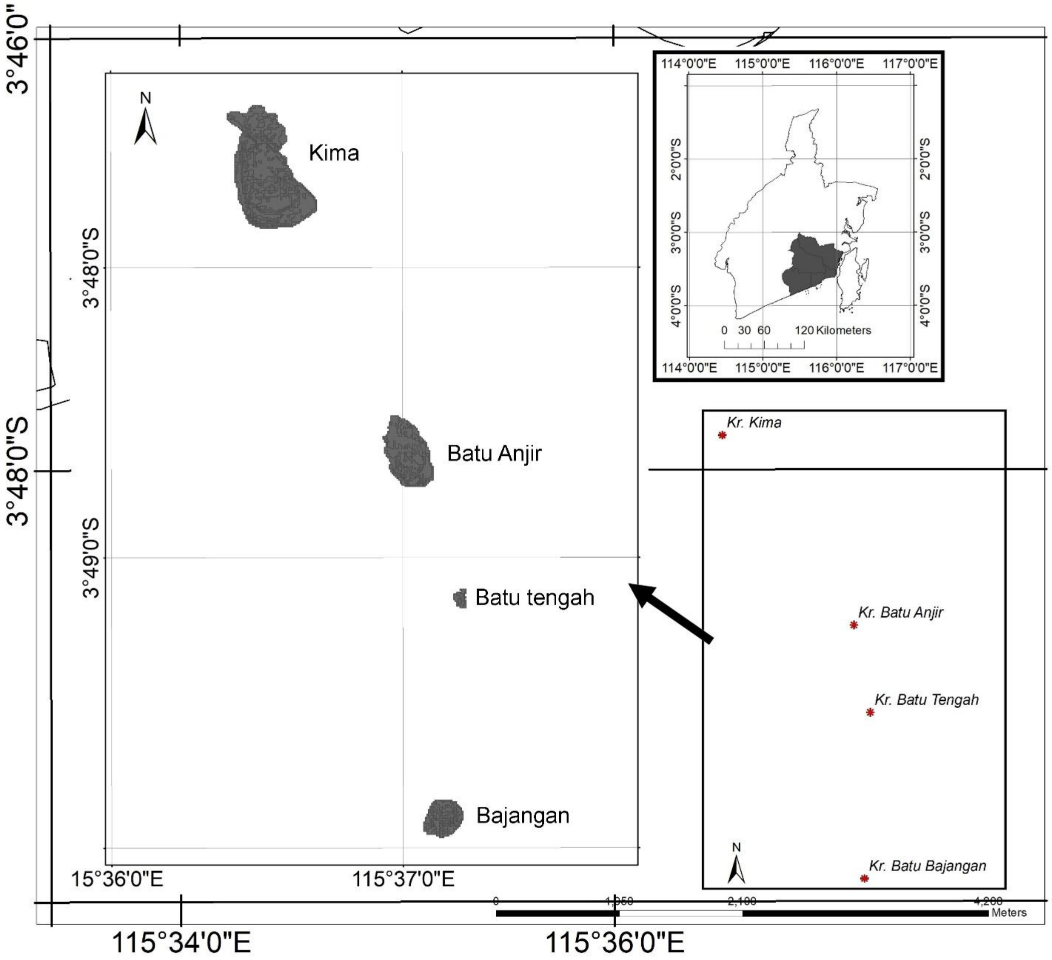

Fig. 1. Research location map

Data collection

At each study site, the abundance of sea anemone in coral communities was recorded using photo belt-transect method **(English *et al.*, 1997)**, 30x1m transect, with three replicates.

Response and factor variables

In this study, the response (dependent) variable is the abundance (number of individuals) of six sea anemone species (*Stichodactyla gigantea*, *Stichodactyla mertensii*, *Entacmaea quadricolor*, *Heteractis crispa*, *Heteractis malu*, and *Heteractis magnifica*), recorded at each sampling site as discrete count data. The continuous predictor variables include current velocity (Curr), turbidity (Tur), sea surface temperature (SST), salinity (Sal), and percent coral cover (PC).

Data analysis

The relationship between anemone species as response variable and environmental factors current velocity (Curr), turbidity (Tur), sea surface temperature

(SST), salinity (Sal), and percent coral cover (PC)—was examined using parametric statistical analyses. Differences among sites were first tested using one way ANOVA. Since individual species of anemone was count type data, prior to ANOVA, it was transformed to ln(x+1). When significant differences were detected, post hoc the Tukey HSD was conducted to identify specific pairwise differences among sites.

Community structure patterns of anemone species, count data were explored using non-metric multidimensional scaling (NMDS) based on Bray–Curtis dissimilarity (metaMDS function). Environmental variables were fitted as vectors onto the NMDS ordination to assess their influence on species distribution using the *envfit* procedure. Beta diversity and multivariate dispersion among sites were evaluated using the *betadisper* analysis to test for homogeneity of community variance. NMDS scores were plotted using spider plots derived from principal coordinate analysis (PCoA) to visualize spatial differences among sites.

All statistical analyses were performed using the MASS package **(Venables & Ripley, 2002; R Core Team (2024)**, and the vegan package **(Oksanen *et al.*, 2025)**.

RESULTS AND DISCUSSION

The abundance of sea anemones varied spatially among the four study sites. A significant difference in total anemone abundance was detected among sites based on the combined counts of six species (ANOVA: F = 5.039, *P* = 0.03). Sites Km and BT exhibited generally lower total abundance compared to BA and Bj (Fig. 2). Post hoc pairwise comparisons using Tukey’s HSD test indicated that BA–Km and Bj–Km differed significantly, whereas the remaining site comparisons (BT–Km, BA–BT, Bj–BT, and Bj–BA) were not significant (Table 1).

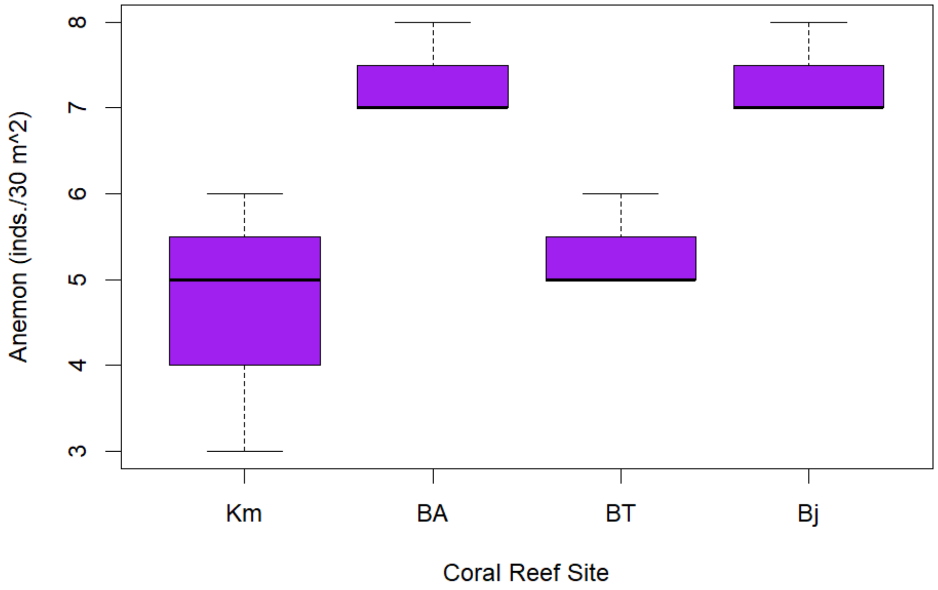

Fig. 2. Total of abundance anemone species across reef site (Km:Kima, BA: Batu Anjir, BT: Batu Tengah, Bj: Bajangan)

Table 1. Tukey HSD multiple comparisons of means of response (ln(x+1)), factor levels for coral reef site (Km:Kima, BA: Batu Anjir, BT: Batu Anjir, Bj: Bajangan), Response: Anemone individual species (count).

Site Comparison	Mean.different	Lower.bound	Upper.bound	*P*. adj.
BT-Km	0.135	-0.280	0.550	0.731
BA-Km	0.411	-0.004	0.826	0.052*
Bj-Km	0.411	-0.004	0.826	0.052*
BA-BT	0.276	-0.139	0.690	0.224
Bj-BT	0.276	-0.139	0.690	0.224
Bj-BA	0.000	-0.415	0.415	1.000

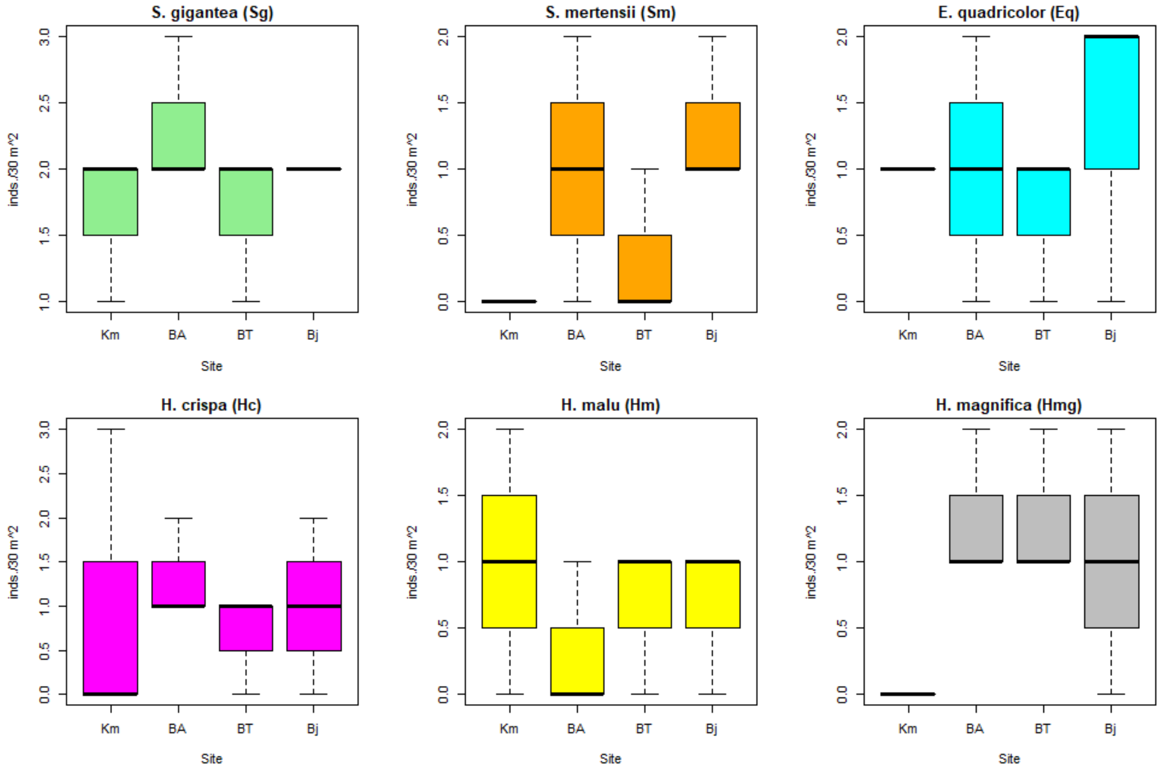

Fig. 3. Abundance of six anemone species (*Stichodactyla gigantea*, *Stichodactyla mertensii*, *Entacmaea quadricolor*, *Heteractis crispa*, *Heteractis malu*, and *Heteractis magnifica*) across reef site (Km:Kima, BA: Batu Anjir, BT: Batu Anjir, Bj: Bajangan)

Despite the significant difference in total abundance among sites, multivariate analysis revealed no significant difference in species composition. Non-metric multidimensional scaling (NMDS) based on Bray–Curtis dissimilarity of log(x+1)-transformed data produced a stable ordination with low stress (stress = 0.096), indicating a good representation of community structure (Fig. 4).

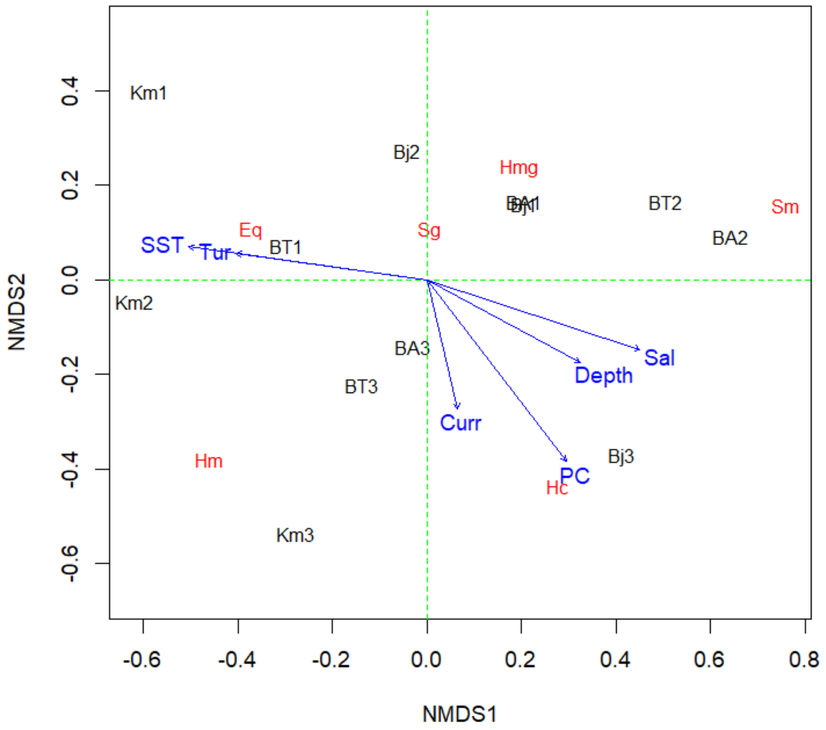

Fig. 4. NMDS ordination (Bray–Curtis on log(x+1)-transformed counts) of sea anemone assemblages across four sites (Km, BA, BT, Bj). Environmental vectors from *envfit* are overlaid; line color/linetype denotes significance ($P < 0.05$). The direction indicates increasing values and arrow length approximates correlation strength. Stress = 0.096.

The PERMANOVA test confirmed that community composition did not differ significantly among sites (F= 1.80, R^2= 0.403, P= 0.156), and the betadisper analysis showed that multivariate dispersion was homogeneous (Tukey's post hoc, P> 0.96), verifying that the PERMANOVA result reflected comparable community structure rather than differences in within-site variability (Fig. 5). However, environmental vector fitting (envfit) revealed that sea surface temperature (SST; r^2 = 0.570, P= 0.023), salinity (Sal; r^2= 0.495, P= 0.048), and percent coral cover (PC; r^2= 0.514, P= 0.046) were significantly associated with the ordination pattern, while depth, current velocity, and turbidity were not (P> 0.05). These results indicate that environmental gradients influenced abundance variation rather than species turnover across sites (Fig. 4).

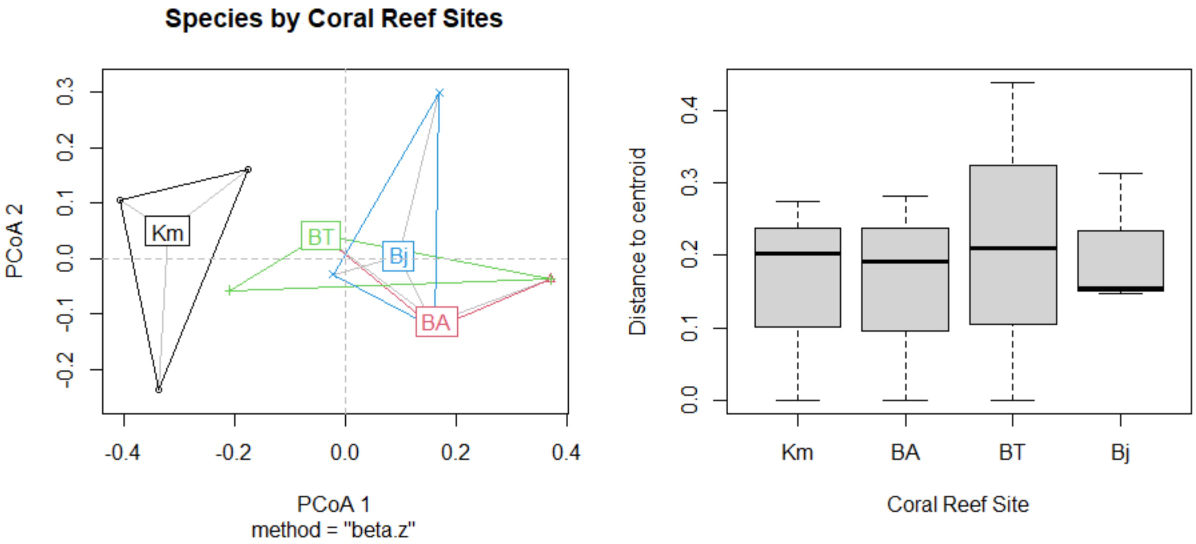

Fig. 5. Multivariate dispersion (betadisper) showing distances of samples to their group centroids (Bray–Curtis). Boxes summarize dispersion per site (Km, BA, BT, Bj). Pairwise Tukey tests indicated no significant differences among sites (adjusted $P > 0.96$).

NMDS revealed coherent assemblage patterns with good ordination quality (stress = 0.096). Although visual separation among sites was apparent, PERMANOVA did not detect statistically significant differences in community composition ($F = 1.80$, $R^2 = 0.403$, $P = 0.156$). The betadisper analysis confirmed homogeneous multivariate dispersion among sites, supporting that the nonsignificant PERMANOVA result is not driven by unequal within-group variances. Environmental fitting identified SST, salinity, and coral cover as significant correlates of the main compositional gradients, whereas depth, current velocity, and turbidity were not significant. Collectively, these findings suggest that spatial turnover in anemone assemblages is modest at the current sampling extent ($n = 12$), but variation aligns with thermal conditions and habitat availability (coral cover), implying potential sensitivity of assemblages to shifts in seawater properties and benthic habitat quality.

Although total sea anemone abundance differed significantly among sites, the multivariate analyses (NMDS and PERMANOVA) did not detect significant differences in community composition. This indicates that spatial variation among sites was driven primarily by differences in density (α-abundance) rather than species replacement or turnover (β-diversity). In other words, some sites supported higher numbers of anemones (e.g. BA and Bj), but the relative composition of species remained similar across all sites, being consistently dominated by Stichodactyla gigantea and Entacmaea quadricolor, with low representation of Heteractis species. This pattern explains why univariate ANOVA detected significant differences, whereas PERMANOVA did not, as ANOVA is sensitive to total abundance, while PERMANOVA evaluates multivariate shifts in species composition **(Anderson, 2001)**.

The non-significant betadisper result further supports this interpretation, confirming that within-site dispersion was homogeneous, and therefore, the lack of PERMANOVA significance was not driven by differences in variance structure but by genuine similarity in community composition among sites. Similar patterns have been reported in benthic and coral-associated assemblages where environmental gradients influence organism abundance without altering species composition **(Clarke & Warwick, 2001; Legendre & De Cáceres, 2013)**. Ecologically, this suggests that while local conditions (e.g., habitat quality, substrate availability, or micro-environmental variability) may influence population size, they are not strong enough to cause species turnover within the anemone assemblage—indicating community stability with abundance-based variation rather than compositional restructuring. This pattern reflects a resilient assemblage structure in which species coexistence remains stable despite spatial environmental gradients. Such stability further implies that ecological pressures in the studied area primarily modulate population densities rather than drive shifts in species identity.

The environmental fitting analysis (envfit) further supported this interpretation by revealing that differences among sites were associated primarily with environmental gradients rather than shifts in species identity **(Ariadi *et al.*, 2025)**. Specifically, sea surface temperature (SST), salinity, and percent coral cover were significantly correlated with the ordination space, suggesting that these environmental factors influence anemone abundance patterns. SST is a well-known driver of cnidarian physiology, affecting metabolic rates, symbiont stability, and reproductive performance **(Suggett & Smith, 2020)**. Slight thermal variation among sites may increase or reduce physiological stress tolerance in different species of host sea anemones, potentially influencing local abundance rather than inducing species turnover **(Ariadi *et al.*, 2025)**. Likewise, salinity emerged as a significant predictor, consistent with the known stenohaline characteristics of anthozoans, where deviations from optimal salinity ranges can reduce tentacle extension, feeding efficiency, and survival **(Navas *et al.*, 2021)**. In addition, the significant association between coral cover and anemone distribution likely reflects their shared dependence on stable benthic substrates. Higher coral cover is often an indicator of reduced physical disturbance and greater habitat complexity, which may enhance substrate availability and provide hydrodynamic protection, facilitating anemone attachment and persistence **(Hoeksema & Crowther, 2011)**.

The findings indicate that while environmental variability among sites affects the abundance of sea anemones; it does not necessarily alter species composition, which remained relatively stable across locations. This pattern is typical of communities where environmental gradients act as abundance modulators rather than drivers of taxonomic turnover **(Legendre & De Cáceres, 2013; Ariadi *et al.*, 2025)**. Moreover, the lack of strong species replacement among sites suggests that the six sea anemone species observed may share similar ecological tolerances within the studied environmental range, resulting in low beta diversity but detectable differences in local population densities. Therefore, the observed patterns reflect abundance-based responses to environmental variation rather than restructuring of assemblage composition. This also implies that key environmental factors—such as temperature, salinity, and coral cover—likely operate within tolerance thresholds shared by all species, allowing them to persist despite spatial differences in habitat conditions. Consequently, managing habitat quality at the site level becomes essential, as even subtle environmental shifts could disproportionately influence local abundances without immediately triggering species-level losses. Such patterns have also been reported in other benthic cnidarian assemblages inhabiting environmentally heterogeneous shallow reef systems **(González-Mujares *et al.*, 2022; Martínez *et al.*, 2023)**, supporting the conclusion that local habitat variability modulates numerical responses without causing community reorganization.

The univariate analysis (one-way ANOVA) detected significant differences in sea anemone abundance among sites, and this result remained consistent regardless of whether the response variable was expressed as total abundance per sampling unit (row sums) or mean abundance across species (row means following log-transformation). This consistency occurs because both metrics represent the same ecological signal—variation in total assemblage magnitude—and differ only by a constant scaling factor **(Legendre & Legendre, 2012; Ariadi *et al.*, 2024)**. Therefore, the significant ANOVA result reflects genuine differences in population density rather than an artifact of data transformation or aggregation. However, this finding does not contradict the NON-significant PERMANOVA result because ANOVA evaluates univariate differences in abundance, whereas PERMANOVA evaluates multivariate differences in species composition **(Anderson, 2001)**. In this study, sites differed in total anemone abundance but maintained similar species composition, which explains why only the univariate test was significant.

CONCLUSION

This study showed that spatial variation in sea anemone assemblages among sites was driven by differences in abundance rather than species composition. Although total sea anemone abundance differed significantly among sites, multivariate analysis indicated that species composition remained relatively homogeneous, suggesting low beta-diversity and an absence of species turnover at the spatial scale studied. Environmental fitting analysis revealed that sea surface temperature, salinity, and coral cover were the main environmental factors influencing local variations in abundance. These findings indicate that local habitat quality and seawater conditions shape sea anemone distribution patterns through abundance responses rather than changes in species identity. Future studies incorporating additional ecological variables such as biotic associations and seasonal dynamics may provide deeper insight into the mechanisms structuring sea anemone assemblages in shallow.

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