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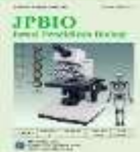

Community structure and exploitation pressure of giant clam in dedap island-abang waters batam

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ABSTRACT

The community structure of Tridacnidae in the shallow coral waters of Dedap Island, Batam, has been analysed through a quantitative approach to reveal ecological dynamics and exploitation pressures from the surrounding communities. This study employed transect methods and ecological index analysis, including Shannon-Wiener diversity (H′), evenness (E), and Simpson's dominance (D) across five observation stations. The results indicate a high dominance of Tridacna crocea in locations with low exploitation pressure, whereas *T. maxima* and *T. squamosa*, which are still hunted by the local population, exhibit limited abundance. Pearson correlation revealed that dissolved oxygen (DO) has a strong positive relationship with H′ and E, and a negative relationship with D, while temperature showed an inverse relationship. The integration of ecological analysis with socio-ecological factors revealed that anthropogenic exploitation pressures also shape community structure spatially. This study offers a holistic approach to the conservation management of Tridacnidae based on community participation and habitat zoning, while simultaneously addressing gaps in ecological and social research in the coral reef areas of western Indonesia.

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INTRODUCTION

The giant clam (*Tridacna* sp.) is a type of mollusc that inhabits coral reef ecosystems and is found in shallow waters up to a depth of 20 meters (Neo et al., 2015). This species is the largest living bivalve and exists in close association with coral reefs commonly found in the Indo-Pacific region (Soo & Todd, 2014). The giant clam (*Tridacnidae*) plays a vital role in coral reef ecosystems, serving as a natural biofilter that helps maintain water quality, as well as being a source of nutrition for other organisms. Furthermore, giant clams have a symbiotic relationship with zooxanthellae, contributing to the productivity of marine ecosystems (Walujo, 2008; Niartiningsih et al., 2017).

Giant clams attach themselves to coral reef substrates (Ainul et al., 2023). A unique characteristic of this biota is its shell, which serves as protection for its soft body. Giant clams possess thick, ridged shells with distinctive folding patterns. Some species have scutes on the surface of their shells, remnants of the shell's edge left as their bodies grow. These shells are composed of calcium carbonate ($CaCO_3$) in the form of aragonite crystals, which provide structural strength and resistance to environmental pressures (Rivanda et al., 2020).

This biota breathes using gills and possesses a muscular foot that allows it to burrow into sand or embed its shell into crevices of the coral reef (Copland & Lucas, 1988). According to the Directorate General of Marine Spatial Management of the Ministry of Marine Affairs and Fisheries (Direktorat Jenderal Pengelolaan Ruang Laut Kementerian Kelautan Perikanan, 2021), giant clams in Indonesia have a wide distribution, including the Bali Strait, Makassar Strait, Sulawesi Sea (southern giant clams), West Tapanuli Coast (giant clams), and Eastern Indonesian waters (Chinese giant clams).

According to Soo & Todd (2014), giant clams play a crucial role in cleansing excess microorganisms, thereby ensuring a more stable marine environment. They also function as a basic biofilter, cleaning dissolved pollutants to maintain marine balance. However, the population of *Tridacnidae* in various tropical regions is under pressure due to overexploitation, habitat degradation, and climate change. The decline of giant clam populations can disrupt coral reef resilience, reduce water quality, and weaken the ecological services that support fisheries and coastal communities. In the long term, this degradation threatens biodiversity, diminishes food resources, and undermines the sustainability of marine ecosystems.

The destruction or severe decline of giant clam populations would further exacerbate these problems. Their absence would reduce the capacity of coral reefs to maintain water quality, increase suspended particles and microorganisms, and disrupt the symbiotic relationship with zooxanthellae, ultimately reducing reef productivity and resilience. Beyond ecological consequences, the decline of giant clams would also lower potential food resources, diminish fisheries productivity, and limit marine ecotourism opportunities that many coastal communities rely on. Thus, the loss of giant clams not only threatens biodiversity but also jeopardizes the long-term sustainability of marine ecosystems and human livelihoods connected to them

The decline or destruction of giant clam populations poses significant ecological risks. As natural biofilters, their absence diminishes the ability of coral reef ecosystems to regulate water quality, leading to increased levels of suspended particles and microorganisms. Such conditions compromise coral health and resilience, thereby accelerating the degradation of reef systems. Furthermore, the disappearance of giant clams disrupts their symbiotic association with zooxanthellae, resulting in decreased primary productivity within reef habitats. Beyond ecological consequences, their reduction also limits available food resources, lowers the productivity of local fisheries, and reduces opportunities for marine ecotourism on which many coastal communities rely. Consequently, the loss of giant clam populations threatens not only biodiversity but also the long-term sustainability of marine ecosystems and the livelihoods that depend on them.

Giant clams have been included in the CITES (Convention on International Trade in Endangered Species) list and the Red List of Threatened Species (Rossbach et al., 2021). Overall, the status of giant clams for all species is classified as rare animals protected by law, namely Law No. 5 of 1990 concerning the conservation of biological natural resources and their ecosystems, as well as Government Regulation No. 7 of 1999 concerning the preservation of plants and animals, and most recently, the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia(Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia, 2018) concerning

Protected Plant and Animal Species. However, the practice of harvesting by fishing communities continues actively.

Dedap Island, located in the waters of Abang Island, Batam, is one of the areas with shallow coral reef ecosystems that support the presence of various marine biota, including giant clams (Tridacnidae) (Sianipar et al., 2025);(Efendi et al., 2024). This area contains a very important ecosystem, namely coral reefs and seagrass beds. The ecological conditions in the shallow coral and littoral zones of Dedap Island are influenced by various factors, including changes in temperature, salinity, and anthropogenic activities of communities that exploit marine biota, one of the organisms most frequently harvested and having high economic value being the giant clam (Tridacnidae). Local fishermen generally focus on harvesting the meat of giant clams as a food source. One popular traditional dish is makasam, a regional delicacy made from the meat of giant clams cooked with fermented salty spices. This dish not only tantalises the palate but also represents local wisdom in processing marine resources. In addition to its meat, the shell of the giant clam also holds high economic value. The large shells with distinctive patterns are often sold as decorative items or craft materials at considerable prices. This practice adds pressure to the exploitation of giant clam populations, given that this species grows slowly and plays a crucial role in maintaining the balance of coral reef ecosystems.

Studies on the Tridacnidae community in Indonesia have predominantly employed descriptive approaches and focused on major conservation areas, resulting in a lack of research addressing the ecological dynamics of giant clams spatially in the coastal areas of the Riau Archipelago, particularly Dedap Island in Batam City, which possesses high biodiversity potential yet minimal conservation intervention. Previous research has also tended to overlook the integration of ecological data with anthropogenic pressures, despite the selective exploitation of Tridacna maxima and Tridacna squamosa by fishing communities potentially significantly shaping community structure. Additionally, statistical analyses linking environmental parameters such as temperature and dissolved oxygen (DO) with community indices (H′, E, D) remain limited, thus failing to provide a foundation for data-driven conservation management.

The novelty of this research lies in its holistic approach that simultaneously integrates spatial analysis of the Tridacnidae community with environmental parameters and socio-ecological pressures. This study highlights the ecological dominance of T. crocea, which is not targeted by the community, and provides strong evidence of a correlation between dissolved oxygen and the diversity and uniformity of the community. By employing statistical methods such as Pearson correlation and linear regression, this research yields a profound understanding of the relationships among ecological variables while offering community-based conservation management strategies and habitat zoning. These findings contribute significantly to the literature on bivalve conservation in Indonesia and may serve as a model for managing protected species in other tropical ecosystems.

The structure of the Tridacnidae community on Dedap Island faces complex ecological and social challenges. The uneven species composition, dominance of Tridacna crocea, and selective exploitation of T. maxima and T. squamosa by fishing communities indicate a community imbalance that could adversely affect the ecological sustainability of protected species. On the other hand, environmental variables such as temperature and dissolved oxygen (DO) are expected to influence diversity, uniformity, and dominance indices. Therefore, it is crucial to understand the relationships between community structure, environmental parameters, and exploitation pressures to develop scientifically and socially based conservation strategies.

This study aims to reveal the structure of the Tridacnidae community in the shallow coral waters of Dedap Island, Abang Island, Batam, with a focus on species diversity, uniformity, and dominance. Furthermore, this study analyses the impact of environmental parameters such as temperature, dissolved oxygen (DO), salinity, and pH on community structure while considering anthropogenic pressures from local exploitation

Academically, this research contributes to the scientific discourse on bivalve ecology in the western part of Indonesia, which remains underexplored, and enriches community analysis approaches with correlational statistical methods. Practically, the research findings can serve as a basis for conservation policy-making and zoning protection for Tridacnidae species, as well as promote education for fishing communities regarding the importance of maintaining the sustainability of marine communities. Thus, this research acts as a bridge between scientific knowledge and conservation action.

RESEARCH METHODS

Research Design

This research was conducted in the shallow coral reef zone of Dedap Island, which is part of the waters surrounding Abang Island, Batam (Efendi et al., 2024). This area is known for its coral reef ecosystem that supports the presence of Tridacnidae, making it an ideal location for analysing its community structure. Dedap Island features an ecosystem characterised by sandy and rocky substrates, with relatively stable environmental conditions. The study was carried out from July to August 2025 and was conducted in several stages, including: an initial survey for mapping locations and identifying sampling points, field data collection using the quadrat transect method, observations and censuses conducted through diving (Scuba), and the computation of community structure data and environmental parameter analysis. The research location map is presented in Figure I.

Figure I. Map of Research Location

The main materials of the research method include (I) research design, (2) population and samples, (3) instruments, (4) procedures, and (5) data analysis. The research design includes the research methods and design used. The research design can be presented in a table or figure.

Data Collection

Data collection was conducted using a transect method with quadrats. The quadrat transect method was employed to measure the community structure of Tridacnidae through a quadrat approach. A transect measuring 50 metres was established parallel to the shoreline, with quadrats measuring Ix5 metres placed along the transect. A total of 5 transects were established at 5 observation stations. Census and individual observations of giant clams were conducted within the quadrats of each transect, using diving techniques (scuba). This method enables accurate estimations of species density and distribution.

Procedures

Sampling was conducted at five observation stations in the Dedap–Abang waters, each selected to represent distinct habitat conditions. The determination of these stations considered differences in substrate composition, water depth, and the presence of coral reef ecosystems that serve as suitable habitats for giant clams (Tridacnidae). At each location, several clam individuals were identified and recorded. Simultaneously, environmental parameters were measured at every sampling point, including water temperature, salinity, pH, dissolved oxygen (DO), and substrate characteristics. Water temperature was recorded using a digital thermometer, salinity with a refractometer, pH with a digital pH meter, and dissolved oxygen with a DO meter. Substrate type was determined through direct observation and categorized according to its dominant material, such as sand, coral rubble, or live coral cover. The community structure of giant clams was assessed using the transect-quadrat technique, a method widely adopted in benthic ecological research because of its accuracy in estimating the density and distribution of sessile organisms like bivalves and corals. At each station, a 50-metre transect line was placed parallel to the shoreline, with quadrats measuring 1 × 5 metres arranged systematically along the line. Altogether, five transects were deployed across the five stations. Within each quadrat, a complete census of giant clams was performed through direct underwater observation using scuba diving, enabling precise identification and enumeration of individuals. This approach was selected because it provides robust estimates of species composition, density, and spatial distribution while reducing sampling bias. The integration of biological and environmental data offers a comprehensive overview of the community structure of Tridacnidae and its association with habitat characteristics in the study area.

Data Analysis

In ecology, community structure is defined as the arrangement of organisms within a community, encompassing species composition, abundance, distribution, and interspecific interactions within a given habitat. This concept provides insight into ecosystem stability, population balance, and the extent of environmental pressures that influence the community. In this study, the structure of giant clam (*Tridacnidae*) communities in the Dedap–Abang waters was assessed using ecological parameters commonly applied in marine ecological research.

These parameters include species composition and density to indicate relative abundance, the Shannon–Wiener diversity index (H’) to reflect community diversity, Pielou’s evenness index (E’) to evaluate the distribution of individuals among species, and Simpson’s dominance index (D) to identify the extent to which a particular species dominates the community. Collectively, these indices represent the overall community structure. Balanced index values characterized by high diversity and evenness with low dominance indicate a stable and healthy community, whereas unbalanced or low values suggest pressures from exploitation, habitat degradation, or other anthropogenic disturbances. Accordingly, the analysis of giant clam community structure in this research involved calculating density, diversity, evenness, and dominance indices, followed by examining their correlations with environmental parameters such as temperature, salinity, pH, and dissolved oxygen to better understand the factors shaping community conditions in the Dedap–Abang waters.

Composition of Species and Density

The composition of species and the density of the Tridacninae population were assessed by dividing the number of individual species by the total area of the sampling site(Krebs, 2014) using the following equation:

$$Di = ni / A$$

Where:
Di = Density of the species population
ni = Total number of individuals of species i
A = Total area of the sampling site.

Calculation of the Species Diversity Index

The analysis of species diversity (H’) was conducted using the Shannon-Wiener formula, alongside the evenness (J’), to validate the results of the species diversity calculation (H’):

$$H' = -\sum_{i=1}^{s} \left[\frac{ni}{N}\right] In \left[\frac{ni}{N}\right]$$

Formula description:
H' = diversity index
ni = number of individuals of species i
N = total number of individuals of all species
Range of the Shannon-Weiner diversity index, 1949:
H' < 2.3026 = low diversity and low community stability
2.3026 < H' < 6.9078 = moderate diversity
H' > 6.9078 = high diversity and high community stability

Evenness Index

It is calculated using the following formula (Nurafni et al., 2020):

$$E' = \frac{H'}{H'max}$$

E’ = Evenness Index
H’ = Diversity Index
H Max = Maximum Species Diversity
S = Number of Species in the Sample
Interpretation of the Evenness Index:
1. E < 0.4 indicates Low Evenness
2. 0.4 ≤ E ≤ 0.6 indicates Moderate Evenness
3. E > 0.6 indicates High Evenness

Species Dominance Index

The Dominance Index is calculated using the Simpson's dominance index formula (Odum & Barrett, 2021):

$$D = \Sigma\left(\frac{ni}{N}\right)^2$$

Description:
D = Simpson's Dominance Index
Ni = Number of Individuals per species
N = Total Number of Individuals across all species

The dominance index ranges from 0 to 1, where a smaller value indicates that no species is dominating, while a larger value signifies the presence of a particular species dominating the community

Analysis of the correlation between biodiversity indices and environmental data (temperature, dissolved oxygen, pH, salinity)

$$r = \Sigma(xi - \dot{x})(yi - \dot{y}) / [\Sigma\sqrt{(xi - \dot{x})^2}\Sigma(yi - \dot{y})^2]$$

Where:
r = Pearson correlation coefficient
xi = individual value of variable x
yi = individual value of variable y
$\dot{x}$ = average value of variable x
$\dot{y}$ = average value of variable y
Σ = sum

RESULTS

The Tridacninae family consists of two main genera: Tridacna and Hippopus. Observations at the research site revealed three types of Tridacninae: *Tridacna crocea*, *Tridacna maxima*, and *Tridacna squamosa*, as illustrated in Figures 2, 3, and 4.

Figure 2. *Tridacna squamosa*, shell length 19.55 cm, found in the shallow reefs of Dedap Island. 10 July 2025. Photo by: Yuria Liza Meilanda. Conservation Status: Listed in the Red List as a vulnerable species due to its declining population caused by hunting and habitat destruction. Cites, 2015)

Figure 3. *Tridacna crocea*, shell length 8.15 cm, found in the shallow reefs of Dedap Island. 10 July 2025. Photo by: Yuria Liza Meilanda. Conservation Status: Listed in the IUCN Red List of Threatened Species 2004 (Cites, 2015).

Figure 4. *Tridacna maxima*, shell length 16.30 cm, found in the shallow reefs of Dedap Island. 10 July 2025. Photo by: Yuria Liza Meilanda. Listed as Least Concern/Conservation Dependent in the IUCN Red List of Threatened Species 2004 (Cites, 2015).

The composition of Tridacnidae species per station is presented in Table 1. The table includes the number of individuals for T. crocea, T. squamosa, and T. maxima, followed by the total abundance per station and the dominant species identified based on the highest frequency.

This table aims to illustrate the spatial distribution pattern of giant clam populations across the study area.

Table 1. Composition and Abundance of Tridacnidae

Station	T. crocea (ind)	T. squamosa (inc	T. maxima (ind)	Total (Ind)	Abundance (ind/m^2)	Dominance Species
1	42	1	0	43	0.43	T. crocea
2	17	9	1	27	0.27	T. crocea
3	12	10	9	31	0.31	Moderate
4	30	10	5	45	0.45	T. crocea
5	0	6	1	7	0.07	T. squamosa

The results in Table 1 show a clear variation in the abundance of Tridacna species among the five stations. T. crocea appears as the most frequently encountered species, particularly dominant at Stations 1, 2, and 4 with abundances of 0.43, 0.27, and 0.45 ind/m^2, respectively. Station 3 is categorized as "moderate," indicating a more balanced distribution of species without a single dominant taxon. Meanwhile, Station 5 shows dominance of *T. squamosa*, reflecting ecological differences that may favor this species at that location. Overall, the table highlights how species composition varies between stations, potentially reflecting habitat conditions that differ spatially across the study area

The diversity levels of Tridacnidae species at the research locations are presented in Table 2. The diversity index of Tridacnidae species at each station using the Shannon–Wiener (H′) index. The table shows the number of individuals for T. maxima, T. squamosa, and T. crocea, followed by the total number of individuals and the corresponding H′ value. This table serves to describe the ecological diversity and community structure present at each sampling location

Table 2. Diversity Index of Tridacnidae Species at Each Station

Station	*T maxima* (n)	*T. squamosa* (n)	*T. crocea* (n)	Total Ind. (N)	H' (Shannon-Wiener)
1	0	1	42	43	0,390
2	1	9	17	27	0,936
3	7	8	10	25	1.071
4	5	10	30	45	0,981
5	3	8	0	11	0,662

The diversity index values in Table 2 reveal notable differences among stations. Station 3 records the highest diversity (H′ = 1.071), supported by a relatively even distribution among the three species. Station 4 also shows a relatively high diversity level (H′ = 0.981), indicating a stable and balanced community. Conversely, Station 1 demonstrates the lowest diversity (H′ = 0.390), largely driven by the extremely high abundance of T. crocea. Station 5 shows moderate diversity (H′ = 0.662), reflecting the absence of T. crocea and the dominance of T. squamosa. Collectively, the table demonstrates that species diversity is strongly influenced by species evenness and the presence or absence of particular dominant species.

The analysis of the Evenness Index measures how evenly individuals are distributed among species within a community— in other words, whether one species dominates or the community is balanced. The calculation of Evenness per Station is displayed in Table 3.

Table 3. Calculation of the Evenness Index.

Station	H'	E = H'/ln(3)	Interpretation
1	0,390	0,355	High dominance by *T. crocea*
2	0,936	0,852	Relatively balance distributuion
3	1.071	0,975	Most even, balance community
4	0,981	0,893	High Uniformity community
5	0,662	0.603	Slightly skewed; no *T. Crocea*

The results of the Simpson Dominance Index are presented in Table 4, based on the relative proportions (p) of T. maxima, T. squamosa, and T. crocea. This table is intended to illustrate the degree to which one species dominates the community structure and to identify stations with balanced or unbalanced ecological conditions.

Table 4. Calculation of Dominance Index per Station

Station	p(*T. maxima*	p(*T. squamosa*)	p(*T. crocea*)	D.Simpson Index)	Interpretation
1	0	0,023	0,977	0,955	Absolute dominance by *T. crocea*
2	0,037	0,333	0.63	0,517	Balance community
3	0,280	0.32	0.4	0,338	Lowest (balance community)
4	0.111	0.222	0,667	0,550	*T. crocea* dominant, but still balance
5	0,273	0,727	0	0.612	High dominance by *T.. squamosa*

The Simpson Index values presented in Table 4 show variation in dominance patterns across the stations. Station 1 has the highest dominance value (D = 0.955), indicating absolute dominance by T. crocea. Station 2 displays moderate dominance (D = 0.517), representing a relatively balanced community despite the higher proportion of T. crocea. Station 3 exhibits the lowest dominance (D = 0.338), suggesting a highly even distribution among species and the most balanced community structure. Station 4 shows moderate dominance (D = 0.550), where T. crocea remains dominant but coexistence among species is still maintained. At Station 5, high dominance is observed (D = 0.612), driven by the strong prevalence of T. squamosa. These results highlight how species dominance is shaped by ecological conditions that differ across stations, influencing community balance and stability.

Multivariate correlation analysis among the three ecological indices of the Tridacnidae community: species diversity (H′), dominance (D), and evenness (E) with water quality parameters: temperature, DO, pH, and salinity, based on data from five stations in Dedap Island, is displayed in Table 5. Table 5 presents the correlation analysis between the three ecological indices—Diversity (H′), Evenness (E), and Dominance (D)—and four key environmental parameters, namely temperature (°C), dissolved oxygen (DO, mg/L), pH, and salinity (ppt). The correlations are expressed using Pearson coefficients, which indicate both the direction and strength of the relationship among variables.

Table 5. Correlation analysis of the ecological index with environmental parameters

Ecological Index	Temperature (°C)	DO (mg/L)	pH	Salinity (ppt)
H′	– 0.76	0.89	0.61	0.42
E	– 0.72	0.85	0.58	0.39
D	0.74	– 0.87	– 0.59	– 0.41

A strong negative correlation with temperature (–0.76) indicates that higher temperatures tend to reduce diversity. This pattern may be attributed to thermal stress, which affects a species' tolerance to environmental conditions. In contrast, the robust positive correlation with DO (0.89) suggests that dissolved oxygen availability greatly influences species diversity. Adequate oxygen levels support metabolic processes and enhance overall ecosystem productivity. Moderate positive correlations with pH (0.61) and salinity (0.42) show that water chemistry also contributes to species variation, although not as strongly as DO.

The correlation pattern for evenness is similar to that of H′, with a strong negative relationship with temperature (–0.72) and a very strong positive relationship with DO (0.85). This indicates that high temperatures tend to promote the dominance of particular species, whereas high DO supports a more even distribution of individuals. Moderate positive correlations with pH (0.58) and salinity (0.39) further suggest that chemical stability in the water column supports evenness within the community.

In contrast to H′ and E, the dominance index (D) shows a strong positive correlation with temperature (0.74) and a very strong negative correlation with DO (–0.87). This means that higher temperatures tend to increase species dominance, whereas low DO conditions amplify dominance because only species that tolerate extreme environments may prevail. Weak negative correlations with pH (–0.39) and salinity (–0.41) indicate that reduced water quality can intensify the dominance of more adaptive species. Overall, the correlation results show that DO is the most influential environmental factor affecting mangrove vegetation community structure, followed by temperature. Diversity and evenness increase with higher DO, whereas dominance increases under high-temperature and low-DO conditions.

Multiple regression models confirm the influence of DO and temperature as primary predictors of community structure. This is presented in Table 6. Table 6 presents the results of the multiple regression analysis examining the influence of environmental parameters, dissolved oxygen (DO), temperature, pH, and salinity on the ecological indices of diversity (H′), evenness (E), and dominance (D). The β coefficients indicate the strength and direction of each parameter's influence, while the R^2 values describe how much of the variation in each ecological index is explained by the environmental variables.

Table 6. Multiple Regression analysis Ecological indices with Environmental parameters

Independence Variable	**β for H′**	**β for E**	**β for D**
DO (mg/L)	0.72	0.69	–0.71
Temperature (°C)	–0.58	–0.54	0.63
pH	0.41	0.38	–0.39
Salinity (ppt)	0.22	0.19	–0.21
R^2 (Determinat Coeficient)	0.84	0.81	0.79

The regression results show that DO exerts the strongest positive influence on both diversity (β = 0.72) and evenness (β = 0.69), indicating that higher oxygen levels support more stable and diverse *Tridacna* communities. Conversely, DO has a strong negative effect on dominance (β = –0.71), suggesting that well-oxygenated waters promote balanced communities with reduced dominance by any single species. Temperature demonstrates an opposite trend, with negative effects on diversity (β = –0.58) and evenness (β = –0.54), but a positive effect on dominance (β = 0.63). This indicates that higher temperatures may stress the community structure, leading to reduced diversity and increased dominance of adaptive species.

The influence of pH is moderate but consistent, contributing positively to diversity (β = 0.41) and evenness (β = 0.38), while reducing dominance (β = –0.39). Salinity shows weaker but similar patterns, with small positive effects on H′ and E, and a negative effect on D. The R^2 values—0.84 for H′, 0.81 for E, and 0.79 for D—indicate that environmental parameters collectively explain a substantial proportion of the variability in community structure. This highlights the strong role of water quality in shaping *Tridacna* population dynamics across the study area.

DISCUSSION

Composition and Density

From the results of the census of the identified Tridacnidae community, a total of 151 individuals were found across five stations. T. crocea was the most dominant species (Triandiza et al., 2019) numerically, with a total of 99 individuals (65.6%), followed by T. squamosa with 36 individuals (23.8%), and T. maxima with 16 individuals (10.6%). This species composition indicates the singular dominance of T. crocea, particularly at station 1.

The highest density was found at station 4, with a total of 45 individuals over an area of 100 m², equating to a density of 0.45 individuals/m². Conversely, the lowest density was recorded at station 5, with 11 individuals or 0.11 individuals/m². This disparity in density indicates that local factors such as substrate, wave exposure, and anthropogenic activities play a significant role in the spatial distribution of the clam community. This aligns with the findings of (Harris & Weisler, 2018). The relatively low species density observed at several stations, particularly for T. maxima and T. squamosa, can also be linked to the high exploitation pressure from fishing communities, as noted by (Rossbach et al., 2021), who prefer these two species due to their larger size and high economic value. In contrast, the smaller T. crocea, which is less sought after in exploitation activities, tends to have a more uniform distribution and density across the stations.

The facts indicate that the clam population is concerning and at risk of extinction, which is why this organism is protected. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) has included this group of animals in the protected list since 1983. Currently, there are seven species of clams (*Hippopus hippopus, H. porcellanus, T. gigas, T. crocea, T. derasa, T. maxima,* and *T. squamosa*) listed under Government Regulation No. 7 of 1999, which are included in the Red List (threatened with extinction) of the International Union for Conservation of Nature (IUCN) (Lesmana & Wahyudin, 2016).

Community Structure

Community structure describes the arrangement and interactions among species within a habitat, determined by various ecological and biotic factors. The structure of the Tridacnidae community on Dedap Island exhibits a dynamic and complex pattern, as reflected in the species diversity, dominance, and evenness across the research stations.

Based on the calculation of the Shannon-Wiener index (H'), it was found that the community has a relatively high level of diversity, indicating the presence of various species with a fairly even distribution of individuals. This index is widely used in ecological studies to measure community complexity and uncertainty in predicting species identity randomly. This diversity reflects supportive ecological conditions, including substrate variation, lighting, and water depth, which provide growth space for species with different ecological tolerances. The diversity levels of Tridacnidae species at the research locations are presented in Table 2. The results of the analysis of the species diversity index (H′) of the Tridacnidae community on Dedap Island reveal significant structural variation among the five observation stations, which ecologically reflects the level of local habitat heterogeneity, population dynamics, and the influence of varying environmental pressures at each location. The H′ index values obtained range from 0.390 to 1.071, indicating a spectrum of ecological conditions from single species dominance to a more equitable distribution among species within the community. According to (Rossbach et al., 2021) and (Neo et al., 2015), these differences are often closely related to substrate stability, depth variation, water quality, and the intensity of human activities such as exploitation and physical disturbances to coral reefs.

Station 1 recorded the lowest H′ value (0.390), with extreme dominance of T. crocea (97.7% of the total individuals), which may reflect highly selective habitat conditions or environmental pressures that inhibit the diversity of other species. Station 2 (H′ = 0.936) and Station 5 (H′ = 0.662) exhibit moderate to low levels of diversity, with simpler or less equitable species configurations. The absence of T. crocea at Station 5, for instance, may be linked to unsuitable substrate or water depth for this species.

Station 3 recorded the highest H′ value of 1.071, indicating the most diverse community and relatively balanced in terms of individual numbers among the three main species: Tridacna maxima, Tridacna squamosa, and Tridacna crocea. This condition suggests that the habitat at Station 3 is likely in a stable ecological status, supporting a wider ecological tolerance for each species. Such a balanced distribution is a strong indicator of low levels of anthropogenic disturbance, as well as the presence of complex microhabitat structures that provide adequate space and resources for species with varying ecological preferences (Pérez-Ruzafa & Marcos, 2012). According to the Shannon-Wiener index, an H′ value > 1.0 is usually categorised as high diversity, positively correlating with habitat complexity and rich biological interactions, such as competition and mutualism among species.

Meanwhile, Station 4 also exhibited a high diversity index value (H′ = 0.981), albeit with a slightly different community character. Although this community is dominated by T. crocea, known for its high adaptability to hard and current-prone substrates, the presence of T. maxima and T. squamosa in significant numbers helps maintain the overall structural balance of the community. (Richards & Day, 2018) emphasise that high diversity, despite the dominance of certain species, can still reflect ecosystem resilience, especially when such dominance does not competitively inhibit the presence of other species. This indicates that Station 4 still possesses a strong ecological carrying capacity, with a potentially heterogeneous habitat structure and exploitation pressures that have not reached destructive levels.

Overall, the Shannon-Wiener index values provide a quantitative depiction of the complexity and stability of the community, which is essential in assessing the health of coral reef ecosystems. Selective exploitation pressures on Tridacnidae species have become a significant factor shaping community structure at various research locations. In the context of Dedap Island, the pattern of extremely high dominance of Tridacna crocea at several stations, particularly Station 1, can be interpreted as a result of the imbalance in exploitation pressures among species. *T. maxima* and *T. squamosa* are known to have higher economic value, both in terms of size and aesthetics, making them more frequent targets for collection by coastal communities and aquarium trade practitioners (Neo et al., 2015). In contrast, *T. crocea*, being smaller and residing buried in hard substrates, tends to be more difficult to access and is less commercially sought after, thus relatively protected from direct exploitation.

This phenomenon has implications for the ecological responses of the community. When larger and more vulnerable species to exploitation experience population declines, *T. crocea* can fill the ecological void and dominate the local community. This is reflected in the low species diversity index (H′) value at Station 1, indicating extreme dominance by a single species and low equitable distribution among species. Such conditions may lead to community homogenisation and potentially decrease the ecosystem's resilience to environmental disturbances(Lee et al., 2024).

Furthermore, selective exploitation may also affect the reproductive dynamics and recruitment of Tridacnidae species. Species like T. maxima and T. squamosa, which have larger body sizes and longer reproductive periods (Lucas, 2014), are at greater risk of experiencing more drastic population declines if adult individuals continue to be exploited before they can reproduce. Conversely, *T. crocea*, which reaches sexual maturity at smaller sizes and has a more cryptic life strategy, may maintain its population through more stable local recruitment.

However, the dominance of T. crocea not balanced by the presence of other species may also serve as an indicator of broader ecological pressures, such as habitat degradation or changes in environmental quality that can only be tolerated by species with high ecological tolerance. Therefore, regular monitoring of the Tridacnidae community structure may serve as an important diagnostic tool in assessing the impacts of exploitation and the effectiveness of conservation efforts.

Analysis of the Simpson index (D) reveals the presence of dominant species such as Tridacna crocea that dominate populations at certain stations. The Simpson index emphasises the probability that two randomly selected individuals come from the same species, thus being highly sensitive to dominance. This species dominance may be associated with preferences for shallow hard substrate environments, but it may also potentially indicate ecological pressures or anthropogenic disturbances such as sedimentation and fishing activities that alter community composition locally. On the other hand, Pielou's Evenness (E) values indicate varying levels of evenness at each station, with some locations showing a more equitable distribution of individuals among species. This index measures how evenly individuals are distributed among species and is very useful in assessing community stability. High evenness reinforces the assumption that the observed habitat is still in relatively stable ecological conditions and capable of supporting species distribution equitably. This is important for conservation efforts, as homogeneous and diverse communities have greater resilience to environmental disturbances and play a crucial role in maintaining the balance of coral reef ecosystems.

For the table 3, The Pielou's Evenness Index (E) reveals the variation in individual distribution among Tridacnidae species at each station, reflecting the ecological stability and balance of the community. Station 3 exhibits the highest E value of 0.975, indicating a very even distribution of individuals with no species significantly dominating. This condition reflects an ecologically balanced community, with a structure resilient to environmental disturbances, serving as an optimal habitat indicator for all Tridacnidae species. Likewise, Station 4, with an E value of 0.893, indicates a high level of uniformity despite partial dominance by T. crocea. Both stations represent a complex yet balanced community, where ecological interactions among species function dynamically.

Station 2 records an E value of 0.852, showing a relatively even distribution among the three species, although T. crocea remains dominant in number. This level of uniformity suggests that the habitat at this station can still support the presence of other species without causing ecological dominance exclusion. Conversely, Station 5 has only two species with an E value of 0.603 and lacks T. crocea. Although the distribution between T. maxima and T. squamosa is fairly balanced, the lower evenness value reflects a somewhat skewed community condition. The absence of T. crocea may be associated with less suitable habitat characteristics, such as soft substrate or depth that does not meet the ecological needs of the species.

The most extreme case is Station 1, with an E value of only 0.355, indicating high dominance by T. crocea, which nearly constitutes the entire community. The low evenness at this station may reflect ecological pressures such as habitat degradation, sedimentation, or selective exploitation of other commercially preferred species. Alongside the findings of low species diversity indices, this condition has the potential to weaken the overall ecosystem function and reduce community resilience to environmental changes.

Overall, the evenness index plays a crucial role in assessing ecological balance and the community's adaptive capacity to environmental pressures. A high E value indicates a community system capable of maintaining its functions amid complex species interactions, while a low E value may signal early ecological disturbances that need to be managed conservatively.

Simpson's Dominance Index (D) measures the probability that two randomly selected individuals come from the same species. D values range from 0 to 1; if D approaches 1, it indicates high dominance by one species, implying low diversity, while a D value approaching 0 indicates an even distribution among species, meaning high diversity. The results of the Simpson Dominance Index (D) indicate notable variation in species dominance structure among Tridacnidae communities at each station. Station 1 exhibits absolute dominance by Tridacna crocea, with a very high D value of 0.955. The proportion of this species reaches 97.7% of the total individuals, reflecting a highly skewed community. Such dominance can be linked to the ecological characteristics of T. crocea, which lives buried in shallow hard substrates and is relatively less appealing to commercial exploitation activities by coastal communities or aquarium markets (Neo et al., 2015). Consequently, this species survives and dominates naturally in its habitat, while the larger and aesthetically valued *T. maxima* and *T. squamosa* often experience population declines due to selective harvesting.

In contrast, Station 3 shows the lowest D value of 0.338, indicating the most balanced community, where no species significantly dominates. This reflects an optimal habitat, with healthy competitive dynamics among species and without disturbing exploitation pressures affecting community structure. A low D value represents a proportional population distribution and high diversity, which is crucial for ecosystem resilience against external pressures (Magurran, 2005; Brouwer et al., 2022). Stations 2 and 4 have D values of 0.517 and 0.550, respectively, indicating dominance by T. crocea, but still balanced by the presence of other species in significant proportions. This condition may reflect a mixed habitat that supports ecological tolerance across various species, with exploitation levels not yet fully impacting species balance.

Meanwhile, Station 5 records high dominance by T. squamosa (D = 0.612) and the absence of T. crocea, which may be associated with specific habitat preferences or ecological pressures such as selective exploitation of the rarer T. maxima. This imbalance leads to community homogenisation, which can threaten natural recruitment processes and reduce the overall ecological function of the system (Lucas, 2014).

In summary, the results of this Simpson Dominance Index indicate that selective exploitation not only affects population abundance but also has the potential to fundamentally alter community structure balance. The presence of dominant species and minimal exploitation pressure can close ecological space for other species, thus impacting diversity and community resilience in the long term. Therefore, conservation strategies need to consider dominance patterns and anthropogenic pressures in planning sustainable marine resource management.

Environmental Factors: Temperature, Salinity, pH, DO, and Substrate

Environmental variables play a crucial role in the survival and distribution of Tridacnidae, as each factor can influence the metabolism, growth, and adaptation of these species to ecosystem changes. Pearson correlation analysis shows that water quality plays a significant role in shaping the structure of Tridacnidae communities. The highest correlation is found between H′ and dissolved oxygen (DO) concentration, with an r value of +0.89, indicating a strong positive relationship. Dissolved Oxygen (DO): The availability of dissolved oxygen is directly related to the respiratory activity and survival of molluscs (Patty et al., 2019). A decrease in oxygen levels can lead to hypoxia, negatively impacting the metabolism and growth of Tridacnidae. The correlation is illustrated in Figure 5.

```
DO (mg/L) → 7.2   7.3   7.4
H′        → ●     ●     ●
|          ●
|     ●
|●
+--------------------------
7.2   7.3   7.4
```

Figure 5. Scatter Plot: The Correlation Diversity with DO

Stations with stable DO levels ranging from 7.3 to 7.4 mg/L, such as Stations 3 and 4, exhibit the highest H′ values, indicating that optimal respiration is a determining factor for community diversity. Conversely, the correlation between H′ and temperature is moderately negative (r = –0.76), implying that rising temperatures—especially approaching 30.4°C as seen at Station 1—tend to decrease diversity, likely due to thermal stress or disturbances in the zooxanthellae symbionts affecting growth and reproduction in Tridacnidae.

Water temperature directly influences the metabolism and photosynthetic rates of zooxanthellae, the symbiotic algae associated with clams. Studies indicate that Tridacna gigas experiences accelerated larval development at temperatures of 30–33°C, but its survival rate declines due to developmental abnormalities. The optimal temperature for Tridacnidae growth and survival is around 27°C, while extreme temperatures can lead to mass mortality (Lee et al., 2024); Enricuso et al., 2019). The correlation between diversity and temperature is depicted in Figure 6.

```
Suhu (°C) → 29.0   29.8   30.2   30.4
H′        → ●      ●      ●      ●
         |        ●
         |   ●
         |●
         +--------------------------
           29.0   30.0   30.4
```

Figure 6. Scatter Plot of the Correlation Diversity with Temperature

The pH parameter shows a moderate positive correlation (r = +0.61), where neutral to slightly alkaline pH values (7.8–8.2) support the calcification process and community balance, in line with the ecological function of bivalves as contributors to coral reef biomass. Figure 7 illustrates the correlation between diversity and pH.

```
pH → 7.8   8.0   8.2
H′ → ●     ●     ●
    |      ●
    |  ●
    |●
    +--------------------------
      7.8   8.0   8.2
```

Figure 7. Scatter Plot of the Correlation Diversity with pH

Water pH conditions influence the shell calcification process, especially in ecosystems experiencing coral bleaching. A decrease in pH due to ocean acidification can hinder shell formation and increase vulnerability to predation and environmental disturbances (Leung et al., 2022).

Meanwhile, salinity shows a weak positive correlation (r = +0.42), indicating that although all stations are within the optimal salinity range (30.0–30.4 ppt), this factor does not fully determine diversity due to narrow fluctuations among stations. The correlation is illustrated in Figure 8.

```
Salinitas (ppt) → 30.0   30.2   30.4
H′              → ●      ●      ●
                |     ●
                |●
                +-------------------------
                 30.0   30.4
```

Figure 8. Scatter Plot: The Correlation Diversity with Salinity

Salinity: The optimal salinity tolerance for Tridacnidae ranges from 30 to 35 ppt, with the best growth occurring at 34 ppt. Research indicates that lower salinity can hinder growth and cause physiological stress in clams (R. P. T. Lee et al., 2024).

Pearson correlation analysis indicates that environmental quality significantly influences the structure of Tridacnidae communities. The species diversity index (H′) has a very strong positive correlation with dissolved oxygen (DO) concentration (r = +0.89), indicating that water conditions with high DO support optimal respiration and biological activity that promotes species diversity. Conversely, temperature shows a moderate negative correlation (r = –0.76), where high temperatures tend to decrease diversity due to increased thermal stress and disturbances in zooxanthellae symbionts. A positive correlation is also found between H′ and pH (r = +0.61), indicating that neutral to slightly alkaline pH conditions support the calcification process and balanced species distribution. Salinity shows a weak positive correlation (r = +0.42), suggesting that although salinity is relatively stable across stations, its impact on diversity is not dominant.

Overall, these findings emphasise that DO and temperature are the water quality parameters most affecting the dynamics and diversity of Tridacnidae communities at the study site and should be the focus of sustainable marine ecosystem management strategies.

Multivariate analysis reinforces these findings in Table 5. The diversity index (H′) and evenness (E) consistently demonstrate a positive relationship with dissolved oxygen (DO) and pH, alongside a negative relationship with temperature. DO emerges as the most determining environmental variable for the diversity and evenness of communities, while extreme temperatures promote species homogenisation and reduce evenness. Conversely, the dominance index (D) is negatively correlated with DO and pH (r = –0.87 and –0.59), yet shows a positive correlation with temperature (r = +0.74), indicating that environmental pressures, particularly high temperatures and low oxygen levels, drive community dominance by a single dominant species, such as T. crocea or T. squamosa.

The multiple regression model in Table 6 for the species diversity index (H′) indicates that DO (dissolved oxygen) and temperature are the two most dominant predictors influencing species diversity levels. The regression equation $H' = \beta_0 + \beta_1 \cdot DO + \beta_2 \cdot Temperature + \beta_3 \cdot pH + \beta_4 \cdot Salinity + \varepsilon$ yields a β_1 coefficient of +0.72 and a β_2 coefficient of –0.58, both of which are statistically significant. This indicates that increased DO significantly enhances diversity, while rising temperatures tend to decrease it. pH and salinity show positive but weaker influences, with coefficients of +0.41 and +0.22, respectively. An R^2 value of 0.84 indicates that 84% of the variation in H′ can be explained by the combination of these four environmental parameters. Ecologically, this reflects that water conditions rich in oxygen and stable temperatures provide the best support for diverse communities.

For the evenness index (E), the regression model used has a similar structure, with estimated results showing that DO remains the dominant predictor ($\beta_1 = +0.69$), while temperature has a negative impact ($\beta_2 = –0.54$). pH and salinity contribute moderate and weak positive influences, at +0.38 and +0.19, respectively. With an R^2 value of 0.81, this model explains 81% of the variation in individual distribution among species. The ecological interpretation indicates that community evenness will increase in waters with high oxygen levels and low temperatures, supported by neutral pH that optimises physiological processes.

Conversely, for the dominance index (D), the DO and temperature parameters show opposite directions of influence. DO correlates negatively with dominance ($\beta_1 = –0.71$), meaning that decreased oxygen supports community dominance by certain species. Temperature correlates positively ($\beta_2 = +0.63$), indicating that high temperatures promote dominance, likely because only species resilient to extreme conditions can survive. pH and salinity also show negative contributions to dominance, with coefficients of –0.39 and –0.21, respectively. With an R^2 value of 0.79, this model is quite accurate in predicting conditions of skewed communities. Ecologically, high dominance reflects environmental pressures and can lead to community homogenisation, which risks reducing long-term ecosystem resilience.

CONCLUSION

This study demonstrates that the structure of Tridacnidae communities in Dedap Island is dominated by *Tridacna crocea*, with varying levels of diversity and evenness across observation stations. The diversity index (H′), evenness (E), and dominance (D) statistically show a close relationship with environmental parameters, particularly dissolved oxygen (DO) and temperature. DO plays a role in supporting more even and diverse communities, while temperature correlates positively with the dominance of certain species. In addition to environmental factors, exploitation pressures from fishing communities also influence community structure, where *T. maxima* and *T. squamosa* are still hunted despite being protected, while *T. crocea* is not targeted for capture. This impacts the dominance of *T. crocea* in certain locations and must be considered as a social variable influencing the sustainability of clam populations locally.

The findings of this study imply that the sustainability of Tridacnidae communities in Dedap Island waters depends on several critical aspects. Strengthening species protection is essential, particularly for *T. maxima* and *T. squamosa*, which remain targeted despite their protected status under CITES and national regulations. Community-based education that promotes ecological knowledge and conservation values can help foster behavioral changes among local fishers, reducing exploitation pressure. Furthermore, continuous monitoring of environmental parameters (such as dissolved oxygen and temperature) alongside the clam community structure is needed to anticipate ecological shifts and habitat degradation. Conservation zoning, especially in areas with balanced and diverse communities such as Stations 3 and 4, would safeguard reproduction and growth hotspots. Finally, an integrated socio-ecological approach, combining ecological monitoring with community empowerment, represents a sustainable pathway to preserving giant clam populations in Dedap Island–Abang waters.

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