

Population Structure and Anthropogenic Pressure of Sea Urchin Utilisation (*Diadema setosum*) on Shallow Coral Reefs of Dedap Island, Batam

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Abstract

Background: *Diadema setosum* is a key species in maintaining coral reef stability through its role in controlling algal growth. However, exploitation for consumption and trade of its gonads by coastal communities has generated anthropogenic pressures that threaten population sustainability. This study aims to assess the population structure and utilisation pressure on *D. setosum* in the shallow coral ecosystem of Dedap Island, Batam City. **Methodology:** Observations were carried out at five stations using a 50-metre belt transect method with 5×5 m quadrat plots. Data were analysed through descriptive statistics to determine density and distribution, while correlation and regression analyses were applied to examine the influence of environmental parameters (temperature, dissolved oxygen, salinity, and pH). Structured quantitative interviews with local fishermen were conducted to obtain information on harvesting practices. **Results:** The population density ranged from 0.180 to 0.292 ind/m², with a clustered distribution pattern observed at stations farther from human activity. Regression results indicated that temperature significantly increased density, while dissolved oxygen and pH had significant negative effects. Fishermen reported daily harvesting during low tide with yields of 2–3 kg of gonads per person. These findings demonstrate exploitation pressure on *D. setosum*, underscoring the need for ecosystem-based management. **Contribution:** The novelty of this study lies in integrating ecological surveys with socio-economic data, offering comprehensive insights for locally adapted conservation strategies.

Keywords: Anthropogenic Pressure; Dedap Island; *Diadema setosum*, Population Structure



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INTRODUCTION

Coral reef ecosystems are increasingly threatened by both natural disturbances and anthropogenic pressures, making their ecological stability a critical global concern (Hughes et al., 2017). Among the key organisms that contribute to reef resilience are sea urchins (class Echinoidea), which regulate algal growth and maintain ecological balance (Edmunds et al., 2001). Within this group, *Diadema setosum* plays a pivotal role as a herbivorous echinoid that suppresses algal overgrowth, facilitates coral larval settlement, and enhances reef resilience under disturbance events (Zirler et al., 2023; Vafidis et al., 2021). However, the balance of *D. setosum* populations is critical, as both declines and uncontrolled increases may disrupt coral community structure (Bronstein et al., 2016). Despite this ecological importance, *D. setosum* populations are increasingly subjected to anthropogenic pressures, particularly from harvesting for consumption and trade, which threatens long-term sustainability (Nane, 2020; Vimono et al., 2023).

Although population declines of *D. setosum* have been documented across the Indo-Pacific (Muthiga & Mc Clanahan, 2007; Bronstein et al., 2016), site-specific baseline data remain scarce. In Batam, studies have primarily focused on adjacent islands such as Abang Island (Efendi et al., 2024), while Dedap Island—despite its extensive shallow coral habitats and active small-scale fisheries—has not been systematically assessed. This lack of quantitative information on density, size distribution, and spatial patterns poses a challenge for evidence-based management.

The novelty of this study lies in its integration of ecological surveys with socio-economic interviews, providing a comprehensive perspective on both environmental drivers and harvesting pressures on *D. setosum*. Unlike previous regional studies that mainly reported general density estimates, this research applies plot-based, station-specific assessments combined with local fishermen's harvesting data, thus offering more detailed insights into utilisation pressure and population dynamics.

Accordingly, this study aims to (1) determine the density and size distribution of *D. setosum* in Dedap Island's shallow coral reefs, (2) assess its spatial distribution patterns, and (3) evaluate utilisation pressure by the local community. The findings are expected to contribute to the scientific literature on Indo-Pacific sea urchin ecology, while also serving as a reference for sustainable management and conservation policies. In alignment with Sustainable Development Goal (SDG) 14, this research highlights the need for ecosystem-based management and participatory conservation approaches, offering implications for broader policy frameworks in the Indo-Pacific region.

METHOD

Research Time and Location

The study was conducted in April 2025 in the waters surrounding Dedap Island, Batam City, Riau Islands Province, Indonesia. This location was selected due to its extensive shallow coral reef ecosystem, the presence of hard substrates suitable for the habitat of *Diadema setosum*, and the ongoing utilisation activities by local fishermen. The geographical coordinates of each observation station were determined in situ using a handheld GPS (Transect 1: 0°29'50"N 104°15'31"E, Transect 2: 0°29'44"N

104°15'38"E, Transect 3: 0°29'40"N 104°15'42"E, Transect 4: 0°29'38"N 104°15'46"E, Transect 5: 0°29'36"N 104°15'51"E). The stations were selected to represent variations in environmental conditions, including their relative distance from coastal settlements, depth of shallow reef zones (ranging from 1 to 3 m at low tide), and substrate composition dominated by hard coral and sandy patches. Such criteria were applied to capture spatial heterogeneity in habitat conditions and potential gradients of anthropogenic influence across Dedap Island's shallow coral ecosystem.

Table 1. Geographical Coordinates, Habitat Types, and Utilisation Activities at 5 Stations on Dedap Island

Transect	Geographical Coordinates	Habitat/Substrate Type	Utilisation Activities by Local Community
1	0°29'50"N 104°15'31"E	Shallow reef flat, dominated by hard corals and sandy patches	Low fishing and harvesting activity, minimal direct anthropogenic pressure
2	0°29'44"N 104°15'38"E	Coral rubble with scattered seagrass cover	Occasional harvesting of sea urchins during low tide
3	0°29'40"N 104°15'42"E	Mixed coral and sandy substrate with moderate cover of turf algae	Regular small-scale fishing and collection of marine invertebrates
4	0°29'38"N 104°15'46"E	Sandy substrate interspersed with live coral colonies	Frequent harvesting of <i>Diadema setosum</i> for consumption and trade
5	0°29'36"N 104°15'51"E	Reef slope dominated by branching corals	High harvesting intensity, targeting adult <i>D. setosum</i> during low tide

The placement of the stations took into account the representation of habitat condition variations and the levels of utilisation activities by the local community. A map of the location is presented in figure 1.

Materials and Methods

The equipment employed in this study comprises: a handheld GPS for determining the coordinates of observation stations, underwater slates and writing instruments, a 100 m tape measure for transect installation, transect ropes and stakes as markers, and a 5 × 5 m quadrat plot (enclosed with rope/plastic tubing) for observation purposes. Snorkeling gear (mask, snorkel, fins) was utilised for observations in shallow waters.

An underwater camera was used for documentation, a refractometer for measuring salinity or levels of dissolved salts, a pH meter for assessing the acidity or alkalinity of the water, a dissolved oxygen (DO) meter for measuring the oxygen content in the water, and a thermometer for recording water temperature. Additionally, other tools were employed to support sampling, including buckets, nets, rubber boots, and gloves.

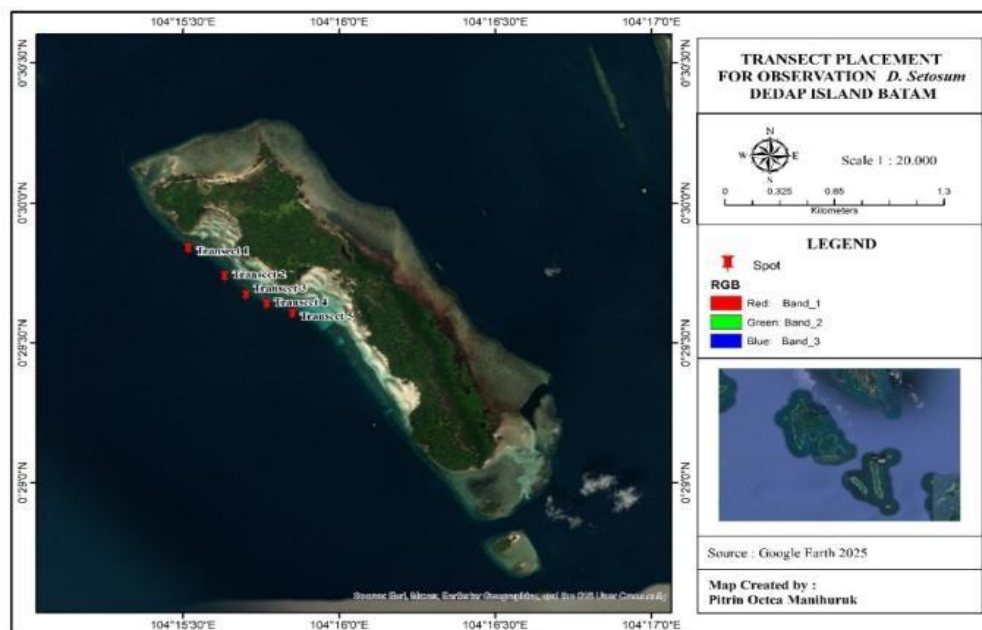


Figure 1. Map of Research Location

Table 2. Instruments Used for Environmental Parameter Measurements

Instrument	Function	Calibration Procedure
Underwater camera	Documentation of sea urchin populations and habitat conditions	Factory-calibrated; visual verification before each dive
Refractometer	Measurement of salinity (dissolved salt levels)	Calibrated using distilled water prior to measurement
pH meter	Measurement of water acidity or alkalinity	Calibrated with standard buffer solutions (pH 4.0, 7.0, 10.0) before sampling
Dissolved Oxygen (DO) meter	Measurement of dissolved oxygen content in water	Calibrated using air-saturated water according to manufacturer's protocol
Thermometer	Measurement of water temperature	Checked against a standard mercury thermometer before field use

Sampling Design

The method employed was a quadrat transect, whereby each observation station was established with a 50 m transect parallel to the shoreline at shallow reef depths ($\pm 1-3$ m). Along the transect, 10 plots measuring 5×5 m were sequentially placed. Observations and censuses of all individuals of *Diadema setosum* present within each plot were conducted during low tide conditions in the dry season (June–August), when water clarity and accessibility to the reef flat were optimal for field measurements.

Density Calculation

Within each plot, all individuals of *D. setosum* were counted directly (via direct visual census), and subsequently recorded.

Utilisation Pressure Recording

Brief interviews with local fishermen were conducted to obtain insights into the intensity of harvesting activities. A total of 2 respondents were selected using purposive sampling, targeting individuals actively engaged in sea urchin collection. Data were obtained through structured questionnaires consisting of standardized, closed-ended questions regarding harvesting frequency, daily catch yields, and market practices. This approach ensured the collection of comparable quantitative data to assess utilisation pressure on *Diadema setosum*.

Data Analysis

Population Density

The population density of *D. setosum* was calculated by dividing the number of individuals of the species by the total sampling area (Krebs, 2014) using the following equation:

$$Di = \frac{ni}{A}$$

Where:

Di = Population density of species

ni = Total number of individuals of species i

A = Total area of the sampling site.

Distribution Pattern

The analysis of the distribution pattern of sea urchins can be calculated using the Morisita Dispersion Index (Morisita, 1959).

$$Id = n \frac{\sum x^2 - \frac{(\sum x)^2}{n}}{(\sum x)^2 - \sum x}$$

Where Id is the Morisita Dispersion Index; n is the number of sampling points; $\sum x$ is the total number of individuals at each point ($x_1 + x_2 + \dots$); and $\sum x^2$ is the sum of the individuals at each point squared. The criteria for the values of the index are as follows (Krebs, 2014):

Id = 1 indicates a random distribution pattern

Id > 1 indicates a clustered distribution pattern

Id < 1 indicates a uniform distribution pattern

Analysis of Correlation and Regression of Density with Environmental Parameters (Temperature, DO, pH, Salinity)

The correlation model utilised is Pearson's correlation, formulated as (Krebs, 2014):

$$r = \frac{\sum (xi - \bar{x})(yi - \bar{y})}{\sqrt{[\sum (xi - \bar{x})^2 \sum (yi - \bar{y})^2]}}$$

Where:

r = Pearson correlation coefficient x_i = individual value of variable x

y_i = individual value of variable y

$\bar{x}$ = mean value of variable x

$\bar{y}$ = mean value of variable y

Σ = summation.

The interpretation of r values follows the classification proposed by (Mukaka, 2012): 0.00–0.19 = very weak, 0.20–0.39 = weak, 0.40–0.59 = moderate, 0.60–0.79 = strong, and 0.80–1.00 = very strong correlation. Positive values indicate a direct relationship, while negative values indicate an inverse relationship. Subsequently, the regression model employed is:

$$Y = \beta_0 + \beta_1(\text{temperature}) + \beta_2(\text{DO}) + \beta_3(\text{Salinity}) + \beta_4(\text{pH}) + \varepsilon$$

RESULT AND DISCUSSION

Density of *Diadema setosum* on Dedap Island

Measurements taken at five observation stations yielded a density of *Diadema setosum* ranging from 0.180 to 0.292 ind/m² (Table 1). Station 4 recorded the highest density (0.292 ind/m²), followed by Station 2 (0.284 ind/m²), while Station 5 exhibited the lowest value (0.180 ind/m²). This variation indicates differences in environmental and anthropogenic pressures across locations.

Table 3. Density of *Diadema setosum* on Dedap Island

No.	Total Individual	Average Individual/Plot	Density (Ind/m ²)
1	53	5.3	0.212
2	71	7.1	0.284
3	60	6.0	0.240
4	73	7.3	0.292
5	45	4.5	0.180

The density of *D. setosum* on Dedap Island is classified as moderate when compared to research reports from other tropical regions, such as Abang Island, Batam (0.15–0.25 ind/m²; Efendi et al., 2024), Setan Island, West Sumatra (1.481 ind/m²; Silalahi, 2008), Western Thailand Gulf ($\pm$ 2.09 ind/m²; Aunkhongthong et al., 2020), and the Mediterranean Sea (0.8 - 5.3 ind/m²; Vafidis et al., 2021). This value indicates that the population on Dedap Island is relatively stable, although there are indications of decline at certain stations due to potential overfishing.

The density of *Diadema setosum* is significantly influenced by temperature, which plays a crucial role in metabolic and reproductive processes. A study by (Sarifudin., 2017) demonstrated that the optimal temperature for the development of *D. setosum* lies within the range of 28 – 31 °C, with the best growth occurring at 28 °C. This finding aligns with observations on Dedap Island, where temperatures around 30°C correlate with high densities.

Variations in density between stations may be affected by anthropogenic pressures and habitat conditions. Station 4, which recorded the highest density, is situated far from human settlements and possesses high habitat complexity,

such as branching corals and large rocks that provide protection from predators (Vafidis et al., 2021). Conversely, Station 5, located near boat routes and fishermen's landing points, exhibited the lowest density, likely due to overharvesting for consumption (Vimono et al., 2023).

These results are consistent with findings by Efendi et al., (2024) on Abang Island, which reported lower densities in locations near human activities. Research in Malaysia by Vimono et al., (2023) also emphasised that locations easily accessible to fishermen show a decline in *D. setosum* abundance. Meanwhile, UAV (Unmanned Aerial Vehicle) studies in Japan (Yamamori & Kato, 2020) confirmed that the spatial distribution of sea urchins is influenced by a combination of factors including distance from land, water depth, and levels of anthropogenic disturbance.

This density variation signals the need for site-specific management interventions. Stations with low densities, such as Station 5, may require prioritisation for restoration or catch regulation. Strategies could include limiting catch quantities or establishing no-take zones, as recommended in the management of marine herbivores in tropical regions.

Distribution Pattern Analysis

The analysis of distribution patterns based on the Morisita Index (Id) at the five observation stations in the shallow reefs of Dedap Island revealed spatial distribution variations. Id values ranged from 0.8125 to 1.3250, with the following interpretations: Station 2 (Id = 1.2175) and Station 4 (Id = 1.3250) exhibited a tendency towards clumped patterns, while Stations 1, 3, and 5 had Id < 1, indicating uniform or random patterns. The results of the distribution pattern analysis are presented in Table 4.

Table 4. Distribution pattern of *Diadema setosum* on Dedap Island

Station	Number of Plots (n)	Total Individuals (N)	$\Sigma xi(xi-1)$	Morisita Id	χ^2 count	Distribution Pattern
1	10	53	212	0,8125	28,125	Random
2	10	71	300	12,175	102,175	Clumped
3	10	60	249	0,9455	34,055	Random
4	10	73	351	13,250	113,250	Clumped
5	10	45	156	0,8667	48,667	Uniform

In general, clumped patterns in *D. setosum* are often associated with microhabitat factors such as coral crevices, hard substrate gaps, and the presence of branching corals that serve as protection from predators and strong currents (Dang et al., 2020). Additionally, the uneven availability of macroalgal food within the shallow reef area may encourage aggregation at specific points.

Conversely, the uniform or random patterns observed at Stations 1, 3, and 5 may indicate several possibilities: (1) the presence of uniform fishing pressure from local communities, leading to reduced local densities and disrupted aggregation, (2) homogeneous substrate conditions without clear protective features, resulting in more

dispersed distributions, or (3) spatial competition among individuals, promoting relatively constant distances between organisms.

These findings are consistent with the distribution study of *D. setosum* on Abang Island (Efendi et al., 2024), which reported variations in patterns from random to clumped, with significance depending on substrate conditions and anthropogenic pressures. This comparison reinforces the indication that although the current spatial patterns on Dedap island do not yet show statistical significance, the tendency towards clumping at Stations 2 and 4 remains important as an early indicator of potential microhabitat areas that could serve as refugia for the remaining population.

From a resource management perspective, areas with $Id > 1$ should receive special attention in long-term monitoring programmes, both to ensure the sustainability of *D. setosum* populations and to maintain their ecosystem functions as algal growth regulators on coral reefs. Given that this species plays a crucial role in maintaining the balance of coral reef ecosystems, information regarding distribution patterns can serve as a reference for establishing protection zones or more targeted catch quota regulations.

Correlation and Regression of Density with Aquatic Environmental Parameters

The correlation calculations between the density of *D. setosum* and aquatic environmental quality parameters are displayed in Table 5, based on a total of 50 density observations ($n = 50$) obtained from five stations with ten quadrat plots each.

Table 5. Correlation of Density with Aquatic Environmental Parameters

Parameters	Correlation (r)	Interpretation
Temperature	+0,93	Very strong positive correlation
DO	-0,94	Very strong negative correlation
Salinity	+0,30	Weak positive correlation
pH	0,50	Moderate negative correlation

The analysis results indicate that temperature has a very strong positive correlation with the density of *Diadema setosum* ($r = +0.93$), suggesting that this species is more abundant at higher temperatures (Al-Risqia et al., 2021). The correlation of density with temperature is illustrated in the scatter plot in Figure 2.

Conversely, DO demonstrates a very strong negative correlation ($r = -0.94$), indicating that density tends to decrease as dissolved oxygen levels increase. The correlation with salinity is classified as weak ($r = +0.30$), while pH shows a moderate negative correlation ($r = -0.50$), indicating that lower pH slightly reduces density. The correlation of density with dissolved oxygen (DO) is depicted in the scatter plot in Figure 3.

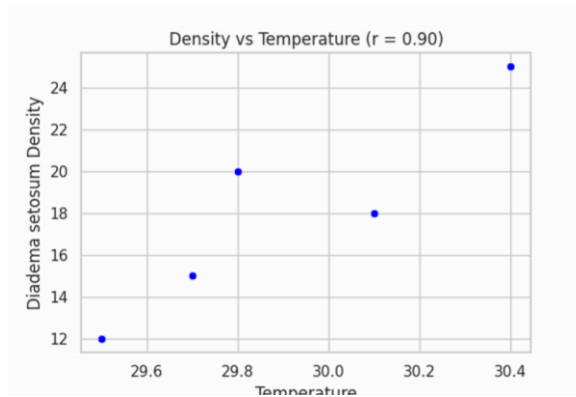


Figure 2. Scatter Plot of Density versus Temperature.

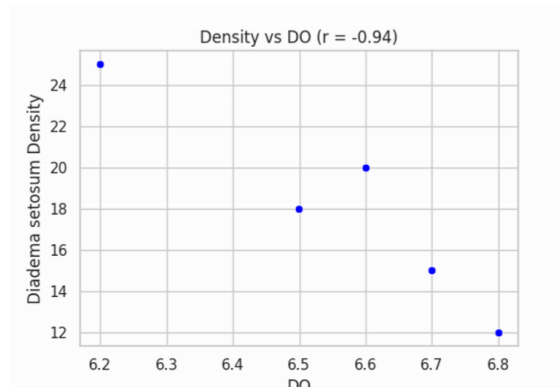


Figure 3. Scatter Plot of Density versus DO

The negative correlation with DO may be attributed to high biological activity in areas with high *Diadema* density, which can lower oxygen levels. A study by [Vimono et al., \(2023\)](#) in Luwuk Bay also indicated that currents and nutrient levels influence the distribution of *Diadema* spp., with high DO not necessarily supporting high densities.

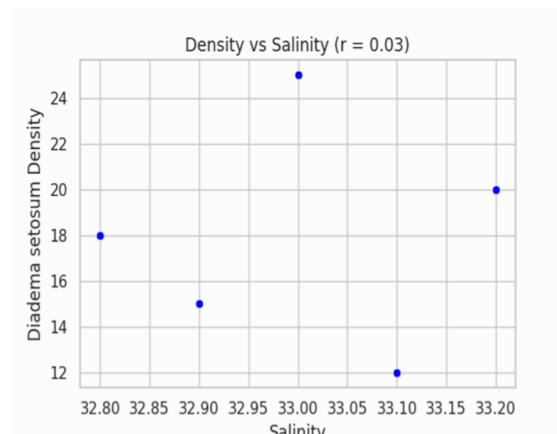


Figure 4. Scatter Plot of Density versus Salinity

The stable salinity on Dedap Island (0.24–0.26 ppt) did not show significant influence; however, laboratory studies by [Sarifudin et al., \(2017\)](#) indicated that *D. Setosum* has a narrow tolerance to salinity, with optimal fertilisation at 31 ppt and a

drastic decline outside the range of 28–37 ppt. The correlation of density with salinity is illustrated in the scatter plot in Figure 4.

The degree of acidity (pH) of seawater tends to be balanced due to marine ecosystems such as coral reefs and seagrass beds, which are habitats for sea urchins and have buffering capacities that can maintain pH values (Alwi et al., 2020). The negative correlation with pH may be related to observations conducted during the day, where pH increases during the day due to photosynthesis and decreases at night as a consequence of respiration. Our findings suggest that when this trend is reversed (low pH during the day, high pH at night), growth and calcification are negatively affected. Previous studies have indicated that marine organisms have the potential to adapt to maximise their growth and calcification during the day when environmental pH is higher (Cornwall et al., 2014). This is supported by Cossa et al., (2024), who showed that sea urchin larvae anticipate diurnal variability and invest more energy in calcification during the day compared to at night, indicating that extreme pH may cause abnormalities in embryos and larvae of *D. Setosum*, thus lower pH may inhibit population development. The correlation of density with acidity (pH) is illustrated in the scatter plot in Figure 5.

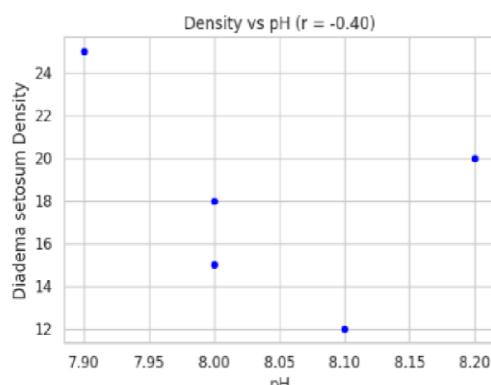


Figure 5. Scatter Plot of Correlation of 1 Density with pH

Results of Multiple Regression Analysis

A multiple linear regression analysis was conducted to evaluate the influence of environmental parameters on the density of *Diadema setosum*. The regression model indicated that temperature, DO, salinity, and pH contribute variably to the density of this species. The resulting regression model is as follows:

$$Y = -12.8476 + 2.9113 \cdot \text{Temperature} - 3.4542 \cdot \text{DO} + 1.1229 \cdot \text{Salinity} - 2.0347 \cdot \text{pH}$$

Where:

- Y : is the density of *Diadema setosum* (ind/m²)
- Temperature : in °C
- DO : in mg/L
- Salinity : in ppt
- pH : is the acidity level of the water. Table 6. Displays the results of the multiple linear regression analysis.

The analysis results indicate that temperature has a significant positive effect on the density of *D. setosum* ($p = 0.0009$), while DO and pH show significant negative

effects ($p = 0.0006$ and $p = 0.0214$, respectively). Salinity has a positive but statistically insignificant effect ($p = 0.0802$). The R^2 value of 0.8503 indicates that the model can explain 85.03% of the variation in the density of *D. setosum*. These findings align with studies by [Moka et al., \(2024\)](#), which demonstrate that the growth of *D. setosum* in seagrass and coral reef ecosystems is influenced by local environmental conditions, including temperature and salinity. Furthermore, [Marquez et al., \(2023\)](#) emphasise that local temperatures can influence the spatial dynamics of marine species densities, particularly for species with affinities for warm waters.

Table 6. Results of Multiple Linear Regression Analysis

No	Variable	Coefficient	P-Value	Standard Error
1	Intersep	-12.8476	0,0911	6.6715
2	Temperature (°C)	2.9113	0,0009	0.4726
3	DO (mg/L)	-3.4542	0,0006	0,5384
4	Salinity (ppt)	1.1229	0,0802	0,5824
5	pH	2.0347	0,0214	0,7553

The decline in DO has been shown to negatively impact the metabolism and survival of marine organisms, as explained by [Mariu et al., \(2023\)](#), who state that low DO can lead to hypoxic conditions and decrease respiratory efficiency. Changes in pH also significantly affect ion regulation and enzymatic functions, directly impacting the survival and reproduction of marine species. In the context of salinity, [Smith & Elliot \(2016\)](#) explain that fluctuations in salinity can act as ecological stressors affecting community structure and species distribution, especially for stenohaline organisms with narrow salinity tolerances.

Overall, these regression results reinforce the understanding that environmental parameters play a crucial role in determining the density and distribution of marine species, as well as supporting conservation efforts based on quantitative and predictive data.

Analysis of Anthropogenic Pressure

Based on interviews with two local fishermen, the average catch of *Diadema setosum* gonads reached 2–3 kg per person per day, with harvesting conducted daily during low tide. These values correspond to a CPUE (Catch Per Unit Effort) of approximately 2–3 kg/day/person, indicating intensive utilisation pressure on the local population. The limited number of respondents ($n = 2$) reflects the constraints of fieldwork, as only a few fishermen in the area were directly engaged in daily *D. setosum* harvesting and available for structured interviews during the survey period. Despite this limitation, the data provide valuable baseline information on local exploitation practices and harvesting intensity. Ecological analysis results indicate that the density of *Diadema setosum* on Dedap Island is significantly influenced by temperature, DO, and pH, with temperature being the dominant factor supporting population abundance. However, the observed population structure also reflects the impact of intensive anthropogenic pressure in the area.

Table 7. Summary of interview results on utilisation of *Diadema setosum* at Dedap Island

Number of Respondents	Average Catch (kg gonads/person/day)	Harvesting Frequency	Effort (CPUE, kg/day/person)
2 (local fishermen)	2–3	Daily, during low tide	2–3

Interviews with two local fishermen, Mr. Nurdin and Mr. Abdulah, revealed that the capture of *Diadema setosum* is conducted traditionally every day, particularly during low tide. This activity focuses on harvesting gonads (eggs) that are consumed and sold, while the shells are discarded on-site. The average catch per person reaches 2–3 kg of fresh gonads per day, indicating a relatively high level of exploitation of the *Diadema setosum* population.

This utilisation pressure poses a risk of overharvesting, particularly as fishing occurs directly in shallow reef zones, which are the primary habitat for this species. A study by [Al-Risqia et al., \(2021\)](#) indicated that excessive exploitation of sea urchins can disrupt the balance of coral reef ecosystems, as *Diadema setosum* plays a vital role in controlling algal growth and maintaining substrate space for other organisms.

Furthermore, the direct harvesting of gonads on-site without maintenance or cultivation processes indicates that this exploitation is not yet based on sustainability. A study by [Delianis et al., \(2016\)](#) emphasises the importance of community-based management for species that hold high economic value but have crucial ecological functions. The combination of environmental pressures (such as temperature and pH fluctuations) and anthropogenic pressures from daily fishing activities can accelerate the decline of *Diadema setosum* populations. Therefore, the findings of this study support the need for ecosystem-based conservation management, such as the establishment of no-take zones, community education, and the development of alternative cultivation methods to reduce direct pressure on wild populations.

CONCLUSION

This study demonstrates that the population structure of *Diadema setosum* on Dedap Island is shaped by both environmental and anthropogenic pressures. Higher densities were observed at stations distant from human activity (0.292 ind/m²), whereas stations near settlements exhibited lower densities (0.180 ind/m²). Regression analysis identified temperature as the dominant environmental factor positively affecting density, while dissolved oxygen and pH showed significant negative influences. Interviews with local fishermen confirmed daily harvesting for gonad consumption, indicating notable exploitation pressure on the population. These findings highlight the broader implication that coral reef-associated species such as *D. setosum* are highly sensitive to the combined effects of environmental variability and human exploitation. Site-specific ecological data, as generated in this study, are crucial for guiding sustainable management and conservation in the Indo-Pacific region. Future research should further integrate long-term ecological monitoring with socio-economic assessments to strengthen adaptive management frameworks. The scientific

contribution of this research lies in its integration of ecological surveys with socio-economic data, providing novel insights into the coupled dynamics of environmental drivers and anthropogenic pressures on *D. setosum* populations in a region where such comprehensive assessments are still limited.

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