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Potency of Gastropods as Ecological Bioindicators in the Anthropogenic Waters of Geger Beach Bay, Bali

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Abstract: The increasing pressure of tourism and urbanization in coastal areas like Bali often leads to environmental degradation, necessitating a robust biomonitoring system. Gastropods serve as ideal ecological bioindicators due to their limited mobility and specific tolerance to environmental stress. This study aims to assess the water quality of Geger Beach Bay using gastropods as indicators. Observations were conducted at three stations—upstream, midstream, and downstream—using the quadrant transect method. Community analysis included diversity (H'), evenness (E), and dominance (C) indices, alongside physicochemical water parameters. The results showed significant variations in community structure. The downstream station recorded the highest diversity (H' = 2.47) and abundance (129 individuals) due to stable salinity, while the upstream station had the lowest diversity (H' = 1.31) despite high DO, likely due to unstable substrate. PCA analysis confirmed that DO, temperature, and salinity were the primary environmental drivers. Low salinity (15-17 ppt) and pH levels indicate freshwater dilution from nearby hotel effluent. Overall, gastropods are effective bioindicators for coastal health, providing a scientific basis for sustainable management, specifically recommending improved wastewater treatment to preserve biodiversity.

Keywords: Bioindicators, Gastropods, Geger Beach, Water Quality.

Introduction

Coastal ecosystems play a crucial role in supporting global marine biodiversity, yet they are increasingly vulnerable to anthropogenic pressures. Environmental degradation in these regions is often characterized by significant alterations in water physico-chemical parameters due to continuous waste inputs and intensive coastal development. Such changes pose a fundamental threat to marine ecosystem functions, making the quality of coastal waters a critical universal issue, particularly in regions experiencing massive tourism and urbanization like Indonesia (Pranoto & Agustriani, 2019). To achieve sustainable management of these essential coastal resources, a highly sensitive and representative ecological monitoring system is universally required.

In the context of environmental monitoring, the biomonitoring approach has proven to be conceptually superior to instantaneous chemical measurements, as it integrates the cumulative effects of pollutants over a long period of time (Rosenberg & Resh, 1993; Setyobudi et al., 2017). Within this framework, macrozoobenthos groups, particularly gastropods, play an essential role as ecological bioindicators. Gastropods are highly suitable for this purpose due to their limited mobility or sessile nature, which ensures they are constantly exposed to local environmental conditions (Santoso et al., 2021). Their communities possess specific tolerance ranges to various pressures; thus, changes in their community structure, such as a decrease in diversity or the dominance of tolerant species, directly reflect the stress conditions or degradation of the aquatic habitat (Mulyani & Ruswahyuni, 2016). The use of biological indices derived from gastropod data, such as the Shannon-Wiener Diversity Index (H') and the Uniformity Index (E), has become a standard scientific practice to quantitatively measure the degree of environmental disturbance, a concept pioneered by Wilhm and Dorris (1968) and widely used today (Sembiring & Purba, 2018).

Geger Beach Bay represents a specific and critical case of these environmental challenges due to its characteristics as a center for massive tourism activities. Specifically, the bay area adjacent to the Mulia Hotel is directly exposed to intense anthropogenic pressures, ranging from large-scale accommodation operations to a high intensity of tourist visits and water recreation. The construction and operation of massive coastal facilities in this area have the potential to produce significant inputs of domestic waste and sediment. These continuous anthropogenic inputs are hypothesized to alter the water quality of the bay, which in turn threatens to disrupt and change the structure of the local macrozoobenthos community (Suryanti & Ruswahyuni, 2020). However, the specific ecological impact of these localized tourism pressures on the gastropod community structure in Geger Beach Bay remains a significant problem that needs to be quantified.

While previous studies have established the general utility of gastropods as bioindicators, the novelty of this research lies in its site-specific ecological assessment focused on the localized impacts of intensive, large-scale resort operations on a semi-enclosed bay ecosystem. Therefore, this study aims to assess the water quality and ecological health of Geger Beach Bay using gastropods as ecological bioindicators. The urgency of this research is to produce an accurate, biologically integrated ecological assessment to formulate and support sustainable coastal environmental management strategies for the future, ensuring that coastal development does not cause irreversible damage to marine biodiversity.

Materials and Methods

Research Location and Time

This research was conducted in Geger Beach Bay, Bali, which is divided into three observation locations:

1. Upstream (Station I): 8° 49' 4.340792" S, 115° 13'27.829723"
2. Middstream (Station II): 8°49' 6.043107" S, 115° 13'28.126040" E
3. Downstream (Station III): 8° 49' 8.558592" S, 115° 13'30.142747"E

At each location, data was collected at three observation points during the research period to observe environmental conditions and water quality.

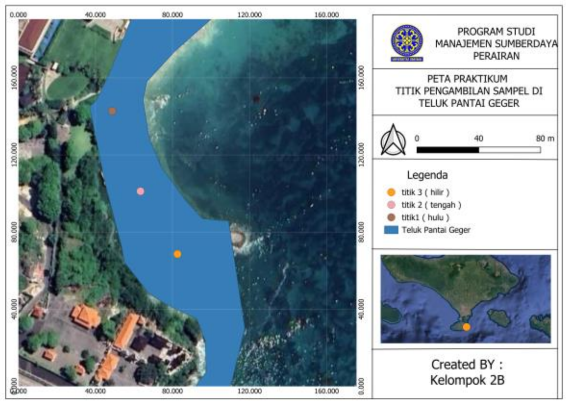

Figure 1. Research Location

Data Collection

The data collection method includes gastropod observation and measurement of the physico-chemical parameters of water quality as follows:

Gastropod Observation

Quadrant Transect Method. A quadrant transect measuring 1 x 1 meter is used at each point and repeated 3 times on each plot (Krebs, 1999) by taking a substrate using a shovel and filtering it using a fine and coarse filter (Brower et al., 1998), then the type of species will be identified and observations will be made to calculate the analysis of data from diversity, uniformity, and dominance.

Measurement of Water Physics and Chemistry Parameters

Water quality parameters measured in-situ and laboratory include: Using a DO meter to assess dissolved oxygen levels and water temperatures. In the laboratory, measurements

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are taken, which include: Using a pH meter to determine the acidity or alkaline level of the water; Using a refractometer to determine the salinity or salinity of the water; Using a spectrophotometer to determine nitrate and phosphate levels by experimental methods. This method is based on the principle that chemical compounds will absorb UV light at a specific wavelength. By measuring the absorption of light by the sample at a specific wavelength, the concentration of the substance being analyzed can be determined. In addition, *the brucine* and *cadmium-reduction* methods are also used to measure nitrates. The *brucine* method is one of the commonly used methods in quantitative analysis to determine the level of nitrate (NO_3^-) in water samples. which will potentially lead to eutrophication that affects the metabolism and distribution of gastropods and aquatic organisms.

Nitrate levels were measured by taking 1 ml of water sample into a test tube, then adding 4 drops of Reagent (NO_3^-) and 0.02 Reagent NO3-2. The solution is then slowly homogenized, transferred to a cuvette, and left for 4 minutes to perfect the color reaction (reduction). The final step is to measure the absorbance value using a spectrophotometer at a wavelength of 540 nm where the results are then converted through a prepared standard nitrate curve equation.

Phosphate analysis began by putting 1 ml of water sample into the test tube, then 0.02 grams of Hanna HI 713-25 Reagent was added. The mixture is homogenized until completely dissolved and transferred to a cuvette to be incubated for 4 minutes until a blue complex is formed (ascorbic acid method). The final stage is performed by reading the absorbance value on a spectrophotometer with a wavelength of 540nm and comparing it with the value on the phosphate standard curve to determine the final concentration.

Data Analysis

The structure of the gastropod community was analyzed using standard ecological indices (Magurran, 2004; Washington, 1984). The specific indices calculated include:

a) Shannon - Wiener Diversity Index Analysis

$$H' = -\sum Pi \times \log Pi$$

b) Uniformity Index Analysis

$$E = \frac{H'}{\ln S}$$

c) Dominance Index Analysis

$$C = \left(\sum pi\right)^2$$

d) Analysis of Water Physico-Chemical

Parameters

The results of the measurement of physico-chemical parameters are compared with class III water quality standards based on Government Regulation No. 22 of 2021. The analysis was carried out in a comparative descriptive manner between stations (upstream, middle, downstream) to see the impact of anthropogenic activities.

Results and Discussion

Gastropod Community Structure and Composition

The composition and structure of the gastropod community were analyzed to provide an initial assessment of the ecological condition in Geger Beach Bay. Observations conducted across the three stations recorded a total of 219 individuals. To quantify the health and stability of this community, standard ecological indices were calculated. The detailed taxonomic composition, abundance per station, and the values for the Shannon-Wiener Diversity Index (H'), Uniformity Index (E), and Dominance Index (C) are presented below.

Table 1. Taxonomy Results & Biota Data

No	Species Name	St 1	St 2	St 3	Quantity
1	*Turritella terebra*	-	4	16	20
2	*Unidentified Columbellidae*	2	3	30	35
3	*Pardalinops testudinaria*	-	-	13	13
4	*Tenguella granulata*	5	17	9	31
5	*Laevistrombus canarium*	2	6	6	14
6	*Monetary policy*	-	8	19	27
7	*Planaxis sulcatus*	-	3	4	7

No	Species Name	St 1	St 2	St 3	Quantity
8	*Ilyanassa obsoleta*	3	5	1	9
9	*Vexillum joliveti*	-	18	1	19
10	*Littoraria irrorata*	-	3	11	14
11	*Clea Helena*	-	10	9	19
12	*Natica vitellus*	-	8	5	13
13	*Pictocolumbella ocellata*	-	13	5	18
	Total				**219**

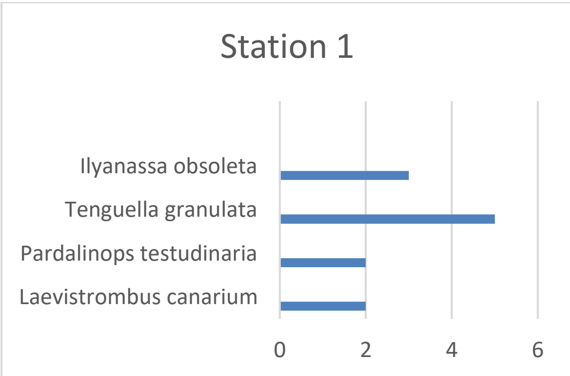

Figure 2. Diversity St 1

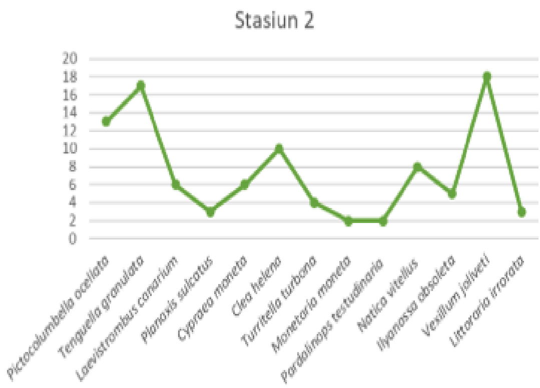

Figure 3. Diversity St 2

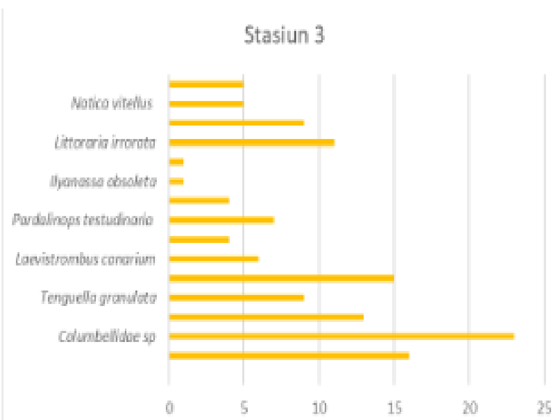

Figure 4. Diversity St 3

Table 2. Diversity, Uniformity, and Dominance Index

Stations	H’	E	C
St. 1	1,31	0,94	0,29
St. 2	2,33	0,91	0,12
St. 3	2,47	0,89	0,1

Table 3. Diversity, Uniformity, and Dominance Categories

Stations	H’	E	C
St. 1	Medium	Height	Low
St. 2	Medium	Height	Low
St. 3	Medium	Height	Low

The spatial dynamics of the gastropod community in Geger Beach Bay show a significant ecological gradient from upstream to downstream. The striking variation in abundance, starting from 12 individuals at Station 1 (Upstream), increasing to 97 individuals at Station 2 (Central), to reaching a peak of 129 individuals at Station 3 (Downstream), indicates that the downstream zone has a much more optimal environmental carrying capacity.

This distribution pattern reflects the strong influence of water hydrodynamics, according to Ayunda (2021), zones that are directly adjacent to the open sea (downstream) generally have a smoother circulation of water masses. This good circulation ensures a supply of nutrients and dissolved oxygen that is crucial for gastropod metabolism, while minimizing sediment accumulation which is often a limiting factor in more isolated upstream areas. Therefore, low populations upstream can be associated with environmental pressures in the form of limited water circulation and higher sedimentation potential, which is less supportive of macrobenthose life. Judging from the stability of the community, the ecological index value at the research site describes the condition of the ecosystem that is in equilibrium.

The Diversity Index (H') which ranges from 1.31 to 2.47 places these waters in the category of moderate diversity, with an upward trend in value that is in line with the gradient heading downstream.

Referring to the criteria of Natan et al. (2024), this condition signifies a sufficiently balanced community structure with adequate aquatic productivity to support various trophic guilds. This stability is reinforced by high Uniformity Index (E) values (0.89 - 0.94) across stations, which indicates that resource sharing between species runs very efficiently. These findings are in line with the study of Tualangi et al. (2023), where high uniformity reflects an even partition of ecological niches, thus minimizing extreme interspecies competition and allowing the coexistence of different types of gastropods in a single habitat.

Furthermore, the analysis of the Dominance Index (C) showed low values (< 0.5) at all three stations, which confirms the absence of a single species that monopolizes resources in Geger Beach Bay. This low dominance is a positive indicator for ecosystem resilience, communities without the dominance of certain species tend to have better resistance to environmental disturbances because ecological functions are spread to various species (functional redundancy) Suryanti et al., (2020). This means that the food chain in the ecosystem does not rely on just one type of biota, thus creating more complex and stable food webs. Specifically, the composition of the species found provides diagnostic insights into the characteristics of the aquatic base habitat.

The presence of *Laevistrombus canarium* (Barbed Snail) scattered in almost all stations validates the existence of seagrass ecosystems with sandy soil substrates or sandy mud, considering that this species is highly dependent on seagrass litter as the main source of feed (Supratman et al., 2024). On the other hand, the abundance of Cypraeidae families such as Cypraea moneta at Stations 2 and 3 is a bioindicator of the heterogeneity of substrates in the form of coral fragments (rubble) or hard rocks. In accordance with Litaay et al. (2022), the Cypraea group does have a habitat preference in the reef flat zone which provides rock crevices as shelter from predators and wave currents, confirming that the central to downstream area of Geger Beach Bay has a more complex habitat topography than the upstream area.

Environmental Water Quality Parameters and PCA Analysis

To contextualize the biological findings and understand the environmental drivers shaping the gastropod community, key physico-chemical water quality parameters were measured in-situ and in the laboratory across all stations. Furthermore, a Principal Component Analysis (PCA) was conducted to correlate these environmental variables with the biological data, identifying the primary physical and chemical factors influencing species distribution in the bay. The measurement results and the subsequent PCA biplot are detailed below.

Table 4. Water Quality Parameters

Parameters	Station 1	Station 2	Station 3
DO (mg/L)	8,3	6,3	7,3
Temperature (°C)	30,4	30,9	30,1
pH	6,53	6,05	6,19
Salinity (ppt)	15	15	17
Nitrate (mg/L)	0,445	0,462	0,478
Phosphate (mg/L)	< 0.001	< 0.001	< 0.001

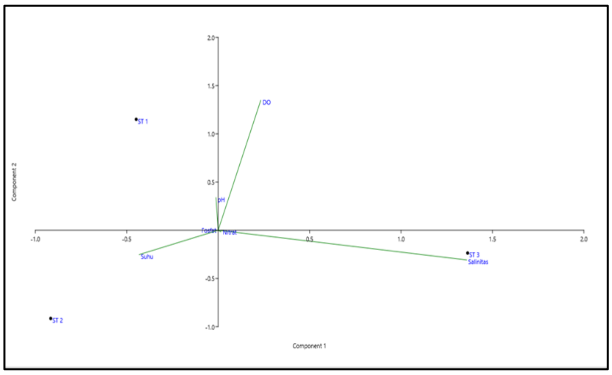

Figure 5. PCA Results

Station 1 (Upstream) is characterized by a high Dissolved Oxygen (DO) vector (upper left quadrant). Despite having a high DO, the station recorded the lowest abundance and diversity (12 individuals, H'=1.31). The phenomenon of "anomalies" in which high DO is not always directly proportional to this high abundance can be explained by hydrodynamic factors or feed availability. Yanti et al. (2022) in their study on the structure of gastropod communities in Bintan explained that although the chemical parameters of water (such as DO) are good, the presence of gastropods is more strongly determined by the underlying substrate. If Station 1 (Upstream) has a heavier current (causing high DO due to aeration) but the substrate is unstable (coarse sand that is constantly moving), then the gastropods will have difficulty attaching and foraging. This is reinforced by Sembel et al. (2024) who stated that gastropod abundance has a stronger correlation with the Total Organic Matter (BOT) content of sediments compared to water DO alone; if the DO is high but the supply of organic matter is low, then the abundance of macrobentos will remain low. Station 2 (Center) on the PCA graph is closely correlated with the Temperature vector. The station's position in the middle of the bay likely causes slower water circulation resulting in the accumulation of solar heat, making temperature the main limiting factor in this area. However, the abundance of gastropods at this station is quite high (97 individuals) This means that the food chain in the ecosystem does not rely on just one type of biota, thus creating more complex and stable food webs, which is a key indicator of ecosystem maturity and resilience (Odum & Barrett, 2005).

According to Rozirwan et al. (2021) who conducted a PCA analysis on mollusk communities at the mouth of the Musi River, water temperature is the main characteristic variable that affects the metabolic rate of gastropods. Warm temperatures within tolerance limits (28°C - 31°C) can spur feeding and reproduction, which explains why abundance at Station 2 remains high despite being dominated by temperature. However, a negative correlation between extreme temperatures and some sensitive species was also noted by Hikmiyah (2025), who found that certain genera (Pictocolumbella) are precisely negatively correlated if temperatures rise too drastically, which may explain why the species composition at Station 2 is different from Station 3.

The PCA results place Station 3 (Downstream) in the lower right quadrant which has a strong Salinity parameter vector. This shows that downstream stations that are directly adjacent to the open sea have higher and more stable salinity conditions than other stations. These environmental conditions were positively correlated with the biological data of station 3 which had the highest total abundance (129 individuals) and the highest diversity (H' = 2.47). These findings are in line with research conducted by Rahman et al. (2024) on mangrove and coastal ecosystems in West Lombok, which used PCA analysis to show that salinity is a key factor influencing the distribution of marine gastropods. They found that stations with salinity close to natural seawater conditions tended to have higher species richness because most marine gastropods were stenohaline (only tolerant of a narrow range of high salinity). In addition, Raiba et al. (2022) in their research in South Buton also emphasized that high salinity (around 28-34 ppt) is very supportive of the life of gastropod epifauna, so individual density tends to increase towards the open sea which is free from freshwater fluctuations.

The Findings of the Decrease in pH measurement results in Geger Beach Bay are directly proportional to the low salinity value which reaches 15-17 ppt. This value shows that the waters of Geger Beach Bay are in a mesohalin or brackish condition, far below the average normal seawater salinity which ranges from 32–34 ppt. This condition is a strong indicator of the existence of a massive dilution phenomenon, both from run-off and high rainfall to the final flow from hotel waste management which is close to the waters of Geger Beach Bay. Pratiwi et al. (2021) stated that the input of fresh water in large volumes not only reduces salinity, but also reduces the buffering capacity of seawater. Low salinity causes the marine bicarbonate system to weaken, making the water more susceptible to extreme pH fluctuations.

The large volume of fresh water intakes sourced from the *wastewater effluent* of hotels around the bay significantly altered the hydraulic profile of the waters. Ecologically, this low pH and salinity exert osmotic pressure on marine organisms. Salinity below 20 ppt can cause physiological stress on stenohalin marine biota (organisms with a narrow salinity tolerance), which must expend more energy for the process of osmoregulation. (Hamzah & Setiawan (2023)) emphasize that a low pH environment (local acidification) can inhibit the calcification process in organisms such as corals and mollusks, which is crucial for the sustainability of the ecosystem in Geger Beach Bay. Therefore, this condition indicates that Geger Beach is strongly influenced by terrestrial dynamics, and further monitoring of the incoming nutrient load is needed to prevent more severe environmental quality degradation.

Conclusion

This study concluded that gastropods proved to be effective as a bioindicator to assess the quality of the waters in Geger Beach Bay, Bali, with clear variations in community structure between upstream, middle, and downstream stations. The upstream station showed the lowest diversity (H' = 1.31) despite the high DO, likely due to unstable substrates and low organic matter, while the middle station had high abundance (97 individuals) but temperature constrained, and the downstream station recorded the highest values (H' = 2.47; 129 individuals) thanks to stable salinity and optimal water circulation. The PCA analysis confirmed DO, temperature, and salinity as the main differentiating factors, with a high uniformity index (0.89-0.94) and low dominance across all stations, signaling a balanced ecosystem that is resilient to anthropogenic pressures such as tourism. Overall, these findings provide a scientific basis for sustainable coastal management, encouraging regular monitoring to preserve biodiversity. It is recommended to treat liquid waste from nearby hotels to stabilize the pH level and salinity of the water.

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