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Effects of Shrimp Aquaculture Effluent on the Habitat Suitability for Macrozoobenthos along the Situbondo Coast

Salimatul Muntafi'ah[1,3*], Hartati Kartikaningsih[1,2], Fitri Candra Wardana[1], Wresti L. Anggayasti[1]

[1] Study Program of Environmental Resource Management and Development, Graduate School of Universitas Brawijaya, Indonesia.
[2] Department of Aquaculture, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Indonesia.
[3] Situbondo Regency Environment Agency, East Java, Indonesia.

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Corresponding Author:
Salimatul Muntafi'ah
salimatulmuntafiah76@gmail.com

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Abstract: Shrimp aquaculture generates wastewater that may affect coastal ecosystem quality if not properly managed. This study aimed to analyze the relationship between shrimp pond effluent quality and macrozoobenthos diversity as an indicator of habitat suitability in the coastal waters of Situbondo, Indonesia. Wastewater samples were collected from pond outlet wastewater treatment plants (WWTP) in triplicate and analyzed for physicochemical parameters, including phosphate (PO_4), ammonia (NH_3), total suspended solids (TSS), biochemical oxygen demand (BOD), and pH. Macrozoobenthos samples were collected at three distances from the discharge point and analyzed using the Shannon–Wiener diversity index (H'). Data were further analyzed using multiple linear regression and Canonical Correspondence Analysis (CCA) to evaluate the relationship between environmental variables and macrozoobenthos diversity. The results showed that PO_4 concentrations at all stations exceeded the environmental quality standard (0.5 mg/L), while NH_3 concentrations exceeded the standard (5 mg/L) at four stations. TSS levels also exceeded the permitted threshold (100 mg/L) at several stations, whereas BOD and pH remained within acceptable limits. The macrozoobenthos diversity index indicated moderate diversity at stations 1 and 2 ($H' \approx 2$), suggesting moderate environmental stress, while stations 3, 4, and 5 showed low diversity ($H' < 1$), indicating polluted conditions. Regression analysis indicated that nutrient and suspended solid parameters negatively influenced macrozoobenthos diversity, with PO_4 and NH_3 showing the strongest effects. The findings demonstrate that shrimp pond effluent can alter benthic community structure and confirm that macrozoobenthos are effective bioindicators for assessing ecological impacts in coastal ecosystems.

Keywords: Macrozoobenthos; Shannon diversity index; Shrimp ponds; Situbondo coast; Water quality parameters

Introduction

Situbondo Regency is one of the regions in East Java Province that has a relatively long coastline, compared to other regions. This has led to the proliferation of shrimp farming businesses in the coastal area of Situbondo Beach. While shrimp aquaculture can boost income and improve community welfare, if not handled sustainably, it could lead to environment al deterioration. The purpose of this study is to look into the connections between various water quality metrics. This study examines the relationship between PO_4, NH_3, TSS, BOD, and pH resulting from shrimp farming activities and the diversity of macrozoobenthos in nearby coastal areas, in order to assess how the biota respond to these environmental conditions. This study was conducted on five pond samples in Mangaran, Arjasa, and Kapongan subdistricts, each with three repetitions. Previous research found that some macrozoobenthos are resistant to water pollution, while

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others cannot survive in polluted environmental conditions. Mollusks and annelids can be found in polluted waters, while echinoderms are commonly found in clear and calm waters. The phylum Arthropoda is very vulnerable to community disturbances and is therefore commonly found in mangrove ecosystems (Rosdatina et al., 2019).

In coastal systems affected by intensive aquaculture, macrozoobenthic communities respond to multiple water quality parameters (PO4, NH3, TSS, BOD, and pH) through shifts in species composition, diversity, and functional groups, making macrobenthic indices valuable integrators of ecosystem health (Gao et al., 2024; Chris & Amaewhule, 2022; Li et al., 2021). Across temperate and tropical estuaries, phosphate and ammonia supply, as well as chlorinated organic loads reflected by BOD, frequently modulate dissolved oxygen regimes and sediment geochemistry, thereby selecting for tolerant opportunists (e.g., certain Polychaeta and Mollusca) over sensitive taxa, with pH acting as a broad constraint on community structure (Gao et al., 2024; Chris & Amaewhule, 2022; Li et al., 2021).

Meta-analytic syntheses and comparative field studies show that polychaetes and crustaceans often dominate stressed, eutrophic littoral habitats, while echinoderms and some epibenthic taxa decline under elevated nutrients and reduced DO, particularly when coupled with increased turbidity and fine sediments (TSS) from aquaculture effluent (Chris & Amaewhule, 2022; Li et al., 2021; Liang et al., 2025). Long-term, multivariate analyses in estuarine systems demonstrate that depth, salinity, DO, and nutrient gradients (NOx, NH4, PO4) are consistent primary drivers of macrobenthic community composition and diversity, with shifts toward disturbance-tolerant taxa under chronic nutrient and organic loading associated with aquaculture practices (Tang et al., 2024; Gao et al., 2024; Duarte et al., 2022; Castro-Cubillos et al., 2022). In line with regional benthic assessments, integrated ecological-quality frameworks—such as AMBI, M-AMBI, and related indices—often reveal degraded benthic health in zones influenced by anthropogenic inputs, reinforcing the utility of macrozoobenthos as bioindicators for monitoring the ecological effects of shrimp farming on adjacent coastal biota (Duarte et al., 2022; Chris & Amaewhule, 2022). Collectively, these findings support using a targeted panel of water-quality metrics (PO4, NH3, TSS, BOD, pH) to interpret observed macrozoobenthic diversity patterns around Situbondo's shrimp-pond landscapes and to assess biotic responses as proxies for broader ecosystem integrity, while acknowledging potential taxon-specific nuances and regional variation reported in comparable coastal systems (Zhang et al., 2013; Purushothaman & Krishnan, 2024; Afzal et al., 2023; Xu et al., 2025).

The destruction of these aquatic ecosystems will also have an impact on aquatic biota such as benthos that usually live at the bottom of the water, where a decrease in the abundance and composition of these organisms is usually an indicator of ecological disturbance occurring in a river water body (Doni, 2010; Ridwan et al., 2016; Lammertsma et al., 2018; McCormick & Hoellein, 2016; Bierschenk et al., 2017). Riverine and estuarine inputs, including freshwater inflows and terrestrially derived organic matter, can alter salinity, oxygen levels, and nutrient regimes, thereby shaping benthic community structure and function across freshwater–marine continua (Bierschenk et al., 2017; Lecher & Mackey, 2018; Kim et al., 2024).

Benthic organisms are also sensitive indicators of environmental change in coastal margins and river-influenced shelves, where shifts in sediment chemistry, organic matter supply, and hydrodynamic forcing from rivers can drive changes in diversity, biomass, and ecological roles within benthic-pelagic coupling (Suokhrie et al., 2021; Seike et al., 2020; Aued et al., 2018). In addition, anthropogenic inputs such as litter and microplastics accumulate in riverine benthic sediments and riparian zones, potentially modifying habitat quality and microbial interactions that support benthic communities; these disturbances underscore the need to integrate cross-ecosystem perspectives when assessing benthic health from rivers to coasts (Hoellein et al., 2014; McCormick & Hoellein, 2016; Simon-Sánchez et al., 2019). Where river-derived materials reach marine environments, benthic foraminifera and other sessile biota respond to altered bottom-water chemistry and organic fluxes, making them valuable proxies for reconstructing and monitoring sedimentary and ecological responses to riverine forcing in marginal-marine settings (Stassen et al., 2012; Suokhrie et al., 2021; Pérez-Asensio & Ramírez, 2020). Consequently, declines or reorganizations in benthic communities not only reflect local habitat degradation but also signal broader ecosystem-wide consequences for energy flow, nutrient cycling, and trophic interactions in river-dominated seas and adjacent coastal systems (Bluhm & Gradinger, 2008; Tang et al., 2024; Chen et al., 2020).

Shrimp pond waste that exceeds quality standards was found to pose a negative impact on coastal ecosystems (Herawati et al., 2025). The results of this study state that TSS, NH3, NO_3, and PO_4 from pond waste reduce the landing and nesting activities of sea turtles. Meanwhile, this study shows that liquid shrimp pond waste affects the suitability of macrozoobenthos habitats. These findings confirm that pond water quality management is very important for maintaining the sustainability of coastal ecosystems. The findings of this study are intended to offer guidance for decision-making in pond management and coastal ecosystem conservation.

Method

Research Location

This research was conducted in Situbondo Regency, East Java Province, with field data collection carried out from October to November 2025. The sampling method used in this study was saturated sampling (Fadilla et al., 2021). This technique was selected because the population that met the research criteria was limited; therefore, the entire eligible population was included as the research sample. Based on data obtained from the Situbondo Regency Environment Agency, there are 142 shrimp ponds distributed across several subdistricts. Among these, 28 ponds were identified as having environmental documents, including UKL-UPL and wastewater technical approval (Pertek Air Limbah). Most of these ponds are located in three subdistricts: Mangaran, Kapongan, and Arjasa. Furthermore, this study applied additional criteria for selecting the research samples, namely ponds that (1) possess environmental documents and technical approvals, (2) have an area larger than 5 hectares, and (3) have a production schedule that coincided with the research period. Based on these criteria, five ponds were identified as meeting all the requirements and were therefore selected as research samples. These consisted of one pond located in Lamongan Village, Arjasa District; one pond located in Landangan Village, Kapongan District; and three ponds located in Tanjung Pecinan Village, Mangaran District.

Thus, all ponds that met the criteria were used as sampling points to obtain a comprehensive picture of the water quality and macrozoobenthos conditions in the representative shrimp ponds in Situbondo Regency. The coordinates of each station are as follows:

Table 1. Sample Point Coordinates

Station	Location	Coordinates
Point 1	Landangan Village, Kapongan Subdistrict	7° 40' 46.48" S, 114° 5' 17.18" E
Point 2	Lamongan Village, Arjasa Subdistrict	7° 42' 53.11" N, 114° 8' 44.47" E
Point 3	Tanjung Glugur Village, Mangaran Subdistrict	7° 36' 48.19" S, 114° 2' 39.44" E
Point 4	Tanjung Glugur Village, Mangaran Subdistrict	7° 37' 0.90" S, 114° 3' 4.41" E
Point 5	Tanjung Glugur Village, Mangaran Subdistrict	7° 37' 18.65" S, 114° 3' 26.89" E

Figure 1. Sample point map

Tools and Materials

The tools used to collect samples are as follows: 1 x 1 m transect, camera, shovel, cool box, multi-level sieve, plankton net (mesh size 1 mm), writing instruments, permanent markers, gloves, sample bottles, ziplock plastic bags, buckets, measuring cups, and label paper.

The materials used include distilled water, tissue, 70% alcohol, wastewater samples from pond outlets, macrozoobenthos samples, and an identification book (FAO, 1998).

Data Collection Techniques

Water Quality Assessed via Physicochemical Parameters

Water samples were taken at the pond outlet ex-situ. During transportation, samples were stored in a cool box containing ice. The water quality analysis was conducted at the Environmental Laboratory of Banyuwangi Regency. Laboratory findings for five water quality parameters (PO_4, NH_3, TSS, BOD, and pH) were used to assess the level of pollution and compliance with wastewater quality standards as stipulated in Ministry of Environment's Regulation No. 1/2025. The procedures for water sample collection and analysis are as follows: SNI (Indonesian National Standards):

Table 2. Research Method

Parameter	Unit	Method	Analysis Location
PH	-	SNI 6989.11-2019	In-situ
BOD	mg/L	SNI 6989.72: 2009	Ex-situ
PO_4	mg/L	SNI 6989-31:2021	Ex-situ
NH_3	mg/L	SNI 06-6989.30-2005	Ex-situ
TSS	mg/L	SNI 6989.3-2019	Ex-situ

The Ministry of Environment has established the following quality standards:

Table 3. Quality Standards for Aquaculture Wastewater

Parameter	Unit	Maximum value
PH	-	6 - 9
BOD	mg/L	50
PO_4	mg/L	0.5
NH_3	mg/L	5
TSS	mg/L	100

Macrozoobenthos Parameters

Macrozoobenthos sampling was conducted during low tide using 1x1 m quadrant transects, repeated three times at each station. Sediment samples within the 1x1 m transect at a depth of 5-10 cm were collected using a shovel and then filtered. The biota was placed in plastic ziplock bags and preserved in 70% alcohol. Sorting and identification of macrozoobenthos were carried out in the Situbondo District Environment Agency laboratory. Identification was based on FAO (1998) references. The number of individuals of each identified benthos species was counted to obtain diversity (H'), number of species (Taxa), and abundance (Individuals) values.

The identification data was then used to calculate the Shannon-Wiener diversity index (H'), which represents the steadiness of the aquatic community structure (Izzah & Roziaty, 2016; Maulana & Kuntjoro, 2023). A high H' value indicates relatively stable water conditions that support biota life, while a low H' value indicates environmental pressure due to increased waste loads or pollution. This analysis forms the basis for assessing the relationship between wastewater quality and pond ecological conditions, and is an important indicator in formulating sustainable shrimp pond management strategies in Situbondo Regency. The formula used to calculate H' (Shannon diversity index) is as follows

$$H' = -\sum_{i=1}^{s} \frac{ni}{N} \ln \frac{ni}{N} \quad (1)$$

Description:
H' = Shannon diversity index
S = number of species
ni = number of individuals of species i
N = total number of individuals of all species
H' < 1: Low diversity (environment polluted or dominated by one species)
1<H'<3: Moderate diversity (environment beginning to be stressed)
H'>3: High diversity (stable and relatively unpolluted environment)

Data Analysis

This study uses a quantitative approach, which is research conducted to test certain theories by examining the relationship between variables (Berlianti et al., 2024). The quantitative approach was chosen because it is able to describe the relationship between environmental parameters and macrozoobenthos responses in a measurable way. In this study, two statistical analysis approaches were used, namely Multiple Linear Regression and Canonical Correspondence Analysis (CCA).

Multiple linear regression is used to analyze the simultaneous effect of several independent variables on one dependent variable. The dependent variable is H' (macrozoobenthos diversity), while the independent variables are PO_4, NH3, TSS, BOD, and PH values. According to a previous research (Imran et al., 2014), the relationship between dissolved oxygen (DO) concentration and variations in physical-chemical factors, including temperature, TSS, and Dh (depth), can be modeled using multiple linear regression analysis. To show the relationship between each water quality parameter (PO_4, NH_3, TSS, BOD, and pH) and the macrozoobenthos diversity index (H'), the R^2 value, P value, and ρ value (Spearman) were used. The R^2 value serves to determine how strongly the model explains the variation (the closer to 1, the stronger the relationship). In the meantime, the significance level (whether the relationship is statistically significant) is indicated by the P value. The ρ value (Spearman) indicates the direction and strength of the relationship (+ or -).

This study applied Canonical Correspondence Analysis (CCA) following the approach of a recent study (Herawati et al., 2024), who analyzed the link between water quality parameters and fish community structures in mangrove habitats. The study showed that CCA is effective for identifying the environmental variables that most influence biota composition. This relevance supports the selection of CCA in our study to evaluate the relationship between shrimp pond wastewater quality and macrozoobenthos habitat suitability on the

Situbondo coast. Unlike the study Herawati et al. (2024), which had limitations of three stations and one sampling period, this study used more stations and periodic sampling repetitions, resulting in a more comprehensive analysis of the response of macrozoobenthos to environmental pressures from shrimp pond effluent.

Result and Discussion

This study tested the quality of liquid waste from shrimp farm wastewater treatment plants by comparing it with the Indonesian Ministry of Environment's Regulation No. 1/2025 concerning Shrimp Farm Wastewater Treatment. The water quality measurement results are presented in Table 4.

Phosphate (PO_4)

The results of this study show that the PO_4 values at the five stations exceed the quality standard threshold as stated in the Indonesian Ministry of Environment's Regulation No. 1/2025 (0,5 mg/L). Station 2 had the lowest value (0.6636 mg/L), whereas station 3 had the highest value (1.8971 mg/L).

Table 4. Water Quality Measurement Results from the Pond Outlet

Parameter	Unit	Station					Quality standards
		1	2	3	4	5	Shrimp ponds
PH	-	7.97	7.38	7.34	7.66	7.31	6 - 9
BOD	mg/L	<1	4.28	5.32	3.47	19.34	50
PO_4	mg/L	0.8157	0.6636	1.8971	1.2717	1.3182	0.5
NH_3	mg/L	5.15	0.6557	8.700	23.56	17.56	5
TSS	mg/L	120.4	21.8	90.5	32.47	258	100

The increase in phosphate levels in pond waste is not only caused by leftover feed but also comes from the excretion of cultivated organisms. Phosphorus excreted through urine is highly soluble, thus having a high potential to trigger eutrophication. Previous studies support this finding. Sugiura (2025) asserts that urinary phosphorus is the most environmentally damaging form of phosphorus because it can directly pollute waterways. Consistent with this, it was found that stations situated farther from the coast exhibited lower phosphate concentrations compared to other locations (Hamuna et al., 2018). Additionally, it was stated that phosphate concentrations in water can be influenced by the season, where the rainy season can increase phosphate levels originating from land runoff (Fadilla et al., 2021).

Total Ammonia (NH_3)

The results of this study show that the NH_3 values at stations 1, 3, 4, and 5 exceed the quality standards set in Ministry of Environment's Regulation No. 1/2025 (5 mg/L). Station 2 had the lowest concentration (0.6557 mg/L), whereas station 4 had the highest (23.56 mg/L). Previous research conducted in the waters of Depapre Beach, Jayapura (Hamuna et al., 2018) showed that stations located far from the coast had lower total ammonia concentrations than other stations. Managing the water quality of shrimp pond effluent is an important step in preventing environmental degradation. One strategy for managing pond wastewater is to reduce nutrient inputs from feed and fertilizer. The higher concentrations of ammonia and phosphate in the water are mainly due to excess nutrients from these sources.

Previous research Romadhona et al. (2016) emphasized that partial (staged) harvesting techniques are one mitigation effort to reduce shrimp density and biomass in ponds so that effluent content such as ammonia at the end of the cultivation period can be minimized.

TSS (Total Suspended Solids)

The measurements show that TSS at several pond outlet stations exceeds the quality standard, indicating a greater accumulation of aquaculture waste. Station 5 had the highest TSS value (258 mg/L), while Station 1 had the lowest (120.4 mg/L), both of which were above the 100 mg/L threshold.

TSS larger than 1 μm will affect light penetration into the water and inhibit the photosynthesis process. Previous finding Mustofa (2017) shows that relatively low TSS concentrations before harvesting increase sharply during the harvesting process, making harvesting the phase that contributes most to the high suspended solids load in pond waste. These findings confirm that without proper management, TSS spikes can pollute receiving waters. Therefore, preventive measures are needed through wastewater treatment before discharge into the environment, such as sedimentation, filtration, or pond treatment to reduce TSS levels before discharge into the environment.

Another study Rohani et al. (2015) also reported that TSS levels in shrimp ponds can reach 13-640 mg/L, exceeding the established quality standards. However, shrimp are still able to grow well because feed management and water quality are carried out professionally so that the impact of high TSS can be minimized. Furthermore, other results (Bachtiar et al., 2024) shows that TSS concentrations in mangrove waters are still within safe limits and have not caused significant ecological pressure.

BOD (Biochemical Oxygen Demand)

BOD is a parameter that reflects the oxygen required by microorganisms to decompose organic matter in water. Elevated BOD values reflect higher levels of organic pollution. High BOD signifies that significant amounts of organic material, originating from plants and animals, have decomposed, thereby requiring aquatic organisms to use more oxygen for degradation. It is remarkable that the BOD values measured at the five stations did not exceed the 50 mg/L quality standard outlined in Ministry of Environment Regulation No. 1/2025.

The concentration of dissolved oxygen can be impacted by environmental factors such salinity, temperature, water turbulence, and atmospheric pressure. When temperatures are high and air pressure is low, the level of dissolved oxygen generally declines. Research Harmayani et al. (2023) shows that increases in TSS, ammonia, BOD, and COD due to anthropogenic activities significantly reduce water quality. These findings are relevant to the conditions in this study, where shrimp pond waste on the Situbondo coast shows a similar pattern, namely the potential to increase pollutant parameters that can affect the suitability of the macrozoobenthos habitat. Besides water quality parameters, the type of substrate also significantly affects the survival, growth, and diversity of macrozoobenthos (Fadilla et al., 2021).

pH

Previous studies have shown that pH dynamics in shrimp ponds are influenced by various factors, including water quality, feed management, and the use of probiotics during the cultivation process (Fahrurrozi et al., 2023). Findings Liwu et al. (2023) also show that the pH of pond water is generally within the optimal range of 7.5–8.5, which is in line with the ideal range for the growth of vaname shrimp, which are still tolerant to pH levels of 6–9. These results are consistent with this study, in which the pH values at several outlet stations were still within an acceptable range and therefore did not constitute a major pollutant parameter. However, pH fluctuations remain important to monitor because they can affect the sensitivity of aquatic organisms. In this study, the lowest pH was recorded at station 5 (7.31), while the highest pH was at station 1 (7.97), and both were still within safe limits for aquatic organisms.

The overall water quality measurement results at each station are presented in a graph in Figure 2.

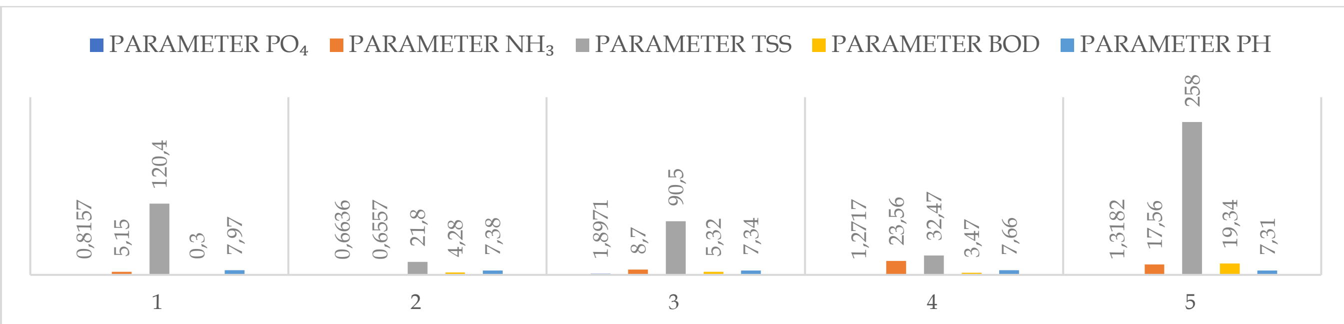

Figure 2. Water quality parameter comparison in shrimp ponds

After comparing water quality parameters with established quality standards, the next step is to assess the water conditions based on the composition and structure of the macrozoobenthos community. This analysis is carried out by calculating the biodiversity index (H'), species richness (Taxa_s) and total individual counts (Individuals) so that the response of the benthic biota to measurable environmental pressures can be determined. The macrozoobenthos diversity study results are displayed in Table 5. Station 2 had the greatest H' value, whereas Stations 3 and 4 had the lowest. The number of species (Taxa_S) exhibits a similar pattern, with Station 2 having the greatest number of species and Stations 3 and 4 recording the fewest.

In contrast, Stations 3, 4, and 5 showed lower individual counts compared to the other stations. Overall, Station 2 showed a more diverse and denser macrozoobenthos community, while Stations 3 and 4 had lower diversity and density of individuals. These differences indicate variations in habitat quality between stations, possibly influenced by the accumulation of pond waste and water quality conditions. A comparison of the diversity index (H'), number of taxa (Taxa_s), and number of individuals at each station is shown in Figure 3. The figure shows striking differences between stations in terms of both diversity and individual density, illustrating the variation in ecosystem conditions at the study site.

Table 5. Water Quality Parameter Values and Macrozoobenthos Index

Station	PO_4	NH_3	TSS	BOD	PH	H'	Taxa_s	Individuals
1	0.8157	5.15	120.4	< 1	7.97	2.033	11	41
2	0.6636	0.6557	21.8	4.28	7.38	2.076	12	51
3	1.8971	8.700	90.5	5.32	7.34	0	1	2
4	1.2717	23.56	32.47	3.47	7.66	0.693	2	2
5	1.3182	17.56	258	19.34	7.31	0	1	2

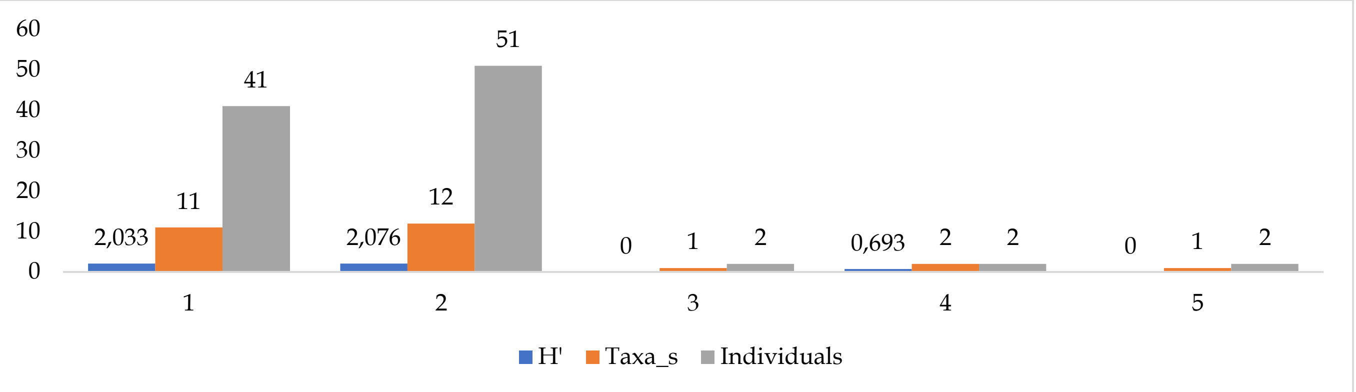

Figure 3. Comparison of H', Taxa_s, and individuals

After discussing water quality parameters and comparisons of H', Taxa_S, and the number of macrozoobenthos individuals, Analyzing the connection between the macrozoobenthos community and water quality was the next stage. Canonical Correspondence Analysis (CCA) was used to provide a thorough understanding of how all environmental factors collectively affect the distribution of macrozoobenthos across the study stations after linear regression was used to assess the impact of individual water quality parameters on diversity.

As shown in Table 6, negative β coefficient values indicate that the diversity index (H') will increase if certain parameter values decrease. Specifically, H' will increase by 1 unit if PO_4 decreases by 1.397 mg/L, NH_3 decreases by 0.0297 mg/L, TSS decreases by 0.00092 mg/L, BOD decreases by 0.0269 mg/L, and pH increases by 0.4962.

The t-value indicates the strength of a variable's influence; a large t-value indicates a strong and significant influence, while a small t-value indicates a weak influence. For example, PO_4 has a t-value of 36.078, indicating a very strong and significant influence, while TSS with a t-value of 2.0534 only has a weak influence, although it is still close to the significance threshold.

In the significance test, a variable is deemed statistically significant when its p-value is < 0.05; if the p-value is ≥ than 0.05, the variable is considered not significant. The Adjusted R^2 value of 99.927% indicates that 99.927% of the variation in H' can be explained by the combination of the variables PO_4, NH_3, TSS, BOD, and pH.

Table 6. Analysis of the Influence of Water Parameters and Macrozoobenthos Diversity

Value of H' against	β	t-calculate	p	Adjusted R Square	Significance F
PO_4	-1.39686	-36.0776	4.78E-11	0.999272	1.076E-14
NH_3	-0.02974	-13.1727	3.47E-07		
TSS	-0.00092	-2.05336	0.070231		
BOD	-0.0269	-3.24711	0.010044		
pH	0.496189	3.749754	0.004556		

Canonical Correspondence Analysis (CCA) results indicate that Axis 1 accounts for 84.45% of the variation in the macrozoobenthos community, whereas Axis 2 accounts for 15.55%. This indicates that most of the distribution patterns of the community are determined by environmental factors related to Axis 1. The results of the CCA analysis can be explained as follows:

The coastal waters receiving shrimp pond effluents in Situbondo exhibited spatial variation in pollution pressure among sampling stations. Concentrations of NH_3, PO_4, BOD, and TSS were higher at stations 3, 4, and 5 compared to stations 1 and 2, indicating greater nutrient and suspended solid loads associated with longer culture periods and the absence of wastewater treatment. Effluents from shrimp aquaculture are known to contain high levels of nutrients and organic particulates, which can increase ecological stress in coastal environments (Romadhona, 2016; Herawati, 2025). Excessive nutrient inputs may promote eutrophication, while elevated TSS can disrupt benthic biota through substrate smothering (Hamuna, 2018; Sinaga, 2024).

Differences in pollution intensity were reflected in the structure of the macrozoobenthic community. The Shannon–Wiener diversity index (H′) at stations 1 and 2 indicated moderate diversity, suggesting that pollution pressure remained at a tolerable level for benthic organisms. This condition is likely associated with shorter culture duration (DOC ±18 days) and the presence of aeration and preliminary wastewater handling at station 2, which reduced effluent loads discharged into the coastal area. In contrast, stations 3, 4, and 5 showed lower H′ values, limited taxa richness, and a dominance of tolerant species such as *Meretrix*, *Oliva*, and *Ocypode*, indicating increased ecological stress due to accumulated organic pollutants during later culture stages.

These findings are consistent with previous studies showing that higher pollutant loads reduce benthic diversity and alter community structure (Maulana, 2023; Rosdatina, 2019). Compared with relatively unpolluted locations such as Pulau Penyengat, where benthic diversity is maintained under low pollution pressure (Rosdatina, 2019), the Situbondo coastal system exhibited reduced benthic diversity accompanied by elevated pollutant concentrations, similar to conditions reported in Pangandaran where coastal waters are impacted by shrimp aquaculture effluents (Herawati, 2025).

Overall, the results demonstrate that macrozoobenthos serve as effective bioindicators for assessing ecological changes in coastal receiving waters influenced by shrimp aquaculture activities, and that H′ values are capable of describing spatial gradients of pollution pressure among stations.

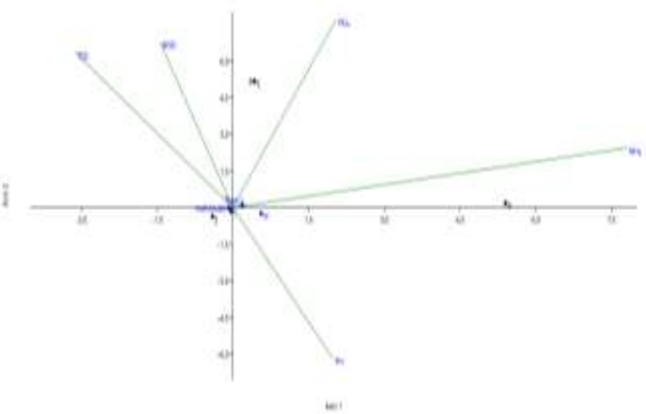

Figure 4. Results of canonical correspondence analysis (CCA) between macrozoobenthos communities and environmental variables at the study site

Conclusion

The findings demonstrate that effluent loading from shrimp aquaculture influences the ecological condition of receiving coastal waters, as reflected by shifts in benthic community structure. Sites exposed to higher nutrient and suspended solid inputs exhibited reduced diversity and taxa richness, as well as an increased dominance of tolerant species, indicating elevated ecological stress. In contrast, areas receiving lower effluent loads maintained more stable benthic assemblages. These results confirm that benthic macroinvertebrates serve as sensitive bioindicators for detecting the ecological consequences of aquaculture discharge in coastal environments. The study highlights the need to integrate effluent management into shrimp farming operations to minimize ecological impacts and sustain coastal ecosystem integrity.

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Author Contributions

Conceptualization, S.M. , H.K and F.C; methodology, S.M.; software, S.M.; validation, S.M., H.K. and F.C.; formal analysis, S.M.; investigation, S.M.; resources, H.K., F.C., and W.L; data curation, S.M.; writing—original draft preparation, S.M.; writing—review and editing, S.M., H.K., F.C., and W.L.; visualization, S.M.; supervision, H.K., and F.C.; project administration, S.M.; funding acquisition.

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Conflicts of Interest

The authors declare that they have no known competing financial interests.

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