VOLUME 12 NOMOR 1 JUNE 2025 ISSN 2548 – 611X

JURNAL
BIOTEKNOLOGI & BIOSAINS INDONESIA

Homepage Jurnal: http://ejournal.brin.go.id/JBBI/index

# THE INFLUENCE OF PHYSICOCHEMICAL PARAMETERS ON THE ABUNDANCE OF MACROZOOBENTHOS IN KUNGKILAN RIVER, SOUTH SUMATERA

## Pengaruh Parameter Fisikokimia terhadap Kelimpahan Makrozoobentos di Sungai Kungkilan, Sumatera Selatan

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**ABSTRACT**
Macrozoobenthos are effective bioindicators for assessing freshwater ecosystem health. This study examines the influence of physicochemical parameters and spatial-temporal variation on macrozoobenthic abundance in the Kungkilan River, South Sumatera. Sampling was conducted at upstream, midstream, and downstream sites. Generalized Linear Mixed Model (GLMM) analysis revealed that water depth and transparency had significant positive effects, while iron (Fe) in sediment had a negative effect. Random effects analysis showed that site-level variability (variance = 0.680) was far greater than temporal variability, indicating that spatial differences—especially in the midstream zone—were the dominant drivers of community structure. These findings highlight the importance of localized conservation efforts and reinforce the role of macrozoobenthos as reliable indicators of river health in tropical ecosystems.

**Keywords**: *Bioindicators, Spatial Variation, Tropical Rivers, Functional Feeding Groups, Bioassessment*

**ABSTRAK**
Makrozoobentos merupakan bioindikator yang efektif untuk menilai kesehatan ekosistem perairan tawar. Penelitian ini mengkaji pengaruh parameter fisikokimia dan variasi spasial-temporal terhadap kelimpahan makrozoobentos di Sungai Kungkilan, Sumatera Selatan. Sampel diambil dari bagian hulu, tengah, dan hilir sungai. Analisis Generalized Linear Mixed Model (GLMM) menunjukkan bahwa kedalaman dan transparansi air berpengaruh positif signifikan, sementara konsentrasi besi (Fe) dalam sedimen memberikan pengaruh negatif. Analisis efek acak menunjukkan bahwa variasi antar lokasi (varian = 0,680) jauh lebih besar dibandingkan variasi temporal, yang mengindikasikan bahwa perbedaan spasial—terutama pada segmen tengah—merupakan faktor utama pembentuk struktur komunitas. Temuan ini menegaskan pentingnya strategi konservasi berbasis lokasi dan memperkuat peran makrozoobentos sebagai indikator kesehatan sungai di wilayah tropis.

**Kata Kunci:** *Bioindikator, Variasi Spasial, Sungai Tropis, Functional Feeding Groups, Bioasesmen*

***Received**: 23 April 2025* ***Accepted**: 15 July 2025* ***Published**: 17 July 2025*

## INTRODUCTION

Freshwater ecosystems are among the most biodiverse and productive environments on Earth, providing a range of ecosystem services critical for both ecological processes and human well-being (Vári et al., 2022). Rivers, in particular, serve as vital corridors for nutrient cycling, water purification, and habitat connectivity. However, these systems are increasingly subjected to anthropogenic pressures such as agricultural runoff, industrial discharge, urbanization, and mining activities, all of which can alter their physicochemical characteristics and profoundly impact aquatic biodiversity (Cheng et al., 2022).

Macrozoobenthos, or benthic macroinvertebrates, are key biological components of freshwater ecosystems. They contribute significantly to organic matter decomposition, nutrient recycling, and food web dynamics (Teristiandi & Yuliana, 2024). Due to their relatively sedentary nature, varying life cycle stages, and sensitivity to changes in environmental conditions, macrobenthos are widely recognized as reliable bioindicators of ecological integrity and water quality (Lukhabi et al., 2024). Their community structure, abundance, and functional composition can reflect both natural variations and anthropogenic disturbances in aquatic environments.

Physicochemical parameters such as dissolved oxygen (DO), pH, temperature, depth, flow and others are critical determinants of macrozoobenthic distribution and abundance (Ge et al., 2025). Variations in these parameters can affect physiological processes, habitat suitability, and the availability of food resources for benthic organisms (Pati et al., 2023).

In tropical regions like South Sumatera, rivers such as the Kungkilan River play an essential role in sustaining biodiversity and supporting local livelihoods. Nevertheless, comprehensive studies examining the relationships between physicochemical water properties and biological communities in these rivers remain relatively scarce.

Understanding how environmental variables shape macrobenthic communities is crucial for informing conservation strategies and management policies aimed at preserving riverine ecosystems under increasing anthropogenic stress (Munyai et al., 2025). Therefore, this study aims to reveal the influence of selected physicochemical parameters on the abundance of macrobenthos in the Kungkilan River, South Sumatera. This research seeks to identify key environmental drivers of macrozoobenthic abundance patterns and enhance the understanding of biophysical interactions in tropical freshwater ecosystems. The findings are expected to provide critical inputs for the sustainable management and conservation of riverine biodiversity in South Sumatera and similar tropical regions.

## MATERIALS AND METHOD

### Location and Time

The study was conducted in the Kungkilan River, located in South Sumatera, Indonesia. The river traverses diverse land-use areas, including upstream regions characterized by more natural areas, midstream areas impacted by agricultural and mining activities, and downstream sections influenced by urban settlements. Three sampling sites were selected along the river, representing upstream, midstream, and downstream locations to capture environmental gradients and human disturbance levels. Research activities were carried out from September 2022 to December 2022.

### Sampling Design

Field sampling was conducted during the dry season to minimize the effects of seasonal hydrological variability. Three replicates were collected from each site, resulting in a total of nine samples for both macrozoobenthos and physicochemical analyses.

### Physicochemical Parameters

Water quality parameters were measured in situ at each sampling point including dissolved oxygen (DO), temperature, depth, transparancy, flow, rainy day, rainfall pH, heavy metal (Fe and Mn) in sediment and water.

### Macrozoobenthos Sampling

Macrozoobenthos were sampled using a Ekman Grab. At each site, three subsamples were taken randomly within a 5-

meter stretch to account for microhabitat heterogeneity. Samples were preserved in 70% ethanol and transported to the laboratory for further analysis.

In the laboratory, macrozoobenthic organisms were sorted under a stereomicroscope and identified to the genus level. Individuals were categorized into functional feeding groups (FFGs) based on feeding habits: collector-gatherers, collector-filterers, scrapers, shredders, and predators.

### Data Analysis

The abundance was calculated to assess the diversity and dominance patterns of macrozoobenthos across the different sampling sites. To determine whether there were statistically significant differences in macrozoobenthos abundance among the sampling locations, a Kruskal-Wallis test was applied. When significant differences were detected, Dunn's post-hoc test was conducted to perform pairwise comparisons between sites.

Generalized Linear Mixed Models (GLMMs) were employed to quantify the influence of physicochemical variables on macrozoobenthos abundance while accounting for variability among sites and time as a random effect. Model selection was based on the Akaike's Information Criterion (AIC) to identify the best-fitting model that adequately described the data. All statistical analyses were performed using R studio.

## RESULT AND DISCUSSION

### Macrozoobenthos Abundance Across Sampling Sites

A total of 171 individual macrozoobenthos belonging to 12 genus were collected from the Kungkilan River. The abundance of macrozoobenthos varied significantly among the three sampling sites (upstream, midstream, and downstream) (Figure 1).

The boxplot illustrates a distinct spatial gradient in macrozoobenthos abundance along the Kungkilan River. The upstream site shows the highest variability and median abundance, with values ranging widely and extending beyond 15 individuals in some samples. This suggests that upstream conditions are more favorable for benthic macroinvertebrate communities, likely due to better water quality and habitat heterogeneity. The relatively high interquartile range also indicates diverse microhabitat conditions supporting a wider range of taxa.

In contrast, the midstream site displays the lowest macrozoobenthic abundance, with a very narrow interquartile range clustered around low values, suggesting a homogenized and potentially disturbed habitat. This indicates a homogenized and potentially degraded habitat, possibly driven by anthropogenic stressors such as sedimentation, agricultural runoff, or mining activities common in the region. Such stressors reduce habitat complexity, oxygen levels, and organic matter quality, leading to the decline of sensitive taxa and simplified community structures (Franca et al., 2025).

Meanwhile, the downstream site shows slightly higher abundance than midstream, but with less variation compared to upstream. The presence of outliers at the downstream site may reflect isolated microhabitats that temporarily support more individuals despite general degradation. Collectively, the pattern underscores a decline in ecosystem quality from upstream to midstream, with only partial recovery downstream. Similar patterns of downstream partial recovery are commonly observed in rivers where depositional zones allow temporary settlement but cannot fully restore biological integrity (Teristiandi, 2021).

**Table 1.** Kruskal-Wallis Test Results

| Statistic | Value |
|---|---|
| Kruskal-Wallis chi-squared | 21.986 |
| df | 2 |
| p-value | $1.682 \times 10^{-5}$ |

The Kruskal-Wallis test revealed a statistically significant difference in macrozoobenthos abundance between sites ($p < 0.05$) (Table 1). Subsequent Dunn's post-hoc test indicated that the abundance at the upstream site was significantly higher than at the midstream and downstream sites (Table 2).

The Kruskal-Wallis test was performed to assess differences in macrozoobenthos abundance across the three sampling sites—upstream, midstream, and downstream—along the Kungkilan River. The analysis revealed a highly significant difference in abundance among sites ($\chi^2 = 21.986$, df = 2, $p = 1.682 \times 10^{-5}$), indicating that at least one site differed substantially in terms of macrozoobenthic community abundance (Table 1). This non-parametric test was appropriate due to the non-normal distribution and unequal variances in the data, as suggested by boxplot visualizations.

To further explore these differences, Dunn's post-hoc test was conducted for pairwise comparisons (Table 2). The comparison between the midstream and upstream sites yielded the most significant result ($p = 1.41 \times 10^{-5}$), underscoring a steep decline in abundance in the midstream section—likely linked to anthropogenic stressors such as pollution or habitat disruption. A significant difference was also observed between the downstream and midstream sites ($p = 2.29 \times 10^{-3}$), though the difference was less pronounced. In contrast, the downstream–upstream comparison did not reach statistical significance ($p = 0.158$), suggesting that while environmental quality may differ, the total abundance of macrozoobenthos at these two sites may be similar, potentially due to dominance by tolerant species in the downstream region.

These findings clearly establish a statistically supported spatial gradient in macrozoobenthic abundance and highlight the midstream area as a zone of concern requiring targeted management and restoration efforts.

**Functional Feeding Groups Composition**

The distribution of functional feeding groups (FFGs) varied noticeably across the the sampling sites (Figure 2).

**Table 2.** Dunn's Test Results

| Comparison | P |
|---|---|
| Downstream-Midstream | $2.294368 \times 10^{-3}$ |
| Downstream-Upstream | $1.589979 \times 10^{-1}$ |
| Midstream-Upstream | $1.411951 \times 10^{-5}$ |

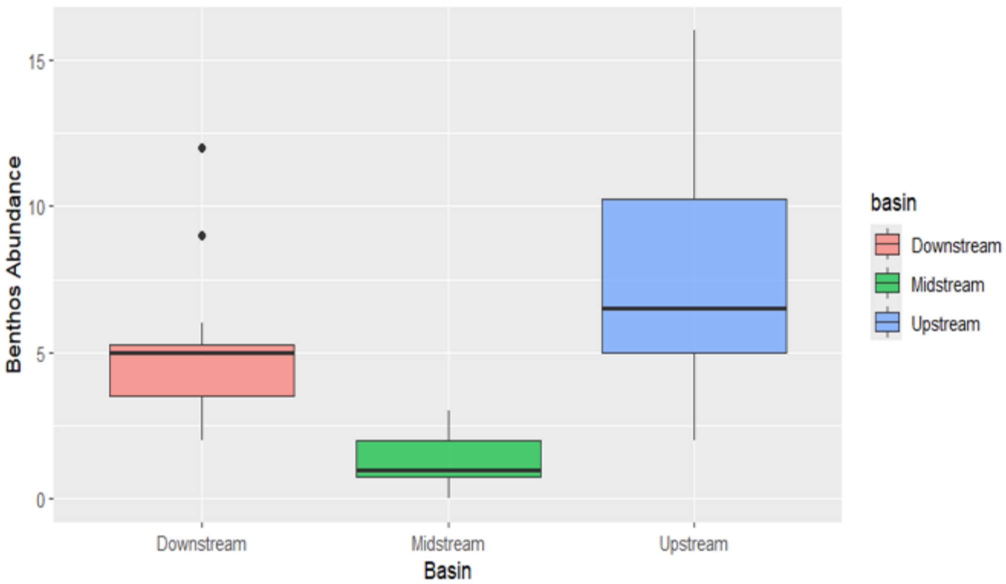


**Figure 1.** The number of macrozoobenthos in three sampling sites

Figure 2 illustrates the spatial variation in the abundance of four main functional feeding groups (FFGs)—collectors, predators, scrapers, and shredders—across the downstream, midstream, and upstream sections of the Kungkilan River. The distribution and dominance of these FFGs reveal clear ecological gradients and reflect habitat quality along the river continuum.

At the upstream site, shredders and scrapers were the dominant groups, with scrapers reaching a median of 6 individuals and shredders up to 5 individuals per sample. This composition suggests a relatively intact and well-oxygenated environment, rich in periphyton and coarse particulate organic matter (CPOM) such as leaf litter. The presence of these sensitive taxa indicates low levels of disturbance and aligns with following findings from GLMM analyses, which identified dissolved oxygen and depth as positive drivers of macrozoobenthic abundance. These results are consistent with another ecological research, where shredders and scrapers are associated with forested headwaters and natural substrates (Fu et al., 2015).

In contrast, the midstream site exhibited severely reduced abundance across all feeding groups, with median values approaching zero and narrow interquartile ranges. The uniform decline suggests intense environmental stress, likely caused by sedimentation, pollution, or mining runoff, which degrade substrate quality and reduce food availability. The near-absence of scrapers and shredders further signals the loss of functional diversity and the collapse of primary energy pathways in this zone (Yagoubi et al., 2023).

In the downstream section, collectors were the most dominant group, with a median abundance of 2–3 individuals and some samples containing up to 12. The prevalence of collectors—tolerant taxa that feed on fine particulate organic matter (FPOM)—reflects adaptation to eutrophic or organically enriched conditions typical of lower river reaches (Bundschuh & Mckie, 2016). Moderate representation of scrapers and predators suggests partial recovery of ecological function compared to midstream, though under conditions still constrained by reduced water quality and sediment accumulation.

The observed shift in FFG dominance—from shredders and scrapers upstream to collectors and generalist feeders downstream—clearly reflects longitudinal changes in habitat quality and resource availability. This pattern supports the utility of functional feeding groups as sensitive ecological indicators of anthropogenic impact and habitat degradation in tropical rivers (Yagoubi et al., 2023).

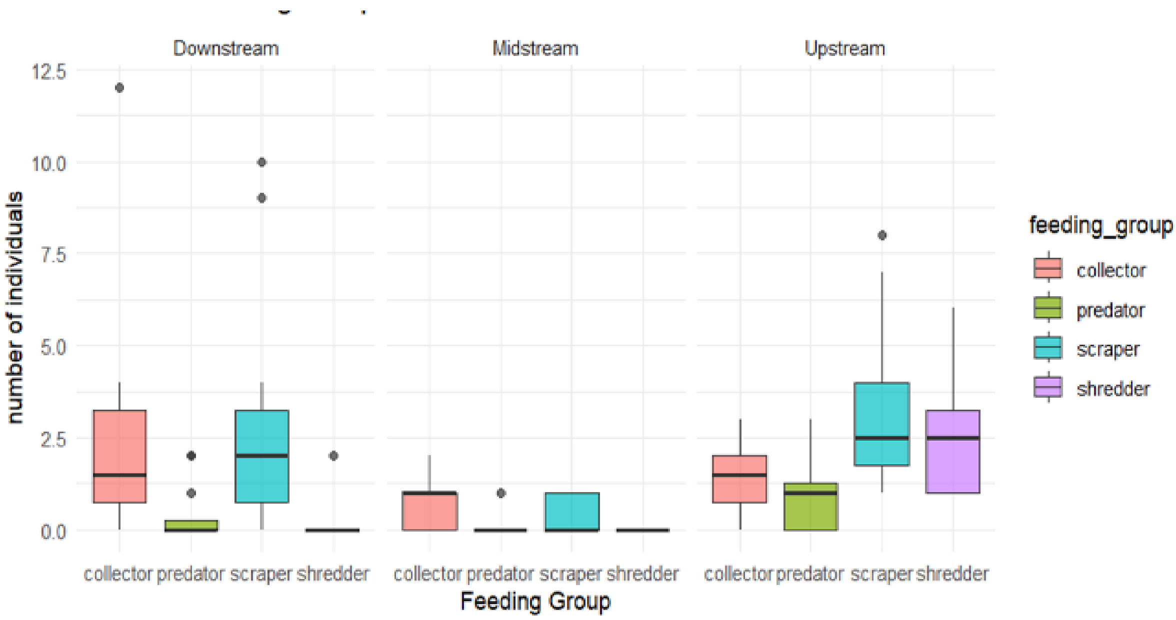


**Figure 2.** The number of functional feeding group in 3 sampling sites

**Relationships Between Macrozoobenthos and Environmental Variables**

The relationships between macrozoobenthic assemblages and environmental parameters were further explored through Generalized Linear Mixed Models (GLMM), providing complementary insights into the ecological drivers shaping community structure along the Kungkilan River.

**Table 3.** the relationship between environmental parameters and macrozoobenthos

| Variable | Estimate | SE | P |
|---|---|---|---|
| (Intercept) | -1.9614 | 3.0977 | 0.5266 |
| flow | -0.1327 | 0.1582 | 0.4015 |
| watertemp | 0.1149 | 0.1063 | 0.2796 |
| depth | -0.3589 | 0.1462 | 0.0141* |
| transparancy | 0.3068 | 0.1479 | 0.038* |
| fesediment | -0.2529 | 0.1282 | 0.0486* |
| mnsediment | -0.1441 | 0.1378 | 0.2957 |
| fewater | 0.1756 | 0.2102 | 0.4035 |
| mnwater | 0.1408 | 0.2502 | 0.5735 |
| rainfall | 0.2027 | 0.1446 | 0.1612 |
| rainday | -0.1284 | 0.2166 | 0.5532 |
| Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' | | | |

The Generalized Linear Mixed Model (GLMM) was employed to assess the relationship between key physicochemical variables and macrozoobenthic abundance, with site treated as a random effect to account for spatial heterogeneity. As presented in Table 3, three environmental parameters—water depth, transparency, and iron (Fe) concentration in sediment—were identified as statistically significant predictors ($p < 0.05$).

Water depth had the strongest positive effect on macrozoobenthos abundance (p =0.0141), indicating that deeper sections of the river provide more favorable conditions for benthic macroinvertebrates. This result may be attributed to several ecological mechanisms. Shallow habitats tend to receive greater light penetration, facilitating periphyton growth and primary productivity, which in turn enhances food availability for grazers and scrapers (Handerson et al., 2021). Additionally, shallower zones often contain coarser substrates and higher flow velocities, which improve oxygenation and may support a broader range of benthic microhabitats (Szałkiewicz et al., 2022). In tropical rivers, such areas are also less prone to stratification and can maintain better water quality in the presence of high biological activity.

Water transparency, reflecting clarity and reduced suspended solids, was also positively associated with macrozoobenthic abundance (p = 0.038). Increased light penetration can stimulate periphyton growth, enhance primary productivity, and improve visual feeding efficiency for taxa such as scrapers, ultimately supporting more robust benthic communities (Izagirre et al., 2009).

In contrast, iron (Fe) concentration in sediment exhibited a significant negative effect (p = 0.0486). Elevated heavy metal levels, commonly linked to mining runoff and industrial discharges, can reduce oxygen diffusion in sediments, alter microbial processes, and introduce toxic stress to invertebrates through direct exposure or ingestion of contaminated particles (Wang et al., 2022; Elnabi et al., 2023; Asare et al., 2025). Such impacts impair burrowing and feeding behavior and may lead to reduced richness and density of macrozoobenthic taxa.

These findings highlight the dual importance of habitat structure (depth) and optical conditions (transparency) in supporting benthic biodiversity, while also underscoring the detrimental effects of sediment contamination by heavy metals such as Fe. The alignment of GLMM outcomes with previous ecological research and observational data confirms the predictive power of environmental gradients in shaping macrozoobenthic assemblages and supports the inclusion of sediment quality metrics in biomonitoring programs.

**Table 4.** The relationship between random effects and macrozoobenthos

| Groups | Variance | SE |
|---|---|---|
| Block | 0.4078 | 0.6386 |
| Temporal | $3.258 \times 10^{-11}$ | $5.708 \times 10^{-6}$ |

Furthermore, the random effects analysis of the Generalized Linear Mixed Model (GLMM) revealed a clear dominance of spatial over temporal variation in determining macrozoobenthic abundance along the Kungkilan River. Specifically, site-level variability showed a variance of 0.680, which was considerably higher than the temporal variability, recorded at $3.258 \times 10^{-11}$ (Table 4). This substantial difference indicates that the spatial heterogeneity among the three sampling sites—upstream, midstream, and downstream—had a significantly stronger impact on macrozoobenthic distribution than the short-term temporal fluctuations observed during the study period.

The elevated variance at the site level highlights the importance of localized environmental conditions in structuring benthic communities. The midstream segment, in particular, contributed most to this variability, likely due to the presence of intensive anthropogenic stressors such as mining runoff, agricultural inputs, riparian vegetation loss, and sediment deposition. These factors alter substrate composition, increase pollutant load, and reduce dissolved oxygen—resulting in habitat simplification, which favors generalist and tolerant taxa while reducing overall macrozoobenthic abundance and diversity (Smith et al., 2003; Kreiling et al., 2022).

In contrast, the upstream segment displayed relatively low variability, reflecting more stable and undisturbed conditions, including intact riparian buffers, minimal land-use pressure, and high habitat heterogeneity. These conditions support the persistence of sensitive taxa and functionally diverse communities. The downstream segment, although exposed to cumulative upstream impacts, exhibited moderate variability, potentially due to natural dilution processes, sediment settling, and channel widening, which offer partial habitat recovery (Tuan et al., 2023; Farguell et al., 2024).

These findings have critical implications for river management. The clear dominance of site-level over temporal effects suggests that spatially targeted conservation strategies are more effective than uniform, system-wide approaches. Management actions should prioritize the midstream zone for intervention, with measures such as sediment control, riparian reforestation, and strict regulation of mining discharges. These actions can mitigate the localized degradation and restore suitable habitat conditions for macrozoobenthic communities.

Furthermore, this analysis reinforces the importance of incorporating spatial structure into ecological monitoring and modeling frameworks. The high responsiveness of macrozoobenthic assemblages to local environmental gradients validates their role as effective bioindicators in tropical freshwater systems (Sahidin et al., 2019; Ernawati et al., 2023). Site-specific variance, when properly accounted for, can provide valuable ecological insight and improve the precision of conservation interventions.

## CONCLUSION

This study shows that macrozoobenthic communities in the Kungkilan River are primarily shaped by water depth, transparency, and iron (Fe) in sediment. Higher abundance was found in deeper, clearer waters, while elevated Fe levels negatively affected community structure. Upstream sites supported more sensitive taxa, whereas downstream and midstream were dominated by tolerant groups. Spatial variation, especially site-level differences, had a stronger influence than temporal factors, highlighting the severe impact of habitat degradation—particularly in the midstream area. These findings underscore the need for targeted habitat restoration and confirm macrozoobenthos as effective bioindicators of tropical river health.

## ACKNOWLEDGEMENTS

The authors wish to thank and acknowledge the Research and Community Service Institute (LP2M) and the Biology Department, Faculty of Science and Technology, State Islamic University Raden Fatah Palembang, for the assistance provided during the course of this study.

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