Distribution of functional feeding group of macrozoobenthos in Lematang River, Merapi, South Sumatera

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Abstract. Merapi is well-known for its extensive coal mining activities, which have a positive impact on the economy but also negatively affect environmental quality, particularly the quality of the river. This study investigates the impact of coal mining on the distribution of functional feeding group (FFG) of macrozoobenthos in the Lematang River, Merapi, South Sumatra. Sampling was conducted at three stations: upstream (ST I), midstream near mining discharge (ST II), and downstream (ST III). Macrozoobenthos were collected using Ekman grab, and water and sediment samples were analyzed for pH, dissolved oxygen and heavy metals (Fe and Mn). Results indicated significant differences in macrozoobenthos density and diversity across stations. ST I exhibited the highest diversity and evenness, reflecting minimal mining impact. In contrast, ST II showed reduced diversity and higher dominance due to heavy metal pollution, indicating severe ecological stress. ST III demonstrated partial recovery with intermediate conditions. High Fe and Mn levels in river were identified as critical factors negatively affecting macrozoobenthos abundance. Furthermore, *Tanytarsus sp*., which were more abundant at ST II, tend to be tolerant, while some species, including *Optioservus* sp. and *Stenelmis* sp., appear to be intolerant. The study underscores the necessity for effective monitoring and management strategies to mitigate the adverse effects of mining activities on river ecosystems. Further research is recommended to explore long-term ecological impacts and develop conservation strategies.

Key Words: coal mining, heavy metal, iron, manganese, macroinvertebrata.

Introduction. Lahat Regency, located in South Sumatra, Indonesia, is renowned for its extensive coal mining activities, which significantly contribute to the region's economy (Sengupta 2021). However, while these mining operations have bolstered local and regional economies, they have also introduced substantial environmental challenges, particularly affecting aquatic ecosystems (Afkarina et al 2019; Haddaway et al 2022). One of the most notable environmental impacts is the degradation of water quality in rivers adjacent to mining sites due to the discharge of mining effluents containing low pH and high concentrations of heavy metals such as iron (Fe) and manganese (Mn) (Teristiandi 2021; Mishra et al 2021; Weinberg et al 2022).

Lematang River in Merapi, South Sumatra, is a prime example of a river affected by coal mining activities. The river serves as a critical habitat for various macrozoobenthos species, which play essential roles in the aquatic food web and are often used as bioindicators of water quality in tropical river systems. Macrozoobenthos, including insects, crustaceans, and mollusks, are highly sensitive to changes in water and sediment quality, making them reliable indicators of ecological health (Masese et al 2009; Teristiandi 2018; Tampo et al 2021; Aprilia et al 2023; Orozco-González & Ocasio-Torres 2023).

Macrozoobenthos are integral to the structure and function of aquatic ecosystems. They contribute to nutrient cycling, organic matter decomposition, and serve as a food source for higher trophic levels, including fish and birds (Wang et al 2021a; Xing et al 2021; Kendzierska & Janas 2024). The categorization of macrozoobenthos into functional feeding groups (FFG) – collectors, scrapers, predators, and shredders – provides insights into the ecological processes and trophic interactions within the ecosystem (Masese et al

2009; Mangadze et al 2019). Each FFG has specific feeding habits and ecological roles, reflecting the availability of food resources and habitat conditions.

Collectors, which feed on fine particulate organic matter (FPOM), and scrapers, which graze on periphyton, are often abundant in areas with high organic content and stable substrates. Predators, which prey on other invertebrates, indicate the presence of a diverse and balanced ecosystem (Mangadze et al 2019; Wang et al 2021a). Shredders, which break down coarse particulate organic matter (CPOM), contribute to the decomposition of leaf litter and other organic debris (Tank et al 2010; Xing et al 2021).

Coal mining activities introduce various pollutants into river systems, including sediments, heavy metals, and other contaminants. These pollutants can alter the physical and chemical properties of water and sediment, leading to adverse effects on aquatic life. The heavy metals can accumulate in sediments and aquatic organisms, leading to increased concentrations in higher trophic levels and posing significant ecological and health risks (Ajibade et al 2021; Wang et al 2021b). The persistence and toxic nature of these metals in aquatic ecosystems make them a serious environmental concern, affecting both biodiversity and ecosystem function (Li et al 2001; Liu et al 2022). Direct effects of heavy metals, such as Fe and Mn, include reduced diversity and abundance of benthic invertebrates, while indirect effects may involve modifications of species interactions and reductions in food quality. Heavy metal contamination can severely impact the structure and function of benthic communities by causing both immediate and long-term ecological damage (Li et al 2001; Qu et al 2010; Wang et al 2021b; Liu et al 2022).

The primary objective of this research is to analyze the distribution of functional feeding group (FFG) of macrozoobenthos in Lematang River and to evaluate the impact of physical and chemical factors on their abundance. This study aims to provide essential insights for managing river ecosystems in regions affected by coal mining activities.

Material and Method

Description of the study sites. The study was conducted along the Lematang River (Figure 1) in Merapi, South Sumatra, Indonesia, from September to December 2022. This region is characterized by its extensive coal mining activities, which significantly influence the local aquatic ecosystems. The sampling locations were strategically chosen to represent different sections of the river to capture the gradient of impact from upstream to downstream areas affected by mining discharges.

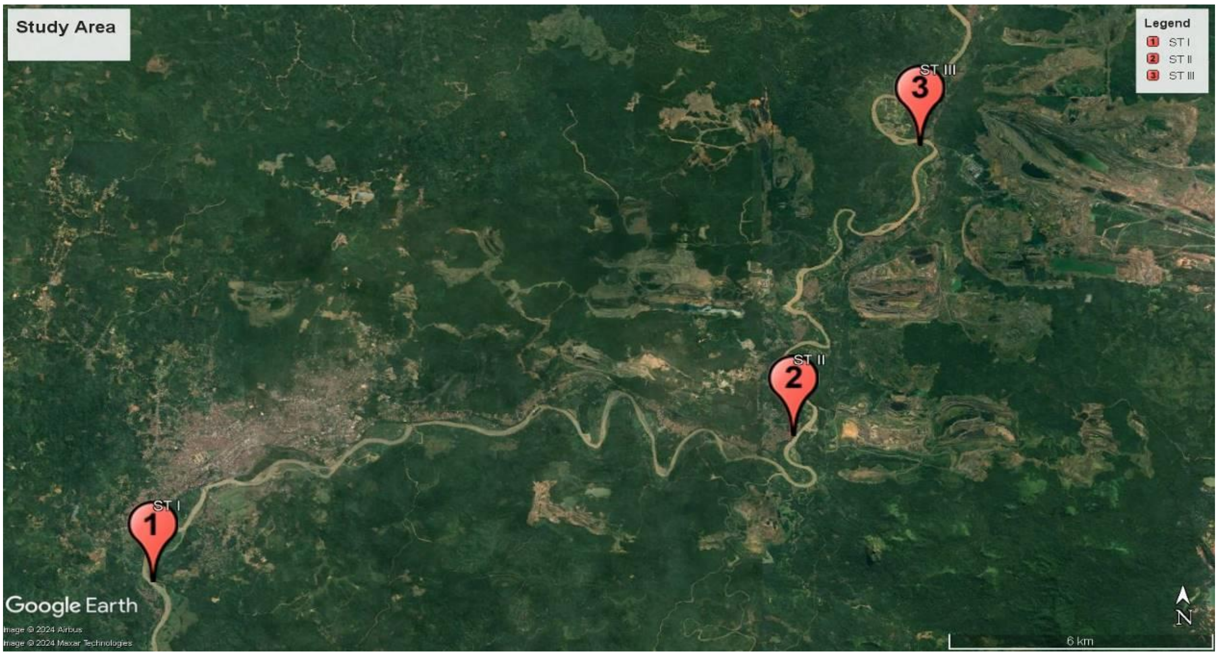

Figure 1. Study area in Merapi, South Sumatera, Indonesia.

Three stations were selected for the study. Station I (ST I) is located upstream and serves as a reference site with minimal direct impact from mining activities. Station II (ST II) is situated midstream near the mining discharge area and is expected to exhibit the highest level of contamination. Station III (ST III) is located downstream, capturing the cumulative impact of mining activities as the river flows.

***Sampling techniques**.* Macrozoobenthos samples were collected using an Ekman grab. This method is widely used in freshwater ecology for its efficiency in capturing a wide range of benthic macroinvertebrates (Cummins et al 2005). Sampling was conducted at three sampling sites on each station once a month from September to December to ensure data reliability and statistical robustness. In the collection process, the Ekman grab was placed against the streambed at each station, and the substrate within the net's area was disturbed by hand to dislodge the macrozoobenthos. The dislodged organisms and sediment were collected in the net and transferred to labeled polyethylene bottles containing 4% formalin solution for preservation. Preserved samples were then transported to the laboratory for identification and analysis. In the laboratory, samples were washed through a series of sieves to remove fine sediments, and macrozoobenthos were sorted under a dissecting microscope.

***Identification of macrozoobenthos**.* Macrozoobenthos were identified to the family level using standard identification keys specific to tropical macrozoobenthos (Merritt et al 2008). Identified organisms were then categorized into their respective FFG: collectors, scrapers, predators, and shredders. This classification helps in understanding the ecological roles and trophic interactions within the river ecosystem (Cummins et al 2005).

***Physical and chemical analysis**.* Water and sediment samples were collected simultaneously with macrozoobenthos sampling to analyze the physical and chemical parameters affecting the macrozoobenthos community. Water quality parameters measured included pH (using a portable pH meter), water temperature (recorded using a digital thermometer), dissolved oxygen (DO, measured using a portable DO meter), transparency (assessed using a Secchi disk), and flow rate (determined using a flow meter). Sediment quality parameters included heavy metal content and particle size distribution. Sediment samples were collected using a grab sampler, air-dried, ground, and sieved to remove debris. The concentrations of Fe and Mn in sediment were analyzed using atomic absorption spectrophotometry (AAS). Particle size distribution was analyzed using standard sieving techniques to determine the composition of the sediment.

***Data analysis**.* Diversity, evenness, and dominance indices were calculated to assess the ecological status of the macrozoobenthos communities. The Shannon-Wiener diversity index (H') provides a measure of species diversity considering both abundance and evenness. The evenness index (E) assesses how evenly individuals are distributed among different species. The dominance index (D) indicates the degree to which a single species dominates the community. Multiple regression analysis was performed to determine the relationship between physical and chemical factors and the abundance of macrozoobenthos. This statistical method helps in understanding how different environmental variables collectively influence the macrozoobenthos community. SPSS (Statistical Package for the Social Sciences) was used for conducting multiple regression and other statistical analyses to identify significant predictors of macrozoobenthos abundance.

Results. The distribution and abundance of macrozoobenthos in Lematang River were examined across three stations: ST I (upstream), ST II (midstream near mining discharge), and ST III (downstream). The Figure 2 revealed the differences in the densities of various taxa at these stations. *Thiara scabra* exhibited the highest density at ST III, suggesting a preference for downstream habitats and a sensitivity to midstream contamination. *Tarebia granifera* followed a similar pattern, with higher densities downstream and lower numbers at ST II. *Tanytarsus* sp. was most abundant at ST I, indicating favorable upstream conditions and a decline in density downstream. *Stenelmis* sp. showed the highest density at ST I, with significant reductions at ST II and ST III, reflecting its sensitivity to pollution. *Pomacea canaliculata* was present only at ST I, with higher density upstream, suggesting adverse effects of midstream pollution. *Optioservus* sp. was primarily found at ST I, with negligible numbers at the other stations. *Melanoides tuberculata* was more abundant at ST I, with reduced densities downstream. *Limnodrilus* sp. and *Corbicula fluminea* were found predominantly at ST III, indicating a preference for downstream habitats. *Chironomus* sp. had higher densities at ST II, showcasing its tolerance to polluted conditions. *Cheumatopsyche* sp. was distributed only at ST III, while *Bezzia* sp. was most abundant at ST I and significantly declined downstream.

The analysis of the diversity, evenness, and dominance indices in Figure 3 for macrozoobenthos across three stations revealed important trends in the ecological health of the Lematang River.

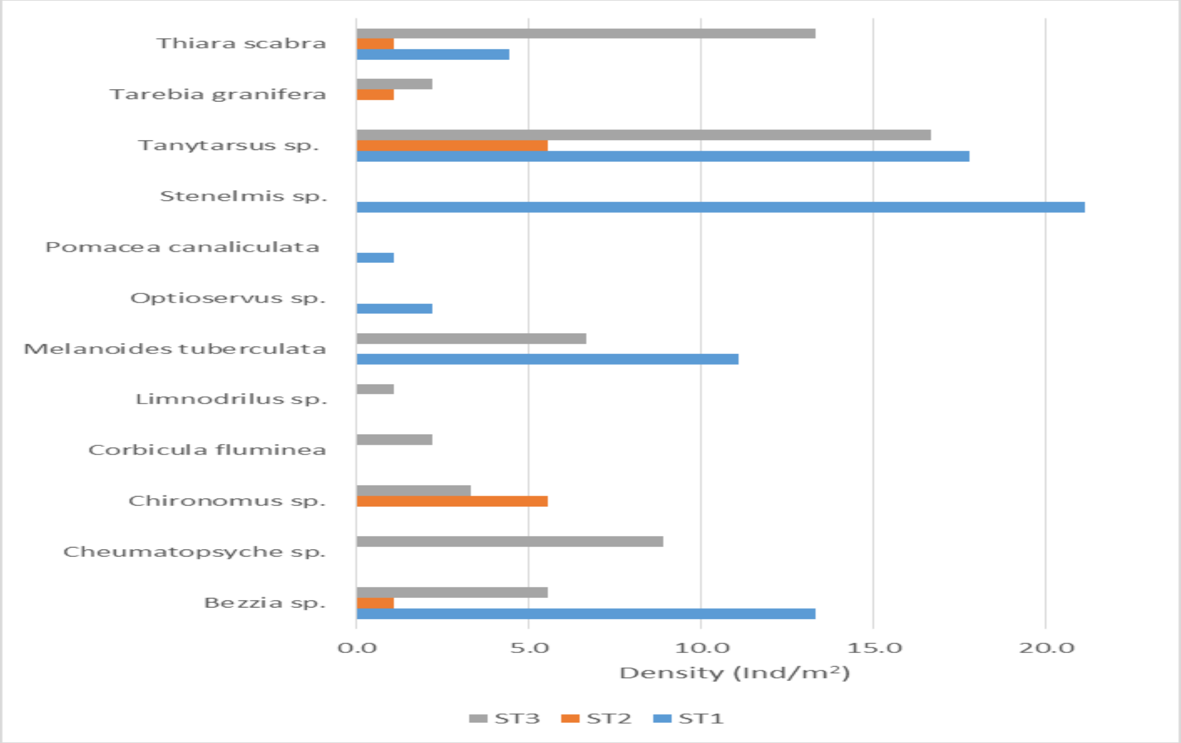

Figure 2. The density of macrozoobenthos in Lematang River.

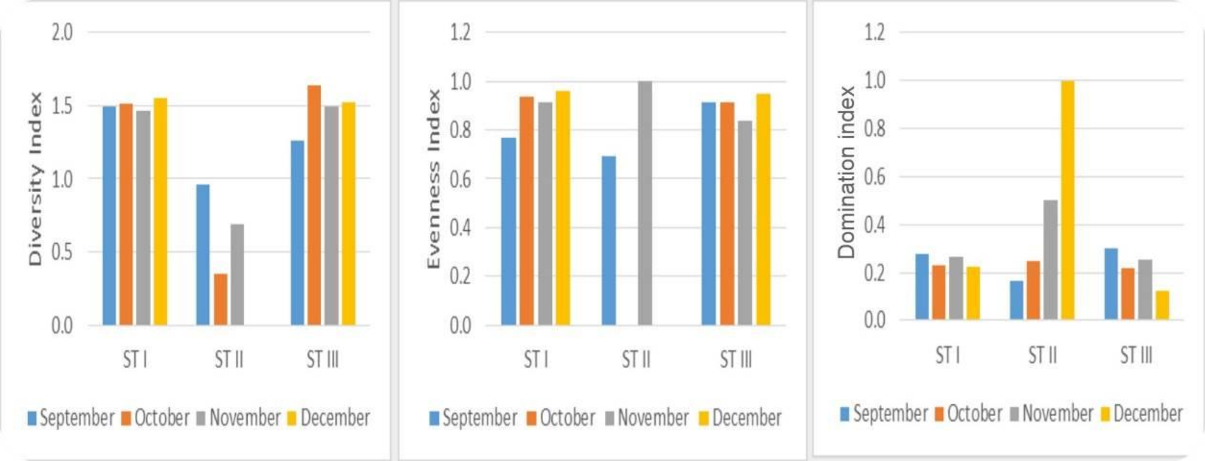

Figure 3. The diversity, evenness, and domination index of macrozoobenthos in Lematang River.

The diversity index (Shannon-Wiener index, H') varied across stations and months. At ST I, the diversity index remained relatively stable, ranging between 1.5 and 1.7 across all months, indicating a consistently diverse macrozoobenthos community. ST II, in contrast, showed significant fluctuations with a notable drop in diversity in October and December, indicating the station's sensitivity to pollution. ST III demonstrated intermediate diversity levels, with a notable increase in diversity in December, suggesting a potential recovery downstream.

The evenness index (E) measures how evenly individuals are distributed among different species. At ST I, the evenness index remained high and stable across all months, indicating a balanced distribution of species. ST II showed more variability, with a lower evenness index in October and November, reflecting an uneven distribution of species likely due to environmental stressors. ST III exhibited moderate evenness, with slight fluctuations but generally higher than ST II, indicating a more balanced community downstream.

The dominance index (D) indicates the degree to which a single species dominates the community. At ST I, the dominance index was low across all months, indicating no single species dominated the community. In contrast, ST II had a significantly higher dominance index in November, suggesting that a few tolerant species dominated the community during this period. ST III showed moderate dominance, with higher values in September and November, but lower in December, indicating a decrease in the dominance of a few species.

Distribution of functional feeding groups (FFG) of macrozoobenthos. The Figure 4 revealed distinct patterns in the density of the macrozoobenthos FFG across three stations from September to December. At ST I, the densities of scrapers were notably high in September, peaking at around 200 individuals per square meter, and remained relatively high in October and November before declining in December. Collectors also showed substantial densities, especially in September and November. Predators, although present, exhibited lower densities across all months, with a slight peak in November. Shredders were the least abundant at ST I, showing minimal presence.

In contrast, ST II exhibited lower overall densities for all FFGs. Scrapers and collectors were the dominant groups but with significantly reduced numbers compared to ST I. Their densities were highest in September and October, dropping considerably in November and December. Predators and shredders were scarcely present at ST II, indicating poor habitat conditions for these groups.

ST III, the downstream station, showed mixed results. Scrapers and collectors were relatively abundant, with the highest density of collectors observed in November at around 150 individuals per square meter. Scrapers had higher densities in September and October. Predators and shredders were present in moderate numbers, with predators showing a consistent but low presence across all months.

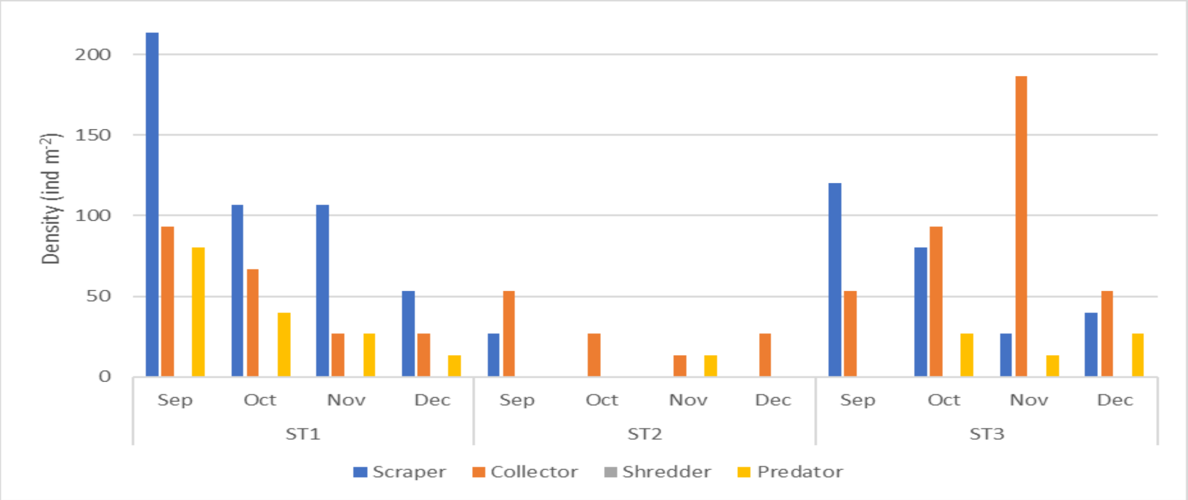

Figure 4. The distribution of functional feeding group of macrozoobenthos in Lematang River.

Impact of physical and chemical factors. Multiple regression analysis (Table 1) revealed that several physical and chemical parameters significantly influenced the abundance and distribution of macrozoobenthos in Lematang River. Notably, the concentration of Fe in sediment emerged as a critical factor with a significant negative impact on macrozoobenthos abundance ($p < 0.05$). High levels of Fe in sediment can create toxic conditions, inhibiting the growth and survival of many aquatic organisms. Water temperature and air temperature also played roles, although their effects were not statistically significant.

The pH levels across the stations were relatively stable, yet slight variations were observed. ST II exhibited a slightly lower pH, correlating with higher metal concentrations, particularly Fe and Mn. Flow rate and depth varied significantly among the stations. ST I had a higher flow rate and greater depth, providing a more oxygenated environment, conducive to a diverse macrozoobenthos community. Conversely, ST II had a reduced flow rate and shallower depth, likely due to sediment deposition from mining activities, resulting in lower oxygen levels and habitat degradation.

Table 1

The multiple regression anlaysis of macrozoobenthos and physicochemical parameters in Lematang River

Variable	*Regression coefficient*	*P*
Dissolved oxygen	1.711	0.100
pH	0.813	0.424
Water temperature	-0.053	0.958
Air temperature	1.758	0.091
Flow rate	-0.747	0.462
Depth	1.335	0.194
Transparency	0.899	0.378
Fe content in water	-0.338	0.738
Mn content in water	0.764	0.452
Fe content in sediment	-2.049	0.052
Mn content in sediment	0.397	0.695

Chemical analysis of water and sediment. The chemical analysis (Figure 5) underscored the significant contamination at ST II, with elevated levels of Fe and Mn in water. These concentrations exceeded the levels considered safe for aquatic life, contributing to the observed decline in sensitive macrozoobenthos species. In contrast, ST I and ST III showed lower concentrations of these metals, supporting healthier macrozoobenthos communities.

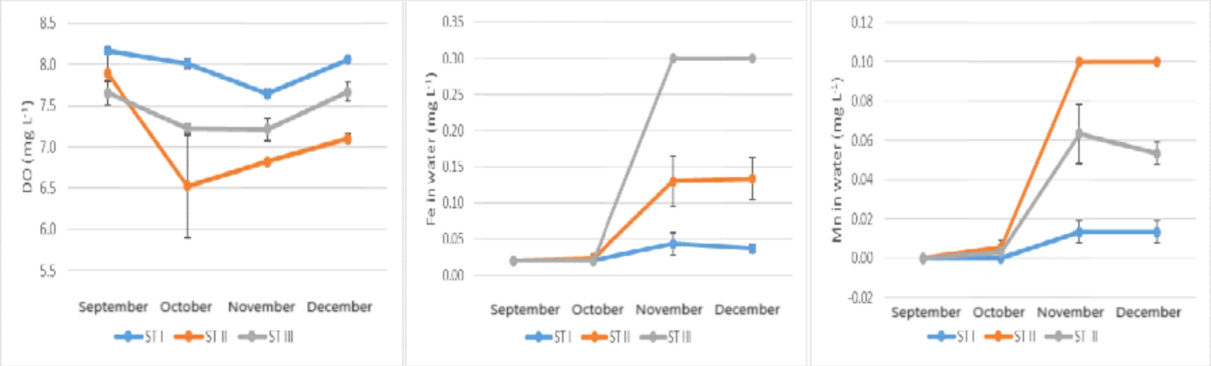

Figure 5. The DO, Fe and Mn concentrations in water of Lematang River.

Discussion. The macrozoobenthos community structure and distribution in Lematang River provide crucial insights into the ecological health of the river, particularly in relation to the impacts of coal mining activities. The higher densities of *T. scabra* and *T. granifera* at ST III suggest that downstream habitats may provide suitable conditions for these species, possibly due to accumulated organic matter or lower immediate impact of pollutants compared to midstream areas. Their lower presence at ST II highlights their sensitivity to pollution, corroborating findings from other studies that indicate these species thrive in cleaner water conditions (Appleton et al 2009; Miranda & Perissinotto 2012).

The presence of *Stenelmis* sp. and *Optioservus* sp. primarily at ST I indicates that upstream conditions are more favorable, likely due to lower pollution levels and more stable substrates. The significant decline in their densities at ST II and ST III points to their intolerance to heavy metal contamination and habitat disturbance, aligning with previous research showing their preference for unpolluted environments (Elliot 2008).

The higher abundance of *M. tuberculata* at ST I and its reduction at midstream and downstream stations suggest that upstream conditions are more conducive to their survival. This pattern is consistent with their known preference for cleaner water and stable habitats (Teristiandi 2018).

Limnodrilus sp. and *C. fluminea* were more prevalent at ST III, indicating a potential adaptation to downstream conditions where organic matter may be more abundant. Their presence at lower densities upstream suggests they can tolerate a range of environmental conditions but may prefer habitats with higher organic content. Studies have shown that *Limnodrilus* species are known for their tolerance to pollution and ability to thrive in organically enriched sediments (Atanacković et al 2023). Similarly, *C. fluminea*, an invasive bivalve, has been observed to flourish in environments with high organic matter, reflecting its adaptability and role in nutrient cycling within aquatic ecosystems (Parra et al 2021; Bespalaya et al 2023).

The higher density of *Chironomus* sp. and *Tanytarsus* sp. at ST II underscores its known tolerance to polluted conditions, particularly those with high levels of organic pollution and heavy metals. These taxa are often used as indicators of degraded water quality (Wang et al 2021a). The relatively even distribution of *Cheumatopsyche* sp. across the stations suggests it has a broader tolerance range to varying environmental conditions, including moderate levels of pollution. The highest density of *Bezzia* sp. at ST I and significant decline at downstream stations indicate its sensitivity to pollution and presence of their prey such as mosquito larvae (Hribar & Mullen 1991).

The indices of diversity, evenness, and dominance for macrozoobenthos in Lematang River provide valuable insights into the ecological impacts of coal mining activities on the river's health. The high and stable diversity and evenness indices at ST I indicate favorable upstream conditions with minimal pollution, abundant food resources, and stable habitats. This reflects a well-balanced ecosystem where species are evenly distributed, and no single species dominates, indicating high biodiversity and ecological health.

In contrast, ST II, located near the mining discharge area, exhibited significant fluctuations in all indices, highlighting severe ecological stress due to mining discharges. The notable drop in diversity and evenness indices in October and December, coupled with the spike in dominance index in November, suggests that the macrozoobenthos community at ST II is dominated by a few pollution-tolerant species. This indicates habitat degradation and reduced biodiversity, which aligns with previous studies showing that heavy metal pollution from mining activities can drastically reduce biodiversity and alter community structures (Ouma et al 2022).

The intermediate conditions at ST III suggest a partial recovery of the macrozoobenthos community downstream. The increase in diversity and evenness indices in December indicates improved ecological conditions, possibly due to dilution and sedimentation of pollutants as the river flows downstream. However, the moderate dominance index throughout most months suggests that some species still dominate the community, reflecting ongoing but reduced ecological stress.

The results of this study highlight the profound impact of coal mining activities on the aquatic ecosystems of Lematang River, with distinct variations in the macrozoobenthos community observed across three different sampling stations: upstream (ST I), midstream (ST II), and downstream (ST III). The significant differences in the distribution and abundance of Functional Feeding Groups (FFG) at these stations underscore the varying degrees of ecological stress and habitat conditions influenced by mining discharges.

At ST I, the macrozoobenthos community exhibited high diversity and evenness indices, indicating a well-balanced ecosystem with minimal anthropogenic disturbance. The dominance of collectors and scrapers at this station suggests that the environment provides ample food resources, such as FPOM and periphyton (Barbour et al 1999; Mangadze et al 2019). The presence of shredders, although in smaller numbers, further indicates the availability of CPOM, essential for these organisms (Barbour et al 1999). These findings suggest that ST I maintains relatively stable and favorable conditions for a wide range of macrozoobenthos, resulting in high biodiversity.

Conversely, ST II, situated near the mining discharge area, presented a starkly different ecological scenario. The severe reduction in the abundance of collectors and scrapers, along with the near absence of predators, highlights the significant ecological stress at this station. The high dominance index (D) observed at ST II indicates that a few tolerant species dominate the macrozoobenthos community, a common response to environments heavily polluted with heavy metals such as Fe and Mn. The instability of the substrate at ST II, due to sediment contamination from mining activities, has created a harsh environment for most macrozoobenthos, leading to a substantial decline in biodiversity. These results are consistent with previous studies that have shown heavy metal pollution to drastically reduce diversity and alter species interactions in benthic communities (Qu et al 2010; García-García et al 2024).

ST III, located downstream, displayed an intermediate ecological condition between ST I and ST II. While the abundance of collectors and scrapers remained high, similar to ST I, the dominance index at ST III was slightly higher, indicating a less even species distribution. The presence of predators in moderate numbers at ST III suggests that the trophic structure, while affected by upstream pollution, is still relatively intact. The conditions at ST III support a diverse macrozoobenthos community, although it is evident that the cumulative impact of pollutants as the river flows downstream has affected its ecological balance.

The multiple regression analysis identified several key physical and chemical parameters influencing the macrozoobenthos communities. Sediment Fe concentration emerged as a critical factor with a significant negative impact on macrozoobenthos abundance ($p < 0.05$). High Fe levels in sediment can create toxic conditions, inhibiting the growth and survival of aquatic organisms. This finding aligns with research by Vuori (1995), which highlighted the adverse effects of heavy metals on aquatic insects. Additionally, slight variations in pH levels were observed across the stations, with ST II exhibiting lower pH levels correlating with higher metal concentrations. Lower pH can increase the solubility of heavy metals, exacerbating their toxicity to aquatic organisms (Zhang et al 2014; Sintorini et al 2021).

The chemical analysis of water and sediment highlighted the significant contamination at ST II, with elevated levels of Fe and Mn far exceeding safe levels for aquatic life. This contamination poses risks of bioaccumulation and biomagnification, potentially impacting the entire aquatic food web. This process not only affects the health of individual species but can also disrupt entire ecosystems by altering predator-prey relationships and reducing biodiversity (Dehghani et al 2021; Saidon et al 2023). In contrast, ST I and ST III exhibited lower concentrations of these metals, supporting healthier macrozoobenthos communities. These findings underscore the urgent need for stringent monitoring and regulation of mining discharges to mitigate their adverse effects on river ecosystems.

To address these challenges, comprehensive monitoring and effective management strategies are essential. Routine monitoring of water and sediment quality, combined with bioassessment programs using macrozoobenthos as bioindicators, can provide early warnings of ecological disturbances. Implementing best management practices in mining operations, such as constructing sedimentation ponds, erosion control measures, and treating wastewater before discharge, can significantly reduce pollutant release into the river. Restoring and rehabilitating degraded habitats by stabilizing substrates, re-establishing native vegetation, and improving water quality can enhance the resilience of aquatic ecosystems.

Conclusions. This study demonstrates the significant influence of physical and chemical factors, particularly heavy metal concentrations, on the distribution and abundance of macrozoobenthos in Lematang River. The presence of coal mining waste has led to notable changes in macrozoobenthos community composition, emphasizing the need for comprehensive monitoring and effective management strategies. The findings underscore the importance of protecting and preserving river ecosystems in mining regions to ensure their ecological integrity and sustainability. By implementing best practices, engaging local communities, and fostering ongoing research, we can mitigate the negative impacts of mining activities and promote the health and resilience of aquatic ecosystems. Further research is recommended to explore the long-term ecological effects of mining-related pollution and to develop effective strategies for habitat restoration and conservation. Through collaborative efforts and innovative approaches, we can achieve sustainable management of river ecosystems in the face of growing environmental challenges.

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Conflict of interest. The authors declare that there is no conflict of interest.

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