BIOTROPIA ISSN: 0215-6334 | e-ISSN: 1907-770X
The Southeast Asian Journal of Tropical Biology
Vol. 31 No. 3, 2024: 359 - 371
DOI: 10.11598/btb.2024.31.3.2267

Research Article

ECOLOGICAL INDICES OF MANGROVE GASTROPOD COMMUNITY IN NICKEL MINING IMPACTED AREA OF POMALAA, SOUTHEAST SULAWESI

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ARTICLE HIGLIGHTS

- Gastropods (Invertebrates: Mollusca) have the potential to be developed as biological indicators of the health of coastal aquatic environments
- The development of gastropod communities has been proven to provide a significant ecological response in assessing environmental quality in the mangrove in relation to overburden waste input from nickel mining activities.
- Overburden waste systemically degrades the ground floor (substrate) of the mangrove ecosystem as an area where the entire life cycle of the gastropod community is carried out.

Article Information

Received : 24 May 2024
Revised : 19 July 2024
Accepted : 21 July 2024

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ABSTRACT

This research aimed to determine the structure of gastropod community in the nickel mining impact area in the mangrove ecosystem of Tambea Village, Pomalaa District, Southeast Sulawesi Province. The scope of this research was gastropod community influenced by nickel mining activities, especially the impact of overburden waste input (reddish-orange colored sediment) toward the health status of the aquatic environment based on the ecological indices of the gastropod community in the mangrove ecosystem of Tambea Village. Two sampling methods were adopted in this research: (1) purposive sampling method to determine stations (locus) and (2) simple random sampling method to determine the distribution of substations or sampling points. Gastropod samples were taken using handpicking techniques. The structure of gastropod community in mangrove area affected by overburden waste showed low diversity index values (H' = 0.81), low species richness (R = 1.75), moderate evenness (E = 0.50), and dominance of certain species (C = 0.54). The results of this research showed the massive impact of overburdened waste, which can systemically degrade the life of the typical fauna that make up the mangrove ecosystem. Three gastropods species were observed to live in the research location, namely *Telescopium telescopium, Terebralia sulcata,* and *Terebralia palustris* having low abundance (1-9 ind./m^2) which can survive in environment exposed to overburden waste. Many of gastropod species were found dead, indicated by the finding of 2 shells of *Ellobium aurisjudae*. The input of overburdened waste may imply degradation system of the aquatic environment, especially in the mangrove ecosystem. This research offers outlooks of overburden waste on aquatic biota in mangrove ecosystems and other complimentary ecosystems. In the end, the condition of the gastropod community in a watered area becomes a basis of the health status of the water environment.

Keywords: Ecological index, gastropods, mangrove, nickel mining, overburden

INTRODUCTION

Coastal area is vulnerable to environmental changes, and so are the organisms living in the environment (Boruff *et al.* 2005; Wahyudi 2009; Basir 2010). The decline in environmental quality in this region is caused by anthropogenic activities which tend to be environmentally unfriendly (Singer & Battin 2007; Norris & Thoms 1999; Dziock *et al.* 2006). Tambea Village is one of the active open-cut nickel mining system operating in Pomalaa District, Southeast Sulawesi Province. The impact of nickel mining activities in Tambea Village is visible from changes in the environmental tone around the mangrove ecosystem and coastal areas in general. The condition of the substrate, water, and mangrove roots is orange-reddish, due to the input of overburden waste or waste rock in the form of acid mine sludge/Acid Rock Drainage (ARD) which contains low minerals (Hamzah *et al.* 2015; Hamzah 2009; Zubayr 2009).

Overburden waste has polluted the Tambea mangrove area for the last 2 decades and has accumulated ± 10-30 cm overburden waste covering the original (natural) substrate (Hamzah 2009; Zubayr 2009). The overburden phenomenon that has been occurring for a long time, and continues to this day, can massively degrade the habitat of gastropod communities and has implications for the decline of taxa (species) and their abundance in waters as well as resulting in the loss of species that are classified as sensitive (Timm *et al.* 2001; Chakrabarty & Das 2006).

The input of overburden waste into the Tambea mangrove ecosystem does not only disturb the mangrove vegetation and other coastal plants, but also threatens the life stability of the gastropod community as part of the association (Purnama *et al.* 2024a; 2024b). Mangrove gastropods are known as benthic organisms (dominantly epifauna), spending the entire life cycle at the bottom of the waters or occupying the substrate as their life niche. The bottom water substrate in the mangrove ecosystem is the habitat of the gastropod community (Chukaeva & Petrov 2023; Menon *et al.* 2023; Laraswati *et al.* 2020; Wahyudi *et al.* 2015; Campbell & Reece 2008). Therefore, any disturbances arising from various anthropogenic activities, especially exposure to overburden waste, can cause loss of habitat and ecological niche of gastropod communities (Purnama *et al.* 2024a). In the end, the phenomenon of overburden waste exposure can eliminate the existence of the gastropod community as one of the keystone species in its ecological environment (Purnama *et al.* 2024b).

Accordingly, empirical research regarding the ecological indices of gastropods in areas with exposure to overburden waste in the mangrove ecosystem of Tambea Village is very important to carry out, considering that research related to this has never been carried out in Southeast Sulawesi in particular and Indonesia in general. Apart from that, this research has important value as a source of renewable novel scientific information about gastropod communities that can survive in areas exposed to overburden waste from nickel mining activity. This research aimed to determine the ecological indices of gastropod communities in mangrove areas exposed to overburden waste in Tambea Village, Pomalaa District, Southeast Sulawesi Province.

MATERIALS AND METHODS

Materials and Tools

Materials used in this research were distilled water and 70% alcohol (to preserve the samples). Meanwhile, tools used in this research were quadrat transects, gloves, hand scoops, plastic bags to store samples, sample baskets, label paper, and an instrument for taking samples in the field.

Research Sites

The research was carried out in mangrove ecosystem in Tambea Village, Pomalaa District, Kolaka Regency, Southeast Sulawesi Province. The research location is directly connected to the upstream flow, where the existing nickel mining area is located, which carries overburden waste. The research location (-4.219927, 121.584465) was transformed into station dimensions, totaling 5 sample areas spread across the Tambea Village mangrove ecosystem. These 5 stations were representatives of the entire extent of the mangrove ecosystem at the research location. An overview of the research location is presented in Figure 1.

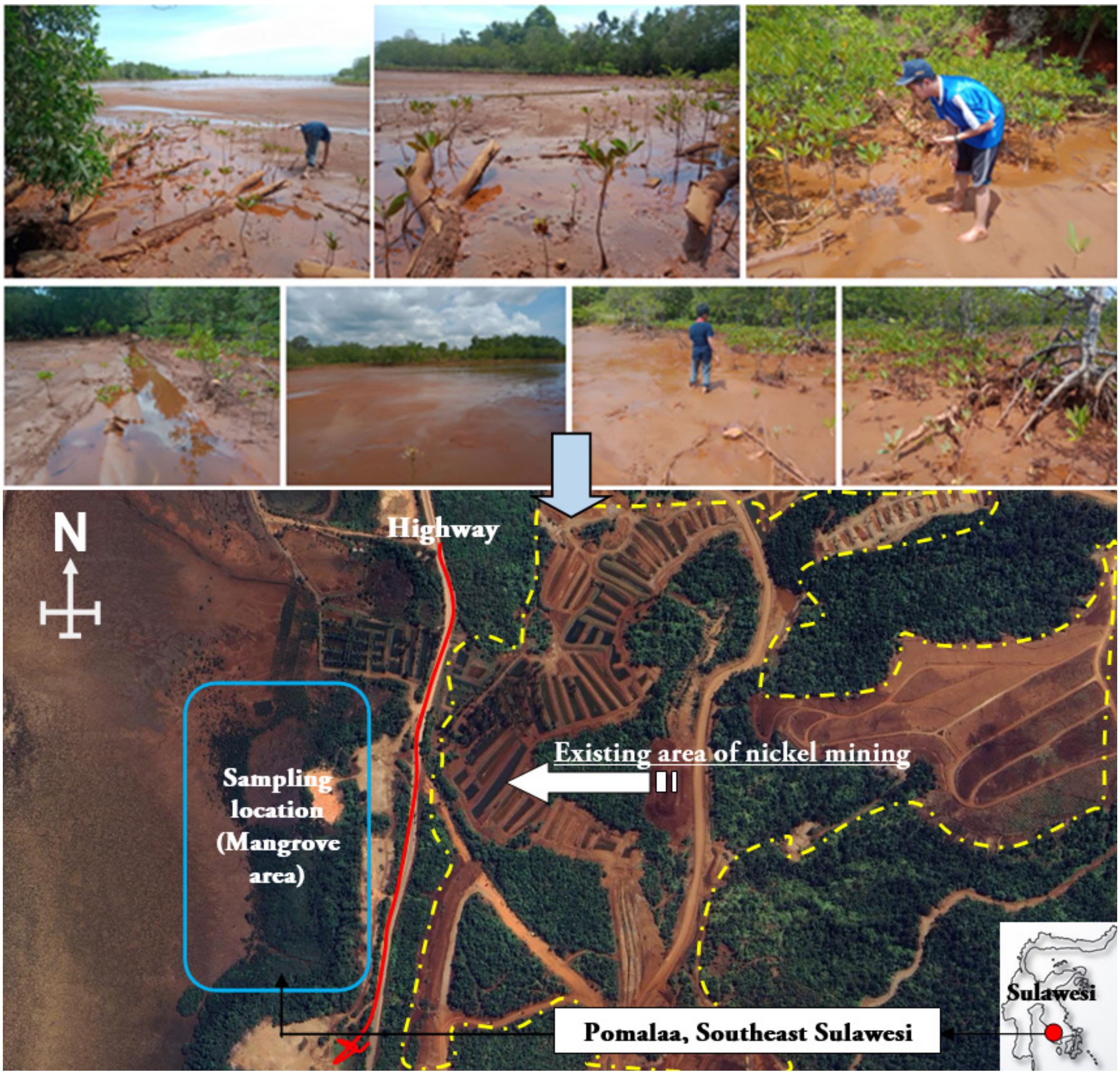

Figure 1 Research location in the Tambea mangrove ecosystem which is exposed to overburden waste from nickel mining activities

Description of the Problem or Reason for the Research

Gastropods live in their natural environment as fungivores, carnivores, omnivores scavengers, and detritivores based on their food habits and have a role as prey or food for several fish species (mangrove jack), birds (poultry), and crustaceans in the mangrove ecosystem (Lalita 2016; Alongi 2009; Cappenberg *et al.* 2006). All biological activities related to food habits and ecological roles take place on the ground floor or substrate of the mangrove ecosystem (benthos-epifauna) (Chukaeva & Petrov 2023; Menon *et al.* 2023). Continuous exposure to overburden waste can permanently damage the residential habitat of most gastropod communities (Purnama *et al.* 2024a). Moreover, the input of overburden waste has been ongoing for approximately 2 decades. In other words, the loss of natural substrate which is covered by overburden sediment waste, directly affects the life system of gastropod community, considering that the activities that support the gastropod's survival are carried out at the bottom of the waters (Purnama *et al.* 2024a; 2024b). Therefore, this research needs to be carried out as updated empirical information regarding taxa and ecological indices of gastropod communities that live in mangrove areas with overburden waste exposure. Gastropods exposed to overburden waste has the shell appearance that tend to be corrosive, as is shown in Figure 2.

Figure 2 Condition of mangrove gastropods exposed to overburden waste

Data collection methods

Data of ecological indices in this study was obtained through sampling activities applied in gastropod community at the research location. Purposive sampling method was used to determine research location, based on the presence of mangrove areas exposed to overburden waste in Tambea Village. Subsequently, the distribution of sampling points (substations) at the research location (station) was determined using a simple random sampling technique to cover a wider sampling area and increase the possibility of obtaining a greater number of gastropod samples. Simple random sampling is a technique where sample elements are randomly selected from a homogeneous population, giving each component an equal chance of being selected (Odum 1993).

Mangrove gastropods are very easy to collect when the waters are receding, because they have a dominant life habit of sticking to the roots, stems, and leaves of mangroves, while the rest are usually found on the ground floor (water substrate) as benthic epifauna organisms. Therefore, the technique for collecting gastropod samples at each station was the handpicking method or hand-picked without special fishing equipment.

Data analysis

Data obtained from sampling results were then analyzed to obtain the following ecological indices.

1. Gastropod density was calculated using formulation according to Yasman (1998):

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

where:

A = abundance (ind./m^2)
xi = number of individuals (ind.)
ni = sample plot size (m^2)

2. Gastropod species diversity was determined by using the Shannon-Wiener diversity index (Odum 1993):

$$H' = - \sum_{i=1}^{s} \left[\left(\frac{ni}{N}\right) \text{x Ln} \left(\frac{ni}{N}\right) \right]$$

where:

H' = Diversity Index
ni = number of individuals of the ith species
N = total number of individuals

According to Wilhm (1975) the diversity index criteria are divided into 3:

H' < 1.0 = low species diversity
1.0 < H'< 3 = moderate species diversity
H' > 3 = high species diversity

3. Gastropod Uniformity Index was calculated using the formula according to Odum (1993):

$$E = \frac{H'}{\text{Ln } S}$$

where:

E = Evenness index
H' = Diversity index
S = number of species

Criteria for the Evenness Index value are as follows:

E < 0.31 = low level of species evenness
0.31 > E > 1 = medium level of species evenness
E > 1 = high level of species evenness

4. Species richness index (Margalef Type Wealth Index) was calculated based on the formula according to Ludwig & Reynolds (1988), as follows:

$$R = \frac{(S - 1)}{\text{Ln } N}$$

where:
S = number of species
N = number of individuals

Criteria for the Margalef Type Wealth Index value are as follows:

D < 2.5 = low level of wealth
2.5 > D > 4 = medium level of wealth
D > 4 = high level of wealth

5. Dominance Index was calculated using the formulation according to Odum (1993):

$$C = \Sigma \left(\frac{ni}{N}\right)$$

where:

ni = number of the ith individual
N = the total number of individuals of all species

Criteria for the dominance index are:

0 < C < 0.5 = no species dominates
0.5 < C < 1 = there is a species that dominates

RESULTS AND DISCUSSION

There are only 3 gastropod species in the mangrove with a fairly good density (2-3 ind./25 m^2) namely *Terebralia sulcata*, *Terebralia palustris*, and *Telescopium telescopium*. This condition is commensurate with the distribution of gastropod ecological indices in the Tambea mangrove area in the "low category". The ecological indices of gastropods in the existing nickel mining area in Tambea Village, Pomalaa is presented in Table 1.

Table 1 Ecological indices of gastropod community in the existing nickel mining area in Tambea Village, Pomalaa-Southeast Sulawesi

No.	Ecological index	Value	Category
1	Diversity (H')	0.81	Low diversity
2	Species Richness (R)	1.75	Low species richness
3	Evenness (E)	0.50	Medium evenness
4	Dominance (C)	0.54	There is a species that dominates

Table 1 reflected in the condition of the ecological indices which have values and categories of low species diversity and richness, moderate evenness, and dominance of certain species. Values of these ecological indices may imply degraded condition, especially on the "ecological floor (substrate)" which is a living niche and food source for the entire gastropod community due to the continuous input of nickel mining overburden waste.

The structure of the gastropod community in mangrove area showing low diversity index values (H' = 0.81), low species richness (R = 1.75), moderate evenness (E = 0.50), and dominance of certain species (C = 0 .54), maybe affected by overburden waste. The dominance of the Potamididae family and the very low presence of individual species in populations and communities means that the ecological indices of gastropods in the Tambea mangrove ecosystem are in a low category which may be attributed to the ecological disturbance and pressure. Ernanto *et al.* (2010) stated that if a community is composed of a very few species and if only a few species are dominant then the species diversity is low. If a community growth is disrupted, it will cause a significant reduction in diversity (Wirakusumah 2003). Likewise, when diversity is low, there will be intra- and interspecific competition and high environmental pressure/disruption. Mustofa *et al.* (2023) explained that low diversity values may have been caused by ecosystem imbalances due to environmental pressure, resulting in only certain species being able to survive.

Furthermore, according to Clark (1974) in Budi *et al.* (2012), the diversity expresses the variety of species existed in an ecosystem. If an ecosystem has a high diversity index, then the ecosystem tends to be balanced. On the other hand, if an ecosystem has a low diversity index, it indicates that the ecosystem is in a state of stress or degradation. Rau *et al.* (2013) explained that the wealth index value tends to be high if a community has a large number of species and each type is represented by one individual, whereas the index value will be low if the community has a relatively small number of species and each type has a large number of individuals.

The Evenness Index value in this study fell in the medium category, with a tendency for low values (close to the low evenness category) and there was a dominance of a certain species. *T. sulcata* showed a wide distribution in the Tambea mangrove area and were found in most sampling stations. It is peculiar to find *T. sulcata* climbing mangrove roots and trunks as well as small mounds around the mangrove area (Fig. 5).

Nybakken (2005) emphasized that biotic and abiotic environmental factors will influence the abundance and evenness of species that are small and have high values due to the large similarity of species. Dominance of an individual or species shows how strongly that individual dominates an area, typifying adaptation to the environment, hereby dominate the habitat (Nontji 2007; Odum 1993). Evenness index in the low to medium category indicates that the number of gastropod species is not evenly distributed and there is no variation in the gastropod species. The smaller the value of species uniformity, the smaller the value of evenness of the aquatic community, where the distribution and number of individuals are not the same. There is also a tendency for certain species to dominate in the community (Saraswati *et al.* 2020). Variations in evenness index values are caused by environmental factors that influence gastropod adaptation.

There are no climbing gastropods, such as *Littoraria scabra* and *L. melanostoma*, which are usually found in the stems, roots, and leaves of mangrove vegetation. *Littoraria scabra* and *L. melanostoma* are classified as sensitive to environmental disturbances and changes. The condition of gastropods in mangrove area of Tambea Village is very different from that in other mangrove areas in Indonesia, which are not affected by overburden waste. Hutama *et al.* (2019) reported that gastropod species found in the North coast of Semarang comprised 8 species and 4 families which include four species in the Order Cerithiodea, including *Cerithidea* sp., *Cerithidea alata*, *Cerithidea cingulata*, and *Telescopium telescopium*. The two species found of the Order Littorinoidea were *Littoraria melanostoma* and *Littoraria carinifera*. One species found of the Order Neritoidea was *Nerita* sp., and one species found of the Order Ellobioidea was *Cassidula* sp. There were 14 species of gastropods found in the mangrove ecosystem of Aceh Besar and Banda Aceh (Irma *et al.* 2012). In the Awur Bay mangrove forest area, 16 species of gastropods were found (Silaen *et al.* 2013).

The low abundance and ecological indices of the gastropod community in the Tambea mangrove ecosystem may also be influenced by the relatively sparse condition of mangrove cover (Fig. 5). The same results were shown in the research of Haryoardyantoro *et al.* (2013), in which that mangrove area having low tree density surrounded by pond areas will directly cause a low abundance of the organism community. The condition of mangrove forest vegetation affects gastropod diversity. For example, high abundance and diversity of gastropod species are usually found in dense stands of mangrove forest trees (Silaen *et al.* 2013). The mechanism of differences in community structure, ecological index, and abundance of gastropods related to the size of the mangrove area is a reflection of differences in the structure of the mangrove habitat (Singh *et al.* 2020). The results of measuring several key water quality parameters that are directly related to the input of overburden waste at the research location are presented in Table 2.

Table 2 Average of measurements results of several key water quality parameters

No.	Stations	Key Parameter	Value	Information
1.	Station 1	TSS (mg/L)	214.00	**Exceeds threshold** (Acoording to Decree of the State Minister for the Environment Number 51 of 2004 concerning seawater quality standards)
		Turbidity (NTU)	141.6	
		Waters brightness (cm)	57.5	
		Color of waters (Pt-Co)	500	
2.	Station 2	TSS (mg/L)	224.00	**Exceeds threshold** (Acoording to Decree of the State Minister for the Environment Number 51 of 2004 concerning seawater quality standards)
		Turbidity (NTU)	139.2	
		Waters brightness (cm)	53.5	
		Color of waters (Pt-Co)	500	
3.	Station 3	TSS (mg/L)	238.00	**Exceeds threshold** (Acoording to Decree of the State Minister for the Environment Number 51 of 2004 concerning seawater quality standards)
		Turbidity (NTU)	148.4	
		Waters brightness (cm)	56.5	
		Color of waters (Pt-Co)	500	
4.	Station 4	TSS (mg/L)	265.00	**Exceeds threshold** (Acoording to Decree of the State Minister for the Environment Number 51 of 2004 concerning seawater quality standards)
		Turbidity (NTU)	151.5	
		Waters brightness (cm)	59.5	
		Color of waters (Pt-Co)	500	
5.	Station 5	TSS (mg/L)	246.00	**Exceeds threshold** (Acoording to Decree of the State Minister for the Environment Number 51 of 2004 concerning seawater quality standards)
		Turbidity (NTU)	143.2	
		Waters brightness (cm)	55.3	
		Color of waters (Pt-Co)	500	

The condition of Tambea mangrove waters is greatly influenced by overburden waste input (Table 2). This refers to the concentration of each parameter that exceeds the water quality standard threshold (Decree of the State Minister for the Environment Number 51 of 2004). As water quality parameters exceeds threshold limits, gastropods' ecological indices are low.

The gastropod community structure in the mangrove areas of the Tambea Village was low, due to the degrading environment caused by overburden waste input from nickel mining activities (open pit and topsoil stripping) (Table 2). Thus, the overburden waste input degrades the overall functionality of the entire complimentary systems causing the loss of various gastropod species, which are typical inhabitants of the mangrove ecosystem. The Potamididae family remains adaptive to the conditions covered by overburden sediment waste (Purnama *et al.* 2024a). The adaptability of the Potamididae family in disturbed areas manifests its high tolerance to changes in water quality and the environment, in general (Purnama *et al.* 2024a).

Apart from that, the survival of Potamididae family is also related to their ability to act as a tree fauna snail or climber when there is a disturbance in the waters (*T. sulcata* and *T. palustris*). *T. telescopium* can immerse as an infauna, although it is considered as epifauna around the mangrove root system to protect itself from various ecological disturbances and establish its biological niches. This is in accordance with the findings of Maturbongs & Elviana (2016) who reported that the mangrove ecosystem is the most preferred habitat for the Potamididae family and has a wide geographical distribution and is also found in high densities in the mangrove ecosystem.

Odum (1998) also explained that a species with the highest density indicates that the organism can occupy a larger space and thus, can develop more. The Potamididae family is the only family of gastropods that natively inhabits mangroves (Egonmwan 2008; Jamabo & Davids 2012). Therefore, the Potamididae family has a very high level of dependence on the existence of mangroves for their subsistence needs and has the potential to be an indicator of the mangrove ecosystem (Vannini *et al.* 2008; Penha-Lopes *et al.* 2010). Native gastropods are a species of snail whose entire life cycle occurs in the mangrove area, while facultative gastropods have certain migration patterns to come to and leave the mangrove area (Budiman 1991). The species of this family are associated with the mangrove ecosystem as a place to find food, and shelter, as well as a place for spawning and rearing (Wells 2003; Wells & Lalli 2003; Kamimura & Tsuchiya 2004; Fratini *et al.* 2008; Lorda & Lafferty 2012). The average abundance of gastropod species in areas is presented in Figure 3.

Average abundance of gastropod species in the area affected by overburden (Fig. 3) shows the dominance of *Terebralia sulcata* (6-9 ind./m^2) over the other two types of gastropods (1-3 ind./m^2). Fifty percent (50%) of the coastal Tambea Village is dominated by mangrove vegetation. Ecological functions of mangrove roots systems enable them to trap sediment outflows coming from the mining discharges resulting to the accretion of sediments in the mangrove areas. This condition may have direct impact on the presence of gastropods which is very limited in the sapling age group, except for the *T. sulcata* which is found on each side of the Tambea mangrove area. *T. sulcata* tends to avoid puddles and high tides by climbing the roots, stems and dry branches of mangroves as well as mounds which makes this species able to survive the input of overburden waste (Fig. 5).

The presence of gastropod communities in the mangrove ecosystem of Tambea Village, Pomalaa is very low. This can be seen from the individual representation of each species in ecological space, where of the 3 species found (*T. sulcata*, *T. palustris*, and *T. Telescopium*) only *T. sulcata* has a population abundance that tends to dominate, namely 6-9 ind./ m^2. Meanwhile, the dominance index of the other two species ranged from 1-3 ind./m^2. In other words, the representation of individual *T. palustris* (1-3 ind./m^2) and *T. Telescopium* (1-2 ind./m^2) in an area of 1 m2 is very low (Fig. 3). Meanwhile, according to Arbi *et al.* (2022), in the mangrove ecosystem of Pari Island, Jakarta, *T. palustris* tends to be present in large aggregations, and *T. sulcata* is generally found solitary. In contrast to those in the Tambea mangrove area, it is *T. sulcata* that has a greater population abundance. This finding is in agreement with research findings of Masagca *et al.* (2010) who reported that the high-density value of *T. sulcata* is caused by *T. sulcata* lives and develops in mangrove areas in large numbers, especially on most types of muddy substrates. These results are supported by the explanation of Dharma (1988) and Budiman (1988) who reported that mangrove forests are the most preferred habitat for the Potamididae family which have a wide geographical distribution and are also found in high abundance in the mangrove ecosystem.

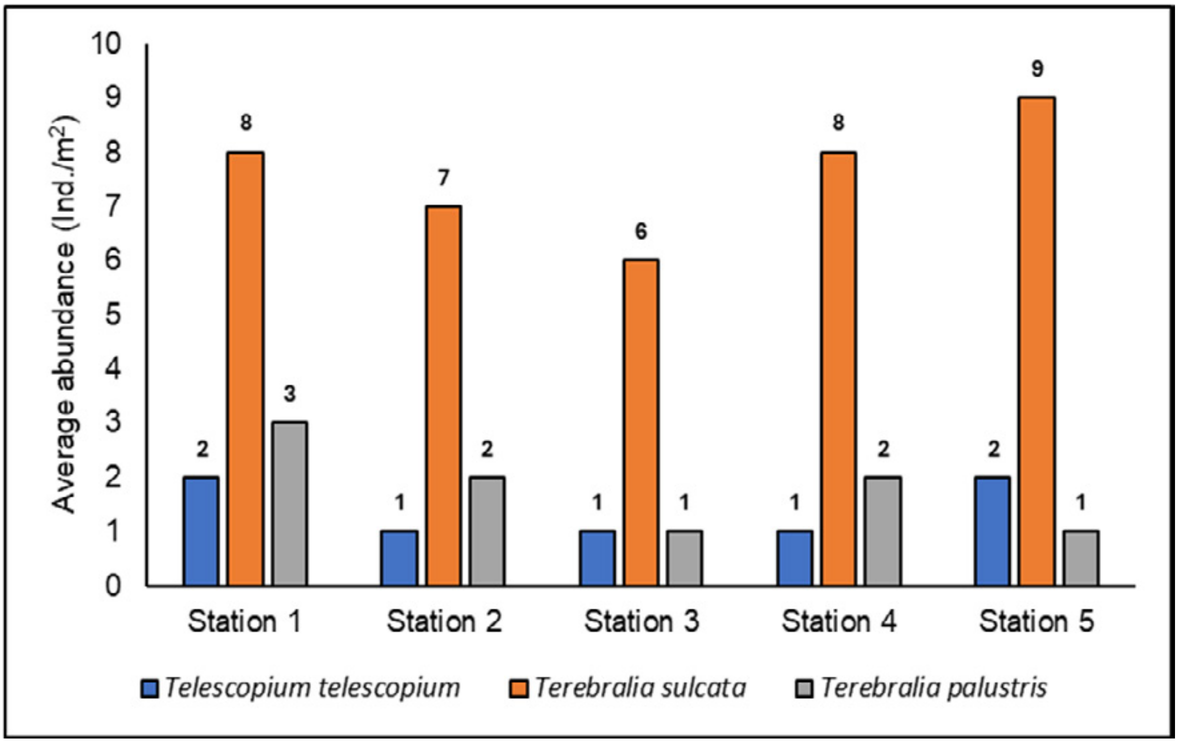

Figure 3 Average abundance of gastropod species in areas affected by overburden in the Tambea, Pomalaa mangrove ecosystem

Figure 4 The sapling phase dominates the estuary mouth area, so that the effectiveness of the mangrove forest's function as a sediment trap is not optimal

Figure 5 Life habits of *T. sulcata* at the research location, avoiding puddles and high tides by moving to higher areas and climbing mounds around the mangrove area (5-10 m from the mangrove vegetation area)

Figure 5 shows the extent of the climbing behaviors of *T. sulcata* moving within the mangrove areas by climbing roots and stems/twigs. It was also observed outside the mangrove area even to the coastal beach vegetation. This behavior maybe a form of adaptation to the environment enabling them to survive and dominate in the Tambea mangrove ecosystem. The condition of the mangrove forest and the gastropods species found in the mangrove forest are shown in Figure 6.

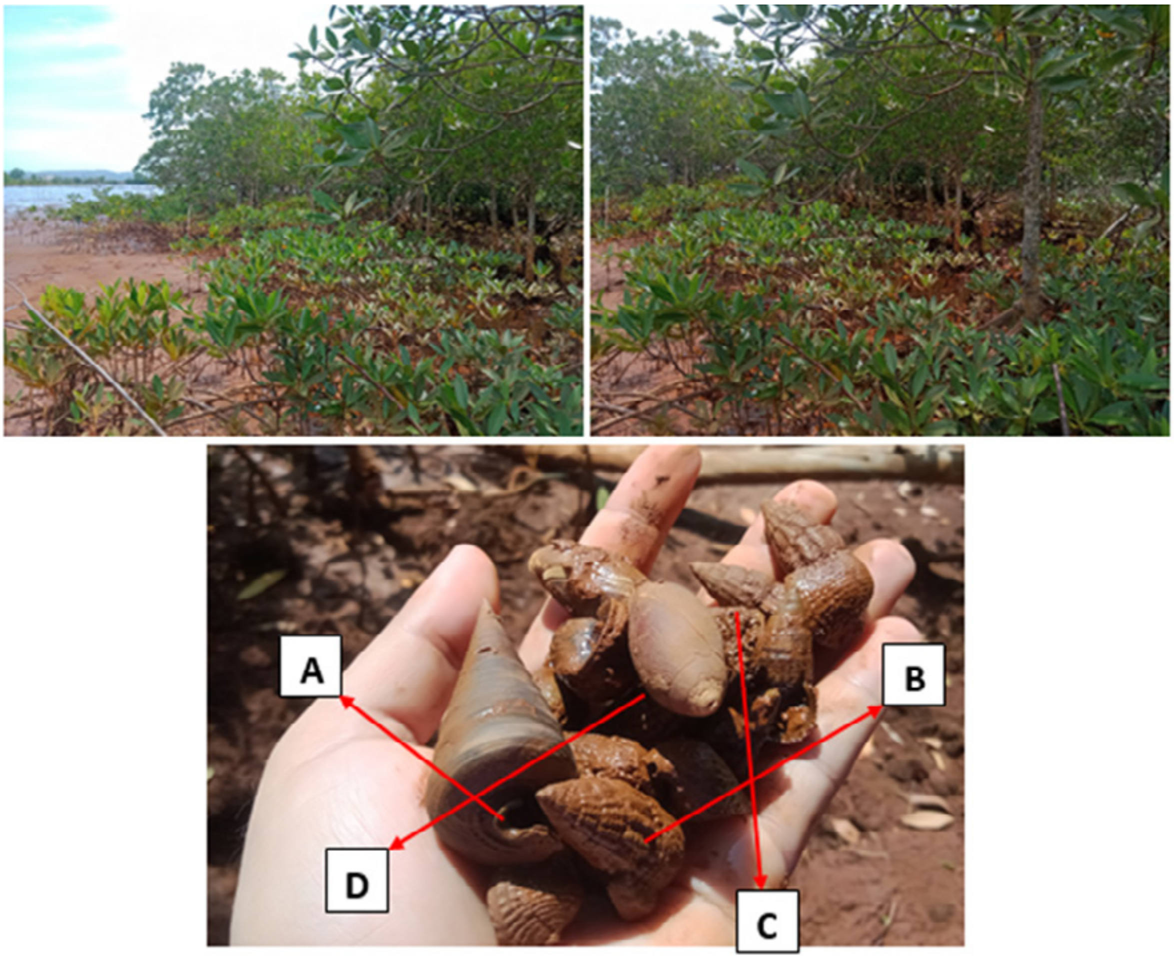

Figure 6 Tambea Village mangrove ecosystem, Pomalaa and the gastropod speices found in Tambea mangroves ecosystem: (A) Telescopium telescopium; (B) Terebralia sulcata; (C) Terebralia palustris; and (D) *Ellobium aurisjudae* found in dead condition (empty shell)

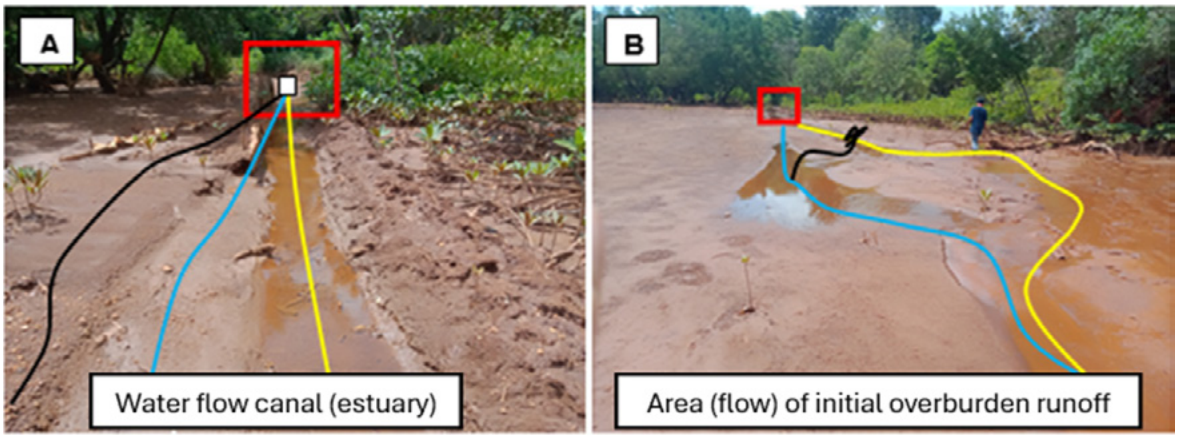

Figure 7 Small estuary which drains overburden waste originating from the upstream nickel mining activities
Notes: (A) estuary (canal), runoff area; (B) overburden sediment waste (reddish-orange).

Community structure of gastropods in the Tambea mangrove ecosystem is very low compared to 61 species of mangrove gastropods identified throughout Indonesia (Pramudji 2001). Meanwhile, the *Ellobium aurisjudae* species was not included because it was found as an empty shell and it may have been dead for a long time. Death of some gastropods may likely to occur because this area receives input of overburden waste (Fig. 1) from river flows that are directly connected to nickel exploitation locations in the upstream mountainous areas (Purnama *et al.* 2024a; Hamzah 2009; Zubayr 2009). The small river flow carrying overburden waste is presented in Figure 7.

The small estuary or canal shown in Figure 7 is a transport medium for overburden waste from nickel exploitation activities in mountainous areas. These photos were taken during the dry season and the water discharge was relatively low, with several streams still continuously carry overburden waste. During the rainy season or in rainy condition, the water discharge was very abundant and expanded the entire Tambea mangrove area as predominantly reddish-orange substrate accretion.

CONCLUSION

The abundance (± 3-5 ind./m^2) and number of taxa (species) (3 species, Telescopium telescopium, Terebralia sulcata, and Terebralia palustris) of the gastropod community exposed to overburden waste were very low. Overburden waste may degrade ecological indices of mangrove gastropods. The ecological indices of gastropod community in Tambea mangrove ecosystem showed low diversity index (H' = 0.81), low species richness (R = 1.75), moderate evenness index (E = 0.50), and dominance of certain species (C = 0.54).

ACKNOWLEDGMENTS

We would like to express our infinite thanks to the management of the Indonesian Education Scholarship (BPI) for their financial support in publishing our article, as well as to the "field sampling team" Muh. Bima Sakti RA., S.T., Irmalasandri Putri, S.T., M.PWK., and Virzikrillah who assisted in collecting data and research documentation at the research location, from the beginning to the end of the research.

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