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Research Article

Existing Condition of Gastropods Community in Coastal Areas Affected by Nickel Overburden in Pomalaa District, Southeast Sulawesi Province, Indonesia

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ARTICLE HIGLIGHTS

The present investigation provides substantiated empirical evidence demonstrating that nickel extraction operations have exerted considerable detrimental effects on the ecological integrity of the Pomalaa coastal region in Southeast Sulawesi. Environmental degradation and disruption of ecological equilibrium have been observed as direct consequences of persistent overburden waste disposal. The introduction of mining overburden into the Pomalaa coastal ecosystem has resulted in the extirpation of critical gastropod taxa and significant population reductions among persisting species when compared with control sites featuring undisturbed substrate conditions. The documented diminished gastropod population densities within nickel mining-affected zones serve as biological indicators of profound environmental deterioration attributable to these industrial activities.

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ABSTRACT

Pomalaa District is the largest existing nickel mining center in Southeast Sulawesi Province, Indonesia. Pollutants from various anthropogenic activities, especially nickel mining overburden, end up in the Pomalaa coastal area. This research aimed to determine the structure of the gastropods community in the impacted area and reference site. This research was carried out in the Pomalaa coastal area, Kolaka Regency, from June to October 2023. Research stations were determined using purposive sampling method and simple random sampling techniques. On-site collecting gastropods samples were carried out manually (handpicking method). Impacted area and reference site showed significant differences in the number of species (16 and 21 species), presence, and density of gastropods, even though their respective ecological index categories were relatively the same (H› = 1.92 & 2.72; R = 2.93 & 3.41; E = 0.55 & 0.78; C = 0.001 & 0.04). In the impacted area, the density of gastropods was very low (1 - 3 ind./m2), whereas at the reference site, the density reached 10 - 30 ind./m2. Gastropods inhabiting rocks or hard substrates, were relatively unaffected by the overburden, proven by stable population with a high density of 45 - 115 ind./m2. Nickel overburden input flowing to the Pomalaa coastal area greatly influenced the gastropods community in terms of species composition and density. On the other hand, the habitat (substrate) of gastropods as benthic organisms was covered and degraded by overburden piles up to 15 - 30 cm deep, which was still increasing over time. On the other hand, in the reference site area, the condition was inversely proportional.

Keywords: ecological index, gastropods, mining, overburden

INTRODUCTION

Grouping and classifying organisms specifically refers to the main structural forms or properties, such as dominant species, life forms (indicators), physical habitat of the community, and functional characteristics or traits. Under natural conditions, a community unit will be formed based on dynamics (anomalies) ranging from unstable to stable and constantly fluctuating depending on the quality of the influencing environment (Bantayan *et al.* 2023; Bravo *et al.* 2021; Ranjan & Babu 2016; Subagio & Muliadi 2014; Udayantha & Munasinghe

2009). Community structure or ecological index is a concept that studies and examines in detail and systematically the composition of species and their abundance in a community (Ates *et al.* 2023; Babushkin *et al.* 2023; Čejka *et al.* 2023; Carobene *et al.* 2023; Degamon *et al.* 2023; De Necker *et al.* 2023; Fitria *et al.* 2023; Montesinos-Navaro *et al.* 2018).

There are three approaches commonly used to describe the ecological index of a community of organisms, namely species diversity, species interactions, and functional interactions (Schowalter 2000; Hau *et al.* 2021; Kudratov *et al.* 2023; Keerthana *et al.* 2023; Liu *et al.* 2023; Lewin *et al.* 2023; Medeiros *et al.* 2023; Mansingh *et al.* 2021; Maria 2020). The linkage of habitat characteristics with ecological indices (composition, size, and species diversity) is the main principle in studying community structure. Changes in habitat even on a small scale will greatly influence community structure because they affect the species level down to the individual as the smallest component that makes up the population in the community (Putro 2017; Pérez-Estrada *et al.* 2023; Ramón *et al.* 2023; Rubal *et al.* 2023).

One of the largest communities of organisms that make up bottom aquatic (benthic) ecosystems are gastropods (Vilenica *et al.* 2024; Thilakarathne *et al.* 2024; Ebadzadeh *et al.* 2024; Aouissi *et al.* 2024; Isfaeni *et al.* 2024; Ernawati *et al.* 2024; Presley & Willig, 2023; Pérez-Estrada *et al.* 2023; Ramón *et al.* 2023; Rubal *et al.* 2023; Sun *et al.* 2022; Vian *et al.* 2022; Yadav *et al.* 2019; Susintowati *et al.* 2019; Nybakken & Bertness 2005). Gastropods are the largest class of the Mollusca (80%) with 100,000 living species and spread across various aquatic habitats (Mukhopadhyay *et al.* 2024; Seinor *et al.* 2024; Curren *et al.* 2024; Hertika *et al.* 2024; Prayudi *et al.* 2024; Guan *et al.* 2023a; Guan *et al.* 2023b; Ruppert *et al.* 2004; Bouchet *et al.* 2008; Strong *et al.* 2008; Davis *et al.* 2015).

The condition of gastropods communities in waters is greatly influenced by the quality of their living environment, especially those originating from anthropogenic activities. Disturbance or input of pollutants in any forms directly impacts the dynamics of gastropods community structure. One of the water areas inhabited by gastropods communities and disturbed by anthropogenic activities is the Pomalaa coastal area (Purnama *et al.* 2024a; 2024b; 2024c).

Pomalaa District is administratively the largest existing nickel mining area in Southeast Sulawesi Province (Hamzah *et al.* 2015; Hamzah 2009; Zubayr 2009), which has been operating since 1968 until now. One of the impacts of nickel mining that has been going on continuously for a long time is the input of nickel overburden into the waters which covers the benthic zone causing the loss of gastropods community and other benthic organisms (Timm *et al.* 2001; Chakrabarty & Das 2006). These occurrences were found in the research conducted by Purnama et al (2024a; 2024b; 2024c; 2024d) in Pomalaa mangrove ecosystem, Southeast Sulawesi Province. In that research, there were 39 gastropods species with high diversity and species richness found in the area with minimal disturbance (reference site), while there were only 7 gastropods species with low diversity and species richness found in the impacted area or mangrove area which was exposed to nickel overburden. There were also evident that certain gastropods species were dominant. In other words, the impacted area has unstable ecological conditions due to disturbances originating from nickel overburden from the nickel mining activities.

Several coastal areas of Pomalaa, particularly those near nickel mining activities (impacted areas), face pollution from nickel metal which affects the water, substrates, and biota. The concentration of nickel tends to be high in aquatic substrates and fluctuates around the standard quality threshold in water and in samples of the gastropods species T. sulcata (Purnama *et al.* 2024a). Additionally, there are physical threats due to nickel overburden input.

Pomalaa coastal area affected by nickel overburden is Dawi-Dawi Village. The nickel overburden in Dawi-Dawi estuary flows from the upstream area where nickel is being extracted (Hamzah 2009; Zubayr 2009). In contrast, Pomalaa District also has regions that remain unaffected by nickel overburden and serve as reference sites. These reference sites are untouched by the nickel overburden because the river basin does not connect to the mining areas. One of the reference sites is the coastal area of Totobo Village, which is lined with mangrove vegetation that helps protect the area from surrounding anthropogenic activities.

The Dawi-Dawi and Totobo coastal areas differ significantly in their ecological characteristics, particularly in the benthic zones and the supporting ecosystems around the areas. This includes variations in environmental disturbances caused by human activities and the corresponding gastropods communities inhabiting these areas.

Therefore, comparative study of gastropods communities inhabiting the impacted area (affected by nickel overburden) and the reference sites (not affected by nickel overburden) in Pomalaa coastal area is very important to carry out. Prior studies on this subject have never been carried out in Southeast Sulawesi Province, in particular and Indonesia, in general. This study aimed to determine the structure of gastropods communities in the impacted area and in the reference site.

MATERIALS AND METHODS

Time and Location

A comparative study of gastropods communities inhabiting the impacted area (Dawi-Dawi Village) and the reference site (Totobo Village) in Pomalaa coastal area was carried out from July to October 2023. The determination of these two locations as research locus were based on their close distance (± 3 km) from the existing center for nickel mining exploitation in the mountainous area (upstream) and the nickel industrial area (factory) in Pomalaa. The research locations are presented in Figure 1.

Dawi-Dawi Village receives direct flow of nickel overburden from the nickel exploitation area, while Totobo Village represents an area with minimum impact from the nickel mining area. Totobo Village was chosen as the reference site because the village borders the affected Dawi-Dawi Village as a nickel overburdened area. The research took place in the coastal area of Pomalaa District, Kolaka Regency, Southeast Sulawesi Province (Figs. 2 & 3).

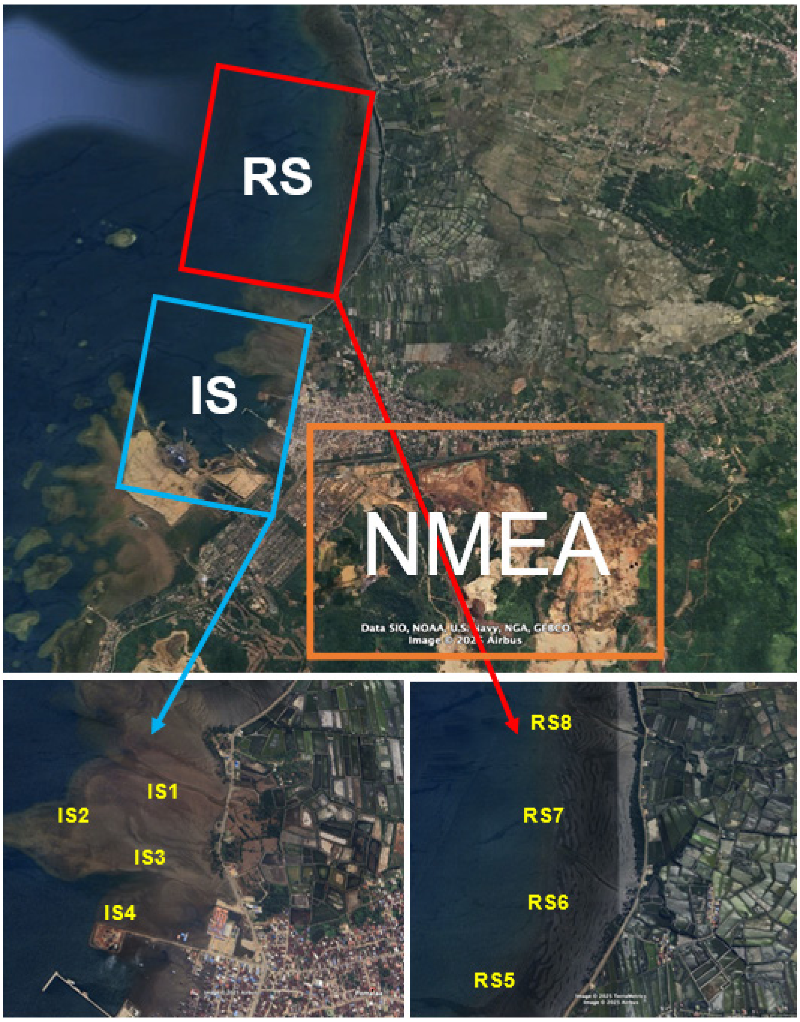

Figure 1 Map of research locations
Notes: IS = Impacted Site; RS = Reference Site; NMEA = Nickel Mining Existing Area
Source: Google Earth (2025)

Figure 2 Coastal areas exposed to nickel overburden (Dawi-Dawi Village, as impacted area)

Figure 3 Coastal areas without exposure of nickel overburden (Totobo Village, as reference site)

Research Stations

Determination

Research stations and sampling points (sub-stations) were determined in detail using the purposive sampling method as well as simple and random sampling techniques to obtain adequate samples having actual conditions related to gastropods communities in the impacted areas and reference sites.

Each research station covered an area of 2,500 m², which corresponded to the area of the sampling zone. The stations were located 50 to 70 m apart from each other. The distance between the impacted area and the reference site ranged from 350 to 400 m.

The transect size used for collecting samples in the field was 1 m². The 1-m² transect was further divided into 16 smaller square transects, each measuring 25 cm², to observe small gastropods and those with infaunal tendencies. These transects were placed randomly throughout the sampling area in an alternating pattern.

Characteristics

Observed locations in this research were divided into 8 stations based on 2 categories, namely the impacted area and the reference site. These eight stations had ecological characteristics that were strongly influenced by the presence of coastal ecosystems, such as mangrove ecosystems (Table 1).

Table 1 Ecological characteristics of each research station

No.	Research station	Ecological characteristics	Category	Coordinate
1	IS 1	On shore with fine sand substrate, without mangrove forest, seagrass, and coral reef	Impacted area (affected by nickel overburden)	4°09'57.61" S 121°36'30.21" E
2	IS 2	On shore (breakwater area), without mangrove forest, seagrass, and coral reef	Impacted area (affected by nickel overburden)	4°09'58.99" S 121°36'20.53" E
3	IS 3	On shore with sand substrate, without mangrove forest, seagrass, and coral reef	Impacted area (affected by nickel overburden)	4°10'10.53" S 121°36'21.34" E
4	IS 4	Rocky shore with sand substrate, without mangrove forest, seagrass, and coral reef	Impacted area (affected by nickel overburden)	4°10'18.37" S 121°36'19.90" E
5	RS 5	On shore (fine sand substrate), with mangrove forest, without seagrass and coral reef	Reference site	4°09'26.54" S 121°36'41.22" E
6	RS 6	On shore (fine sand substrate), with mangrove forest, without seagrass and coral reef	Reference site	4°09'02.20" S 121°36'50.17" E
7	RS 7	On shore (fine sand substrate), without mangrove forest, seagrass, and coral reef	Reference site	4°08'36.41" S 121°36'51.53" E
8	RS 8	Rocky shore, without mangrove forest, seagrass, and coral reef	Reference site	4°08'17.29" S 121°36'55.22" E

Sampling and Identification

Gastropods samples were collected manually using hands (handpicking). Gastropods species were identified using the latest and the most credible identification keys, namely: Worms "World Register of Marine Species" (https://www.marinespecies.org), Molluscabase (https://www.molluscabase.org), Collection of Worldwide Seashells (Collection of worldwide seashells (idscaro.net)).

Nickel Content Analysis

Nickel content was analyzed from water, sediment, and biota (specifically, the gastropods). As much as 250 mL water sample from each station was collected and placed into sample bottles that had been rinsed with a 5% nitric acid solution. Sediment sampling was performed using a plastic hand scoop to collect 0.5 L of sediment from each station. Each sediment sample was placed in a Scott glass bottle that had also been rinsed with a 5% nitric acid solution. For the gastropods samples, the specimens were washed with deionized distilled water for 2 hours, then dried on filter paper or tissue. The cleaned gastropods were transferred to a petri dish and stored in a refrigerator. From the gastropods specimens, 1 g of selected gastropods was digested using concentrated sulfuric and nitric acids at a temperature of 95 °C.

Nickel content was analyzed using an Atomic Absorption Spectrophotometer (AAS) following the SNI 6989.18-2009 test method for water samples and the AAS flame method for sediment and biota samples (Smoley 1992; Akagi & Nishimura 1991; Pennuto *et al.* 2005).

Data Analysis

Gastropods density was calculated using the following formula (Khouw 2016):

$$Density = \frac{Number\ of\ individuals\ of\ species\ i}{Total\ Number\ of\ observation\ plots}$$

Diversity of gastropods species was calculated 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

Diversity Index are divided into 3 criteria (Wilhm 1975), namely:

$H' < 1.0$ = Low species diversity

$1.0 < H' < 3$ = Medium species diversity

$H' > 3$ = High species diversity

Evenness Index was calculated using the following formula (Odum 1993):

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

where:

E = Evenness Index

H' = Diversity Index

S = Number of species

The criteria for Evenness Index value are as follows:

E < 0.3 = Low level of species evenness

0.31 > E > 1 = Medium level of evenness

E > 1 = High level of species evenness

The Species Richness Index (Margalef Index) was calculated with the following formula (Ludwig & Reynolds 1988):

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

where:

S = Number of species

N = Number of individuals

The criteria for the Species Richness Index (Margalef Index) value are as follows:

R < 2.5 = Low level of species richness

2.5 > R > 4 = Medium level of richness

R > 4 = High level of wealth type

The Dominance Index was calculated using the following formula (Odum 1993):

$$C = \sum \left(\frac{ni}{N}\right)^2$$

where:

ni = Number of individuals i

N = Total number of individuals of all species

The criteria for the Dominance Index value are:

0 < C < 0.5 = No type dominates

0.5 < C < 1 = There is a dominant type

RESULTS AND DISCUSSION

Ecological index presented for gastropods community inhabiting the impacted area and the reference site were Diversity Index (H'), Species Richness Index (R), Evenness Index (E), and Dominance Index (C) (Tables 2 & 3)

Table 2 Ecological index of gastropods in the impacted area of Pomalaa coastal area

No.	Ecological index	Grade	Category
1	Diversity index (H')	1.92	Medium
2	Species Richness Index (R)	2.93	Medium
3	Evenness index (E)	0.55	Medium
4	Dominance Index (C)	0.001	There is no particular type that dominates

Table 3 Ecological index of gastropods in the reference site of Pomalaa coastal area

No.	Ecological index	Grade	Category
1	Diversity index (H')	2.72	Medium
2	Species Richness Index (R)	3.41	Medium
3	Evenness index (E)	0.78	Medium
4	Dominance Index (C)	0.04	There is no particular type that dominates

Ecological index for the impacted area showed values close to the low category (H' = 1.92; R = 2.93). On the other hand, the reference site showed ecological index having values close to the high category (H' = 2.72; R = 3.41). Nevertheless, ecological index for both the impacted area and the reference site fell in to the medium category. The Evenness Index for both the impacted area and the reference site was similar both in value and category, i.e., $E_{\text{impacted area}}$ = 0.55; $E_{\text{reference site}}$ = 0.78. There were no species dominance shown in the impacted area and in the reference site ($C_{\text{impacted area}}$ = 0.001; $C_{\text{reference site}}$ = 0.04).

However, there are significant quantitative differences in the number of individuals contributing to these indices. Uneven distribution of individual gastropods was observed in the impacted area (area exposed to nickel overburden). This area was dominated by several species that are less affected by nickel overburden, specifically, gastropods inhabiting hard substrates and rocky habitat, such as *Littoraria scabra, Littoraria undulata, Littorina littorea,* and *Monodonta labio* (Fig. 4). Meanwhile, gastropods inhabiting sandy substrates in the impacted area were found with low individual numbers, namely 1 - 3 ind./m2, such as *Nassarius pullus, Polinices mamilla,* and several other gastropods species. On the other hand, the representation of gastropods community within the reference site was balanced.

Ecological index in the impacted areas was influenced by a significant presence of groups of gastropods inhabiting hard substrates, along with multiple individual species coexisting in the same ecological space. This combination brought the ecological index values of the impacted areas closer to those observed at reference sites. However, there was a notable contrast in regards to the stability of gastropods community in the impacted area and in the reference site. The impacted area showed a decline of gastropods community up to only 1 to 3 individuals per m2, while the reference site exhibited relatively stable condition (Fig. 5).

This finding is similar to the study results conducted by Kaliu and Fitra (2019) on the Pomalaa coastal area, where several areas having different habitat conditions apparently have the same ecological index category, although quantitatively the ecological index values at these stations are quite different, i.e., ranging from low values to approaching the medium to high category, but not exceeding the high ecological index value category, especially in terms of diversity and species richness. This phenomenon is caused by the presence of certain gastropods community with distinctive niches and high species abundance (dominating species), hence, their existence supports the areas and directly increases the ecological index value of certain stations having degrading environmental quality conditions.

In our study, the presence of typical rock gastropods supported the ecological interaction system in the heavily impacted shelf area. The occurrence of gastropods inhabiting rocky habitat and other hard substrates, such as concrete, was resulted from a succession process in a habitat which had artificially changed from its original state. The reference site exhibited a fairly uniform representation of individual species within the population, but it could not be characterized as diverse or rich in species. This limitation was likely due to the absence of mangrove vegetation at several sampling stations within the reference site (Fig. 6).

Figure 4 Gastropods inhabiting hard substrates (rocks)

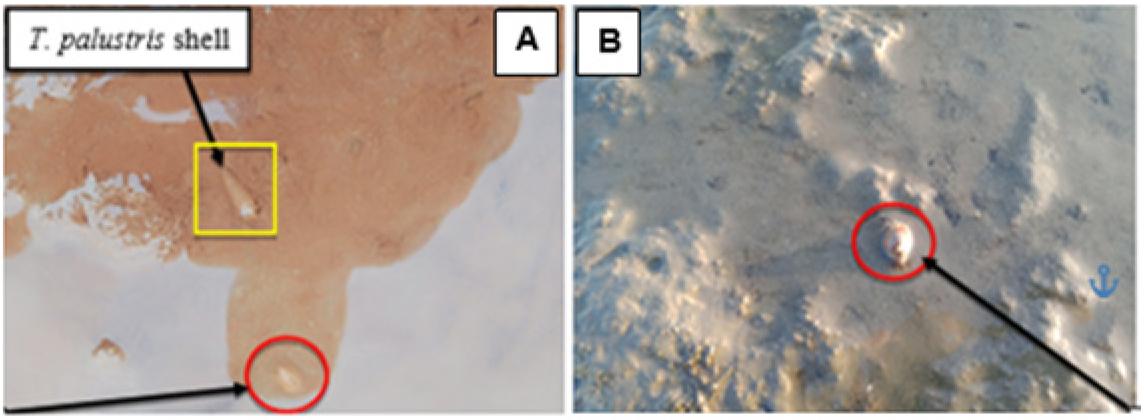

Figure 5 Comparison of the habitat of gastropods species Nassarius spp. in the impacted area (A) and the reference site (B) of the Pomalaa coastal area

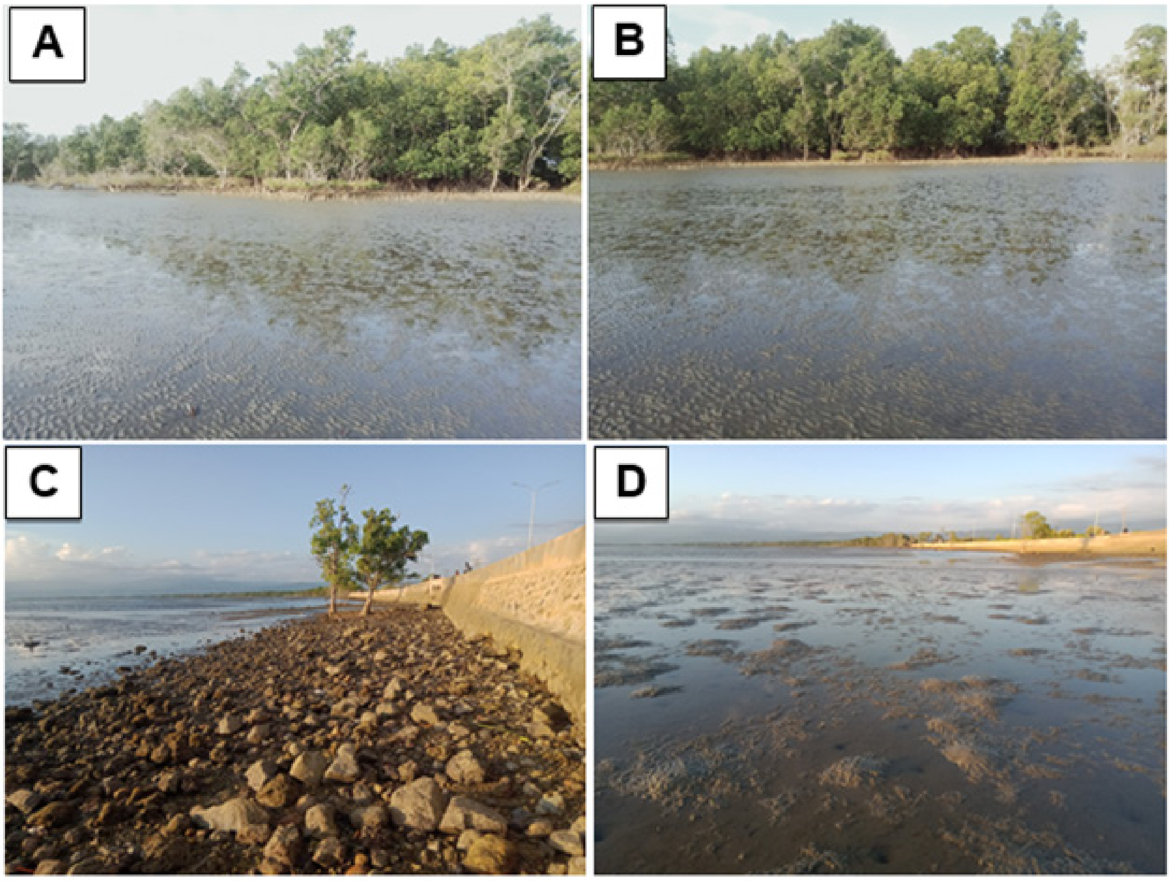

Figure 6 Several sampling stations in the reference site

Notes: A and B = Sampling stations in the front zone of mangrove ecosystem;
C and D = Sampling stations without mangroves or ex-mangrove areas.

As a result, environmental pressures caused by anthropogenic activities, such as sedimentation, directly affected the coastal area. In contrast, other areas within the reference site, which were ecologically protected by the surrounding mangrove ecosystem, showed a significantly higher population density. The increased density was a result of nutrient supply from the mangroves, as sedimentation from land did not reach these beach areas. Instead, the sedimentation was trapped within the mangrove ecosystem. Furthermore, variations in habitat quality among stations in the reference site influenced community dynamics in coastal areas, particularly regarding the presence of certain species and the number of individual gastropods representatives. This was especially true in locations where ecological disruptions, such as pollution from nickel overburden had persisted for an extended period (Purnama *et al.* 2024b; 2024c).

Gastropods community has ecological value as one of the key species in aquatic ecosystems, where some of them are involved in the food chain cycle, namely as a food source for other animals. Apart from that, gastropods can also be used by humans as a source of animal protein (Cappenberg 2006). Previous studies found that the quality of aquatic environment influences the structure of gastropods populations and communities (Yuniarti 2012; Hau *et al.* 2021; Kudratov *et al.* 2023; Keerthana *et al.* 2023; Liu *et al.* 2023; Lewin *et al.* 2023; Medeiros *et al.* 2023; Mansingh *et al.* 2021; Maria 2020).

The representation of individuals in a population is strongly influenced by differences in substrate and habitat characteristics as well as anthropogenic activities (Hamzah 2009; Zubayr 2009; Presley & Willig 2023; Pérez-Estrada *et al.* 2023; Ramón *et al.* 2023; Rubal *et al.* 2023; Sun *et al.* 2022; Vian *et al.* 2022; Yadav *et al.* 2019). One of which is nickel content that accumulates in waters and organisms carried from or originating from nickel mining areas as nickel overburden. Table 4 presents nickel content in water, sediment/substrate, and organisms (gastropods) obtained from the research stations at the impacted and the reference sites, showing significant differences of nickel content in gastropods, water, and sediment samples in the impacted area and reference site in Pomalaa coastal waters.

Overall, nickel content in the water did not exceed the quality standard threshold (0.0022 - 0.0122 ppm), with the highest level was found in the impacted area (0.0122 ppm). In contrast, nickel content in gastropods exceeded the threshold in the impacted area (0.0702 - 0.0864 ppm). Nickel content in gastropods at the reference site (0.0026 - 0.0034 ppm) and transition site (0.0112 ppm), however, remained within the quality standard threshold. Sediment across all locations showed elevated nickel content (13.50 - 92.87 ppm), with the highest nickel content was found in the impacted area (57.81 - 92.87 ppm).

Nickel content in gastropods, water, and sediment reflected the sites' classifications, with the impacted site having the highest concentrations due to nickel overburden and acid sludge from long-term nickel mining, in which the upstream outlet of nickel overburden also located in the impacted area. Meanwhile, the reference and transition sites received diluted input of nickel overburden from the impacted area, which influenced by tidal and wave activity. All locations shared the same ecoregion, contributing to similar hydro-oceanographic conditions.

Water color in the impacted area differed significantly from the reference and transition sites. Within the impacted area, the water color appeared to be reddish-brown (Fig. 2), a typical soil color having nickel content, while within the reference site the water color was clear or translucent (Fig. 3). Water analysis showed that the turbidity value in the impacted area was 500 Pt.Co indicating severe turbidity due to nickel overburden. On the other hand, turbidity value in the reference site was 60 Pt.Co, which was close to marine tourism standard of 30 Pt.Co.

Research conducted by Zubayr (2009) and Hamzah (2009) highlighted that Pomalaa coastal waters was polluted by nickel from ferronickel mining, particularly from tailings and waste rock. Tailings consist of silica and other minerals, while waste rock includes low-mineral acid mine drainage.

Table 4 Nickel content in gastropods, sediment, and water

No.	Location	Nickel (Ni) content			Threshold value of nickel content in water, sediment, and organism
		Gastropods (ppm)	Water (ppm)	Sediment (ppm)	
1	Impacted site 1	0.0702**	0.0036ᴥ	92.87**	"0.05 ppm" (According to the Decree of the Minister of Environment of the Republic of Indonesia Number 51 Year 2004 concerning sea water quality standards)
2	Impacted site 2	0.0864**	0.0122ᴥ	57.81**	
3	Transition site	0.0112ᴥ	0.0031ᴥ	36.93**	
4	Reference site 1	0.0034ᴥ	0.0023ᴥ	18.64**	
5	Reference site 2	0.0026ᴥ	0.0022ᴥ	13.50**	

ᴥ = Did not exceed the threshold
** = Exceeded the threshold

Up to today, there is limited research conducted on nickel content measured in organisms and sediments, making this study crucial for understanding the water current effects on the health of aquatic organisms and environment. Ecologically, the greatest impact of nickel mining overburden comes from sedimentation, leading to erosion upstream and causing shallowing process in the estuaries, resulting in the degraded gastropods habitats. The resulting loss of living space and food caused by the nickel overburden disrupts the gastropods community, potentially leading to the decline of gastropods population (Wali *et al.* 2020; Hamzah *et al.* 2015).

Nickel is one of the essential metals. However, excessive exposure to nickel can cause health issues, including systemic, immunological, neurological, and reproductive disorders, as well as developmental problems and even death. Nickel is also a carcinogenic metal which can disrupt physiological functions of an organism, resulting to the death of an organism, particularly in sessile biota like gastropods, when nickel content exceeds a certain threshold. Previous research showed that high nickel (Ni) content in sediments correlated with the disappearance of sensitive gastropod species, with only about 20% of gastropods population was able to adapt.

Results of our research provided concrete comparisons that have been empirically clarified based on density data and ecological indices of the gastropods community in the impacted area and the reference site. Nickel overburden in the impacted area was massive and caused systemic impact on the structure of the gastropods community in the waters of Pomalaa coasteal area.

The impacted area and the reference site showed very significant differences in terms of species and the number of individuals in each sampling area. This is an indication of the degradation of gastropods habitat in the Pomalaa coastal area, especially in the areas exposed to nickel overburden (the impacted area). Pollution causes the decline in abundance and biodiversity of aquatic organisms, one of which is the mollusk community (Zahidin 2008). Riniatsih and Kusharto (2009) added that the diversity of gastropods species was very low in polluted waters. This statement is in line with the research results of Nugroho *et al.* (2012) which stated that the waters of Genuk, Semarang, which was polluted by surrounding industrial activities, had a significant influence on the abundance of gastropods. Furthermore, Prabuning (2010) emphasized that in the northern coastal waters of Tanjung Emas Port, Semarang, from the East Canal Flood area to the West Canal Flood area, Semarang, the waters was polluted, causing a negative influence on the life of the gastropods community in the waters.

Our study indicated that the substrate of the waters played a crucial role in the sustainability of the gastropods community. This finding was supported by the data, showing that the number of gastropods individuals in areas unaffected by nickel mining waste (the reference site) was significantly higher than in areas impacted by nickel overburden (the impacted area), which were supported by other studies.

Munandar *et al.* (2016) highlighted that the abundance of macrozoobenthos, including gastropods, was influenced by habitat conditions such as bottom sediments and water quality. Gastropods distribution is affected by local environmental factors, food availability, predation, and competition, including sediment texture, temperature, salinity, pH, organic matter, and oxygen content (Ruswahyuni & Nata 2008). Mollusks, particularly gastropods, exhibit high species diversity across marine habitats, but their survival is linked to water quality and habitat characteristics, including pollutants (Pratiwi & Ernawati 2016).

Research conducted by Mardatila *et al.* (2016) in Diatas Lake, West Sumatra Province showed a diversity index (H') of 1.07, which was categorized as medium. The diversity index of a population is influenced by the number of species and the evenness of each species. The low diversity in the waters of Kelabat Bay was caused by uneven distribution of the gastropods found (Abdullah *et al.* 2021). This finding is supported by Gray (1981) in Mardatila *et al.* (2016) which stated that low diversity index values at a station can be caused by an uneven number of individuals of each species.

Research carried out by Rahmasari *et al.* (2015) indicated that the total abundance of mollusk species at Mertasari Beach was 124.5 ind./m², significantly higher than the 0.17 - 1.83 ind./m² found by Pratiwi and Ernawati (2016) in Nusa Lembongan, where low dissolved oxygen levels (2.60 - 6.90 mg/L) were a factor. In contrast, Laharjana (2016) reported an abundance at Serangan Beach of 106.6 ind./m², also higher than the finding in Nusa Lembongan, was correlated with a better oxygen level (4.16 - 5.26 mg/L). According to Syamsurisal (2011), higher dissolved oxygen supported greater benthic populations. The gastropods diversity index at Mertasari Beach was classified as medium, indicating a fairly balanced ecosystem (Wahyuni *et al.* 2015). This finding contrasts with research findings of Wahyuni *et al.* (2015) in Menaming Dam, which reported a lower diversity index (0.55 - 1.05) due to several factors, such as polluted substrates and food source availability (Rachmawaty 2011). Mertasari Beach hosts 15 mollusk families compared to 3 families found at Menaming Dam.

In their research, Rahmasari *et al.* (2015) noted that gastropods diversity was influenced by the bottom substrate. Nybakken and Bertness (2005) stated that particle size of substrate affected the distribution and abundance of organisms, influenced by water retention and suitability for digging or the easiness for organisms burrowing. Cappenberg (2006) also found that substrate type significantly affected mollusk species, especially Gastropods. The diversity index for Gastropods varies by location, with Bengkal Beach showing the highest index at 2.4398, followed by Talang Siring Beach at 2.0988, and Jumiang Beach with the lowest at 1.6200. The ecological index conditions in several places are similar to those in this study, where ecologically, ecosystem conditions with high levels of disturbance can reduce ecological integrity, and vice versa (Rahmasari *et al.* 2015).

Comparisons of average gastropods species density in the impacted area and reference site in Pomalaa coastal area are presented in Figures 7 and 8.

The number of species, presence (number of individuals), and species density of gastropods in the impacted area and the reference site showed differences, although the respective ecological index categories were relatively the same (Tables 2 & 3).

The number of species found in the impacted area were 16 species, while in the reference site there were 21 species (Tables 5 & 6).

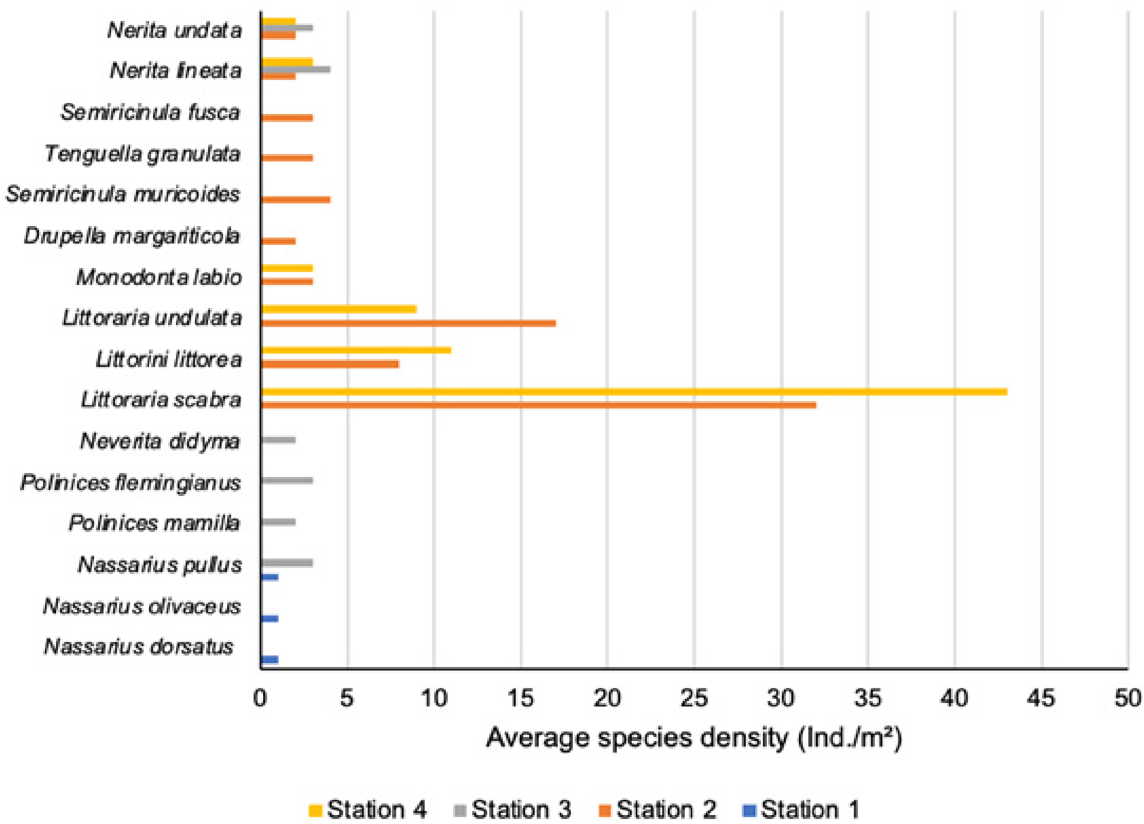

Figure 7 Average species density of gastropods in the impacted area

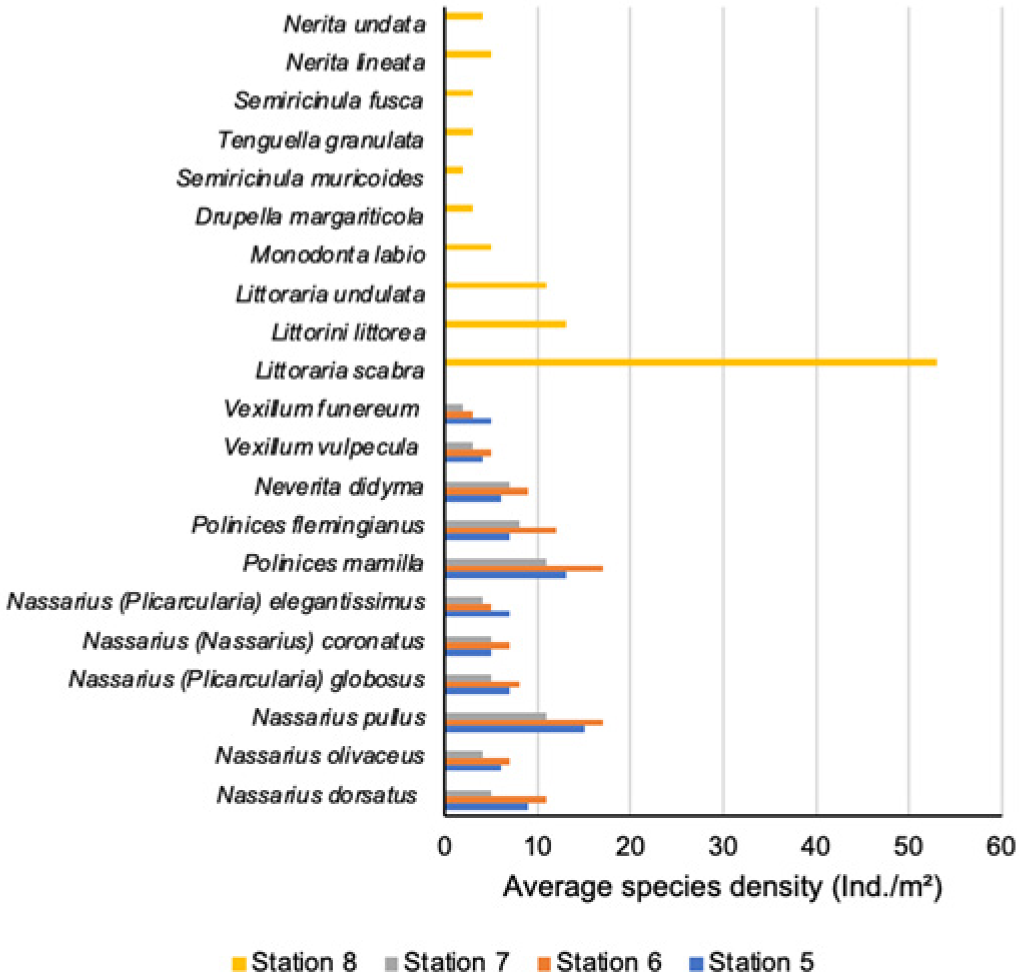

Figure 8 Average gastropods species density in the reference site

Table 5 Presence of gastropods species at each station in the impacted area (Dawi-Dawi Village)

No.	Gastropods species	Research station of impacted area (IS)			
		IS 1	IS 2	IS 3	IS 4
1	*Nassarius dorsatus*	+	-	-	-
2	*Nassarius olivaceus*	+	-	-	-
3	*Nassarius pullus*	+	-	+	-
4	*Polinices mamilla*	-	-	+	-
5	*Polinices flemingianus*	-	-	+	-
6	*Neverita didyma*	-	-	+	-
7	*Littoraria scabra*	-	+	-	+
8	*Littorini littorea*	-	+	-	+
9	*Littoraria undulata*	-	+	-	+
10	*Monodonta labio*	-	+	-	+
11	*Drupella margariticola*	-	+	-	-
12	*Semiricinula muricoides*	-	+	-	-
13	*Tenguella granulata*	-	+	-	-
14	*Semiricinula fusca*	-	+	-	-
15	*Nerita lineata*	-	+	+	+
16	*Nerita undata*	-	+	+	+

Notes: + = Existed; - = Did not exist

Table 6 Presence of gastropods speies at each station in the reference site (Totobo Village)

No.	Gastropods species	Research station of the referene site (RS)			
		RS 5	RS 6	RS 7	RS 8
1	*Nassarius dorsatus*	+	+	+	-
2	*Nassarius olivaceus*	+	+	+	-
3	*Nassarius pullus*	+	+	+	-
4	*Nassarius (Plicarcularia) globosus*	+	+	+	-
5	*Nassarius (Nassarius) coronatus*	+	+	+	-
6	*Nassarius (Plicarcularia) elegantissimus*	+	+	+	-
7	*Polinices mamilla*	+	+	+	-
8	*Polinices flemingianus*	+	+	+	-
9	*Neverita didyma*	+	+	+	-
10	*Vexillum vulpecula*	+	+	+	-
11	*Vexillum funereum*	+	+	+	-
12	*Littoraria scabra*	-	-	-	+
13	*Littorini littorea*	-	-	-	+
14	*Littoraria undulata*	-	-	-	+
15	*Monodonta labio*	-	-	-	+
16	*Drupella margariticola*	-	-	-	+
17	*Semiricinula muricoides*	-	-	-	+
18	*Tenguella granulata*	-	-	-	+
19	*Semiricinula fusca*	-	-	-	+
20	*Nerita lineata*	-	-	-	+
21	*Nerita undata*	-	-	-	+

Notes: + = Existed; - = Did not exist

In the impacted area, species density was very low (1- 3 ind./m2), whereas in the reference site the density reached 10 - 30 ind./m2 (ratio = 1 : 10). Species density in the reference site was high, especially for gastropods living in hard substrates or rocky habitat which were relatively unaffected by nickel overburden even tough their surroundings were exposed to the overburden. High species density of 45 - 115 ind./m2 with stable species composition was found in gastropods community inhabiting hard substrate or rocky habitat, such as *Littoraria scabra, Littorini littorea, Littoraria undulata, Monodonta labio, Drupella margariticola, Semiricinula muricoides, Tenguella granulate, Semiricinula fusca, Nerita lineata,* and *Nerita undata* (Fig. 4).

Results of our study were identical to the research resuts of Purnama *et al.* (2024a; 2024b; 2024c; 2024d) who found the same condition, where gastropods community in a mangrove area affected by overburden experienced a very drastic decrease in the number of species and individuals due to the loss of ecological space that was the niche of the mangrove gastropods community in the Pomalaa mangrove ecosystem.

Gastropods inhabiting rocky habitat have a very high density and form groups in boulders. In addition, the gastropods community is not influenced by nickel overburden because rocks, gravel, and other hard substrates are not able to capture or store sediment, hence, when high tide occurs, the sediment carried in the overburden flow will be washed away by the water flow and settle to the bottom of the water.

Rocky habitat is part of the coastal ecosystem. Interactions between gastropods species inhabiting rocky habitat or hard substrates and gastropods species living in other types of habitat in coastal areas occur in intersecting ecological spaces. Gastropods species that inhabit substrates or bottom of waters tend to use rocks as shelter from the currents and waves in coastal areas and as hiding place from predators. Apart from that, the hard substrate also becomes a feeding ground (grazing) area for gastropods because the hard substrate is overgrown with algae (Purnama *et al.* 2024a, 2024b, 2024c).

The diversity and abundance of gastropods species are influenced by the bottom substrates of their habitats. On the south coast of Pamekasan Madura Regency, the total diversity index of gastropods is 3.0075, indicating high diversity. The most abundant species is *Nassarius distortus*, followed by *Littoraria scabra* and *Nassarius leptospirus*, with relative abundances of 11.21%, 9.09%, and 8.03%, respectively. Jumiang Beach has a lower diversity index of 1.6200, classified as moderate, with 8 gastropods types and 105 individuals. This beach is affected by human activities, which may impact biodiversity. The dominant species here is also *Nassarius distortus*. Talang Siring Beach's diversity index is 2.0988, with 12 gastropods types and 123 individuals. The most common species is *Nassarius jacksonianus*. Bengkal Beach has a diversity index of 2.4398, hosting 16 gastropods types and 245 individuals. This beach benefits from a nearby mangrove ecosystem, supporting a variety of species, with *Littoraria scabra* and *Cerithium corallium* being the most dominant. Overall, environmental conditions significantly influence gastropods diversity across these locations (Kurniawan *et al.* 2024; Rahmasari *et al.* 2015).

Jumiang Beach features a sand-type substrate, resulting in only eight types of gastropods compared to other beaches (Rahmasari *et al.* 2015). Nybakken and Bertness (2005) explained that the instability of sandy substrates limits the settlement of larger organisms. Research by Hawari *et al.* (2014) indicated that gastropods at Pandan Beach also exhibit lower diversity on sandy substrates compared to muddy ones. The lack of vegetation on Jumiang Beach further reduces gastropods species, as they rely on detritus from plants (Rahmasari *et al.* 2015). In contrast, Talang Siring Beach, with its sandy clay substrate, supports 12 types of gastropods (Rahmasari *et al.* 2015). Bengkal Beach, with a clayey silt substrate, hosts 16 types of gastropods, the highest among the locations studied (Rahmasari *et al.* 2015). This is attributed to the presence of mangrove forests, which provide optimal conditions for gastropods (Kurniawan *et al.* 2024; Rahmasari *et al.* 2015). Nybakken and Bertness (2005) noted that mangrove ecosystem promotes minimal water movement, allowing fine sediment to accumulate. The organic material from decomposed mangrove debris enriches the sediment, providing a vital food source for gastropods, as reported by Onrizal *et al.* (2009). Several research results in several areas above showed that the species composition found on the coast, especially with fine sand substrate characteristics, is relatively the same (Kurniawan *et al.* 2024; Rahmasari *et al.* 2015).

CONCLUSION

The nickel overburden impacted area and the reference site showed differences in the number of species, i.e., 16 species in the impacted area and 21 species in the referece site, as well as differences in the presence (number of individuals) and density of gastropods. Even though the ecological index categories were the same, the magnitude of the value of index were tends to be different (H' = 1.92 & 2.72; R = 2.93 & 3.41; E = 0.55 & 0.78; C = 0.001 & 0.04, for impacted area and reference site, respectively). In the impacted area (on short) the density of the gastropods community was very low (1 - 3 ind./m2), whereas at the reference site, the density reached 10 - 30 ind./m2. Gastropods living on rocky habitat or those living on hard substrates were relatively unaffected by nickel overburden even though their surroundings were exposed to overburden. Gastropods species composition that living on rocky habitat had a tendency to be stable with a high population density of 45 - 115 ind./m2. Nickel overburden input on the Pomalaa coast greatly influenced the structure of the gastropods community, both in terms of species and density.

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