The impact of tailings flow on the abundance of deep-sea meiofauna in Sumbawa waters

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Abstract. The potential effect of the mining activity in Batu Hijau, Sumbawa, Indonesia, is a by-product called tailings. Before being discharged into the sea, the tailings have been carefully processed on land, so that do not contain chemical elements that are harmful to living resources. The tailing slurry flowing with velocity of 5.7 – 6.4 meters/second at the opening of pipeline and 0.5 – 1.0 meter/second along the seabed, and finally come to rest at a depth of 3,000 – 4,000 meters. From forty sediment sampled was observed that six sampling sites were not found any meiofauna, whereas other sites meiofauna found with varied taxa diversity and its abundance. From the analysis on relationship between meiofauna abundance and the percentage of tailings it can be concluded that high percentage of tailings greatly influences the taxa diversity and meiofauna abundance in sediments. However, besides the presence of tailings as mentioned above, physical instability of the sediment as the impact of tailings flow is highly influential to the meiofauna community.

1. Introduction

A copper/gold mine located in Batu Hijau, Sumbawa Island, Indonesia, was previously operated by PT Newmont Nusa Tenggara (PTNNT). Since 2016, the operation of the mine was handed over to PT Amman Mineral Nusa Tenggara (AMNT). Up to now, it has processed ore at a rate of 120,000 tons per day. A major by-product of this mining is finely ground rock material from the milling process called tailings, which flows by gravity as a slurry or mixture of water and crushed rock through a pipeline. Then, the residues of tailings are discharged to the deep ocean floor of Lombok Basin through a pipeline at 125 meters deep, which is still under the depth of thermocline layer of 70 – 116 meters below sea level, at Senunu Canyon. The position of tailings discharge below the surface mixed layer, euphotic zone, and upwelling zone, make stable deposition of tailings on the seabed [1]. The tailings residue that flows to the seabed takes quite quickly due to the steep submarine canyon, and tailings itself is about three times denser than seawater, and finally come to rest at a depth of 3,000 – 4,000 meters. It has been measured that the velocity of tailings flow at the end of pipeline and seabed were 5.7 – 6.4 and 0.5 – 1.0 meter/second, respectively. The tailings flow may greatly affected the fauna living on the seafloor, where one of them is meiobenthic fauna. Based on biological testing summarized, PTNNT’s tailings have been classified as a non-hazardous material to marine biota[2].

Meiofauna is small metazoan organisms and have been methodologically defined as organisms passing through a 500 to 1000μm, but retained on a 32μm mesh [3-5]. They represent the most abundant fauna in marine sediment, extending from high littoral to abyssal zone. Meiofauna in a benthic community may play roles as food resources for others meiofauna, active in biodegradation
process of organic matter [6], food resources for higher trophic levels, and gives sensitive responses to environmental perturbation [7]. Therefore, this zoobenthic metazoans has been suggested as a tool for environmental indicator of habitat health [8-9]. In terms of sensitivity to anthropogenic disturbance, these small benthic metazoan groups have advantages over any pelagic organisms since they are less mobile and short-lived.

The purpose of this study was to determine the impact of tailings on meiofauna community structure in the Senunu canyon, where the tailings flow over the surface of their habitat. Data analysis of community structure related to environmental conditions could be done by applying the multivariate statistical which discriminates sites by their meiofauna abundance [10]. Given the taxonomic problems on meiofauna in pollution studies, there have been developed methodologies by using major taxonomic levels which are higher than species [2].

2. Method
2.1 Sampling
The survey was carried out on May 16 till June 12, 2018, by using RV Baruna Jaya VIII at the southern waters of Sumbawa Island (Figure 1). The seabed of South Sumbawa waters is forming row of valleys (canyons) and ridges. Both valleys and ridges in the western and eastern parts are relatively larger than those existing in the middle of the study area. Figure 2 shows the positions of the valleys and ridges in three dimensions (3D), where the blue-dotted line shows the position of the valleys while the red-dotted line is the ridge position. Based on the picture, it can be seen clearly that the valleys and ridges are elongated from north to south and relatively perpendicular to the coastline of Sumbawa Island. Through the position of tailings pipeline, it can be predicted the direction of the tailings sediment flowing from the end of the pipe to the Lombok Basin as illustrated with the solid light bluish color arrow lines. The position of each sediment sampling station is located on both of the valleys and ridges.

![Figure 1. Map showing the survey area](image)

![Figure 2. 3D seabed of the survey area and sampling sites](image)

Forty sediment samples for meiofauna enumeration were taken from sub-sampled sediment that was collected by the box core at the depths of 200 to 4500 meters. The sub-sampling of the sediment was performed by using a piston style core made from a cut off end of a 50 ml syringe with inner diameter 3 cm inserted into sediment until 10cm deep. These sediment samples were preserved in 5% formalin and stained with Rose Bengal for further examination. Determination of the percentage of tailings material within the sediment was carried out by following the methods of [11].

2.2 Sample sorting
In the laboratory, the sediment samples for meiofauna study were washed through a set of two sieves, the upper one with a mesh of 1000 μm size and the lower one with a mesh of 32 μm size. Animals passing from the upper sieve but retained on the lower sieve were considered as zoobenthic
meiofauna. The extraction of meiofauna from the sediment retained on the second sieve was proceeded through strong swirl decantation as applied by [12] and followed by microscopic sorting. Identification and counting of meiofauna collected were done under microscope on lined Petri dish. All meiofauna collected from each sampling site were enumerated into major taxa levels. Abundance values of meiofauna are expressed as average number of individuals per 10cm² per station.

2.3 Statistical analysis

Multivariate analyses were used to observe the presence of meiofauna communities at each sampling site and their abundance in accordance with the tailing percentages as described by [13]. Clustering was done on the basis of the Bray-Curtis similarity measure:

\[
\delta_{jk} = \frac{\sum_{i=1}^{s} |Y_{ij} - Y_{ik}|}{\sum_{i=1}^{s} |Y_{ij} + Y_{ik}|}
\]

where: \(Y_{ij}\)=score for the ith species in the jth sample; \(Y_{ik}\)=score for the ith species in the kth sample; \(\delta_{jk}\)=dissimilarity between the jth and kth samples summed over all s species. \(\delta_{jk}\) ranges from 0 (identical score for all species) to 1 (no species in common), and the complement of the similarity is:

\[
S_{jk} = 1 - \delta_{jk}
\]

The ordination used was a non-metric multidimensional scaling (MDS) and was attempted to construct a “map” of the sites with similarity samples. All these data analyses are included in a set of computer programs of PRIMER (Plymouth Routine In Multivariate Ecological Research) developed by Plymouth Marine Laboratory, UK [13].

3. Result and discussion

Table 1 explains the presence of meiofauna taxa and its abundance at each station, which also includes the depth of sediment sampling and the percentages of tailings sediment. Meiofauna was not present in 6 (six) sampling sites, respectively 24, 25, 34, 50 and 51. And 9 (nine) sites were categorized with zero percentage of tailings (Sites 3, 18, 22, 25, 37, 43, 48, 59 and 60). As many as 10 (ten) taxa of permanent meiofauna were recorded at the seabed of Senunu waters, i.e. Nematoda, Harpacticoid Copepoda, Polychaeta, Turbellaria, Oligochaeta, Ostracoda, Nauplii, Kinorhyncha, Foraminifera, and Tanaidacea; also juvenile bivalve as a temporary meiofauna. Nematoda seems to appear consistently at all stations, except at the stations where no meiofauna exists. It has been studied that nematodes are more adaptable to the extremely low oxygen content, even below redox discontinuity layer (RPD) [14], since the respiration rate of this benthic nematodes significantly lower compared to animals from better oxygenated environments [15].

| Sta. | Depth (meter) | Tailings (%) | Average abundances of meiofauna taxa (individuals/10cm²) |
|------|--------------|--------------|----------------------------------------------------------|
|      |              |              | Nem Har Pol Tur Oli Ost Nau Kin For Tan J.b Total |
| 1    | 1030         | 2            | 7 0 1 0 0 0 1 0 0 0 9 |
| 2    | 650          | 3            | 3 0 1 1 0 0 0 0 0 0 5 |
| 3    | 200          | 0            | 6 13 7 4 0 4 7 1 1 0 43 |
| 6    | 1524         | 30           | 13 6 3 0 0 0 0 0 0 0 22 |
| 7    | 1305         | 40           | 32 0 0 10 0 0 0 0 0 0 46 |
| 8    | 719          | 40           | 0 0 0 4 0 0 0 0 0 0 4 |
| 10   | 477          | 15           | 57 4 0 7 0 1 0 0 4 0 73 |
Sites no. 24 and 25 have tailings percentage of 15% and 0% respectively, but no meiofauna was found in those two sites. It is suspected that both sites have strong sediment movement, which according to the conducted measurement the sediment movement on seabed was 0.5 – 1.0 meter/second, making it impossible for meiofauna to live. The movement of the sediment slurry at those two sites became accelerated since its seabed has a steep downward angle, as illustrated on the seabed contour (Figure 2). Therefore, stability of sediment is one major requirement for the survival of meiofauna since this meiobenthic animal is slender, vermiform, and lives among the sand grains.

Meiofauna abundance was analyzed further by applying Bray-Curtis similarity index on double square root of meiofauna abundance, yielding a classification as shown in Figure 3. The cluster performed into six groups at similarity of 50%. Group A and B are consisting of Site 52 and 8 respectively. Other groups are more numerous sites within, such as Group C (Site 2, 35, 17, 26, 14, 20 and 28), D (57, 3, 63, 21, 36, 59, 11, 45, 10 and 18), E (6, 12, 13, 32, 1 and 22), and F (41, 43, 48, 19, 31, 29, 60, 7 and 37).

A multidimensional scaling (MDS) ordination from the same pooled data gives a clearer representation on grouping of meiofauna abundance (Figure 4a). The sizes of green circle symbols on the MDS ordinations are derived from Table 1. The sites with a high abundance meiofauna taxa were clumped together in group D with the highest numbers of meiofauna is 154 ind.10cm⁻²(Figure 4b).

Figure 4c shows 2-D MDS configuration of the sites with meiofauna abundance and superimposed symbols of lineal dimensions proportional to the depth each site where the largest circle represents
as 4500 m deep and the smallest circle equals to 200 m deep. In general, the configurations on the water depth of the sites obviously shows no real grading among the groups. Accordingly, the community patterns of meiofauna in Senunu Canyon is not really affected by the depths of seafloor. It is already well known that meiofauna could be found from high littoral to the abyssal zones [16-23]. And, among those meiobenthic metazoans, nematodes tend to be relatively most abundant in samples from the deepest stations. The presence and abundance of nematodes which are always high compared to other taxa at the sediments, even in the deeper sediment layers, is very closely related to the quantity and quality of food sources, as well as, its oxygen content [24].

Figure 3. Shows the classification of meiofauna abundance at the Senunu Canyon.

Figure 4. Two-dimensional MDS configurations for (a) meiofauna standardized root-transformed abundance (stress coefficients = 0.15). (b – d) Same configuration with circles representing values of environmental variables superimposed. (b) Circles representing the total meiofauna abundance at sites, largest circle = 154 ind. 10 cm². (c) Circles representing water depth, largest circle = 4500 meters. (d) Circles representing percentage of tailing, largest circle = 90%.

The contrast results are shown in Figures 4b and 4d wherein the picture shows contradictions, namely in groups that have a large percentage of tailings (Figure 4d) when compared to the same group in Figure 4b shows very little meiofauna abundance. Both of these figures show that tailings sediments are very influential to the presence of meiofauna in the Senunu canyon. The potential effects of the deposition tailings sediment in a poorly managed deep sea tailings placement may produce potential negative consequences, such as bioaccumulation of metals, toxicity of milling reagent and dissolved metals, increased photic zone turbidity, and habitat alteration [25]. However, the treatment of tailings removal in Batu Hijau to the seabed of Senunu Canyon has been known to have been very good where the tailings disposal pipeline is located below the thermocline layer and the tailing sediment itself has been classified as a non-hazardous material to marine biota [2].

Based on the above facts, it can be said that the reduction or absence of meiofauna at the bottom of the Senunu Canyon is more likely due to the instability of sediments as the habitat of this meiofaunal fauna. Since meiofauna has very short generation time and lack of pelagic larval dispersion, these groups of benthic animals become very sensitive to environmental changes [26], where sedimentary structures are the main factor that determines the presence of meiofauna[7]. Besides, several abiotic factors, such as temperature, salinity, hydrodynamic and sedimentary processes, sediment grain size, oxygen level and food availability may affect the abundance, diversity, distribution of meiofauna [27-31]. It has been studied that heterogeneity of sediment, especially in oxygen minimum zones, may control the community structure of meiofauna within sediment [32]. It should be taken into account.
also that meiofauna would not survive on freshly tailings materials, unless the tailings settled and incubated properly in the sea and no further addition of fresh tailings. Only by then metazoan meiofauna will recolonize soon. Mesocosm and microcosm experiments of meiofauna recolonization into tailings sediment were well established in tailings from freshly mined ore after 40 days and statistically indistinguishable from natural unaffected controls after 97 and 203 days [2]. Finally, meiofauna is represented as a good indicator for such anthropogenic impacts, and they may give a spontaneous reflection on spatial and temporal changes. However, it is difficult to make correct interpretation of meiofauna responses without any information about the abiotic factors on their surrounding habitat. Therefore, measurements on its environmental conditions are fundamental in the interpretation of the observed patterns. Considering environmental parameters together with meiofauna indices strengthens scientific interpretations and provides useful tools for the detection of anthropogenic disturbances.

4. Conclusion
Disturbances to the diversity and abundance of meiofauna at the bottom of Senunu Canyon were not only determined by the high percentage of tailings but also by the instability of the sediment which is always flowing downward to the deeper seabed. If the mining activities are shutdown, at least within 40 days, then the abundance of meiofauna would return to normal condition. Lesson learned from this environmental study has also demonstrated that using major taxa for meiofauna is very meaningful.

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References
[1] Ellis D and Ellis K 1994 Very Deep STD Mar. Poll. Bull. 28 472-476
[2] Gwyer D, Batterham G J, Waworuntu J, Gultom T H, Prayogo W, Susetiono and Karnan 2009 Recolosnisation of mine tailing by meiofauna in mesocosm and microcosm experiments Mar. Poll. Bull. 58 841-850
[3] Bouwman L A 1987 Meiofauna Biological Surveys of Estuaries and Coast ed J M Baker and W J Wolff (Cambridge: Cambridge University Press) pp 140-156
[4] Fencl D 1974 The ecology of micro- and meiobenthos Ann. Rev. Ecol. Syst. 9 99-121
[5] Gerlach S A 1971 On the importance of marine meiofauna for benthos communities Oecologia 6 176-190
[6] Dye A H 1983 Composition and seasonal fluctuations of meiofauna in a Southern African mangrove estuary Mar. Biol. 73 165-170
[7] Coull B C 1988 Ecology of the marine meiofauna Introduction to the Study of Meiofauna ed R P Higgins and H Thiel (London: Smithsonian Institution Press) pp 18-38
[8] Heip C, Warwick R M Carr M R, Herman P H J, Huys R, Smol N and Van Holsbeke K 1988 Analysis of community attributes of the benthic meiofauna of Frierfjord/Langesundfjord Mar. Ecol. Prog. Ser. 46 171-180
[9] Kennedy A D and Jacoby C A 1999 Biological indicator of marine environmental health: meiofauna – a neglected benthic component? Environ. Monit. Assess. 54 47-68
[10] Field J G, Clarke K R and Warwick R M 1982 A practical strategy for analyzing multispecies distribution patterns Mar. Ecol. Prog. Ser. 8 37-52
[11] Terry R D and Chilingar G V 1955 Summary of concerning some additional aids in studying sedimentary formation by Shvetsov M S J. Sediment. Petrol. 25(3) 229-234
[12] Faubel A 1982 Determination of individual meiofauna dry weight values in relation to definite size class C. Biol. Mar. 28 339-345
[13] Clarke K R 1993 Non-parametric multivariate analyses of changes in community structure Aust. J. Ecol. 18 117-143
[14] Willems K A, Sharma Y, Heip C and Sandee A J J 1984 Longterm evolution of the meiofauna at sandy station in Lake Grevelingen, The Netherlands Neth. J. Sea Res. 18 (3/4) 418-433
[15] Ott J and Schiemer F 1973 Respiration and anaerobiosis of free living nematodes from marine and limnic sediments Neth. J. Sea Res. 7 233-243
[16] Reise K 1983 Biotic enrichment of intertidal sediments by experimental aggregates of the deposit-feeding bivalve Macomabalthica Mar. Ecol. Prog. Ser. 12 229-236
[17] Somerfield P J, Gee J M and Warwick R M 1994 Soft sediment meiofauna community structure in relation to a long-term heavy metal gradient in the Fal Estuary system Mar. Ecol. Prog. Ser. 105 79-88
[18] Somerfield P J, Gee J M and Aryuthaka C 1998 Meiofauna communities in a Malaysian mangrove forest J. Mar. Biol. Ass. U.K. 78 717-732
[19] Shirayama, Y 1984 The abundance of deep sea Meiobenthos in Western Pacific in relation to environmental factors. Oceanol.Acta7 (1) 113-121
[20] Danovaro R, Gambi C, Manini E and Fabiano M 2000 Meiofauna response to a dynamic river plume front Mar. Biol. 137 359-370
[21] Danovaro R, Tselepidides A, Otogui A and Croce N D 2000 Dynamics of meiofaunasssemblages on the continental shelf and deep-sea sediment of the Cretan Sea (NE Mediterranean): relationships with seasonal changes in food supply Prog. Oceanogr.46 367-400
[22] Sommer S and Pfannkuche O 2000 Metazoan meiofauna of the deep Arabian Sea: Standing stocks, size spectra and regional variability in relation to monsoon induced enhanced sediment regimes of particulate organic matter Deep-Sea Res. (2 Top. Stud.Oceanogr.)47 2957-2977
[23] ZeppilliaD, Bongiornia L, Cattaneoe A, Danovaro RandSantos R S 2013 Meiofauna assemblages of the Condor Seamount (North-East Atlantic Ocean) and adjacent deep-sea sediments Deep-Sea Res.(2 Top. Stud.Oceanogr.)98(A) 87-100
[24] Schratzberger M and Ingels J 2017 Meiofauna Matters: The Roles of Meiofauna Benthic Ecosystems J. Exp. Mar. Biol. Ecol. 502 12-25
[25] Kline ERandStekoll M S 2001 Colonization of mine tailings by marine invertebrateMar. Environ. Res.51 301-325
[26] Bongers T and Ferris H 1999 Nematode community structure as a bioindicator in environmental monitoring Trend Ecol. Evol. 14(6) 224-228
[27] IngelsJ, Tchesunov A V and Vanreusel A 2011 Meiofauna in the Gollum Channels and the Whittard Canyon, Celtic Margin – How local environmental conditions shape nematodestructure and function PLoSONEdoi: 10.1371/journal.pone.0020094
[28] Lizehe C, Suinfg F, Jie Y and Xiping Z 2012 Distribution of meiofaunaabundance in relation to environmental factors in Beibu Gulf, South China Sea Acta Oceanol. Sin.31 92-103
[29] Ngo X Q, Smol N and Cah V A 2013 The meiofauna distribution in correlation with environmental characteristics in 5 Mekong estuaries, Vietnam Cah. Biol. Mar. 54 71-83
[30] Zeppilli D, Bongiorni L, Cattaneo A, Danovaro R and Serrao-Santos R 2013 Meiofauna assemblages of the Condor Seamount (North-East Atlantic Ocean) and adjacent deep-sea Sediments Deep-Sea Res. (2 Top. Stud.Oceanogr.)98 87-100
[31] Gorska B, Grzelak K, Kotwicki L, Hasemann C, Schewe I, Soltwedel T and Wlodarska-Kowalczuk M 2014 Bathymetric variations in vertical distribution patterns of meiofauna in the surface sediments of the deep Arctic Ocean (HAUSGARTEN, Fram strait) Deep-Sea Res. (1 Oceanogr. Res. Pap.)91 36-49
[32] Gooday A J, Escobar E, Ingole B, Levin L A, Neira C, Raman A VandSellanes J 2010 Habitat heterogeneity and its influence on benthic biodiversity in oxygen minimum zones. Mar. Ecol.31 125-147