Surveying the Effects of the Deep-Sea Tailings Disposal of Mine Wastes in Toledo City, Cebu, Philippines Three Decades After Mine Closure

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Abstract. From 1971 to 1991, a major mining company performed submarine tailings disposal (STD) with the outfall at the coast of Ibo, Toledo, reaching up to 100,000 tons per day. In this study, five sampling points were selected near the outfall to determine if the STD is still a major factor in the physicochemical conditions and concentration of heavy metals in the area near the outfall in Tañon Strait 28 years after the last disposal of mine tailings. The study found that Fe, Mn, and Cu contents on beach sediments significantly decreased around the outfall, as well metal contents on seawater which are within the DAO-2016-08 standards. Physicochemical parameters showed values within the normal range and standards. Comparing the species count from 1983 to 2019, the drastic decline can be attributed to ocean acidification, acid mine drainage, and siltation from Sapangdaku River.

1. Introduction
One of the first two large-scale mines to practice submarine tailings placement (STP) in the world was in Toledo City, Cebu, Philippines, aimed to addressing the lack of a tailings storage facility due to financial reasons or geotechnical conditions which poses concerns regarding safety.

From the 1950s to 1970s, the mine dumped their tailings into the Sapangdaku River, 21 km from the concentrator, which flows out into Tañon Strait. According to the residents, the tailings were visible near the surface of the water, filling the riverbank [1]. To solve this problem, the mine came up with an alternative by discharging tails through a launder pipeline into the sea which was completed in 1971. By 1974, when the Carmen Concentrator became operational, 59 million tons of tailings were already dumped through the pipe [1]. Ideally, STP should be deep enough to not affect marine organisms living within the euphotic zone. However, according to Ellis and Robertson [2] the pipe only extended 10 m vertically, as seen in Figure 1, posing imminent threat to the marine ecosystem around the outfall located at Ibo, Toledo.

Disposal of tailings started in 1972 and ended in 1990, discharging up to 100,000 tons of tailings per day. The ecological effects of this disposal were studied in 1983, providing details on the physicochemical and biological status of Tañon Strait [1]. The study showed that the considerable amounts of suspended sediment and high Cu concentration may have caused a significant decrease in number and relative number of species in the areas near the outfall.

Another study conducted analysed the geochemical dispersion of the heavy metals along the coast and showed that the zone immediately around the outfall is the only area affected by high metal values of Cu, Pb, Zn, Fe, and Co [3].
This study compares the state of biodiversity and water quality of Toledo City, Cebu in 1983 and 2019 by metal concentrations and physicochemical parameters in sediment and water samples to determine if the submarine tailings from the mine are a major factor in the physicochemical conditions and amounts of heavy metals in the areas near the mine outfall in Tañon Strait 28 years after the last disposal. Data collection is limited to five sampling points near the outfall. For sediment collection, one set of samples are taken using grab sampling and for water collection, two sets of samples are taken - one for low and one for high tide. For marine biodiversity assessment, only the species count from the five 25-m long transect lines is used due to diving time limitations at 30-m depth. For river sample collection, the heavily silted Sapangdaku River restricted the boat from going farther from the sea, resulting in collection of brackish water for river discharge sample.

The study is expected to benefit the coastal communities in the area who rely on fishing as livelihood. It will also serve as baseline for remediation or mitigation for damages, if any. It can also serve as reference for future plans to use STD as means for disposal.

2. Methodology

2.1. Sample Collection - Water Quality and Sediment Samples
Acid-washed 60mL sampling bottles and sealable plastic were used for sample collection. Divers were equipped with proper diving gear and a computer that checks depth during sample collection. As shown in Figure 2, samples were collected at two-kilometer intervals – south of the tailings outfall (SP1), near the tailings outfall (SP2), and north of the tailings outfall (SP3, SP4, SP5). River discharge samples from Sapangdaku River (RD) and coal power plant discharge (CD) were also collected.

Three water samples were taken per sampling point—surface, middle, bottom—to create a depth profile for each point. Sampling areas for surface and bottom were approximately 1m below and above, respectively. Sediment samples were also collected in a plastic bag through grab sampling at the bottom of each sampling point. The samples were collected at a depth range of 0-32 m at each sample location for two different times of the day - high tide and low tide.

2.2. Marine Biodiversity
Line Transect Sampling was used to estimate the abundance per unit area of marine species [4]. The line was created parallel to the coast and within a 30-meter radius from the tailings outfall. Observations on physical characteristics of species such as coral reefs and fish fauna were also recorded.
2.3. Testing Facilities
Physicochemical parameters such as pH, temperature, salinity, total dissolved solids and dissolved oxygen were determined on site using a pH probe, digital thermometer, and a refractometer. Water and sediment samples were stored under low temperature (4 °C) and were not exposed to light before being brought to the testing laboratories for analysis. The fresh samples were tested for metal content, (Cu, Fe, and Mn) in water samples using ICP-OES and XRF in the sediment samples.

3. Results and Discussion

3.1. Physicochemical Parameters
For the physicochemical parameters, the standard values used are based on the local regulation DAO 2016-08 for marine waters of Class SC (recreational waters) and SD (navigable waters) [5]. Five parameters have been collected and analyzed. These are salinity, total suspended solids (TSS), pH, temperature, and dissolved oxygen (DO).

Average salinity values for high tide and low tide in each sampling point are graphed in Figure 3. There are abnormal values since the average for seawater is 2.4-3.5 mg/L. Aliño’s study in 1983 showed that the average salinity for his sampling points was 3.4-3.5 mg/L [1]. The decrease in salinity can be attributed to the dilution of seawater due to the constant circulation of ocean water over the years. TSS values shown in Figure 4 are lower than the maximum allowable value for surface waters of the type SC and SD. Compared to the previous results, TSS are also significantly lower. The highest level was found near the Sapangdaku river discharge and may be attributed to the nearby dredging.

The standard range for pH for marine waters of classes SC and SD are 6.5-8.5 and 6.0-9.0 respectively. Figure 5 shows that the values are within the standard range set, pH values are relatively lower than the average pH of seawater which is 8.1. The mine closure in 1994 left tailings stored in a pit which leaked into the river in August 1999 and caused a massive fish kill which may have contributed to the slight lowering of pH. Ocean acidification also causes the release of more carbon dioxide which permeates into the ocean, causing the production of H+ ions in the water column.

Figure 3. Depth Profiles of Salinity on Sampling Points.

Figure 4. Depth Profiles of Total Suspended Solids on Sampling Points.
Figure 5. Depth Profiles of pH on Sampling Points.

Figure 6. Depth Profiles of Dissolved Oxygen on Sampling Points.

Figure 6 shows the depth profiles of DO values in each of the sampling points. Acceptable DO values are pegged at 5.0 mg/L and levels were higher in all points with the highest at SP2. More flora species were also observed in this area. SP1 and SP2 are located in shallow depths where they are exposed to enough sunlight for photosynthesis. The general trend in Figure 6 shows that the DO levels during high tide are higher than in low tide since more ocean water containing dissolved oxygen is introduced. However, SP1 does not follow this trend due to the probable consumption of free oxygen by biological and chemical processes in the area.

3.2. Comparative Study

Compared to Aliño’s study, DO levels are lower than the standards with a range of 4.7-6.4 mg/L. A slight change in temperature was noted but this can be attributed to the general climate change trend in the Philippines with an average annual increase of 0.0108 °C observed [6]. The change in temperature may possibly have caused the increase in DO levels in the area.

3.3. Metal Dispersion

3.3.1. Water Samples. The depth profiles of the metals are shown in Figures 7, 8, and 9, respectively. Copper ranges from 0 to 4.36 ppb (parts per billion) which is less than the threshold value (20 ppm) or the average Cu concentration of seawater which (90 ppb). The amount present does not pose harm to the marine biodiversity in the area. Iron, ranging from 25 - 401 ppb is very much less than the standard seawater value of 1.5 ppm but higher than the average concentration of Fe in seawater, 20 ppb (Figure 8). The highest level was detected at SP1 – middle during low tide and the lowest level was at SP2 – surface during high tide. Fe concentrations may be attributed to weathering of naturally occurring iron minerals such as chalcopyrite and bornite from Sapangdaku River discharge since rich deposits of these minerals are found near the river area [7]. The release of acid mine discharge from the damaged mine pit due to drainpipe failure last August 1999 has been continuously discharging acid waters into Sapangdaku River. At low levels of salinity, Fe is dissolved in water, so expectedly the river discharge sample (SP4) should have the higher Fe concentration compared to the other points [8], but due to its high salinity the dissolved iron ions are not affected.
Manganese concentrations from 0 to 8.07 ppb are all lower than both the DAO 2016-08 standard threshold which is 40 ppm and the average Mn concentration in seawater which is 10 ppb. The highest level was detected at SP4 – surface during low tide. This may be the result of high turbidity which can intensify the reaction of Mn (II) ions to Mn (IV) precipitates [8]. The present amount of Mn does not pose any harm to the marine biodiversity in the area.

3.3.2. Sediment Samples. For the sediment samples, composition of the same metals was analysed using XRF to obtain metal composition. Sediment analysis is important because heavy metals have higher density than ocean water, thus they are most likely to accumulate at the bottom as sediments. Sediments with very high number of metals can result to the bioaccumulation of metals in fauna and flora exposed to these sediments [9]. The concentrations of Cu at SP1–SP5 are summarized in Figure 10 and are compared with the results gathered by Añó in 1983. All values are uniformly low except for a peak at SP3 which may be attributed to the presence of a port in the area contributing contaminants from debris during transfers of ore from the port to the ships.

Meanwhile, Fe concentrations decreased at SP1 and SP2 and increased at SP3-SP5 as summarized in Figure 11. For SP3, again, this can be attributed to the presence of a port that handles copper ore composed of chalcopyrite-bearing biotite diorite porphyry with some bornite minerals [7]. Meanwhile, at SP4 and SP5, elevated Fe may have been caused by the river discharge and could have been intensified by the river dredging during the sample collection.

Mn results show no abnormalities in the trend of concentrations as shown in Figure 12. Of the three metals, only the Cu and Mn have significantly decreased from 1983 to 2019.

![Figure 7. Depth Profiles of Cu Concentration.](image1)

![Figure 8. Depth Profiles of Fe Concentration.](image2)

![Figure 9. Depth profiles of Mn concentration.](image3)

![Figure 10. Cu concentration comparison - 1983 and 2019.](image4)
3.3.3. Marine Biodiversity. Due to limitations in the species identification, the transect line showed only the following organisms: 1 seaweed (Sargassum sp), 2 fishes (Amphiprion melanopus, 1 unidentified), 1 anemone (Heteractis crispa), and seagrass (unidentified) as shown in Table 1. While the study tried to choose sampling points near the study original areas in 1983, it should be noted that the species count in 1983 were done at depth ranges between 2.5 – 6.5 m while our study went up to 30 m deep. The total species count in Looc, Bato, and Matab-ang in 1983 were found considerably higher than the current count of 5.

Migratory fishes were seen from afar during transect line surveying on SP2. According to Bureau of Fisheries and Aquatic Resources – Region VII, the commercial fishes present in 1970s were herrings, round scads, tunas, and bigeye scads [10]. With the proclamation of Tañon Strait as a protected seascape last 1998 [11] commercial fishes are assumed to still be present. However, since these are migratory no record of their presence was found because transect lines only cover reef species. Additionally, burrows were found at the bottom, indicating organisms below the sea bottom that were not visible during surveying.

The decline of marine species can be attributed to the acidification of seawater, shown in Figure 5. The increased acidity is an indication of increased atmospheric carbon dioxide absorption of the water. Ideally, CO₂ binds with water to form H₂CO₃ which consequently binding with free calcium ions to form shells for corals and other organisms. But with the increased CO₂ levels, H₂CO₃ dissociates to H⁺ ion and bicarbonate ion (HCO₃⁻). Since shell-building organisms (i.e. corals) cannot remove the carbonate in HCO₃⁻ due to higher affinity of hydrogen to carbonate than calcium, shells cannot form causing a decrease in coral population.

The decline of marine species can also be attributed to high sediment load coming from Sapangdaku River and previously from the outfall. Results of transect line surveying on SP2 showed barren sea bottom with a few sea anemones and clown fishes, and scattered sea urchins on very fine sand or silt.

At SP4 and SP5, the bleached coral reefs are covered in silt which is most likely from the Sapangdaku River which recorded high total suspended solids due to its heavily silted condition as well as the ongoing dredging operations at the mouth of the river.

Moreover, it should be noted that the scope of this study is only the effects of submarine tailings and mine activities. Assessment of other anthropogenic impacts are not included but it might have a huge impact to the decline in marine biodiversity especially with Toledo City continuing its rapid urbanization compared to other cities in Cebu outside Metro Cebu. [12].

Table 1. Species Count Comparison - 1983 and 2019.

| Alino (1983)                | Recent count (2017)               |
|-----------------------------|----------------------------------|
| Matab-ang (9 km N of outfall) – 57 species | Talavera (SP5, 8 km N of outfall) – 0 species |
| Bato (3 km S of outfall) – 49 species | Sangi (SP2 to 4, 0 to 6 km N of outfall) – 4 species |
| Looc (1.5 km S of outfall) – 36 species | Looc (SP1, 2 km S of outfall) – 1 species |

Figure 11. Fe Concentration Comparison - 1983 and 2019.

Figure 12. Mn Concentration Comparison - 1983 and 2019.
4. Conclusion and Recommendations

The results of the study show that there is a difference between parameter values of the average ocean water and the gathered samples from the area but are still within the DAO 2016-08 standards for class SC and SD waters. Compared to the range of parameter values gathered by Aliño in 1983, there is a decrease in salinity and dissolved oxygen. Lower values in salinity suggests that there is more non-marine water input due to river discharge and addition of two coal power plants. Decrease in dissolved oxygen suggests that there is also a decrease in the number of oxygen-producing organisms such as seagrass and seaweeds.

Over the past 36 years, the metal concentrations (Cu, Fe, and Mn) also decreased significantly in amount. However, there is also a drastic decrease in the species count. These suggest that, at present, the degradation of marine environment is not mainly because of Atlas Mines’ submarine tailings disposal but is also a combination of these reasons – in a decreasing order of impact: (1) acid mine drainage, (2) presence of port and coal power plants, (3) urbanization, and (4) ocean acidification.

To improve the results of the study, the researchers recommends the following:

1) Increase the sampling points at shorter intervals to have a better analysis of the source of contaminations and pollutants.
2) Replicate sample gathering to increase reliability of results
3) Have longer transect lines to have a better approximation of species count.
4) If collecting river samples, consider other means of accessing the river such as entrance by land

The researchers would also like recommend for continuous marine water quality and biodiversity assessment in the area, especially that Toledo City is urbanized. Possible mitigations should be engineered to limit anthropogenic impacts on marine environments. Progress and environment protection should not be mutually exclusive.

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