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Decreased Dissolved Oxygen Affecting Sustainability of Mussel Farming in East Manila Bay, Philippines

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Abstract Manila Bay is surrounded by industrial, urban and populated cities of the Philippines and exposed to various pollutants. A hydrodynamic model previously simulated with the influence of tides, winds, rivers and pharmaceutical pollutants showed high dissolved organic pollutant concentration near Pasig & Pampanga Rivers and on the eastern side of the bay where mariculture, especially mussels proliferate (Enova et al, in progress). These organic pollutants may contribute to lower dissolved oxygen (DO) and hypoxic conditions (<2 mg/L) deeper than 4 m in Navotas, and 6 meters in Paranaque. Low DO levels at the bottom waters are consistent with anecdotal reports from fisherfolks that mussels survive at the upper 2 meters of the water column in the past few years rather than at the seafloor. Monitoring of dissolved oxygen is vital in this area as it may affect mussel growth and reproduction. Moreover, targeted monitoring and analysis of specific organic pollutants and other factors that may contribute to hypoxia is recommended for a more comprehensive discussion of the health of Manila Bay and sustainability of mariculture.

Keywords: Hypoxia, Manila Bay, Pollutant Transport, Mariculture

1. Introduction

Manila Bay, Philippines, is a coastal embayment near the major provinces of the Philippines. Due to its proximity to highly urbanized cities, it is exposed to various pollutants. Some types of pollutants, especially organic pollutants, consume oxygen during decomposition, which in turn may decrease the oxygen level in the water body, causing hypoxia.

In previous studies by Jacinto et al (2011) and Sotto et al (2014), it was found that during the Northeast monsoon, a band of hypoxic near-bottom water form between Bataan on the west and Manila on the east despite the season's strong winds, limited water stratification and good mixing (Jacinto et al., 2011). During the Southwest monsoon, hypoxia formed in the middle area of the bay where stratification may occur (Sotto et al., 2014). Sotto et al's (2014) results also point to the worsening state of hypoxia in Manila Bay in terms of increase in area and shoaling of oxycline.

A hydrodynamic model that was previously developed using Delft3D-FLOW with the influence of tides, winds, rivers, and dissolved pharmaceutical pollutants (pollutant data from Mariano et al, in progress) show possible pollutant transport and high dissolved pharmaceutical pollutant concentration near Pasig & Pampanga Rivers (Enova et al, in progress). Pollutant transport was initially modeled to be mostly from Pasig River going north to Navotas area, and from Pasig River going south to Parañaque and Bacoor area (Enova et al, in progress). The result of the hydrodynamic model is also consistent with the previous models showing forward in time particulate model of Cruz & Shimozono (2021) in which particulate floating litter was simulated to be mostly accumulating on five hotspots along the northeastern coastline of Manila Bay (Cruz & Shimozono, 2021). As high pollutant concentration is predicted to be generally higher in the Eastern Manila Bay section, sampling and pollutant studies should be focused more on these areas.

Mussel aquaculture and fisheries in the Eastern portion of Manila Bay is also prevalent in three main areas: Navotas, Parañaque, Metro Manila and Bacoor, Cavite. In fact, up to 34% of the country's mussel production (8600 MT) are produced in Metro Manila and Cavite (Philippine Statistics Authority, 2020). Sadly, these areas are also prone to exposure to various pollutants which may decrease dissolved oxygen levels.

We explored through field survey methods the water quality in some areas in East Manila Bay, particularly mussel aquaculture areas in Navotas, Parañaque, Metro Manila and Bacoor, Cavite. The objective of this short study is to determine water quality conditions in terms of dissolved oxygen (DO) in aquaculture areas of East Manila Bay. The study is limited to three aquaculture sites of East Manila Bay, particularly (1) Navotas, Metro Manila, (2) Parañaque, Metro Manila and (3) Bacoor, Cavite. The field survey is limited to one time sampling.

2. Methodology

2.1. *Study Site*

Manila Bay is adjacent to the major provinces of the Philippines. Based on the results of the model by Enova et al (in progress), high pollutant concentration is possible mostly in East Manila Bay. Thus, the field survey was limited to East Manila Bay mussel aquaculture sites namely (1) Navotas, Metro Manila, (2) Parañaque, Metro Manila, and (3) Bacoor, Cavite.

In Navotas, Metro Manila, the jump off point was at Barangay Navotas West, Navotas, while in Paranaque, the jump off point was at the Las Pinas – Paranaque Wetland Park (LPPWP), Paranaque, and for Bacoor, Cavite was Brgy Sineguelasan, Bacoor. Sampling was done in June 2022 and July 2022.

Figure 1. Sampling Sites in East Manila Bay

Table 1. Study Sites and Coordinates

Area	Site Name	Coordinates
Navotas	Nav-Mus-01	14.6527°N 120.9089°E
Navotas	Nav-Mus-02	14.6526°N 120.9085°E
Navotas	Nav-Mus-03	14.6525°N 120.9086°E
Paranaque	LPP-Mus-01	14.5000°N 120.9611°E
Paranaque	LPP-Mus-02	14.4987°N 120.9579°E
Paranaque	LPP-Mus-03	14.4950°N 120.9619°E
Bacoor	Bac-Mus-01	14.4898°N 120.9367°E
Bacoor	Bac-Mus-01	14.4929°N 120.9313°E
Bacoor	Bac-Mus-01	14.4952°N 120.9269°E

2.2. *Field Survey Methodology*

HANNA Multiparameter was used to measure Dissolved Oxygen in the water. The HANNA Multiparameter was calibrated with freshly prepared sodium sulfite solution as the zero DO and HANNA Quick Calibration solution. Dissolved oxygen measurements using HANNA Multiparameter were noted every half meter (0.5 m) depth.

3. **Results and Discussion**

Hypoxic conditions (below 3 mg/L) were detected in Navotas and Parañaque mussel aquaculture areas (Figure 3). During our June 2022 sampling in Navotas, the dissolved oxygen was at 0-5 mg/L, with less than 2 mg/L beyond 4 meter depths. In Parañaque in July of 2022, which was during Southwest monsoon, dissolved oxygen was at 1.5 mg/L to 6.0 mg/L, with less than 2 mg/L beyond 6 meters depth. For Bacoor, dissolved oxygen content was higher at 2.0-8.0 mg/L.

The dissolved oxygen profiles of Navotas vs Parañaque and Bacoor is consistent with the results of the hydrodynamic model which showed high pollutant concentration going North to Navotas (Enova et al, in progress). High organic pollutant concentrations, such as decomposing organic matter and pharmaceuticals, would consume dissolved oxygen, decreasing the dissolved oxygen content, potentially creating hypoxic conditions. As Parañaque and Bacoor are farther from the Pasig River, the pollutant concentration is relatively lower and dissolved oxygen content of the surface waters is higher. The oxyclines span 0.5 to 6 m with Navotas area reaching hypoxia the shallowest at 2 m, Parañaque at 4 m, and Bacoor at 6 m.

According to fishermen in the mussel aquaculture areas, live mussels were mostly found at within 1 to 2 m depths, beyond which most of the mussels were dead and fall to the bottom sediment, consistent with the findings of low dissolved oxygen beyond four meters depth. Interestingly, despite the measured hypoxic conditions, there are still a lot of catch fisheries in the area, as attested by fishermen's accounts and the presence of the big number of fish nets in the vicinity. The fishermen rely on wild stocks of mussel larvae and juvenile and only aid adult mussel development by placing bamboos or ropes in which the juvenile mussels could attach, but they are just essentially relying on the natural supply and transport of planktonic mussel larvae, which attests to the reliable abundance of natural stocks.

Figure 2. Mussels (*Perna viridis*) in 1.5 m depth close to Navotas during June 2022 southwest monsoon sampling.

Mussels are filter feeders that rely mostly on marine phytoplankton as their food source. In a study in Eastern Visayas, Philippines, *Perna viridis* mussel dry weight positively correlates with DO content of water (Toralde et al., 2021). In another study of *P. Viridis* reproductive biology, mussel gomatosomadic index (GSI), an index for its reproductive condition, was positively correlated with DO, salinity, Chlorophyll-A, nutrients such as nitrate and phosphate, and water plankton abundance (Asaduzzaman et al., 2019). Moreover, DO was found to have major contributions to the maturation and spawning stage of mussel *P. viridis* (Asaduzzaman et al., 2019). Thus, if dissolved oxygen content in mussel farming areas of East Manila Bay were low, then this would affect the growth and reproduction of mussels in the area such as *Perna viridis*.

Despite hypoxic conditions in the mussel farms, mussel production in Metro Manila (Navotas and Parañaque) is still stable at an average of 325 MT for 2011-2020 (Philippine Statistics Authority, 2020). It is notable that mussel production in Cavite is higher at 5675 MT for 2011-2020 (Philippine Statistics Authority, 2020). A varying but generally increasing trend in mussel production is observed in both Cavite and Metro Manila. Other factors could contribute to the increase in mussel harvest despite the effects of oxygenation, such as high nutrient loads in Manila Bay, and increase in mussel farming structures in the area. It is possible that as the mussels were only found alive at the upper 2 m of the bay, more structures were established, thus compensating for the lost harvest at the bottom. However, this practice may further aggravate the hypoxic conditions as more structures and more mussels would need more oxygen demand. At some point, if the structures, organic matter inputs, and pollutants in the area are not managed, hypoxia may aggravate and system-wide mussel harvest may decline or worse, eutrophication and fish kills might occur.

Hypoxic parts of the water column may persist especially during the Southwest Monsoon as dissolution of oxygen in surface waters only go as far as 2 meters. Based on the 3D hydrodynamic model of Manila Bay, freshwater tends to stay on the top 5 m depth in this area (Enova et al, in progress). The high input of freshwater to the system promotes stratification, decreasing mixing of oxygen from surface to the bottom, and increases nutrient and organic matter inputs which intensifies oxygen demand. During the dry season, there is less freshwater discharge, thus stratification and hypoxia is weakened. Further DO measurements need to be done for the other seasons, but data from Sotto et al (2014) suggest persistence of hypoxic conditions during southwest monsoon on near-bottom depths. In particular, near-bottom hypoxic conditions were observed in their surveys conducted July 2010, August 2011 and August 2012 (Sotto et al, 2014).

Increase in Sea Surface Temperature (SST) may also contribute to persistence of hypoxia due to decreased oxygen solubility at higher temperatures. Increased temperatures not only reduces oxygen supply, but potentially increases oxygen demand due to respiratory and metabolic requirements (Breitburg et al, 2018). Global forecasts and recent models note an increase in SST especially in coastal areas, which may in turn contribute to the spread of hypoxic areas.

Organic matter inputs, which intensify oxygen demands, may also increase during the rainy season (June to November), as more organic matter is swept to the sea, along with increased river flows. Currently, a lot of land reclamation and sediment dredging are happening in East Manila Bay, which may also aggravate hypoxia, as previously buried anoxic organic matter is being resurfaced to the water column. Land reclamation may also create areas of stagnant water by blocking the natural water flows, such as in the area of the LPPWP, Parañaque inner lagoons.

4. Conclusions

Hypoxic conditions in mussel farming areas in East Manila Bay may affect survival, growth and reproduction of mussels such as Perna viridis. The low dissolved oxygen content is one of the reasons why fishermen observe live mussels only at the upper two meters of the water column. Despite the stability of mussel harvest in the past years, if the mussel production, organic matter inputs, pollutants, and dissolved oxygen in the area are not managed properly, mussel harvest may decline or worse, fish kills may occur.

Further measurements of vertical profiles of dissolved oxygen need to be done for the other seasons to verify persistence of hypoxia at such a shallow depth, especially near Navotas, Metro Manila. Dissolved oxygen may be indicative of association with organic pollutants as DO complemented the results of the previous hydrodynamic model simulating transport of organic pollutants. Dissolved oxygen are bulk measurements and analysis of more specific type of organic pollutants, such as emerging or persistent types, can refine policy considerations in the aim to clean-up Manila Bay due to the Philippines Supreme Court 2008 Mandamus (G.R. 171947-48) to clean-up, rehabilitate, preserve, and restore the bay (G.R. Nos. 171947-48 Supreme Court En Banc, 2008). Targeted analysis of PPCPs to represent the dissolved pollutant load and Polycyclic Aromatic Hydrocarbons (PAHs) for the particulate pollutant are recommended for a more comprehensive discussion of sources and pathways and possible sinks of organic pollutants albeit in a smaller section of Manila Bay.

Despite the worrying findings in water quality, Manila Bay continues to be a large producer of mussels and various catch fisheries. Providing secure and safe food supply in the light of current global shortage with mariculture seems to be a reputable source, but possible pollutants need to be managed.

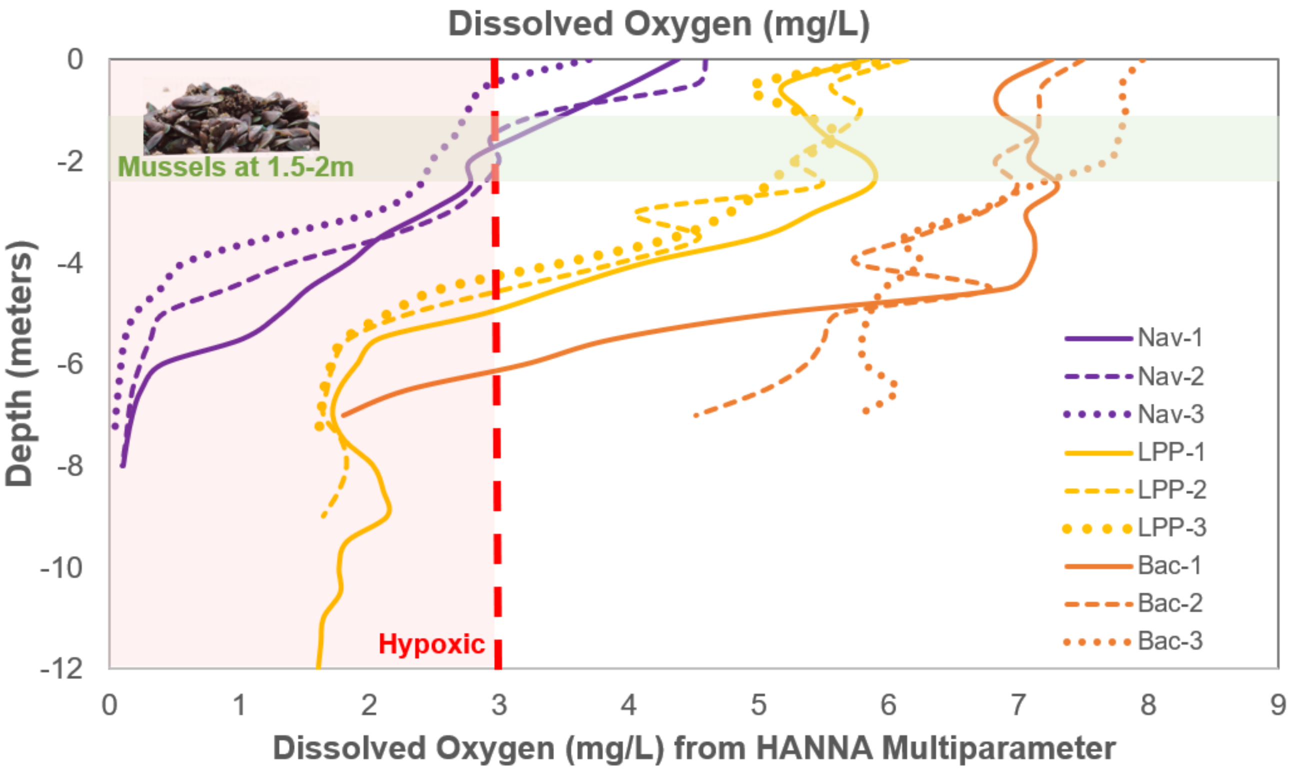

Figure 3. Dissolved Oxygen (mg/L) measurements from HANNA Multiparameter for Navotas, Parañaque, and Bacoor sampling sites. Dissolved oxygen is lowest near Navotas, with 4-5 mg/L at the surface and abruptly decreasing below 3 mg/L at 2 m depth. Dissolved oxygen is highest near Bacoor, Cavite, with 7-8 mg/L at the surface up to 6 m depth.

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