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Short Communication

Large variations of salinity and dissolved oxygen and their effects on macro benthic communities in Lake Sihwa, the west coast of Koreay

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ABSTRACT

Since the dyke construction the lake Sihwa has undergone unstable environments such as large fluctuation of salinity and oxygen due to irregular exchanges of water between the outer saline zone and the inner brackish one, inflow of a good deal of pollutants from non-point and point sources and water stagnancy. It indicates that the lake ecosystem has a variability of species composition and species density. Especially, benthic organisms lack the ability to cope up with changes in the environment because most of them are sedentary and have limited mobility, thus the variation gives rise to change in the community structure. The Sihwa macrobenthos have responded to the severe environment, which was reported in some previous studies. However, these studies referred to the succession of macro fauna for only three years of the initial stage after the dyke construction. In the present paper, I report on the long-term responses of the macrobenthos to the large variation in salinity and dissolved oxygen for fifteen years after the birth of the lake.

Introduction:

Several coastal regions in Korea have suffered from hypoxia since the 1970s. We present the first review of Korean coastal hypoxia, focusing on its spatiotemporal variation, controlling factors, and effects on marine ecosystems. The review considers the two hotspots of the natural Jinhae Bay and artificial Shihwa Bay, which are referred to as "Korean dead zones." The hypoxia in the JB is attributed to eutrophication due to domestic and land-used waste input and thermal stratification based on the naturally sluggish water circulation, whereas the hypoxia in the SB is due to eutrophication resulting from domestic, land-used, and industrial waste input and haline stratification as a consequence of the artificially created water stagnation. The bottom-water hypoxia and stratification has led to an imbalance in nitrogen:phosphorus ratio between surface and bottom waters. Hypoxia has also created undesirable benthic community changes in the both bays:

(1) mass mortality of large species and recolonization with elevated abundances of opportunists in JB, and

(2) decrease of the number of species, abundance, and diversity of benthic communities in SB.

Therefore, it behooves us to pay attention to these environmental changes. This review will be helpful in determining the direction of future studies of Korean coastal hypoxia.

The intensification of anthropogenic activities during the Anthropocene has caused a number of serious problems in marine environments, such as acidification and hypoxia, which have become urgent socioeconomic and political issues. Oxygen is a prerequisite for all life on Earth, but "deoxygenation," a term used to express dissolved oxygen loss, has been dramatically extended and/or enhanced in marine environments. The areal extent of coastal hypoxia (DO $\leq$ 2 mg L^{-1} or ~63 μmol L^{-1}) has increased remarkably in recent decades due to the increase in coastal eutrophication, leading to significant changes in biogeochemical cycling and marine ecosystem structure.

The northern Gulf of Mexico and Chesapeake Bay which receive massive nutrient loadings through river runoff, are frequently referred to as hypoxic coastal regions. In these regions, seasonally chronic hypoxia generally develops through the combination of biogeochemical and physical effects in the bottom waters, although spatial and temporal variability exists.

In recent decades, to enable the receipt of agricultural and industrial waters, many artificial structures, such as dams and dykes, have been constructed in estuarine systems in East Asia as interfaces between seawater and freshwater. These artificial structures have unintentionally contributed to the development of coastal hypoxia by restricting water circulation and accumulating organic matter in the water columns and sediments. A strong cause and effect relationship likely exists between the presence of these artificial structures and the development of coastal hypoxia. However, few studies have focused directly on this relationship.

Several coastal regions in South Korea have suffered from coastal hypoxia caused by eutrophication, in addition to the effects of the artificial structures. In the southern coast, bottom-water hypoxia in semi-enclosed Jinhae Bay and Gamak Bay lasts for several months during the summer. The spatial extent of hypoxia in JB has increased with anthropogenic eutrophication over last four decades threatening benthic ecosystem and aquaculture production reported that summer hypoxia cover about 54% of the total area and has a fatal effect on the benthic ecosystem by creating dead zone in JB. On the other hand, bottom-water hypoxia in western coast did not occur due to tidal mixing, which provides well-flushed condition in the coastal area until the dyke construction. Hypoxic bottom waters were first reported in areas adjacent to the river mouth blocked by dykes in the Shihwa Bay, Cheonsu Bay, and Yeongsan Bay. Until now, hypoxia has developed in summer months in these bays due to blockage of tidal mixing and water circulation by dyke and results in significant changes in the biogeochemistry and ecosystem structures.

General Characteristics:

JB is located on the southeastern Korean coast, and is a shallow semi-enclosed bay with many islands. Geomorphologically, it consists of seven sub-bay systems: Masan Bay, Jindong Bay, Danghang Bay, Dangdong Bay, Wonmun Bay, Gohyeon Bay, and Haengam Bay. Gadeok Channel is the primary pathway for the exchange of seawater between JB and the South Sea. Geographic complexity and isolation have led to the natural development of extremely sluggish water circulation in JB. During the summer, low-salinity water, formed mainly by freshwater discharge from a number of small streams and heavy precipitation from the Asian monsoon, occupies the surface layer of JB, partially contributing to the development of stratification. JB system has low physical energy due to enclosed geomorphology and limited water circulation, leading to strong seasonal stratification. During phase I, which is the period from March to May when hypoxic conditions form and the bottom-water DO level decreases rapidly toward hypoxia, thermal stratification is developed gradually due to solar heating, this relationship is supported by the strong negative correlation between the bottom-water DO concentration and ΔT in JB.

Ecological Responses:

The presence of the dyke has significantly altered the SB ecosystem in terms of its biogeochemical properties and benthic community composition, due to the effects of anthropogenic isolation, reported extremely high concentrations of ammonium (~450 µM), with rapid oxygen consumption in the halocline (~6–8 m depth), measured during a hydrographic survey conducted in March 1996 (during the desalination era of 1994–1997); these findings indicate excessive accumulation of reduced N in the bottom-water. Bottom-water hypoxia was distributed widely during summer 1997, together with high ammonium (27.2–628.5 µM) and low nitrate (1.5–2.7 µM) concentrations. Accumulation of ammonium and deficiency of nitrate indirectly indicate inhibition of the coupled nitrification (i.e., NH+4NH4+ □ NO□2NO2- □ NO□3NO3-)-denitrification (i.e., NO□3NO3- □ NO□2NO2- □ N2O/N2) processes under hypoxic condition in the SB, which is contradictory to the JB (refer section Biogeochemical and Ecological Responses). Denitrification is largely dependent on nitrate availability, so hypoxic condition may show different features. However, there is little information about direct denitrification activity in the SB, so a research on this topic is needed. In addition, excessive accumulation of phosphate (3.4–50.9 µM), resulting from the substantial release of iron-bound P from sediment, was found in the hypoxic bottom-water. In March 1996, significantly elevated H2S (~45 µM), which is toxic to benthic organisms, was observed in the hypoxic bottom-water in SB. In the marine environment, H2S is produced mainly by sulfate reduction, which is a type of anaerobic respiration. In addition, a low pH value (~6.8), indicating "coastal acidification" that may threaten CaCO3-shelled benthic organisms, was recorded in the hypoxic bottom-water. Therefore, bottom-water hypoxia during the desalination era contributed to acidification in the SB ecosystem.

Conclusion:

Bottom-water hypoxia has altered nutrient cycling, reducing the DIN:DIP ratio in the JB. N-limitation in the bottom-water of JB seems to be associated with denitrification and/or excessive P efflux in sediment. On the contrary, N removal through denitrification seems to be suppressed in SB due to low nitrate availability during desalination era. However, no direct evidence was found to support these arguments. P-limitation, driven by N-dominated eutrophication, was also found in the surface waters of JB. Future research should investigate the influence of nutrient limitations on primary production and whether the unbalanced nutrient cycling structure will change rapidly or be strongly sustained due to rapid anthropogenic modifications. Algal production is an important source of organic matter for hypoxia formation in both areas. However, supply of terrestrial substances cannot be ignored because both areas are receiving large and different anthropogenic PON loadings. Therefore, further qualitative and quantitative investigation about the contribution of allochthonous and autochthonous POMs to hypoxia dynamics in both areas is necessary. Coastal hypoxic regions are important contributors to greenhouse gases. Production of greenhouse gases is enhanced substantially in hypoxic waters. Given that the JB hypoxic zones have been expanding significantly, they may be form a significant coastal source region for atmospheric emissions of greenhouse gases. However, coastal greenhouse gases production has not yet been measured in this area. Significant relationships between bottom-water hypoxia and pH have been found in the JB and SB systems, implying that hypoxia is associated with "coastal acidification." However, we do not have sufficiently accurate long-term pH data to confirm this relationship. To assess the impacts of reduced pH conditions on marine organisms in both bays, we urgently need to conduct long-term pH monitoring. In SB, the operation of a TPP has increased seawater exchange rates (5.6-fold) since 2012. However, little information on how the bottom-water conditions have changed is available because detailed surveys in this area have been halted. Therefore, we have no information on whether bottom-water hypoxia in SB is persisting or has disappeared, or on whether the benthic ecosystem in SB is recovering.