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Impacts of environmental and anthropogenic stresses on macrozoobenthic communities in Jinhae Bay, Korea

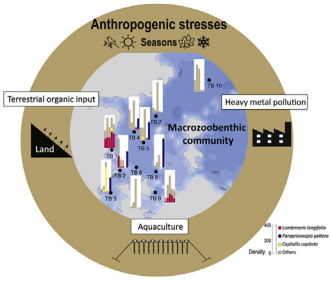
Hanna Bae [a], Jung-Ho Lee [b], Sung Joon Song [a], Jinsoon Park [c], Bong-Oh Kwon [a], Seongjin Hong [d], Jongseong Ryu [b], Kyungsik Choi [a], Jong Seong Khim [a, *]

[a] School of Earth and Environmental Sciences & Research Institute of Oceanography, Seoul National University, Seoul, Republic of Korea
[b] Department of Marine Biotechnology, Anyang University, Ganghwagun, Incheon, Republic of Korea
[c] National Marine Biodiversity Institute of Korea, Seocheon, Republic of Korea
[d] Department of Ocean Environmental Sciences, Chungnam National University, Daejeon, Republic of Korea

HIGHLIGHTS

- Spatiotemporal dynamics of macrofaunal assemblages in Jinhae Bay were addressed.
- Peak abundances in spring and distinctive species shifts in summer were characteristic.
- Oyster farming was one potential anthropogenic stress affecting macrofaunal communities.
- Analysis of five ecological quality indices indicated moderate pollution in given area.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, spatiotemporal dynamics of macrofaunal assemblages and their associations with environmental conditions were examined in Jinhae Bay (10 sites), where the obvious sources of pollution including industries, oyster farms (hanging cultures), and municipal discharges has surrounded. The survey had performed over five consecutive seasons in 2013–2014. Target sedimentary variables included grain size, organic content, C/N ratio, carbon and nitrogen stable isotope ratios, and some heavy metals. Five ecological quality indices (EcoQ) were calculated from the benthic community data to evaluate ecological qualities in site-specific manner. Jinhae Bay is a shallow (depths range, 11–24 m) and typical semi-enclosed bay. The benthic environments represented mud dominated bottoms (>70%) with fairly substantial organic content levels (>2%) over all five seasons. Seasonal patterns were observed with peak abundances in the spring and distinctive macrozoobenthos species shifts in the summer. The spring bloom could be explained by drastic increases of some polychaetes, mainly *Capitella* sp., at certain site, particularly near the shore. The oyster farms situated in the innermost locations seem to provide organic-rich bottoms being dominated by opportunistic species and/or organic pollution indicator species, such

* Corresponding author. School of Earth and Environmental Sciences & Research Institute of Oceanography, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 08826, Republic of Korea.
E-mail address: jskocean@snu.ac.kr (J.S. Khim).

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as *Lumbrineris longifolia*, *Capitella* sp., and *Paraprionospio patiens*. In general, the EcoQ indicators indicated that Jinhae Bay was moderately polluted, with exceptionally poor EcoQ in a few locations during the specific season(s). Overall, adverse effects on benthic community was broadly attributable to contaminations of heavy metals and nearby aquatic farm activities in Jinhae Bay, which requires a prompt action toward ecosystem-based management practice in the given area.

1. Introduction

Marine sediment would comprise one of the largest and oldest habitats in the world showing relatively great biodiversity and production under the dynamic physicochemical changes though (Gray, 2002). Meantime, terrestrial contaminants tended to accumulate in estuarine and coastal sediments, say a spot for final sink, reaching their concentrations being capable of harmful effects to organisms. The negative effects on growth and/or reproduction of macrozoobenthos in contaminated sediments have long been evidenced in Korean coastal waters, particularly in semi-closed industrial bays (Khim and Hong, 2014). Moreover, the alteration of natural species composition including species extinction could be found in the heavily contaminated coastal sites, and thus following long-term population changes would become a significant ecosystem threat in the given environment. As macrozoobenthos are one representative sedentary organism in coastal area, the monitoring of macrozoobenthos community would be a reliable indicator which would address the benthic ecological quality associated with coastal sediment pollution (Gray et al., 1992).

Many studies have investigated spatiotemporal changes of macrozoobenthic communities in relation to the natural and/or anthropogenic disturbances (Crawford et al., 2003; Metzger et al., 2007). Aquaculture is an important industry worldwide in socio-economic aspects but also considered as one of the representative anthropogenic activities due to water-column eutrophication followed by planktonic blooms in coastal areas. Further a hypoxic condition in bottom water and further inside of sediment would have a bad influence on benthic ecological quality (Pearson and Rosenberg, 1978). Also, the continuing input of terrestrial organic matter from various land-use activities could affect the long-term changes of macrozoobenthic communities. A convergence of evidence from numerous previous studies pointed out the transportation of land-based organic matter into coastal systems as one of the common pathways to bring coastal environmental deterioration (Weston, 1990; Essink, 2003; Gamito, 2008). Of note, these adverse effects tend to be most severe in the areas with poor water exchange, say semi-enclosed industrial bay system (Read and Fernandes, 2003).

Next, the heavy metal pollution would be one significant category relating to the anthropogenic stresses resulting in adverse toxic effects on benthic organisms. For example, sedimentary zinc has been known to cause early survival of benthic invertebrates (Watzin and Roscigno, 1997) and interstitial cadmium has shown to give negative effects on recolonization of macrozoobenthos (Hansen et al., 1996). More recently, the long-term accumulation of sedimentary heavy metals in semi-closed industrialized bays revealed the alteration of macrozoobenthic community structure (Josefson et al., 2008; Ryu et al., 2011). Of note, the long-term ecological effects by the persistent organic pollutants, which could commonly co-occur with heavy metals, have also been evidenced in highly contaminated coastal sediment, in Korea (Ryu et al., 2016), but mechanism or direct effect for long-term association remains in question.

Efforts to improve and protect ecological quality of coastal areas from such man-made impacts have long been practiced worldwide. The assessment of ecological quality (EcoQ) status was one of key components in terms of management tools. The European Water Framework Directive (WFD) has led to a development of these tools for analysis of macrozoobenthos community. Single or limited indices tend to over- or underestimate the benthic ecological conditions in the given area. The present study adopted the European WFD's EcoQ approach which classifies ecological status into five scales (high, good, moderate, poor, and bad) to assess the benthic ecological condition in the study area.

As well known, contaminants tend to accumulate in estuarine and coastal sediments and further bioaccumulate, thus potential adverse effects associated with sediments becomes a serious problem, particularly in semi-enclosed bay system, including our study are of Jinhae Bay. Jinhae Bay is exposed to obvious point-sources of coastal pollution including industries, oyster farming (hanging culture), and municipal sewage discharges. Since 1980s, the nearby coastal area has been heavily impacted by drastic increases in industrialization and human populations which seemed to deteriorate macrozoobenthos community (Hong, 1987; Lim et al., 1992; Seo et al., 2014). In particular, Jinhae Bay is known as one of the large aquaculture production areas for the oyster culture, where coastal eutrophication has long been a significant environmental issue (Lim et al., 1992, 2006). The macrozoobenthos community might reflect the historical feature of geographical conditions in which both single and/or multiple parameters could collectively influence certain ecological alteration.

In the present study, we aimed to address the macrozoobenthos relationship between several important sediment variables and macrozoobenthic communities (viz., species composition and abundances) in semi-enclosed industrialized bay system of Jinhae area. In particular, spatio-seasonal association of macrozoobenthos assemblages to potential anthropogenic sources around Jinhae Bay area was highlighted. The assessment of benthic ecological quality over five seasons was also presented in order to identify the major anthropogenic source(s) in the given environmental conditions. Finally, we discussed a long-term community change of macrozoobenthos in association with representative human activities around the Jinhae Bay region since late 1980s (Fig. S1 of the Supplementary Materials (S)).

2. Materials and methods

2.1. Study area

The study area is situated in the south-western part of Jinhae Bay, Korea (Fig. 1), which is a shallow semi-enclosed bay. A channel was located in southern part of study area, between Tongyeong and Geoje island and oyster farming is prevailing over seasons in large scale with >500 ha of aquaculture area. Jinhae Bay is surrounded by three major cities, Changwon, Tongyeong, and Geoje, of which populations reach >1 M, >250 K, and >400 K, respectively. A sewage treatment plant, which was located in the innermost of