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Spatiotemporal variations in macrofaunal assemblages linked to site-specific environmental factors in two contrasting nearshore habitats

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ABSTRACT

A long-term study on a benthic community was conducted in two different localities, one in semi-enclosed bay of Jinhae (n = 10, south coast) and the other in open sea area of Samcheok (n = 10, east coast), Korea, respectively. We aimed to identify the spatiotemporal patterns of macrozoobenthos and the environmental variables influencing such patterns in the two contrasting habitats. The macrozoobenthos assemblages on the soft bottom of the subtidal zone were analyzed over the 3 years, encompassing 12 consecutive seasons, in 2013–2016. Among the 22 environmental variables measured, organic matter, dissolved oxygen, mean grain size, and water depth showed clear differences between two study areas. Accordingly, several ecological indices (such as the number of species, abundance, dominant species, and diversity index (*H*')) generally reflected site-specific benthic conditions. The macrofaunal community in the Jinhae showed typical seasonal fluctuations, whereas the Samcheok community showed no significant change over time and space. Region- or site-dependent temporal variabilities of macrofaunal assemblages are depicted through cluster analysis (CA), indicating distinct temporal changes in the composition of dominant species. In particular, the abundance of some dominant species noticeably declined in certain seasons when several opportunistic species peaked. Such faunal succession might be explained by significant changes to specific environmental factors, such as bottom dissolved oxygen, grain size, and water depth. Principle component analysis further identified major environmental factors, i.e., sediment properties in Jinhae and water quality parameters in Samcheok community, respectively. In addition, discriminant analysis confirmed the presence of several site-specific parameters for the faunal assemblage groups identified through CA. Finally, indicator value analysis identified species that were representative across stations and regions in accordance with their habitat preference and/or species tolerance. Overall, the two contrasting nearshore habitats showed distinct community differences, in time and space, that were influenced by site-dependent environmental conditions.

1. Introduction

Benthic organisms play a key role in marine ecosystem dynamics; for example, macrozoobenthos are reliable indicators of varying environmental conditions (Ryu et al., 2016). Macrozoobenthos are relatively sedentary and reflect the ecological conditions of subtidal habitats, exhibiting clear responses to the pollution gradients of various contaminants (Ryu et al., 2011; Yoon et al., 2017). Thus, macrozoobenthos is considered as a key component for determining ecological quality, particularly in shallow water systems. Macrozoobenthic responses to anthropogenic environmental changes are relatively tolerant in time and space (Foshtomi et al., 2015; Iskaros and El-Otify, 2003). Thus, monitoring macrozoobenthos contributes to the understanding of relationships between biotic and abiotic components in the dynamic marine ecosystem (Guest et al., 2016; Hagberg and Tunberg, 2000; Yasuhara et al., 2007).

Many studies have reported a significant association between macrozoobenthic composition and the properties of sediments

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(Gray et al., 2002; Olsgard et al., 2003; Thorson, 1950), water temperature (Rosa and Bemvenuti, 2006), dissolved oxygen (DO) (Middelburg and Levin, 2009), and, in particular, water depth (Kröncke et al., 2003; Paterson and Lambshead, 1995; Rex, 1981). Significant variation in the structure of macrozoobenthos occurs across seasons, and is primarily associated with temperature and other variables (Mahoney and Livingston, 1982; Susan et al., 2014) or the introduction of species (Essink and Kleef, 1993). Although many studies have focused on associations, few have examined the mechanisms that cause an increase or decrease in biological diversity in the dynamic marine ecosystem. The effects of environmental variables on macrozoobenthos would vary depending on habitat conditions, such as geomorphological feature, type and/or degree of anthropogenic pressures etc. Few studies have addressed the temporal association of biotic and abiotic parameters in contrasting habitats through seasonal monitoring. Uncertainty in ecosystem responses due to the combined and mixed effects of varying environmental parameters remains an open question, particularly when predicting long-term changes in the structure of macrozoobenthic assemblages.

Furthermore, most bays and coastal areas are subject to environmental deterioration caused by a high degree of land use and other human activities, which influence sediment and water quality, leading to changes in the ecosystem (Bae et al., 2017; Kim et al., 2017). The Jinhae Bay is a semi-enclosed habitat that is vulnerable to anthropogenic stresses and hypoxia. Long-term anthropogenic pressures caused by urbanization, land-driven coastal pollution, or oyster farming seemingly have the most severe effect on shallow, semi-enclosed bays with poor water exchange (Newton et al., 2014; Read and Fernandes, 2003). In comparison, the Samcheok coast is a nearshore open sea area, with relatively smaller anthropogenic stresses than those in Jinhae Bay. The Samcheok coast is considered to be a relatively lesser contaminated region, but there is shipping activity near the coast, representing one potential environmental stressor (Lee et al., 2011). Thus, it is important to track long-term changes in benthic populations that might lead to significant ecosystem threats in a given environment.

Various statistical tools have been proposed and applied to interpret the relationship between the environment and macrozoobenthos; for instance, several studies have applied useful statistical methods, such as indicator value analysis (IndVal) (Dufrene and Legendre, 1997; Hermand et al., 2008; Noh et al., 2017), principal component analysis (Anderson and Willis, 2003), and discriminant analysis (DA) (Ryu et al., 2011). IndVal is often used to identify representative species and groups as indicators of habitat preference, environmental changes, and anthropogenic effects (Liu et al., 2017; Valença and Santos, 2012); thus, it represents a powerful tool of site-specific ecosystem responses in dynamic coastal environments.

Here, we conducted a comparative investigation of a semi-enclosed bay and an open coastal area in Korea during the study period of 3 years, encompassing 12 consecutive seasons, where we compared spatiotemporal patterns of macrozoobenthos at both the community and species levels. Specifically, we aimed to: 1) investigate how macrozoobenthos communities (viz., species composition and abundance) were associated with 22 target variables in the two contrasting habitats, 2) analyze how dominant species responded to highly heterogenic environments, and 3) identify indicator species under the prevailing environmental conditions of each habitat using various statistics. We hypothesized that certain environmental conditions could be predicted by the presence of certain indicator species across seasons and years in the macrozoobenthos community.

2. Materials and methods

2.1. Study area

In the present study, two contrasting habitats were selected for the long-term monitoring of macrozoobenthos in two subtidal regions. First, Jinhae Bay, which is located on the south coast of Korea, is a shallow semi-enclosed bay that has monitoring stations at 11–24 m water depth (Fig. 1A & Table S1). This area has long been associated with severe coastal pollution, and is a representative hot-spot for pollution in Korea. Anthropogenic pressures include neighboring industries and populated cities, shipyards, commercial fishing, and oyster farming. In particular, the harvesting of oysters occurs year-round at a large scale with >500 ha of aquaculture area. A sewage treatment plant, which is situated in the innermost part of Jinhae Bay, discharges up to 200 tons of sewage per day.

Second, Samcheok coastal area is located on the east coast of Korea (Fig. 1B & Table S1), of which coastline is directly exposed to the open ocean. The water depth at the monitoring stations of the Samcheok coastal area (15–52 m, mean = 37 m) was relatively deeper than those in Jinhae stations (11–24 m, mean = 18 m) (Fig. 1A & Table S1). Although shipping activity and tourist visiting could be potential anthropogenic sources in this region, geographical features and oceanographic conditions might have weakened sedimentary pollution in a given area (Lee et al., 2011).

2.2. Sampling and laboratory analyses

Sampling was conducted in Jinhae Bay (n = 10; T1–T10) and Samcheok coastal area (n = 10; S1–S10) from October 2013 to July 2016 (Table S1). Subtidal sediment samples were collected over 12 consecutive seasons during the 3-year period to analyze macrofaunal assemblages and sedimentary parameters. In brief, during each sampling event, two samples were collected using a van Veen grab, covering a surface area of 0.1 m^2. Sediment samples from van Veen grab were sieved on site using a 1-mm mesh size. Pooled samples were used to identify species, with all individuals being counted. Surface sediments (<3 cm) were subsampled from a grab sample to analyze sediment parameters, such as grain size (including % gravel, % sand, % silt, % clay, sorting, skewness, and kurtosis) and organic content. Grain size was analyzed by the dry sieve and pipette method (Konert and Vandenberghe, 1997), given as mean grain size (Mz). Organic content was determined by burning sediment to ashes at 550 °C for 4 h (Heiri et al., 2001) to obtain weight loss after combustion. In addition, environmental variables of seawater on the sea bottom were monitored using a multi-probe (YSI 556 MPS) that measured pH, salinity, DO, and temperature.

2.3. Data analyses

Cluster analysis (CA) was carried out with PRIMER 6 statistical software (PRIMER-E Ltd., Plymouth, UK). The original data matrix was reduced by eliminating species that contributed <1% of total abundance. Bray-Curtis similarity coefficients were calculated and the data were subjected to group average sorting. Abundance was fourth root-transformed to balance it across the recorded taxa in the measure of similarity (Clarke and Warwick, 2001). Non-metric multidimensional scaling (NMDS) was also used to place sampling stations in two-dimensional space based on the same similarity matrix used for CA with information of the dominant species. The analysis of similarities (ANOSIM) test was performed to confirm that these groups differed significantly. After identifying the groups by using the CA, DA was performed to extract significant discriminant functions and to identify the major environmental variables