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Red tides in Masan Bay, Korea, in 2004–2005: III. Daily variations in the abundance of mesozooplankton and their grazing impacts on red-tide organisms

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ABSTRACT

To investigate the role of mesozooplankton in the dynamics of red tides in Masan Bay, Korea, we measured the abundance of mesozooplankton in daily samples collected from June 1, 2004 to May 31, 2005. Mesozooplankton were abundant in the winter, but rare in the summer, and had a range of abundance of 3–52,843 ind. m^{-3}. Similarly, both copepods and cladocerans were abundant in the winter, but rare in the summer, and had ranges of abundance of 0–48,817 ind. m^{-3} and 0–10,951 ind. m^{-3}, respectively. Invertebrate larvae were abundant in the fall but not in other seasons. The biomass of copepods was significantly positively correlated with salinity, dissolved oxygen, the biomass of the phototrophic dinoflagellates *Heterocapsa triquetra* and *Prorocentrum minimum*, and the biomass of the heterotrophic dinoflagellate *Gyrodinium glaucum*, but negatively correlated with water temperature and the biomass of heterotrophic bacteria and small algae. In addition, the biomass of cladocerans was significantly positively correlated with salinity and the biomass of euglenophytes and *G. glaucum*, but negatively correlated with water temperature. The biomass of invertebrate larvae was significantly positively correlated with water temperature, but negatively correlated with dissolved oxygen. These observations suggest that copepods and cladocerans may increase their populations by feeding on large phytoplankton in cold water, whereas invertebrate larvae may prefer warm water. The grazing coefficients for the copepods *Acartia* spp. on co-occurring *Pfiesteria*-like dinoflagellates (PLDs), *P. minimum*, *Skeletonema costatum*, *H. triquetra*, *Heterosigma akashiwo*, and *Scrippsiella trochoidea* were 0.104, 0.083, 0.042, 0.034, 0.033, and 0.030 d^{-1}, respectively. These results suggest that grazing by *Acartia* populations in Masan Bay can have a considerable impact on the populations of PLDs and *P. minimum*, but only a moderate impact on *S. costatum*, *H. triquetra*, *S. trochoidea*, and *H. akashiwo*.

1. Introduction

Red tides have occurred in the coastal and offshore waters of many countries as well as in the mid-ocean (Holmes et al., 1967; Jeong, 1995; Imai et al., 2001; Sordo et al., 2001; Alonso-Rodriguez and Ochoa, 2004; Seong et al., 2006; Lee et al., 2013; J.Y. Park et al., 2013a). They can alter the balance of food webs and cause large-scale mortality of fish and shellfish (ECOHAB, 1995; T.G. Park et al., 2013b). Studies of red-tide formation and persistence suggest that grazing pressure may play an important role inbloom dynamics (Watras et al., 1985; Turner, 2006). Grazing by mesozooplankton is believed to sometimes contribute to the decline of red tides (Calbet et al., 2003; Tan et al., 2004).

Many mesozooplankters such as copepods, cladocerans, and invertebrate larvae are known to feed on red-tide organisms (Houde and Roman, 1987; Turner et al., 1988, 2012; Carlsson et al.,

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1995; Liu and Wang, 2002; Broglio et al., 2003; reviewed by Turner, 2006; Cohen et al., 2007; Waggett et al., 2008; Jeong et al., 2004a, 2010a). In turn, they are good prey for adult fish and shellfish (Sanders and Wickham, 1993; Lazareva and Kopylov, 2011). Thus, mesozooplankters play important roles in marine ecosystems. To understand the role of mesozooplankton in red-tide dynamics, we must examine four questions. First, which mesozooplankton species are abundant during a red tide? A correlation between the abundances of the dominant mesozooplankton and the red-tide organism may give clues to their predator–prey relationship. Second, are the dominant mesozooplankton able to feed on the red-tide organism? Many studies have observed these predator–prey relationships in laboratory experiments (Sanders and Wickham, 1993; Huskin et al., 2000; Jeong et al., 2001; Kim, 2005; Song, 2007). Third, at what rate do predators ingest red-tide species? Many studies have also measured these rates (Sanders and Wickham, 1993; Ban et al., 1997; Hansen et al., 1997; Jeong et al., 2001; Kim, 2005; Song, 2007). Finally, what is the impact of grazing by predators on the red-tide species? The grazing impact can either be measured directly or calculated (Turner and Granéli, 1992; Calbet, 2001; Calbet et al., 2003; Tan et al., 2004).

Masan Bay, Korea, is a highly eutrophicated bay with frequent red tides (Han et al., 1991; Yoo, 1991; Kwak et al., 2001; Lee and Lim, 2006). To explore the role of mesozooplankton in red-tide dynamics in Masan Bay, we measured the abundance of mesozooplankton (i.e., copepods, cladocerans, invertebrate larvae, etc.) on a daily basis for 1 year. We also looked for correlations between the abundance of mesozooplankton and physical and chemical factors, the abundance of co-occurring red-tide organisms (Jeong et al., 2013), and heterotrophic protists (Yoo et al., 2013). By combining field data on the abundances of mesozooplankton predators and the target red-tide organism with the ingestion rates of the predators on the prey obtained from the literature, we estimated the grazing coefficients attributable to the predator on co-occurring red-tide prey. The results of the present study provide a basis for understanding the role of mesozooplankton in red-tide dynamics in eutrophic bays.

2. Materials and methods

2.1. Abundance in Masan Bay, Korea

Masan Bay is located in the southeastern part of Korea (Fig. 1). This bay is long and semi-enclosed (5-km long and 2-km wide with a 1-km mouth). A large city, Changwon, surrounds the bay, and three streams enter the bay.

Mesozooplankton samples were collected at a pier in Masan Bay (Station SNUMS; 1.2–2.4-m deep depending on tide) by towing a 303-μm-mesh, 45-cm-diameter, conical plankton net with a flowmeter obliquely from the bottom to the surface every day from June 2004 to May 2005. Samples were taken at 10:00 h. Each plankton sample was poured into a 500-ml polyethylene bottle and preserved with 4% formalin. Species identification and determination of the abundance of mesozooplankton were performed using dissecting and inverted microscopes at magnifications of 40× and 200×. The calanoid copepods *Acartia omorii* and *Acartia hongi* (Soh and Suh, 2000) which coexist in the coastal waters off Korea are similar, and it is very difficult to distinguish between the two species. Thus, we used *A. omorii*/*A. hongi* for these taxa.

Simultaneously, surface water samples were taken from the pier to measure physical, chemical, and biological properties (Jeong et al., 2013; Yoo et al., 2013).

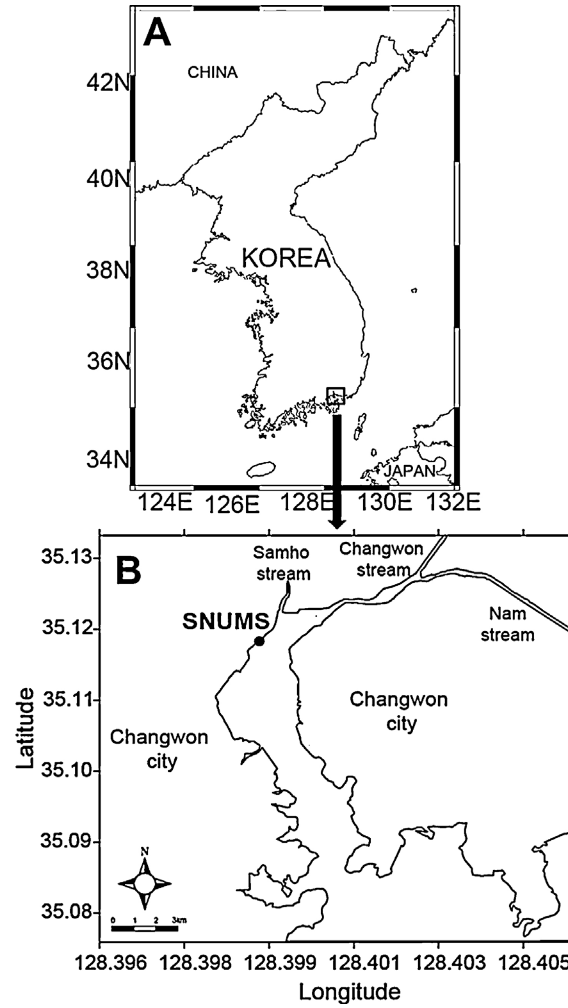

Fig. 1. Map of the sampling station (SNUMS) in Masan Bay, Korea (A). (B) Enlarged from (A).

2.2. Biomass conversion

The biomass of each mesozooplankton taxon was obtained from the literature, if known, or estimated from the taxon's biovolume according to Berggreen et al. (1988), Durbin and Durbin (1992), Hansen (1993), and Hansen et al. (1997).

2.3. Correlations

The correlation coefficients between mesozooplankton and physical, chemical, and biological properties were calculated using Pearson's correlation (Conover, 1980; Zar, 1999).

2.4. Grazing impact by mesozooplankton on red-tide organisms

Grazing coefficients for each predator–prey relationship were estimated by combining field data on the abundances of the mesozooplankton predators and the target red-tide organism, with the ingestion rates of the predators on the prey obtained in the literature, with some assumptions. *Acartia hudsonica* (*Acartia clausii*) is known to feed on *Skeletonema costatum* (Deason, 1980). It was assumed that the ingestion rate for *Acartia omorii*, the dominant *Acartia* species in this study, was the same as that for *A. hudsonica*. In addition, *A. omorii*/*Acartia hongi* are known to feed on the heterotrophic dinoflagellates *Pfiesteria piscicida*, *Stoeckeria algicida*, and *Luciella masanensis* (Jeong et al., 2007b). These 3